Contra Costa Water District
Comments on the December 13, 2013
Draft Bay Delta Conservation Plan and Accompanying Draft EIR/EIS

Exhibits

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January 16, 2013

The Honorable Ken Salazar
Secretary
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1849 C Street, N. W.
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The Honorable John Laird
Secretary
California Natural Resources Agency
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The Honorable Michael L. Connor
Commissioner
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1849 C Street, N. W.
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Dear Secretary Salazar, Secretary Laird, Deputy Secretary Meral,
and Commissioner Connor:

We are writing to you in advance of the planned release of the public review draft of the Bay Delta Conservation Plan (BDCP), out of a deep concern over the status of this effort. We are united in a desire for a successful project that can be supported by project proponents, Delta stakeholders, and the public. That chance for success is substantially diminished as a result of the alternatives analysis that we have seen thus far. Up to now, the BDCP process has been strongly focused on advancing a large capacity conveyance which, along with the suite of associated conservation measures, will be burdened with large uncertainties and for which a solid business case has not yet been made. These unquantified risks include impacts on listed species, impacts on the Delta landform, hydrology and water quality, open-ended costs to direct water users and to the public, political controversy, and potentially lengthy litigation.

Absent so far has been a portfolio-based alternative that features a smaller conveyance facility with additional, complementary investments in local water supply sources, regional coordination, south of Delta storage, levee improvements, and habitat restoration (see attachment) as advanced in the coalition letter sent by other organizations today. We believe that it is critical to evaluate in detail a conveyance as small as 3,000 cfs, as it would provide considerable water supply benefits to the export community while better protecting broader interests in the Delta. Such a facility would also realize significant financial savings in comparison with a larger conveyance facility, face fewer legal and political challenges, and potentially be completed sooner. With accompanying investments in proven, cost-effective regional water strategies, this approach could increase export area water supplies and reduce the vulnerability of water supplies and Delta infrastructure to disruption from earthquakes and other disasters. We urge that this conceptual alternative be seriously considered in the BDCP process, including the required CEQA/NEPA analyses and the Clean Water Act Section 404 alternatives analysis.

A portfolio approach could produce superior benefits at a similar or lower cost to water users and the public, and at reduced levels of environmental impacts. It has the potential to be consistent with the best available science and, as a result, may be more readily permittable and capable of delivering benefits more rapidly. It would appear that a solid business case can be made for such an alternative; in any event, the business case must be made before any project proceeds.

We fully appreciate the magnitude of the challenges facing the Delta, and urge a comprehensive solution that is both affordable and science-based. We recognize the enormous effort you have undertaken toward this end, and hope that this conceptual alternative will continue to advance the discussion.

Sincerely,

Jerry Brown
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Bob Filner
Mayor
City of San Diego

Attachment

A Portfolio-Based BDCP Conceptual Alternative

The eight components described below represent a conceptual alternative, not a proposed BDCP project. The analysis of this alternative is intended to assist BDCP in developing the most cost-effective and environmentally beneficial final BDCP project that can be implemented and produce benefits rapidly. Variations on the approaches below should be analyzed as well, including a full range of conveyance capacities.

Guiding Principles

Science-Based Ecosystem Management: Credible, proven science will determine ecosystem improvements and water management, using on-the-ground results as the central driver of decision-making.

Water Supply Reliability: The BDCP can contribute to improved water supply reliability by reducing the physical vulnerability of Delta water supplies and embracing a portfolio approach that recognizes that water suppliers and the public have a broad range of options both in and outside of the Delta to meet their water needs and improve reliability.

A Strong Business Case: A strong business case is central to the success and financial viability of the BDCP. Sound economic principles and cost-benefit analysis must inform water supply improvements so that water ratepayers understand that the benefits they will receive from the project are reasonably proportional to what they are being asked to pay.

Water Quality: Delta water quality will be strongly influenced by the final BDCP plan, with potential impacts and benefits to export water users, local municipalities, Delta residents, Delta farmers and the ecosystem.

Conceptual Elements of a Diversified Portfolio Approach

New Conveyance Facility: Focus BDCP analysis on one 3,000 cfs North Delta intake facility and a single tunnel sized for 3,000 cfs gravity flow. This smaller facility would lower BDCP costs, improve reliability and reduce opposition. If implementation proves successful in meeting biological goals and objectives, a second phase could be constructed subsequently, but would not be permitted at this time.

Project Operations: Analyze, as a starting point for analysis of future SWP and CVP operations, the best science available today. In particular, analyze the operations proposal developed by state and federal biologists to conserve and manage a full range of covered Delta fish species, including consideration of the need to protect upstream fisheries resources.[1] Project operations should utilize a "big gulp, little sip" approach that increases exports in wet years – when water is available in excess of environmental needs

[1] The work of state and federal agency biologists to produce a science-based operational scenario is summarized on pages 1-16 of this BDCP presentation - http://www.essexpartnership.com/wp-content/uploads/2012/11/BDCP_CS5_Update_NGO-Meeting_11_14_12v3.pdf

– and reduces diversions in average and drier years, particularly during key periods such as the spring and fall. Such an operations proposal has been developed over the past year by state and federal fish agency biologists. This is an important agency analysis that should be subjected to additional refinement in an open, transparent process, utilizing independent external peer reviewers. It is essential not to delay a detailed analysis of the likely yield of a new facility based on the best available science.

Estimated Water Exports: ~ 4 - 4.3 MAF/ year (2025). This is an initial estimate of average exports. BDCP has not yet modeled a 3,000 cfs facility with additional South of Delta storage and the agency-developed operational scenario included in this proposal.

Reduced Reliance on the Delta through Investments in South of Delta Water Supplies: DWR, many Urban Water Management Plans and other analyses have concluded that local water supply tools including conservation, water recycling, and other approaches, can provide reliable, sustainable and plentiful new sources of supply that will also be cost-effective over the long run. These sources can also be provided rapidly through additional investments. There is approximately as much new water available from these new water supply sources as is currently exported from the Delta.

This conceptual alternative proposes a smaller capital investment in a Delta facility, in comparison with the current BDCP preliminary project, and investment of savings in local water supply projects. For analytical purposes, this alternative includes a $2 billion investment in water recycling (at a capital cost of approximately $6,430 - 6,470 per AF of permanent water recycling capacity) and a $3 billion investment in urban conservation (at an initial/capital cost of $3,230-4,860 per AF).[2] Urban stormwater capture, groundwater cleanup, and conjunctive use should be included as cost-effective methods for generating future new sources of water, and would also be important elements of a large-scale effort to invest in new local water sources. Additional cost-effective savings can also be obtained from investments in agricultural conservation.[3]

Estimated Yield: 926,000 - 1,245,000 acre-feet of permanent water supply. (309,000 – 311,000 acre-feet from water recycling and 617,000 - 934,000 acre-feet from urban efficiency.)

Improved Water Agency Integration: The principles of integrated regional water management planning should form the foundation for improving cooperation and integration among Bay Area, Central Valley, and Southern California water agencies to provide improved water supply reliability and quality benefits. Increasing integration and

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[2] See attachment for additional detail regarding cost and yield estimates. Note that these are initial/capital costs, not annual per-acre-foot unit costs. A comprehensive BDCP analysis should also address operations and maintenance costs of a full range of alternative investments.

[3] The Department of Water Resources Bulletin 160-2009 http://www.waterplan.water.ca.gov/cwpu2009/index.cfm (Volume 2,Chapter 2, page 2-13) states that agricultural water conservation costs range from $35-$900 per AF. Because of the width of this cost range, agricultural conservation is not included in the conceptual cost and yield numbers above. A final BDCP portfolio proposal should, however, include agricultural water use efficiency investments.

cooperation among these agencies could produce substantial potential benefits and cost-savings. For example, more than a dozen significant water agencies serve the Bay Area. Improved physical connections and increased cooperation among these agencies could reduce risks related to earthquakes and localized drought conditions, facilitate wastewater recycling, and utilize existing infrastructure more efficiently.

In Southern California, additional benefits could be obtained, for example, by facilitating water management agreements and programs among agencies with the potential to construct water recycling facilities and agencies that have groundwater storage resources. The Metropolitan Water District could operate its system to facilitate innovative and cost-effective water management programs between agencies in Southern California and elsewhere in the state. Southern California groundwater agencies could allow water from Southern California surface storage facilities to be managed conjunctively with regional groundwater storage facilities. This could, in essence, create new surface storage capacity at the far lower cost associated with groundwater storage. This approach could help take advantage of the supplies available during "big gulp" opportunities in the Delta. Similar potential benefits may exist through increased integration and cooperation in the agricultural sector.

In all of these opportunities it is imperative that program costs be clearly identified and allocated to the water suppliers that benefit. In this way, each public water supplier is able to account to the public it serves that their water ratepayer dollars are being spent wisely, according to law and in a manner that provides clear benefits.

New South of Delta Surface and/or Groundwater Storage: Include up to 1 MAF[4] of new South of Delta storage, with funding allocated through competitive bidding to evaluate proposed surface, groundwater and conjunctive use projects. Investments should be focused on projects that can be completed quickly and that are most cost-effective. Additional South of Delta storage[5] can allow for greater water exports in wetter years. As discussed above, surface storage south of the Delta could be used conjunctively with groundwater facilities to store wet-year exports for future dry years. This increase in storage capacity must be accompanied by new Delta operations that ensure that the new storage will be operated to implement "big gulp, little sip" operations.

Levee Improvements: Improve existing levees and build setback levees as part of habitat restoration. A $1 billion additional investment could improve Delta levees to protect life, property, and important infrastructure, and also upgrade key levees including the eight western Delta islands to a higher standard with improved stability and resilience

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[4] This 1 MAF storage target is based on limited BDCP modeling and may be revised based on further analysis.

[5] As used in this proposal, South of Delta storage is defined as storage integrated into the existing SWP and CVP Delta export system, including surface and groundwater storage in the Bay Area, the west side of the San Joaquin Valley, Kern County and Southern California. It includes storage controlled by the CVP, the SWP, MWD, Kern County Water Agency and other regional and local agencies.

in the face of seismic risk. Upgrading these key levees would provide significant water reliability benefits and would be an appropriate use of exporter funds.

Regardless of the size of a Delta facility, maintaining and improving Delta levees is critical to ensuring the physical reliability of Delta exports. Even with new conveyance, the CVP and SWP will continue to rely on water exports from the South Delta, particularly in drier years. With a 9,000 cfs facility, exports from the South Delta would constitute approximately 50 percent of total exports. In critically dry years, BDCP currently anticipates that 75 percent of total exports would be diverted from the South Delta.[6] Therefore, the benefits of this proposed investment in levee improvements would be particularly significant in dry years. BDCP does not currently include a strategy to reduce the physical vulnerability of the portion of Delta exports that would continue to rely on the Delta levee system.

East Bay Municipal Utility District, Contra Costa Water District and Delta landowners currently contribute to the maintenance of the levees upon which they rely. An analogous investment by export agencies would produce significant reliability benefits. For example, with average exports of 4 MAF/y, a contribution of $8/AF would produce $480 million to help improve Delta levees over the coming 15 years. Public funds for levee improvements are appropriate to protect Delta residents and infrastructure of regional and state importance (e.g. highways). Additional local contributions may be required.

Delta Floodplain and Tidal Marsh Habitat Restoration: Implement a large scale, approximately 40,000 acre habitat restoration program to benefit Delta fish and wildlife species, to provide a broad range of ecosystem functions and to be integrated with Delta flood management improvements. There is strong scientific evidence that floodplain habitat restoration, combined with adequate flows, can benefit salmon and other species. However, agency "red flag" memos and the National Research Council review of the existing biological opinions concluded that floodplain restoration cannot substitute for required ecosystem flows. Restoration of tidal marsh habitat, also a desirable activity, nonetheless, has far greater uncertainty associated with it, regarding benefits for many covered species, in comparison with the likely benefits of floodplain restoration. Tidal marsh restoration should be included in the BDCP plan as a complement to flow augmentation and floodplain restoration, as it is more likely to benefit some covered fish species in combination with these elements. Habitat restoration, particularly tidal marsh restoration, should in any case be implemented within an adaptive management framework. Existing CVP and SWP mitigation responsibilities, as well as new mitigation responsibilities associated with a new Delta facility, will be paid for by water exporters, while public funding should be focused on conservation benefits that go beyond

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[6] BDCP Draft Effects Analysis, April 13,2012. Tables C.A-24 and C.A-27 from Appendix 5.C - Attachment C-A, which can be found on p. C.A. 83 and C.A. 92 at this link: http://baydeltaconservationplan.com/Libraries/Dynamic_Document_Library/BDCP_Effects_Analysis_-_Appendix_5_C_Attachment_C_A_-_CALSIM_and_DSM2_Results_4-13-12.sflb.ashx

mitigation. This proposal is focused on the coming 15-20 years. Long-term restoration efforts are likely to require additional funding.

Integrating Science into Delta Management: Increase the integration of the best available science into all aspects of Delta and related resource management. The Delta is a complex and highly dynamic system. During the past decade, an expanded investment in science has improved our understanding of this ecosystem. With ongoing investments, that understanding will continue to improve. A long-term investment in science and a program to integrate new scientific results into ongoing management are essential to long-term success. Therefore, BDCP should include the following:

- External independent scientific review at critical points, with clear mechanisms to incorporate peer review results.
- Quantified performance objectives, such as SMART[7] biological objectives and criteria for ecosystem restoration and water operations.
- Governance and adaptive management processes designed to ensure that goals and objectives are achieved, to obtain the best available science over time, and to ensure that scientific results are fully integrated into on-the-ground management.
- Carefully designed roles for the state and federal projects, as well as other stakeholders, to ensure a reliance on objective science.

This science-based approach is not anticipated to result in large increases in project costs. In fact, this approach would increase the cost-effectiveness of BDCP efforts, and should result in savings.

Affording, and Paying for the Portfolio-Based Conceptual Alternative

Our organizations strongly support an analytically-based beneficiary pays approach to BDCP financing. We believe that the analysis of this portfolio approach will assist BDCP in developing detailed cost allocations and in attracting additional funding partners. It will also help reduce pressure for public funds and ensure that such funds are spent effectively and appropriately.

Preliminary cost estimates indicate that this conceptual alternative is less expensive than the current preliminary preferred BDCP project. In addition, some of the investments in this portfolio alternative, such as levee and local water supply investments, are likely to be necessary even with a large Delta facility. Therefore, the actual cost difference between these two different approaches may be larger than indicated here.

This conceptual alternative is more financially viable than the preliminary preferred 9,000 cfs Delta facility project. That project, pegged at $14 billion or more, is proposed to be paid for by water exporters. Proposed habitat restoration could cost up to an

[7] SMART objectives are those that are specific, measurable, achievable, relevant to the goal and timebound.

additional $4 billion, raising the total capital cost of the current approach to approximately $18 billion. By reducing the size of the project to a 3,000 cfs, single-bore facility, many billions of dollars can be freed up to invest in more local supply development and the water exporter shares of the other conceptual alternative components.

The water code requires water users to pay for a new Delta facility.[8] The public share of this conceptual alternative could be funded in part by a reduced water bond. The increased benefits and reduced cost of this approach can assist BDCP in attracting increased funding from beneficiaries, reducing the pressure on the water bond. We believe that the diversified portfolio approach in this conceptual alternative could assist in the effort to develop a broadly supported and effective new water bond.

Estimated Cost Summary

Conceptual Portfolio Component	**Estimated Cost**	**Source of Funding**
New 3,000 cfs North Delta Facility	~ $5-$7 billion[9]	Export water agencies
Local Supply Development	$5 billion	Local water agencies and cost share per state Integrated Regional Water Management Program (IRWMP)
Improved Water Agency Integration	TBD (may be funded through local supply funds described above)	Water agencies and cost share per state IRWMP
New South of Delta Surface and/or Groundwater Storage	~$1.2 billion[10]	Exporters or local water agencies, and public cost share per IRWMP
Levee Improvements	$1 billion	Public, water exporters and other beneficiaries and Delta community
Delta Floodplain and Tidal Marsh Habitat Restoration	$1.7 billion	Export agencies and public
Integrating Science into Delta Management	TBD	Public and water agencies
Total Conceptual Alternative Cost	~$14 to $16 billion	

[8] California Water Code Section 85089.
[9] A BDCP July 1, 2010 presentation estimated the capital cost of a 3,000 cfs facility with 2 18-foot diameter tunnels at $7.2 billion. Using a single tunnel would reduce costs significantly.
[10] See attachment for details regarding cost estimates.

Total Conceptual Alternative Water Supply Benefits

~ 4.9-5.5 MAF/YR.
Delta exports: ~ 4-4.3 MAF/Y.
New South of Delta sources: ~ .93-1.2 MAF/Y

State of California
The Resources Agency
Department of Water Resources
Interagency Ecological Program

Pelagic Organism Decline Progress Report: 2007 Synthesis of Results



January 2008

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E ecutive Su ary

Abundance indices calculated by the Interagency Ecological Program (IEP) through 2007 suggest recent marked declines in four pelagic fishes in the upper San Francisco Estuary (the Delta and Suisun Bay). These fishes include delta smelt which is listed under State and federal Endangered Species acts and the longfin smelt, which has been proposed for protection under those acts. Although several species show evidence of long-term declines, the recent low levels were unexpected given the relatively moderate winter-spring flows of the past several years.

In response to these changes, the IEP formed a Pelagic Organism Decline ("POD") work team to evaluate the potential causes. The major findings through 2007 were synthesized using two conceptual modeling approaches. A basic conceptual model was developed that included the following major components: 1) *previous abundance levels*, which describes how continued low abundance of adults leads to juvenile production; 2) *habitat,* which describes how water quality variables (including contaminants and toxic algal blooms) affect estuarine species; 3) *top-down effects*, which posits that predation and water project entrainment affect mortality rates; and 4) *bottom-up effects*, which focuses on food web interactions in Suisun Bay and the west Delta. Our second set of conceptual models focused on temporal and species-specific interactions of these stressors. Towards this end, we developed individual conceptual models for each species that incorporate seasonal and geographic variability in how stressors act upon a species. We also began to consider how stressors may interact in their effects on each species.

Many studies initiated either by the POD or by others that will provide important POD information are still in progress. We provide preliminary results from these studies whenever possible, but peer-reviewed products will not be available for some time to come. Readers should be cautious when evaluating the relative importance of the hypotheses presented in this report. Hypotheses not based on peer-reviewed literature should be viewed with more skepticism but they represent the newest thinking on POD issues and may become new areas of research. Highlights of new work completed or ongoing since the previous POD progress report in 2005, organized by major components of the basic conceptual model, include:

1. ***Previous abundance*** Recent analyses highlight that stock-recruitment mechanisms and survival among life stages have changed from what was found in earlier pre-POD work. Striped bass, longfin smelt, and threadfin shad previously were able to recover from low abundances, but now show limited resilience. Delta smelt now seem to exhibit a significant stock-recruitment relationship possibly because adult abundance is exceptionally low, so summer survival is a less important factor than it may have been in controlling the population abundance.

2. ***Habitat*** New analyses of water quality data collected concurrently with fish data highlight the importance of Secchi depth (i.e., water clarity or turbidity), specific conductance (a surrogate for salinity), and water

temperature. These relationships vary with season for the three POD species inhabiting the Delta for which data were analyzed. These results have focused new discussion about what constitutes "good habitat" for pelagic fishes. Some incidences of contaminant effects have been observed in bioassay tests of Delta waters; however, the significance of these results for POD fishes or other Delta species needs to be determined.

3. ***Top-down*** Striped bass and largemouth bass are probably the major predators on larger fishes in the Delta. The importance of striped bass as a predator on fishes is well known and there is no indication of a major change during the POD years. Largemouth bass has become more abundant concurrent with the invasion of the aquatic macrophyte *Egeria densa*, which has increased habitat for largemouth bass and other invasive species. Although the increase in largemouth bass seems an unlikely single cause for the POD declines, the increase may be an important contributing factor and will likely make recovery more difficult. Entrainment at the CVP and SWP pumps also seems to be an unlikely single cause of POD but may be important in some years for some species. Removal of pre-spawning delta smelt may be especially important. Recent analyses have focused on the importance of reverse flows in Old and Middle rivers and the possible importance of turbidity as an environmental trigger for upstream migration of delta and longfin smelt.

4. ***Bottom-up*** The importance of co-occurrence of fish with food continues to be a key area of interest. Much of this discussion focuses on food resources for delta smelt. Overall, total biomass of zooplankton has not changed substantially in delta smelt summer habitat; however species composition has changed. New work is focusing on which zooplankton are available to delta smelt (i.e., can delta smelt catch them) and if there are differences in energetic profitability among prey (i.e., does it take more energy to catch.)

The integration of information that has occurred as a result of preparing this progress report has suggested several areas of research for new or augmented ongoing studies. These areas of research will be highlighted in the 2008 POD workplan which is in preparation.

ntroduction

The San Francisco Estuary has been an area of intense interest to humans for many thousands of years because of the ecosystem services it provides. Native Americans exploited the rich food resources available. With the settlement of Europeans, exploitation of resources broadened and accelerated particularly in the mid-1800s. Draining of wetlands for agriculture and urbanization combined with development of an extensive infrastructure for water management and other human activities have been accompanied by declines in nearly all species of native fish (Moyle 2002; Brown and Moyle 2005). The construction and operation of two large water projects, the federal Central Valley Project (CVP), and the State Water Project (SWP) have been especially important. The potential negative effects of these projects on important fisheries were recognized and extensive efforts were made to mitigate the expected effects. Salmon hatcheries were established below some dams and extensive fish screening facilities were established at the pumping facilities in the Delta (Brown et al. 1996). Despite these efforts, populations of important fish species continued to decline in the San Francisco Estuary and its watershed, culminating in listings of a number of species in the 1990s, including winter-run and spring-run Chinook salmon *Oncorhynchus tshawytscha*, Central Valley steelhead *O. mykiss*, delta smelt *Hypomesus transpacificus*, and Sacramento splittail *Pogonichthys macrolepidotus*.

The four primary pelagic fishes of the upper estuary (delta smelt, longfin smelt *Spirinchus thaleichthys*, striped bass *Morone saxatilis*, threadfin shad *Dorosoma petenense*), have shown substantial variability in their populations, with evidence of long-term declines for the first three of these species (Kimmerer et al. 2000; Bennett 2005; Rosenfeld and Baxter 2007). For the three declining species, a substantial portion of the abundance patterns has been associated with variation of outflow in the estuary. However, Fall Midwater Trawl abundance indices for these four pelagic fishes began to decline sharply around 2000, despite relatively moderate hydrology which typically supports at least modest fish production (Sommer et al. 2007). The situation deteriorated over the next several years; abundance indices for 2002-2006 included record lows for delta smelt and age-0 striped bass, and near-record lows for longfin smelt and threadfin shad. By 2004, these declines became widely recognized and discussed as a serious management issue, and collectively became known as the *Pelagic Organism Decline (POD)*.

In response to the POD, the Interagency Ecology Program (IEP) formed a study team in 2005 to evaluate the potential causes of the decline (Sommer et al. 2007). The team organized an interdisciplinary, multi-agency effort including staff from California Department of Fish and Game, California Department of Water Resources, Central Valley Regional Water Quality Control Board, U.S. Bureau of Reclamation, U.S. Environmental Protection Agency, U.S. Geological Survey, California Bay Delta Authority, San Francisco State University, and the University of California at Davis. The study was based on a basic conceptual model of the decline, which continues to be updated and revised as new results are available.

Purpose

The major goal of this report is to synthesize the information collected by the POD investigation. Our approach to synthesize this information is to revise our previous general conceptual model (Sommer et al. 2007) and introduce new conceptual models for each of the POD species: delta smelt, striped bass, longfin smelt, and threadfin shad. The information used in the synthesis is based primarily on information collected through August 2007. We also introduce important new information from fall 2007 (highlighted in *italics*) to reflect the fact that important additional progress has been made in recent months. These newer results are primarily included in the discussions of conceptual models for individual fish species.

Because the POD involves multiple species in a highly variable and heavily-modified environment with multiple and often interacting stressors, we relied on a *weight of evidence* approach (Burkhardt-Holm and Scheurer 2007) to interpret the results from the large number of POD studies. Using this approach, we examined the multiple types of evidence to develop plausible linkages within our conceptual models. This approach was especially important in the development of the four "species models." As an outcome of this approach, the present synthesis of the POD results focuses on the linkages within the conceptual models and their contributions to the overall "POD story" and the individual "fish species stories" rather than providing in-depth examinations of relationships between individual stressors and fish abundance.

Many of the POD studies have not been completed or fully evaluated and we wish to emphasize that our conceptual models represent works in progress. Hence, this progress report will be followed by a more complete data synthesis in 2008. This report is the first of two synthesis reports resulting from a new collaboration of the Interagency Ecological Program (IEP) with the National Center for Ecological Analysis and Synthesis (NCEAS). The present report is primarily a product of the IEP POD management team with input from the NCEAS-POD steering committee. The NCEAS-POD steering committee and work groups will take a larger role in developing the 2008 synthesis report.

This report is divided into several major sections. We first provide some basic background on the POD fishes and review the history of the POD. Second, we present a general conceptual model for the POD. This is basically an update of the conceptual model in the 2005 report. Finally, we develop more detailed conceptual models for each of the POD fishes.

This report has the same limitations as earlier reports from the POD management team. Specifically, many studies initiated by the POD or initiated by others that will provide important POD information are still in progress. Preliminary results from these studies are provided whenever possible, but peer-reviewed products from these studies may not be available for some time to come. We encourage readers to be cautious when evaluating the relative importance of the hypotheses presented in this report. Hypotheses not based on peer-reviewed literature should be viewed with more skepticism. We present them because they represent the newest thinking on POD issues and may become new areas of research.

Descriptions of completed, ongoing and new POD-related studies are being compiled in the 2008 POD workplan.

Background

One of the interesting features of the POD fish declines is that the declining fish species have many differences in their individual life histories. We briefly review the general life history of each species based on descriptions in Moyle (2002) as background for understanding the remainder of the report. Readers are referred to Moyle (2002) and the papers cited in the remainder of the report for additional details.

Delta smelt is a slender-bodied fish typically reaching 60-70 mm standard length (SL) with a maximum size of about 120 mm SL. Delta smelt is endemic to the upper San Francisco Estuary, primarily the Delta and Suisun Bay. Delta smelt is generally associated with the low salinity zone locally indexed by X2, which is the location of the 2 psu isohaline measured near the bottom of the water column (Jassby et al. 1995). Delta smelt feed primarily on planktonic copepods, cladocerans, and amphipods. Delta smelt is basically an annual species and spawn in freshwater in the Delta. Upstream migration generally occurs in the late fall or early winter with most spawning taking place from early April through mid-May. Larval delta smelt move downstream with the tides until they reach favorable rearing habitat. A very small percentage of delta smelt is believed to spawn as 2-year olds. Delta smelt was listed as a threatened species by both the federal and state governments in 1993. The species was recently proposed for endangered status.

Longfin smelt typically reach 90-110 mm SL with a maximum size of 120-150 mm SL. In the San Francisco Estuary, longfin smelt generally occur in Suisun, San Pablo, and San Francisco bays as well as in the Gulf of the Farallones, just outside San Francisco Bay. Longfin smelt is anadromous and spawn in the Delta in freshwater. Longfin smelt spawn at 2-years of age. A few female smelt may live a third year but it is not certain if they spawn again. Most spawning takes place from February through April. The larval longfin smelt move downstream with the tides until they reach favorable rearing habitat near X2 and, later, downstream into Suisun and San Pablo bays. Larger longfin smelt feed primarily on opossum shrimps *Neomysis mercedis* and *Acanthomysis* spp. Copepods and other crustaceans can also be important food items, especially for smaller fish. Although other populations of longfin smelt occur on the Pacific Coast, the San Francisco Estuary population was recently proposed for listing under the state and federal Endangered Species acts as a distinct population segment of the species.

Striped bass is native to the Atlantic Coast of North America. It was introduced to California in 1879. Striped bass is a large (> 1 m), long-lived (> 10 years) species. Striped bass is widespread in the San Francisco Estuary watershed as juveniles and adults. The species can be found in the larger river systems downstream of impassable dams and in the coastal ocean. Striped bass is a generalist predator. Larval and juvenile striped bass feed primarily on invertebrates. Larval and small post-larval bass feed mainly on copepods. As the fish grow, they consume larger invertebrates and fishes.

Striped bass is an anadromous mass spawner. Females spawn at 4-6 years of age and can spawn every year depending on environmental conditions. In the Sacramento River, spawning occurs in the upper parts of the tidal portion of the river and lower portions of the riverine portion of the river. A small proportion of spawning occurs in the San Joaquin River within the Delta. Embryos and larvae drift into the Delta and larval striped bass are associated with X2. As the juveniles grow, they disperse throughout the Delta and San Francisco Bay. Although an introduced species, striped bass supports a popular and economically important recreational fishery.

Threadfin shad was introduced to California in 1954 to provide forage for predatory fish in reservoirs. It was planted in the San Francisco Estuary watershed in 1959. Adult threadfin shad are typically less than 100 mm total length and primarily inhabit freshwater, where they omnivorously filter-feed on phytoplankton, zooplankton, and detritus. They can also selectively sight-feed on individual organisms, primarily zooplankton. Most threadfin shad spawn as 1-year olds in their second summer of life, although some may spawn at the end of their first year. Spawning occurs from April to August, but most occurs in June and July. Larval and juvenile threadfin shad are mainly found in the freshwater portions of the Delta. Threadfin shad is the most abundant pelagic fish in the upper estuary and is exceptionally important as prey for piscivorous species.

The apparently simultaneous declines of these four species of fish were surprising because of the differences in their life histories and differences in how each species utilizes Delta habitats. These differences suggested one or more Delta-wide factors to be important in the declines. The following description of the Pelagic Organism Decline is taken directly from Sommer et al. (2007):

"The Interagency Ecological Program (IEP), a consortium of nine state and federal agencies, has been monitoring fish populations in the San Francisco Estuary (Figure 1) for decades, and has developed one of the longest and most comprehensive data records on estuarine fishes in the world. One of the most widely-used IEP databases is fish catch from the Fall Midwater Trawl Survey, which has been regularly conducted by DFG since 1967 (Stevens and Miller 1983; Sommer et al. 1997). This survey samples the pelagic fish assemblage in the upper estuary, the tidal freshwater and brackish portion of the system from the delta to San Pablo Bay. The most abundant resident pelagic fishes captured are two native species, delta smelt (*Hypomesus transpacificus*) and longfin smelt (*Spirinchus thaleichthys*), and two introduced species, striped bass (*Morone saxatilis*) and threadfin shad (*Dorosoma petenense*). The San Francisco Estuary is physically very dynamic, so it is not surprising that annual abundance of all of these populations is extremely variable (Figure 2), and that much of this variability is associated with hydrology (Figure 3). Historically, the lowest abundance levels for the pelagic fishes typically have occurred in dry years, such as a six-year drought during 1987-1992. Consistent with this observation, several of these species show strong statistical associations with flow during their early life stages (Stevens and Miller 1983; Jassby et al. 1995; Kimmerer 2002a).



Figure ap of the A upper San Francisco Estuary and B the Sacra ento-San oa uin Delta

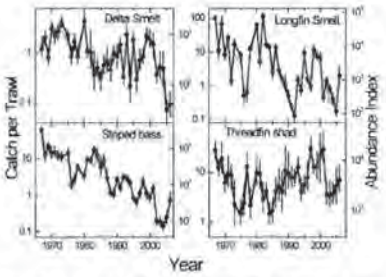


Figure rends in four pelagic fishes fro to based on the Fall idwater rawl, a California Depart ent of Fish and a e survey that sa ples the upper San Francisco estuary Sy bols with heavy lines and error bars left y-a is show ean catch per trawl all stations with appro i ate confidence intervals deter ined by bootstrap analysis i erer and Nobriga , and the thin lines right y-a is show abundance indices No sa pling occurred in or Develop ent of abundance indices fro catch data i described by Stevens and iller Note that the y-a es are on logarith ic scales fro So er et al

The IEP biologists became concerned when Fall Midwater Trawl abundance indices for these four pelagic fishes began to decline around 2000 and deteriorated over the next several years (Figure 2). Abundance indices for 2002-2005 included record lows for delta smelt and age-0 striped bass, and near-record lows for longfin smelt and threadfin shad. By 2004, these declines became widely recognized and discussed as a serious issue, and collectively became known as the Pelagic Organism Decline (POD). Longfin smelt and age-0 striped bass showed some recovery in 2006 but delta smelt and threadfin shad remained at low levels. The abundance of delta smelt is of particular concern because it is listed as a threatened species under both federal and state endangered species legislation.

The extreme variability in the data makes it difficult to say whether these indices are truly at unprecedented low levels. Mean catch per trawl with 95% confidence intervals developed using resampling methods indicate that the recent indices are indeed quite low, and for some species the lowest on record (Figure 2). Abundance improved somewhat for each species during 2006, but the levels remain relatively poor as compared to long-term trends. Moreover, these low abundance levels are remarkable in that winter and spring river flows into the estuary were moderate or very wet (2006) during the recent years (Figure 3), conditions that typically result in at least modest recruitment of most of the pelagic fishes. Longfin smelt is perhaps the best example of this point as the species shows a very strong relationship with delta outflow (Figure 4). The introduction of the overbite clam (*Corbula amurensis*) in 1986 and associated changes in the food web reduced the magnitude of the response of longfin smelt without altering its slope (Kimmerer 2002b). Specifically, the grazing effects from *Corbula* are thought to have resulted in a substantial decline in phytoplankton and calanoid copepods, the primary prey of early life stages of pelagic fishes. As a consequence, comparable levels of flow did not generate the expected levels of fish biomass (as indexed by abundance) after 1986. During the POD years, the abundance indices for longfin smelt deviated substantially from both the pre- and post-*Corbula* relationships with outflow. The situation is similar for young-of-the-year striped bass, whose historical association with outflow was also altered by *Corbula*, whereas the recent abundance indices were well below expected levels based on outflow. Hence, it appears that the response of these pelagic fishes to environmental conditions has fundamentally changed."

The recognition of the POD as an important management issue resulted in IEP undertaking a new program of data analysis and research. The early steps in this program were also summarized by Sommer et al. (2007):

> "In response to the POD, the IEP formed a work team in 2005 to evaluate the potential causes of the decline (IEP 2005, 2006). The team organized an interdisciplinary, multi-agency effort including staff from DFG, California Department of Water Resources, Central Valley Regional Water Quality Control Board, U.S. Bureau of Reclamation, U.S. Environmental Protection Agency, U.S. Geological Survey, California Bay Delta Authority, San Francisco State University, and the University of California at Davis. A suite of 47 studies was selected based on the ability of each project to evaluate the likely mechanisms

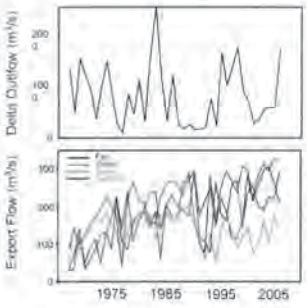


Figure Delta outflow s averaged over water years top and e port flow s averaged over seasons botto Water years begin on October of the previous calendar year Seasons are in - onth incre ents starting in October E port flows are the su of diversions to the federal Central alley Pro ect and State Water Pro ect pu ping plants he outflow and e port data are fro California Depart ent of Water esources http iep water ca gov dayflow fro So er et al

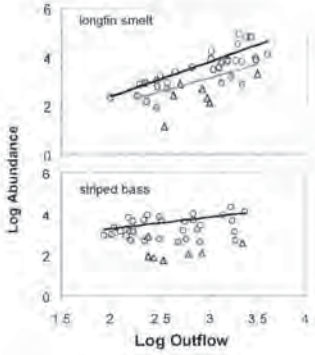


Figure og-log relationships between Fall idwater rawl abundance indices and delta outflow for longfin s elt and young-of-the-year striped bass Delta outflow s values represent the ean levels during anuary une for longfin s elt, and during April uly for striped bass he data are co pared for pre-*Corbula* invasion years white circles , post-*Corbula* invasion filled circles , and during the POD years triangles Fitted lines indicate linear regression relationships that are statistically significant at the P level fro So er et al

for the POD, and the feasibility of each project in terms of methods, staffing, costs, timing, and data availability. In addition to funding for regular IEP monitoring, the program's budget was augmented by $2.4 million in 2005, and $3.7 million for 2006 and 2007 to fund the recommended research."

nitial Conceptual odel Develop ent

Based on the initial observation that fish abundance indices declined abruptly around 2000, the POD Management Team developed an initial conceptual model (IEP 2005). Specifically, we proposed three general factors that may have been acting individually or in concert to lower productivity of pelagic fish populations: 1) toxins; 2) exotic species; and 3) water projects.

After the completion of the first set of studies in late 2005, alternative models were developed based on the results available at that time. Matrix models were created for the four target fish species (delta smelt, longfin smelt, threadfin shad and juvenile striped bass) to summarize the potential role of various stressors in the recent decline. The matrices depicted the consensus of professional judgment of the POD Management Team regarding the extent to which each stressor was likely to have affected each species-life stage during recent years. The level of information used to support the consensus was also ranked. The nine stressors evaluated were: 1) Mismatch of larvae and food; 2) reduced habitat space; 3) adverse water movement/transport; 4) entrainment; 5) toxic effects on fish; 6) toxic effects on fish food items; 7) harmful *Microcystis aeruginosa* blooms; 8) *C. amurensis* effects on food availability; and 9) disease and parasites.

These earlier conceptual models provided a useful way to (1) summarize our understanding of factors that may have contributed to the POD and (2) design the initial suite of research studies; however, they proved to have several shortcomings. First, they did not adequately reflect spatial and temporal variation in the nine stressors evaluated. Second, new data showed several assumptions to be incorrect. Finally, the initial models were relatively cumbersome.

Conceptual odels

The 2007 models represent an improvement over the earlier efforts, but it is important to recognize that they still have numerous limitations. Many of the results and inferences are preliminary at this writing and have not yet been peer-reviewed, so the new models should be considered preliminary, like the previous models. Moreover, the models may have been influenced by potential biases in the sampling programs. Several changes in the size and distribution of the target species have the potential to change our perception of trends in abundances and distributions. This, in turn, would affect our conceptual models. Throughout this discussion we use indices of abundance such as the Fall Midwater Trawl and Summer Townet surveys or catch-per-unit-effort as estimates of abundance. The relationship between these indices of abundance and the actual population size of any species is not known.

Finally, it is important to recognize that the recent decline in pelagic fish species is superimposed over long-term declines for several of these species

and their long-term relationships with other environmental factors. Change-point analyses (Manly and Chotkowski 2006, Manly and Chotkowski, unpublished data) suggest that distinctly different statistical models might be appropriate for different time periods. As described below, a clear line divides the POD era from the years preceding it for some species. There also appear to be multiple periods within the historical record preceding the POD and the periods are not always the same across species. The conceptual models developed here explicitly focus on mechanisms that might have contributed to the decline of pelagic fishes during the POD era. However, the historical antecedents to the POD are a crucial part of the story.

Note that these conceptual models are not intended to exclude other explanations for the observed changes in fish abundance, nor are they designed to set priorities for resource management. Instead, they are intended as examples of how the different stressors may be linked. Moreover, no single model component can explain the declines of all four species. The models will be developed and refined as additional data become available. In the meantime, we believe the new models provide a useful basis for organization of the POD study and the initial synthesis of the results.



Figure he basic conceptual odel for the pelagic organis decline fro So er et al

Basic Conceptual odel

We have developed an intentionally simple basic conceptual model to describe possible mechanisms by which a combination of long-term and recent changes in the ecosystem could produce the observed pelagic fish declines (Figure 5). This conceptual model is rooted in classical food web and fisheries ecology and contains four major components: (1) prior fish abundance, which posits that continued low abundance of adults leads to reduced juvenile production (i.e., stock-recruit effects); (2) habitat, which posits that estuarine water quality variables, disease, and toxic algal blooms in the estuary affect survival and reproduction; (3) top-down effects, which posits that predation and water project entrainment affect mortality rates; and (4) bottom-up effects, which posits that food web interactions affect survival and reproduction. For each model component, our working hypotheses are: (1) the component was responsible for an adverse change at the time of the POD; and (2) this change resulted in a population-level effect. The model components are described in detail in the following sections. The basic conceptual model generally does not evaluate the relative importance of the model components. Often the data are not sufficient to make such judgments. Also it is likely that the relative importance of various components changes with specific environmental conditions (e.g. river flow) within and among years. Finally, the relative importance of factors will differ among the four species. We begin to address this final point in the individual species models presented later in the report.

Previous Abundance

The relationship between numbers of spawning fish and the numbers of young subsequently recruiting to the adult population is known as a stock-recruit relationship. Stock-recruit relationships have been described for many species and are a central part of the management of commercially and recreationally fished species (Myers et al. 1995). Different forms of stock-

recruit relationships are possible, including density-independent, density-dependent, and density-vague types. The latter refers to situations where there is not a statistically demonstrable stock-recruit relationship observable in available data. In any form of a stock-recruit model, there is a point at which low adult stock will result in low juvenile abundance and subsequent low recruitment to future adult stocks even under favorable environmental conditions while the stock 'rebuilds' itself. There is evidence for a density-dependent stock-recruit relationship in San Francisco Estuary striped bass (Kimmerer et al. 2000). However, the adult striped bass stock is currently not particularly low (Figure 6), so stock size is not likely a mechanism contributing to recent very low age-0 striped bass abundance. In other words, there appears to be enough adults in the system for the population to recover.

There is a significant stock-recruit relationship for threadfin shad (Feyrer and Sommer, unpublished data). Fall abundance of pre-adults is a significant predictor of young-of-year abundance the following summer (Figure 7). Similar relationships have been proposed for longfin smelt (Tina Swanson, The Bay Institute, unpublished data). However, current populations of longfin smelt and threadfin shad are similar to low populations observed in previous years (Figure 2). Threadfin shad rebounded fully from previous abundance lows in the 1970s and 1980s. Longfin smelt populations rebounded somewhat in the 1990s following previous lows during the 1987-1992 drought. Note that recovery of these species is only expected if the factors affecting recruitment have not changed substantially. If the factors affecting survival from egg to adult have changed substantially since the beginning of the POD, then recovery might not occur even though recovery from low abundance occurred in the past. The changes in the statistical relationships between outflow and population abundance indices for longfin smelt and striped bass (Figure 4) are evidence that changes in the drivers of recruitment have occurred. These changes are discussed in more detail in subsequent sections.

From a stock-recruit perspective, the present low abundance of delta smelt is of particular concern. The current population is an order of magnitude smaller than at any time previously in the record (Figure 2). The delta smelt stock-recruit relationship appears to be density vague over the entire period that data is available (Bennett 2005), meaning there is no clear relationship between the adult spawning population and the number of adult recruits expected in the following year, as measured by the Fall Midwater Trawl. There was also a historically weak statistical association between summer abundance (as measured by the Summer Townet Survey) and abundance a few months later during the Fall Midwater Trawl Survey, suggesting that delta smelt year-class strength was often set during late summer. However, Feyrer et al. (2007) found that the abundance of pre-adult delta smelt during fall was a statistically significant predictor of juvenile delta smelt abundance the following summer, for the time period 1987-2005. Similarly, delta smelt summer abundance is a statistically significant predictor of fall abundance. These relationships are particularly strong for the period 2000-2006 (Figure 8). The strong relationship in summer to fall survival since 2000 (Figure 8) suggests that the primary factors affecting juvenile survival recently changed and shifted to earlier in the life cycle. These observations strongly suggest

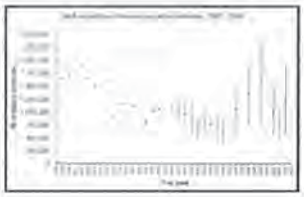


Figure Peterson population esti ates of the abundance of adult striped bass total length fro to Error bars represent confidence intervals California Depart ent of Fish and a e, unpublished data Confidence intervals are not shown previous to Striped bass were only tagged during even years fro to , so no esti ates are available for odd years during that period

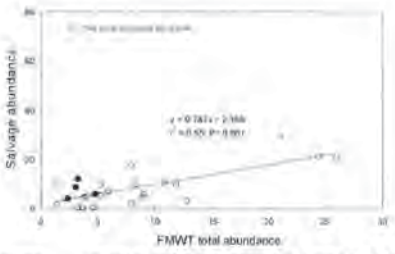


Figure elationship between overall Fall idwater rawl catch per trawl of threadfin shad and the following su er s age- C P salvage abund Shaded points represent the recent ye s of low abundance - he regression line was fitted through all points e cept the ano alously high value in the upper left corner labeled as e cluded fro Feyrer and So er, unpublished data

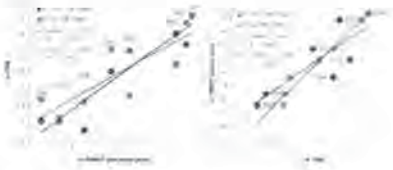


Figure elationships between uvenile and adult lifestages of delta s elt since he ownet Survey is a easure of su er uvenile abundance he Fall idwater rawl is a easure of fall pre-spawning adult abundance he blue circles represent the data fro the full ownet Survey which begins in une and ends when the average fork length of striped bass reaches he red s uares represent data fro uly only egression e uations and coefficients are given in blue font for the full ov Survey data and in red font for the ownet Survey data

that recent population trends are outside the historical realm of variability and resilience shown by these species, particularly delta smelt. Thus, recovery is likely to require changes in the stressors that have produced the current low levels of abundance and perhaps stressors that have since become more important.

Given the unprecedented low abundance of delta smelt since 2000 (Figure 8), serious consideration should be given to evaluation of Allee effects. Allee effects occur when reproductive output per fish declines at low population levels (Berec et al. 2006). In other words, below a certain threshold the individuals in a population can no longer reproduce rapidly enough to replace themselves and the population spirals to extinction. For delta smelt, possible mechanisms for Allee effects include mechanisms directly related to reproduction and genetic fitness such as difficulty finding mates, genetic drift, and inbreeding. Other mechanisms related to survival such as increased vulnerability to predation are also possible and will be briefly discussed in the "top-down" model component section. The interactive effects of multiple Allee effects have not been well explored in ecology and may have important implications for species conservation (Berec et al. 2006).

abitat

Aquatic habitats are the suites of physical, chemical, and biological factors that species occupy (Hayes et al. 1996). The maintenance of appropriate habitat quality is essential to the long-term health of aquatic resources (Rose 2000; Peterson 2003). For the habitat component of the model, a key point is that habitat suitability affects all other components of the model (Figure 5). Hence, changes in habitat not only affect pelagic fishes, but also their predators and prey. Although not a focus of this report, we expect that the habitats of the POD species are especially vulnerable to future climate change. Thus, any findings regarding habitat must be considered in light of expected changes in climate and changes in water management operations anticipated in response to climate change.

Pelagic Fish Habitat

Habitat for pelagic fishes is open water, largely away from shorelines and vegetated inshore areas except perhaps during spawning. This includes large embayments such as Suisun Bay and the deeper areas of many of the larger channels in the Delta. More specifically, pelagic fish habitat is water with suitable values for a variety of physical-chemical properties, including salinity, turbidity, and temperature, suitably low levels of contaminants, and suitably high levels of prey production to support growth. Thus, pelagic fish habitat suitability in the estuary can be strongly influenced by variation in freshwater flow (Jassby et al. 1995; Bennett and Moyle 1996; Kimmerer 2004). Several of the POD fishes use a variety of tidally-assisted swimming behaviors to maintain themselves within open-water areas where water quality and food resources are favorable (Bennett et al. 2002). The four POD fishes also distribute themselves at different values of salinity within the estuarine salinity gradient (Dege and Brown 2004), so at any point in time, salinity is a major factor affecting their geographic distributions. As mentioned earlier, pelagic habitat quality in the San Francisco Estuary can be characterized by changes in X2. The abundance of numerous taxa increases

in years when flows into the estuary are high and the 2 psu isohaline is pushed seaward (Jassby et al. 1995), implying that the quantity or suitability of estuarine habitat increases when outflows are high.

Based on a 36-year record of concurrent midwater trawl and water quality sampling, there has been a long-term decline in fall habitat environmental quality for delta smelt and striped bass, but not for threadfin shad (Feyrer et al. 2007). The long-term environmental quality declines for delta smelt and striped bass are defined by a lowered probability of occurrence in samples based on changes in specific conductance and Secchi depth. Notably, delta smelt and striped bass environmental quality declined recently coinciding with the POD (Figure 9). The greatest changes in environmental quality occurred in Suisun Bay and the San Joaquin River upstream of Three Mile Slough and southern Delta (Figure 10). There is evidence that these habitat changes have had population-level consequences for delta smelt. The inclusion of specific conductance and Secchi depth in the delta smelt stock-recruit relationship described above improved the fit of the model, suggesting adult numbers and their habitat conditions exert important influences on recruitment.

The importance of salinity in this study was not surprising, given the relationships of population abundance indices with X2 for many species. Fall salinity has been relatively high during the POD years, with X2 positioned further upstream, despite moderate to high outflow conditions during the previous winter and spring of most years. Recent increases in fall salinity could be due to a variety of anthropogenic factors although the relative importance of different changes have not yet been fully assessed. *Initial results from 2007 POD studies have identified increased duration in the closure of the Delta Cross Channel, operations of salinity gates in Suisun Marsh, and changes in export/inflow ratios (i.e. Delta exports/reservoir releases) as contributing factors. There appeared to be a curious anomaly in the salinity distribution of delta smelt collected during the September 2007 survey of the Fall Midwater Trawl. All seven delta smelt collected during this survey were captured at statistically significant higher salinities than what would be expected based upon the relationship generated by Feyrer et al. (2007). There could be any number of reasons why this occurred, including the substantial Microcystis bloom which occurred further downstream than normal and may have affected the distribution of biological organisms.*

The importance of Secchi depth (a measure of water clarity or, conversely, turbidity) in the long-term changes in pelagic fish environmental quality (Feyrer et al. 2007) was more surprising. Unlike salinity, interannual variation in water clarity in the Delta is not primarily a function of flow variation (Jassby et al. 2002). The primary hypotheses to explain the increasing water clarity are (1) reduced sediment supply due to dams in the watershed (Wright and Schoellhamer 2004), (2) sediment washout from very high inflows during the 1982-1983 El Nino (Jassby et al. 2005), and (3) biological filtering by submerged aquatic vegetation (Brown and Michniuk 2007; Dave Schoellhamer, USGS, unpublished data). In lakes, high densities of *Egeria densa* and similar plants can mechanically filter suspended sediments from the water column (Scheffer 1999). Vegetation has also been

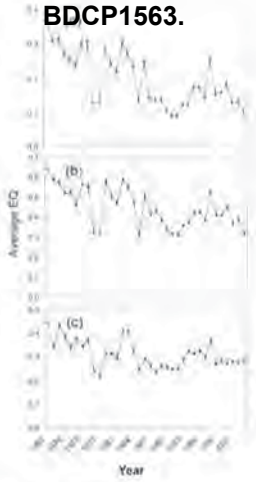


Figure Annual values standard errors of environ ental uality E for a delta s elt, b threadfin shad, c striped bass in San Francisco Estuary based on data fro the Fall idwater rawl fro Feyrer et al E is the probability of capturing the species in a sa ple based on values of specific conductance and Secchi depth for delta s elt and striped bass and based on values of water te perature and specific conductance for threadfin shad

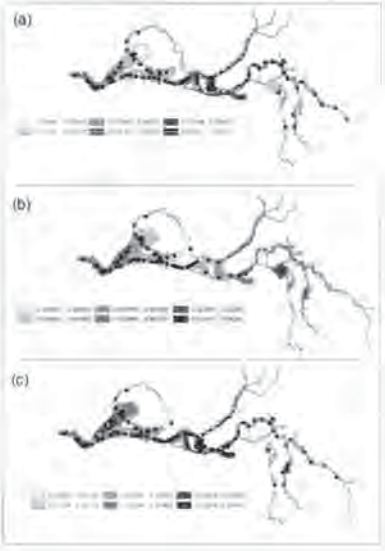


Figure Spatial distribution of long-ter trends in annual E for a delta s elt, b threadfin shad, c striped bass in San Francisco Estuary shown for the region bordered downstrea at Car uine Strait Color shading represents the coefficient for the year ter for individual linear regressions of E versus year for each station ighter shading represents a ore negative slope Open circles and filled circles represent stations with non-significant P or significant regressions P , respectively fro Feyrer et al

shown to facilitate sedimentation in marshes and estuaries (Yang 1998; Braskerud 2001; Pasternack and Brush 2001; Leonard et al. 2002). The mechanisms causing the negative associations between water clarity and delta smelt and striped bass occurrence are unknown, but based on research in other systems (e.g. Gregory and Levings 1998), Nobriga et al. (2005) hypothesized that higher water clarity increased predation risk for delta smelt, young striped bass, and other fishes typically associated with turbid water.

Initial results from a POD-funded study indicate that E. densa, an introduced species, is continuing to spread by expansion of existing patches and invasion of new areas (Erin Hestir et al., UC Davis, unpublished data). Areal coverage of E. densa increased more than 10% per year from 2004 to 2006. Light penetration and water velocity are the factors likely controlling its distribution in the Delta and salinity likely limits its penetration into the estuary (Hauenstein and Ramirez 1986). In clear water, E. densa can grow to depths of 6 m (Anderson and Hoshovsky 2000). If Delta clearing continues, it seems likely that E. densa will spread into progressively deeper water.

Trends in environmental quality for delta smelt differ during the summer period. Specific conductance, Secchi depth, and water temperature all significantly predict delta smelt occurrence in summer, suggesting they all interact to affect delta smelt distribution (Nobriga et al. in press). However, none of the water quality variables were correlated with delta smelt abundance (as indexed by the Summer Townet Survey) at the scale of the entire estuary (Nobriga et al. in press). Based on these habitat variables, Nobriga et al. (in press) identified three distinct geographic regions that had similar long-term trends in the probability of delta smelt occurrence. The primary habitat region was centered on the confluence of the Sacramento and San Joaquin rivers near Sherman Island; delta smelt relative abundance was typically highest in the confluence region throughout the study period. There were two marginal habitat regions, one centered on Suisun Bay where specific conductance was highest and delta smelt relative abundance varied with specific conductance. The third region was centered on the San Joaquin River and the southern Delta. The San Joaquin River region had the warmest water temperatures and the highest water clarity. Water clarity increased strongly in this region during 1970-2004. In the San Joaquin River region, delta smelt relative abundance was correlated with water clarity; catches declined rapidly to zero from 1970-1978 and remained consistently near zero thereafter. These results support the hypothesis that basic water quality parameters are predictors of summer delta smelt relative abundance, but only at regional spatial scales. These regional differences are likely due to variability in habitat rather than differences in delta smelt responses. Water management operations are targeted on keeping the lower Sacramento and San Joaquin rivers fresh for water exports so the range in salinity is probably smaller than the range in turbidity. In the Suisun Bay region, there is a wider range of salinities relative to the other regions, so a response to that variable is possible.

MEETING SUMMARY

BDCP Interactive CalLite Screening Evaluations II – December 1-2, 2008

ATTENDEES:	Allison Dvorak, SWC	Mitchell Mysliwiec, Larry Walker & Associate
	Tom Boardman, SLDMWA	Chet Bowling, USBR
	Jim White, DFG	Spreck Rosekrans, EDF
	Steve Ottemoeller, Friant W.A.	Justin Fredrickson, CFBF
	Richard Denton, for CCWD	Maurice Hall, TNC
	Brett T. Kawakami, CCWD	Derya Sumer, CH2M HILL
	Nazrul Islam, DWR	Armin Munévar, CH2M HILL
	David Fullerton, MWD	Nadira Kabir, URS-Washington Group
	Chuck Hanson, Hanson Evironmental	Yvette Redler, NMFS
	Les Grobar, SWRCB	Karen McCartney, NMFS
	Cindy Kao, SCVWD	Rosalie Del Rosario, NMFS
	Liz Kiteck, USBR-CVO	John Cain, NHI
	John Burke, USBR	Michael Hoover, USFWS
	Sushil Arora, DWR	Dan Easton, MBK Engineers
	Walter Bourez, MBK	
COPIES:	Laura King-Moon, SWC	Paul Cylinder, SAIC
FROM:	Armin Munévar, CH2M HILL	
DATE:	October 15, 2008	

A second round of interactive screening evaluations was held on Monday December 1st and Tuesday December 2nd ant the State Water Contractors building. Allison Dvorak, John Cain, and Armin Munévar led the group through the interactive evaluation sessions.

This two-day session was designed to evaluate four scenarios on the first day and apply "themes" to explore component integration. Five scenarios were chosen to be evaluated based on findings of the first interactive session that was held in October: Fully Isolated North Delta Diversion, Fluctuating Delta Salinity, Increased Spring Inflow, Increased Spring Delta Outflow, and Increased Fall Delta Outflow.

Armin Munévar provided an overview of the scenarios and the reference scenarios to which scenarios would be compared; and the group discussed about general assumptions for all scenarios.

Before evaluating scenarios, Armin showed comparisons of model simulated unimpaired versus operational flow patterns at key locations of the system (Sacramento River at Keswick, Feather River at Thermalito, American River below Folsom, Sacramento River at Verona, and Sacramento River at Freeport). The general observation was that the hydrographs immediately downstream of the major reservoirs was significantly shifted

from spring to summer. Keswick and Thermalito hydrographs showed that unimpaired flow peaked during February through April while operational flows showed significant increases in summer, particularly in July. River flows downstream of Nimbus were less shifted from unimpaired due to the operational requirements and lower storage to inflow ratio at this facility. The hydrograph shifts were considerably greater upstream than at downstream points such as Verona and Freeport due to the significant unregulated flows downstream of the reservoirs.

The following notes summarize the scenarios, observations, and lessons learned from the interactive session. For each scenario simulated in CalLite, the model was run with sub-scenario 1 equal to Existing Facilities with D-1641 standards and sub-scenario 2 equal to a "Basic Dual Conveyance" operation. Thus, the first operational changes for the specific scenario to be analyzed begin with sub-scenario number 3 (i.e. 2_3 for Scenario 2).

Scenario 1: Fully Isolated North Delta Diversion

Objective/Hypothesis

- The concept of this scenario is to explore a fully isolated diversion at Hood (i.e. no South Delta pumping); thus opening much of the central and southern Delta for restoration.

Scenario 1_3

Assumptions:

- Fully isolated north Delta diversion subject to the "basic dual" Hood bypass flow operations
- Initial assessments during the previous CalLite session indicated that significant reductions in exports would occur and that upstream storage would increase. Flow targets were suggested for Freeport in order to achieve desired inflows to the Delta. The operational rules in CalLite held water in storage rather than pay the very high costs of achieving target exports. CalLite was modified to include more appropriate operational rules that would force upstream releases to meet minimum level of exports.
- Group discussed how to operate Delta Cross Channel and initial assumption of opening gate in July and August was accepted.

Observations:

- Simulated operations in this scenario forced releases from upstream in order to make deliveries south of Delta. Under Hood bypass scenarios significant releases are normally required to achieve even the first acre-foot exports. Upstream storages was reduced significantly due to this effect. Considerable drawdown was observed in Shasta and, to a lesser degree, Oroville.

- Project exports were decreased by approximately 600 TAF/YR under this operation. However, it is anticipated that this decrease would be even larger once the study was balanced with more appropriate delivery allocation logic that would reduce impacts to upstream storage.

- There was significant discussion and debate whether to refine this scenario with improved allocation logic. Armin and Walter indicated that this should be done, but that this is not a trivial task and was beyond the initial goal of this session. Spreck questioned the effectiveness of the model and the run and proposed changing demand patterns in the model. Others indicated that this is likely to be scenario to be evaluated in the EIR/S and could be refined later. The general conclusions was that the allocation logic in the model could and should be fine-tuned to accommodate this new system configuration, but that the general observations of effect on exports and some impact to upstream storage would likely remain (although the magnitude of effect on storage is unknown). Impacts to project exports would likely increase with refinement to the allocation logic.
- Delta salinity showed improvement in comparison to earlier analysis. In general, salinity was decreased due to reduced exports and increased Delta outflow. The effect of no south Delta pumping, increases in salinity, was observed primarily in fall and primarily at Victoria Canal stations. X2 was observed to be further west in spring due to reduced exports and increased outflow.
- Exports were often controlled by the Rio Vista flow requirements in July-August period and by Hood Bypass flows in spring.
- There was a discussion about frequency of not meeting core deliveries (Tom Boardman). John Burke stated that the frequency would go further up if the model was refined. Walter Bourez argued that the San Luis operations would change accordingly and projects would be able to meet core demands after refinement in the allocation logic.
- Some discussion that the fully isolated scenario may be a more realistic scenario under sea level rise and/or significant levee failure. David Fullerton suggested that south Delta diversions may continue even under this scenario, just at a reduced rate and would not likely be curtailed indefinitely.

Key Lessons Learned

- Need to refine allocations logic in CalLite to better estimate water cost of this scenario. An expected outcome is considerably lower allocations (deliveries) and improved reservoir storage conditions.
- Limitations on total exports are often controlled by the Hood Bypass requirements and Rio Vista flow requirements
- Need to be aware that fully isolated scenario may not meet water supply objectives. Also need to make the isolated facility strong enough to withstand failure.

Next Steps

- Refine model delivery allocation and San Luis rule curves to better simulate system operations under this new configuration.
- Evaluate this scenario with new North of Delta and South of Delta
- Consider operations with a larger canal a larger canal capacity.

- Evaluate this option with varying Hood bypass flow requirements (Allison Dvorak)
- Consider including an end-of April Shasta storage rule to manage for upstream storage for temperature and instream needs (John Burke)

Scenario 2: Fluctuating Delta Salinity

Objective/Hypothesis

- Variable salinity (increasing salinity in summer and fall of dry years) provides a competitive advantage to native species

Scenario 2_3

Assumptions:

- Net Delta outflow requirement to be relaxed during Jul-Sep to 4000 cfs in W, 3000 cfs in AN, 2000 cfs in BN, 1000cfs in D and 0 cfs in C years.
- Rio Vista, salinity, and EI ratio standards are not included.

Observations:

- X2 location moved eastward during fall, but recovered rather quickly (usually by Dec) to similar conditions to the baseline due to natural runoff.
- 200 TAF/YR supply gain with respect to "basic dual" simulation due to decreased Delta outflow requirements
- Higher fall and/or summer salinity can be managed with a rather rapid return to fresher western Delta conditions in early winter.
- South delta water quality could be severely degraded during these times without mitigating actions such as increased San Joaquin flows or canal turnouts, but rate of recovery is unknown without DSM2 modeling
- Upstream storage is significantly enhanced and coldwater pools would be improved, but river flows would be reduced. Re-imposition of Rio Vista requirements would help mitigate these reductions.
- Exports are improved under a variable salinity assumption, particularly with the summer salinity encroachment.
- X2 K-M equation probably should not be viewed as accurate much beyond 100 km or so, as it was calibrated on historic conditions and may be extrapolating at lower outflow levels.
- Results showing rapid salinity recovery may not be fully applicable in the south Delta as CalLite does not include the dynamics of responding to salt trapping. In addition, ANNs that produce salinity should be viewed as approximate for these locations.

Scenario 2_4

Assumptions:

- Same assumptions as 2_3 except Rio Vista flow requirements per D1641

Observations:

- Results are almost the same except Rio Vista flows are improved in July. Delta outflow, QWEST and OMR flows are almost the same and 200 TAF of supply gain has not changed.
- Salinity is dominated by the net Delta outflow and was not significantly changed.
- Comments from the group that this scenario is not really "variable salinity" as the summer-fall X2 was allowed to migrate eastward.
- Salinity degradation at several Delta locations was mentioned as a concern for NDWA, CCWD, City of Antioch, and others
- Fullerton expressed concern about the impact of this in combination with toxics; decreased outflows could increase toxic concentrations

Scenario 2_5

Assumptions:

- Same assumptions as Scenario 2_4 except Delta outflow requirement of 1000 cfs replaces the 0 cfs requirement in all C years.

Observations:

- The extreme high X2 values that were occasional present in previous scenarios were generally limited to about 100 km with the 1,000 cfs outflow
- It was suggested that biologist be engaged to better understand whether the variation in summer X2 simulated in the model is within the range suitable for species of interest
- Concern was again raised that salinity trapping in the south Delta could prolong response times beyond that considered in the CalLite model
- Salinity at Banks PP improved with the addition of 1000 cfs, but EC still exceeded 1000 uS/cm

Key Lessons Learned

- Under variable salinity scenarios, adding back Rio Vista flows do not have a significant impact on the rest of the system or delta conditions.
- Group discussed about use of this scenario as managing salinity (with smaller intrusion) rather than planning for a catastrophic event. It was brought up by David Fullerton that X2 wouldn't recover as quickly in the San Joaquin River. Possibility of limiting X2 intrusion in the model was discussed. Spreck Rosekrans brought up the discussion of biological basis of this scenario. General consensus was that we did not have enough information about key parameters and their biological effect if we wished to manage salinity in Delta.

Next Steps

- It was agreed that to better estimate X2 locations, more detailed hydrodynamic modeling would be required

- In addition, to better understand how to make this scenario more beneficial, biologist opinion was needed for timing, duration, variability, and magnitude of salinity intrusion and its affect on species in Delta. Species experts best guess.
- Justin Fredrickson mentioned the benefits of taking out Delta agricultural and municipal diverters from the equation by meeting part of their demands through North Delta Diversion and not meeting Delta agricultural and municipal salinity standards.
- Better understand the relationship between toxics and reduced outflow

Scenario 3: Increased Spring Inflow

Objective/Hypothesis

- Evaluate Delta operations with increased inflows designed to substantially restore spring hydrographs on rivers.
- Increase frequency and duration of inundation of bypasses and floodplains

Scenario 3_3

Assumptions:

- Target peak flows in March and April to achieve Yolo bypass inundation of approximately 5,000 cfs. If unimpaired flow at Verona would be greater than 40,000 cfs, then target releases from Shasta and Oroville to achieve a minimum of 45,000 cfs (to get 5,000 cfs spill through the modified Freemont Weir). Increased flows were shared between CVP and SWP (55% and 45%).
- CalLite has been modified to provide flows at Verona based on unimpaired flow using a lookup table that gives greater flexibility in testing alternatives for this scenario.
- To better understand daily inundation frequencies, the modeling team also provided a spreadsheet tool that estimates duration and magnitude of flooding on a daily basis based on historical observations.

Observations:

- Yolo Bypass found to be flooded to greater extent. Frequency of spills greater than 30 days is nearly doubled from the current Freemont Weir configuration.
- However, there were limited times (11 months) in which the additional reservoir releases created spills into the bypass when there would not have been spills without specific upstream releases.
- Upstream releases resulted in a water cost of about 260 TAF/YR.

Key Lessons Learned

- This modified Fremont Weir channel and rating curve is inefficient from the standpoint of spills to release ratios as approximately 20,000 cfs is required in the river to achieve 5,000 cfs over the weir.
- Months of flow targets could be varied to achieve substantial biological benefits while eliminating large water cost. Rosalie mentioned Dec-Jan period could be beneficial for winter run salmon.

Scenario 3_4

Assumptions:

- DFG's proposal for San Joaquin River flows is tested without any increased spring flows in Sacramento River to see the net effect on the system.

SJR River Inflows-DFG

San Joaquin River at Vernalis minimum flow (cfs)

	Water Year Type				
Month	W	AN	BN	D	C
Jan	0	0	0	0	0
Feb	0	0	0	0	0
Mar	0	0	0	0	0
Apr	10000	7500	5000	5000	5000
May	10000	7500	5000	5000	0
Jun	10000	7500	5000	0	0
Jul	0	0	0	0	0
Aug	0	0	0	0	0
Sep	0	0	0	0	0
Oct	0	0	0	0	0
Nov	0	0	0	0	0
Dec	0	0	0	0	0

Observations:

- After some discussion of the San Joaquin River restoration flows, it was determined that they would not be included as currently developed (only partial implementation was available). Rather we could acknowledge that some of the water costs needed to achieve the DFG targets would be met by the SJR flows (only March and April)
- Potential water needs for the April through June flow requirements are on the order of 300 TAF/YR
- Approximately 50% of the increase in SJR flows resulted in increased exports while the other 50% showed as an increased OMR and QWEST flows.

Key Lessons Learned

- Group did not have time to further investigate this scenario, however it was agreed to consider this scenario in combination with other scenarios that would complement the benefits and reduce the water cost.

Next Steps

- John Cain would review modifications to Fremont Weir and suggest additional configurations for consideration
- It was suggest that Dec-Jan period could be tried as an alternative to Dec-May.

- Group discussed about making use of San Joaquin River flows and decided to take a look at DFG's proposed flows and its affects on the system.
- Would be beneficial to better understand the break down of spills with the structural modification
- Engineering analysis to develop a more aggressive Fremont weir notch without creating an excessively expensive notch.
- Develop other spring flow targets not related to Yolo bypass inundation.

Scenario 4: Increased Spring Delta Outflow

Objective/Hypothesis

- Evaluate potential for achieving substantially higher Delta outflow targets without creating adverse water temperatures below key reservoirs.

Scenario 4_3

Assumptions:

- X2 targets were explored based on an Feb-Jun 8RI index approach originally develop by Spreck. Some minor off-ramps for extreme critical years were included for 8RI less than 5 MAF

Observations:

- Outflows were frequently at the maximum allowable of 29,000 cfs for extended periods in the spring. This cap on the outflow requirement prevented actual satisfaction of the targets in many years.
- Exports were reduced by approximately 1.2 MAF/YR
- Upstream storage was lowered considerably, especially during the prolonged drought periods.
- Sensitivity run without CVP South of Delta AG and MI demands indicated that the upstream storage declines were largely the effect of the X2 change, rather than due to high CVP delivery patterns under the new requirement

Scenario 4_4

Assumptions:

- Same as Scen 4_3, but off-ramps for no new X2 targeting in years with 8RI less than 8 MAF to reduce impacts to upstream storage

Observations:

- Storage results were somewhat improved over Scenario 4_3, but BN and AN year types appeared to be still causing issues
- The off-ramp was activated in most if not all of the critically dry years

Scenario 4_5

Assumptions:

- Same as Scen 4_4, but including storage minimums of Shasta greater than 2.8 MAF and Oroville greater than 1.0 MAF before targets would be attempted

Observations:

- Results were similar to Scenario 4_4, but with many periods in which the X2 targets were not activated due to storage requirements
- Storage was increased in many years, but drawdown in years like 1928 and 1986 caused long-term reductions throughout the drought periods. Improved forecasting would facilitate improved management under these hydrologic conditions.

Scenario 5: Increased Fall Delta Outflow

Objective/Hypothesis

- Evaluate potential for achieving higher fall Delta outflow targets without creating adverse water temperatures below key reservoirs.

Scenario 5_3

Assumptions:

- Fall X2 targets (Sep-Nov) were explored based on a water year 8RI index approach originally proposed by Peter Vorster
- Storage criteria were included to limit the potential for upstream impacts (Shasta > 2.8 MAF and Oroville > 1.0 MAF)

Observations:

- Fall X2 targets, as constructed as a sliding scale based on the prior water year 8RI, appeared achievable with relatively low water costs
- Targets appeared to be satisfied in many years under current operations
- Project operations for Delta water quality may be obscuring the effect of these operations
- Exports were reduced by approximately 200 TAF/YR as compared to the Basic Dual scenario

Key Lessons Learned

- Spring X2 targets can be achieved in a number of years, but water costs and storage impacts could be large
- Provision of off-ramps based on upstream storage conditions reduced the impact, but failed to protect declining storage during extended drought periods
- Trade-off between upstream storage and coldwater pool management and Delta outflow is considerable
- Fall X2 targets, as constructed as a sliding scale based on the prior water year 8RI, appeared achievable with relatively low water costs

Themes for Combining Multiple Scenarios

At the end of Day 1, group discussed about possible combinations of scenarios for the next day's session. Two themes were identified:

1) Promoting natural flow hydrograph by making use of increased spring flows, fluctuating salinity, and additional south of Delta storage.
2) Partial delivery of agricultural and municipal demands through Delta while providing supply from North Delta Diversion for the remaining amount.

Group agreed to pay attention to protecting upstream storage while trying different scenarios.

Theme 1: Alternatives that Help Restore Natural Hydrograph in Sacramento River and Delta

Objective/Hypothesis

- Evaluate potential for achieving hydrographs closer to natural pattern without creating significant storage drawdown and adverse water temperatures below key reservoirs.

Theme 1_1: Additional South of Delta Storage

Assumptions:

- CalLite was modified to allow an extra south-of Delta storage of 2 MAF. The new storage acts as an addition to San Luis Reservoir. Capacity and storage sharing for each project is available for user input. In this scenario, the new storage parameters were set as a second San Luis Reservoir.
- Operating rules were set such that the existing San Luis reservoir would be filled up first, while the new storage would be drained first. This allowed higher storage in existing San Luis.
- No additional adjustments to model allocation logic were done. Since this type of modification requires bigger effort, it was decided to do further modifications after preliminary results of the new storage.
- All other assumptions are the same as Basic Dual Conveyance.

Observations:

- Average exports were increased by approximately 700 TAF/YR with the addition of new storage. Most of this increase went to increased Article 21 deliveries for SWP, but the delivery allocation rules would have had more of this supply allocated to firm demands. The model's allocation logic was not updated to allocate deliveries considering the new storage and the additional water moved to San Luis was causing more frequent spills.

- Exports were increased at the higher Sacramento River flow periods and the IF usage increased significantly.
- Upstream storage was increased in Shasta and Oroville.
- Some slight increase in Rock Slough salinity over the base (significant over 1641 due to DCC) because less spring outflow (in wetter months of dry periods) translated into increased salinity in later
- Very little change in X2 due to the increase of exports at high flows rather than moderate to low flows

Theme 1_2: Additional South of Delta Storage with Increased Spring Flows

Assumptions:

- Sacramento River flows at Verona are set to 75% of the unimpaired flow at that location in January, February, March and April.
- All other assumptions are the same including the new storage.

Observations:

- Exports increase by approximately of 370 TAF compared to basic dual conveyance was observed.
- Significant storage drawdown was observed throughout the system. Shasta was lower throughout all dry years since it was trying to meet both increased spring flows and Keswick minimum instream flow requirements.
- X2 approximately stayed the same with little increase (westward movement) in fall.

Theme 1_3: Additional South of Delta Storage with Relaxed Spring Flows

Assumptions:

- Sacramento River flows at Verona are set to 60% in Jan-Mar and 50% in April of the unimpaired flow at that location
- All other assumptions are the same including the new storage.

Observations:

- Shasta storage went back up to levels observed in Theme 1_1.
- Exports increased by approximately 600 TAF.
- Group expressed interest in simulating this spring flow schedule with basic dual conveyance scenario to see the net effect of additional storage over the results.

Theme 1_4: Additional South of Delta Storage with Relaxed Spring Flows, More Restrictive Hood Bypass

Assumptions:

- Sacramento River flows at Verona are set to 50 and 60% of the unimpaired flow at that location in January, February, March and April.
- More restrictive Hood Bypass flows were selected.
- All other assumptions are the same.

Observations:

- Exports decreased by approximately 500 TAF compared to basic dual conveyance was observed.
- Group expressed interest in simulating this spring flow schedule with basic dual conveyance scenario to see the net effect of additional storage over the results.

Key Lessons Learned

- Additional south of Delta storage helped projects pump when water is available at low cost and use it when demands are high. This in return helped provide flows closer to natural hydrograph during critical times of the year.

Next Steps

- Adjustments to model needs to be made for a better estimation of water supply benefits.
- An "optimal" percentage and schedule of unimpaired flows at Verona needs to be explored along with a detailed analysis of Yolo Bypass inundation.
- Different alternatives could be investigated to achieve more natural summer time flows while minimizing upstream storage drawdown.

Theme 2: Partial Delivery of Agricultural and Municipal Demands through Delta

Objective/Hypothesis

- Evaluate benefits of allowing in-Delta users to divert a portion of their water from North Delta Diversion and blend it with Delta water to achieve sufficient water quality for users while allowing increased salinity in Delta.

Theme 2_1: Partial Agricultural and municipal Demands from Delta

Assumptions:

- 50% of Delta agricultural users (SD, WD and CD) and 50% of CCWD's demands are met through North Delta Diversion.
- Salinity requirements are dropped.
- All other assumptions are the same as Basic Dual Conveyance scenario.

Observations:

- Salinity increased in Delta as a result of relaxing salinity requirements.
- Exports increased by approximately 150 TAF compared to basic dual conveyance.
- Delta outflow increased as a result of demands met through Hood diversion.

Key Lessons Learned

- This alternative provides increased flexibility for Delta operations.
- Cost/benefit of this alternative was discussed.

Next Steps

- West Delta demands should be taken out from demand to be met by Hood diversion.
- Increased canal capacity can be tried to improve exports.
- Blending only for M&I water should be considered.
- Blending proportion should be optimized by follow-up studies.
- Benefits of additional in-Delta storage could be tested.



CALFED
BAY-DELTA
PROGRAM

Programmatic Record of Decision

August 28, 2000

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APPENDICES

A. Mitigation Measures Adopted in the Record of Decision

B. Mitigation Measures Not Adopted in the Record of Decision

ATTACHMENTS

1. California Environmental Quality Act Requirements
CEQA Findings of Fact
Statement of Overriding Considerations
Certification by the Secretary, California Resources Agency

2. Environmental Water Account Operating Principles Agreement

3. Implementation Memorandum of Understanding

4. Clean Water Act Section 404 Memorandum of Understanding

5. Conservation Agreement Regarding Multi-Species Conservation Strategy

6. Programmatic Endangered Species Act Section 7 Biological Opinions
A. U.S. Fish and Wildlife Service
B. National Marine Fisheries Service

7. Natural Community Conservation Plan Determination

8. Clean Water Act Section 401 Memorandum of Understanding

9. Coastal Zone Management Act Programmatic Consistency Determination

10. Common Acronyms

2.2.6 Conveyance

As indicated in the Preferred Program Alternative, the CALFED Agencies have chosen to pursue a through-Delta conveyance strategy. The CALFED Agencies therefore will take all reasonable actions to optimize the use of the Delta as the means for conveyance of State and Federal project export water.

The CALFED goal for Delta conveyance is to identify and implement conveyance modifications that will improve water supply reliability for in-Delta and export users, support continuous improvement in drinking water quality, and complement ecosystem restoration. More specifically for export and environmental purposes, conveyance improvements are needed to improve the pumping capabilities of SWP export facilities to: (1) restore water project reliability and operational flexibility; (2) allow the EWA to transfer and store water; (3) allow a reliable water transfer market to function; (4) allow SWP facilities to convey larger amounts of water during periods of high quality water in the Delta to improve water quality for urban use; and (5) provide greater capability for SWP facilities to be used to improve the reliability of CVP supplies for both its water users and wildlife refuges. DWR, Reclamation and USACE will lead efforts to implement these conveyance projects.

DWR and Reclamation will work with the other CALFED Agencies to pursue significant improvements in the water conveyance facilities in the Delta in Stage 1, which will be pursued through project-specific environmental review and permitting.

Actions Included in the Programmatic EIS/EIR

The following projects and actions were analyzed on a programmatic basis in the Final Programmatic EIS/EIR. As CALFED Agencies pursue project-specific environmental study, additional project-specific mitigation may be necessary.

South Delta. The specific actions listed below are components of, or are directly related to, the "South Delta Improvement Program" which has been under study and development for a number of years. The CALFED Agencies intend for these actions in the South Delta to address the needs of the export projects, the Delta ecosystem and local, in-Delta agricultural water users. These components will go forward following the completion of project-specific environmental review and permitting. DWR will lead the CALFED Agencies in implementing these south Delta actions. Environmental review will be completed by the end of 2002. These actions, related to providing for more reliable long-term export capability by the SWP and CVP and protection of local diversions in the Delta, are in addition to historic and current efforts (including annual installation of temporary barriers as well as current year local dredging and diversion improvements).

- **Increase SWP pumping from the current limit from March 15 to December 15 to 8,500 cfs; and modify existing pumping criteria from December 15 to March 15 to allow greater use of SWP export capacity.** Increased pumping can be used to increase water supplies through restoring the SWP's operational flexibility as well as allow diversion of a larger proportion of water supplies in the Delta during periods of good water quality. SWP facilities are used first for SWP purposes, as provided for in SWP water supply contracts. Increased pumping capabilities will also increase opportunities to convey water for the CVP, the EWA and water transfers, since the availability of pumping capacity for non-SWP purposes is expected to increase under this action. Such increased pumping is conditional upon avoiding adverse impacts to fishery protection and in-Delta water supply reliability.

    - Complete environmental review by the end of 2002.
    - Secure appropriate regulatory permits by the middle of 2003 to increase pumping up to 8,500 cfs during periods that are currently restricted. This includes completing a project-specific operations plan that addresses the potential impacts of increased pumping. The operations plan will be developed through an open CALFED process. This pumping increase will increase export capability by up to 100,000 acre-feet per month depending on hydrological conditions, fisheries conditions and availability of storage south of the Delta.
    - Full use of this increased pumping capability will require continued implementation of temporary barriers on an annual basis as well as project-specific actions to protect agricultural diversions and navigation in the South Delta.

- **Increase SWP pumping to the maximum capability of 10,300 cfs.** This is to be accomplished through two sets of specific actions set forth below. As the South Delta Improvement Program is fully implemented through the end of Stage 1, the SWP export capability will increase to 10,300 cfs, greatly expanding benefits for all purposes. Full use of this capacity will depend on protection of agricultural diversions and navigation in the South Delta, hydrologic conditions, fisheries conditions, availability of storage south of the Delta, and use for non-SWP purposes.

    - **Design and construct new fish screens at the Clifton Court Forebay and Tracy pumping plant facilities to allow the export facilities to pump at full capacity more regularly.**

        - Complete funding plan by early 2003.
        - Complete facilities design by the middle of 2004.
        - Seek funding and authority to complete initial fish screens, and begin operations and performance testing by the middle of 2006.

- **Dredge and install operable barriers to ensure water of adequate quantity and quality to agricultural diverters within the South Delta.** This will include installation of an operable Grant Line Canal barrier, which will be constructed and operated in accordance with conditions and directions specified by USFWS, DFG and NMFS. In the interim prior to installation of permanent operable barriers, DWR would continue to install temporary barriers on an annual basis.

    - Complete funding plan by early 2003.
    - Complete facilities design by the middle of 2005.
    - Seek funding and authority to complete Head of Old River barrier by the end of 2006.
    - Seek funding and authority to complete Middle River barrier, Tracy barrier and Grant Line Canal barrier by the end of 2007.

- **Design and construct floodway improvements on the lower San Joaquin River to provide conveyance, flood control and ecosystem benefits.** USACE and DWR will work with the other CALFED Agencies to assure that the Comprehensive Study is consistent with this project.

    - Complete environmental studies by early 2003.
    - Complete project design and funding plan by early 2004.
    - Begin construction by the middle of 2005.

- **Reduce agricultural drainage in the Delta.** Actions to reduce such drainage will include early implementation of projects on Veale and Byron tracts to reduce or relocate major sources of drainage into South Delta channels. The purpose of these projects is to minimize elevated salinity and other constituents of concern to drinking water at urban intakes in the South Delta. These projects will be completed prior to completion of the installation of permanent barriers in Old River near the San Joaquin River, Grant Line Canal, Old River near Tracy and Middle River and before SWP pumping can increase to its full capacity of 10,300 cfs during periods that are currently restricted.

North Delta. CALFED will improve flood protection and conveyance facilities in the North Delta for water quality and fishery improvements, and avoid water supply disruptions. The improvements include:

- **Evaluate and implement improved operational procedures for the Delta Cross Channel to address fishery and water quality concerns.** Reclamation will lead this effort, in cooperation with the other CALFED Agencies, particularly the fishery agencies.

- Begin operational studies (such as more intense fish monitoring on both sides of the Cross Channel, opening and closing the gates on tidal cycles, etc.) by October 2000.
- Complete studies and make specific recommendations by the end of 2003.

- **Simultaneously evaluate a screened through-Delta facility on the Sacramento River of up to 4,000 cfs.** The diversion facility on the Sacramento River is an action to be considered only after three separate assessments are satisfactorily completed: first, a thorough assessment of Delta Cross Channel (DCC) operation strategies and confirmation of continued concern over water quality impacts from DCC operations; second, a thorough evaluation of the technical viability of a diversion facility; and third, satisfactory resolution of the fisheries concerns about a diversion facility. The lead agencies for this effort are DWR and Reclamation, in cooperation with the other CALFED Agencies. The historic emphasis has been on a screened diversion at Hood on the Sacramento River. This and other potential sites between and including Hood and Georgiana Slough will be considered as part of this evaluation. (The water quality section below discusses other related water quality actions and how this facility could fit into the broader water quality strategy.)

  - Develop specific study plan by October 2000.
  - Fund and begin studies through CALFED Agency appropriations by October 2000.
  - Complete water quality and fish effects studies and develop recommendations, taking into consideration the results of the Delta Cross Channel operational study above and evaluation of water quality measures, by the end of 2003.
  - Complete environmental review of recommended program. If fish protection conditions are met and facility is found to be necessary, seek funding and authority to begin construction by the end of 2007.

- **Design and construct floodway improvements in the North Delta (such as on the lower Mokelumne River and Georgiana Slough) to provide conveyance, flood control and ecosystem benefits.** The CALFED Agencies intend that final development and implementation of actions under the Comprehensive Study will be coordinated and consistent with the CALFED Bay-Delta Program.

  - Complete environmental studies by early 2003.
  - Complete project design and funding plan by early 2004.
  - Make decision whether to seek funding and authority to begin construction by the middle of 2005.

Interties. The CALFED Agencies will pursue a number of interties and bypasses in the water system.

- **An intertie between the SWP and CVP facilities at or near Tracy.** This short channel between the State and Federal canals would allow operators to take advantage of fluctuations in Delta water quality at the two project intakes, delivering higher quality to either project canal.

    - Complete environmental work and project design by the middle of 2004.
    - Complete funding plan by the middle of 2004.
    - Make decision whether to seek funding and authority to begin construction by the end of 2004.
    - Assess the connection of the CVP to the SWP's Clifton Court Forebay with a corresponding increase in the Forebay's screened intake.

Complementary Actions

The Framework identified the following actions, which were not analyzed in the Final Programmatic EIS/EIR and will, therefore, require additional environmental review:

- **Install and operate temporary barriers in the south Delta until fully operable barriers are constructed as the South Delta Improvements Program is implemented.** The purpose of this program is to increase water levels in the south Delta for agricultural irrigators in the area to ensure they have an adequate water supply for diversion until such time as a permanent south Delta solution is provided through implementation of other conveyance facilities identified in the South Delta Improvements Program. The Temporary Barriers Program (TBP) has been in place through 1991-2000. One of the barriers in the TBP is the spring Head of Old River barrier which is a critical component of the Vernalis Adaptive Management Plan, an action which the CALFED Agencies have identified for immediate implementation. The TBP is an annual activity requiring the preparation of environmental documentation, securing required regulatory and access permits, interagency coordination, monitoring, modeling, installation, operation and removal. This is ongoing, beginning in FY 2000-2001.

- **Take actions to protect navigation and protect local diverters in the south Delta who are not adequately protected by the TBP.** Although the south Delta barriers provide adequate protection to much of the south Delta, there are still some diverters who suffer from low water levels because they are downstream or located too far away from the barriers. Actions which need to be taken to protect these diverters may include: installation and operation of portable pumps, limited project-specific dredging of existing intakes, and/or project-specific modification to existing diversion structures including the conversion of siphons to pumps. This action requires preparing detailed plans at each diversion location, preparing permit applications, preparation of environmental documentation (as needed), securing applicable permits and funding and finalizing agreements with the diverter as to the scope of work to be done and funding of the work.

Final Draft

CALFED Water Quality Program
Stage 1 Final Assessment

Prepared by:

CALFED Water Quality Program

October 2007.

Executive Summary

The CALFED Water Quality Program (WQP) Stage 1 Final Assessment has multiple purposes: it provides a drinking water quality context for the End of Stage 1 Delta conveyance decision; it integrates and synthesizes the scientific information of Delta drinking water quality from the source to the tap; it uses this synthesis to measure Stage 1 progress and identify water quality actions for Stage 2; and, it attempts to move the WQP to a performance-based program. This report accomplishes this by presenting new analysis along with the synthesis of several recent related studies.

New information was developed by WQP staff and through the financial support of the U.S. Bureau of Reclamation and the CALFED Science Program. URS and Brown & Caldwell were retained to support this report's development.

What is the problem?

The general objective of CALFED agencies is to "continuously improve Delta water quality for all uses, including in-Delta environmental and agricultural uses." The CALFED Water Quality Program has focused on the drinking water objective to "provide good water quality for the millions of Californians who rely on the Delta for all or a part of their drinking water." In the CALFED Bay-Delta Program Record of Decision (2000) the goal of the WQP is to provide "safe, reliable, and affordable drinking water in a cost-effective way," with a target to "achieve either: (a) average concentrations at Clifton Court Forebay and other southern and central Delta drinking water intakes of 50 μg/L bromide and 3.0 mg/L total organic carbon, or (b) an equivalent level of public health protection using a cost-effective combination of alternative source waters, source control, and treatment technologies." Bromide and total organic carbon where singled out as constituents of concern because they can form potentially carcinogenic disinfection byproducts when exposed to disinfectants.

The WQP ROD targets are essentially surrogates for the recognition and continual linkage of source water quality with treated water quality, especially as treated water quality regulations grow increasingly stringent over time. The "equivalent level of public health protection" (ELPH) approach is the backbone of the WQP, and the program is based on the concept of a multiple barrier approach (i.e. "a cost-effective combination of alternative source waters, source control, and treatment technologies"). These objectives are predicated on the assumptions that Delta water is prone to degradation over time and increased use and that treated water regulation is likely to become more stringent in the future.

Where bromide is found at concentrations of concern for drinking water supply in the Delta, the ocean is the source. Uncontaminated freshwater sources in the Delta watershed have very low bromide concentrations; the median bromide concentration in the Sacramento River at Hood is about 14 μg/L and is often less than the 10 μg/L detection limit. Where freshwater has been contaminated with even small amounts of seawater, concentrations are much higher. The average bromide concentrations at the Harvey O. Banks (Banks) Pumping Plant and the Bill Jones (Tracy) Pumping Plant are about 230 μg/L and 260 μg/L, respectively. Contra Costa Water District's Rock Slough intake's average bromide concentrations are probably higher, based on EC data. The North Bay Aqueduct's Barker Slough Pumping Plant, an intake on the sloughs to the west of the Sacramento River at Hood, sees intermediate bromide concentrations of 50 μg/L.

Organic carbon, the other primary constituent of concern for the program, is primarily produced by plants. It comes from recently produced organic material in the watershed, older plant residues in soils, and from peat deposits in the Delta that may be thousands of years old. Complicating our attempts to characterize the sources and processes that lead to disinfection byproduct formation is the fact that organic carbon in water is a varying mix of thousands of different chemical compounds. The relationships between organic carbon quality and disinfection byproduct formation continues to be the subject of a considerable amount of research. Overlaying the concerns about organic carbon in municipal water supplies is the essential role of organic matter in healthy aquatic ecosystems. A considerable amount of WQP effort has been directed towards understanding the sources, transport and impact of organic carbon in the Delta water supply.

Although the focus of the program has been on bromide and organic carbon, other drinking water pollutants of concern have also been addressed. Salinity is closely associated with bromide but is a pollutant of concern in its own right causing corrosion in drinking water systems, taste problems, and limiting the ability to reclaim wastewater. Microbial pathogens, always a threat to public health, are the reason for disinfecting water, and may affect the amount of disinfectant required. Plant nutrients, nitrogen and phosphorous, are of concern primarily because they stimulate algal growth in the system causing treatment problems and taste complaints.

The majority of projects funded by the WQP have been for source investigations and implementation of source control measures directed at reducing the loadings of these pollutants.

Drinking water quality issues are distinguished from most other beneficial use concerns because the water undergoes some form of treatment before its end use. Treatment is perhaps the most critical barrier protecting public health from pathogens and other contaminants in the environment but like any mechanical and chemical process it has its limits. Each of the hundreds of water systems that use Delta water is custom designed for a unique set of local conditions that include the quantity and quality of the available water supply. An important goal for the program in conducting the studies contributing to this report was to develop a better understanding of the connections between Delta water quality, treatment of Delta water, and the quality of the finished water.

Conveyance is the critical link between watershed sources and raw water quality entering a treatment plant and the Delta is the linchpin of water conveyance in the State of California. Water taken from the Delta is a continuously varying mixture of water from the Sacramento River, San Joaquin River, a few smaller tributaries, and water pumped from Delta islands with a little seawater finding its way in from San Francisco Bay. Moving high quality Sacramento River water across the Delta is a balancing act between water quality, water supply, and ecosystem impacts. The end result is that water diverted at the State and Federal pumping plants is, on average, of much lower quality than Sacramento River water entering the Delta. Sophisticated computer models are used to simulate the systems complex mixing patterns and have greatly improved our understanding of the connection between watershed sources and delivered water quality. Changes to conveyance through the Delta or conveyance around the Delta could be configured to greatly improve the quality of water diverted for drinking water supply.

Sources and Causes

The geographic extent of the solution area, stretching from the Oregon border to near the Mexican border, and the complexity of watersheds, storage, and conveyance system required that the problem

be broken down into more manageable chunks. Chapters 1 through 4 provide background information on regulatory context, the program, the Delta, and drinking water treatment. Chapter 5 characterizes water quality from the Delta intakes extending upstream through the Delta and into the tributaries of the San Joaquin and Sacramento Valleys. Chapter 6 addresses water quality downstream of the pumps addressing regional water quality, supply management and treatment differences.

Source Water Quality

The first questions that come to mind related to Delta water quality are 1) What is it like now? and 2) Is it getting better or worse? Unfortunately there are no simple answers to these questions. The following table summarizes water quality at five major Delta drinking water intakes.

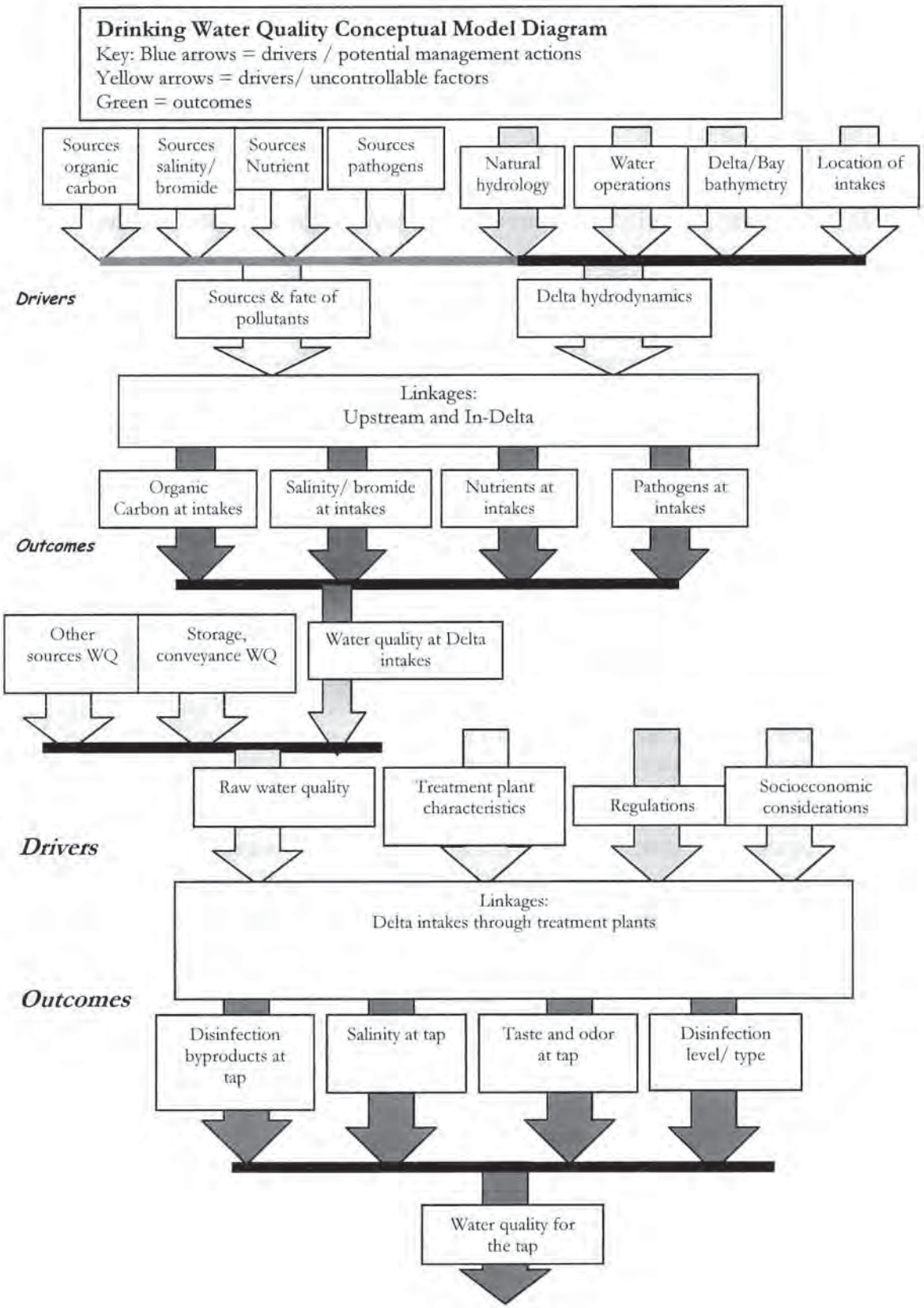
Intake	Period (Number of samples)	TOC RAA range Mg/L	Period (Number of samples)	Bromide RAA range µg/L
H.O. Banks	1986-2006 (170)	3.0 – 4.5	1990-2006 (210)	89 – 424
C.W. Jones (Tracy)	1986-1989 (29)	2.7 – 3.6	1990-2006 (135)	99 – 404
CCWD Old River	1994-2006 (176)	3.0 – 5.0	2005-2006 (188)	133 – 190
CCC (Rock Slough)	1991-2006 (169)	3.0 – 9.0	2005-2006 (188)	180 – 233
NBA (Barker Slough)	1988-2006 (182)	6.0 – 9.4	1990-1996 (99)	42 – 75

Running annual averages (RAA) are used to smooth the data and to more closely match data analysis with the averaging scheme used in the drinking water regulations. The differences between NBA water quality and the other intakes are largely due to the different mix of waters reaching these two locations. As a point of reference, the Sacramento River at Hood has a median TOC concentration of 1.9 mg/L and median bromide of 10 µg/L.

Trends analyses were conducted on data available at the intakes and other tributary locations (chapter 4 and Appendix B). Although statistically significant trends are present in the data (both increasing and decreasing) the reasons for these trends were not clear. They may have been due to the distribution of water year types over the period of record. The early 1990s were very dry while more recent years have been wetter. The safest conclusion is that, except for some local or seasonal changes, water quality has remained about the same over the life of the program (August 2000 to October 2007).

Conceptual Model

A conceptual model was developed to capture the drivers, outcomes, and linkages that result in the observed differences in source water quality and the factors that influence treated water quality.


Drinking Water Quality Conceptual Model Diagram
Key: Blue arrows = drivers / potential management actions
Yellow arrows = drivers/ uncontrollable factors
Green = outcomes
Sources organic carbon
Sources salinity/ bromide
Sources Nutrient
Sources pathogens
Natural hydrology
Water operations
Delta/Bay bathymetry
Location of intakes
Drivers
Sources & fate of pollutants
Delta hydrodynamics
Linkages: Upstream and In-Delta
Organic Carbon at intakes
Salinity/ bromide at intakes
Nutrients at intakes
Pathogens at intakes
Outcomes
Other sources WQ
Storage, conveyance WQ
Water quality at Delta intakes
Raw water quality
Treatment plant characteristics
Regulations
Socioeconomic considerations
Drivers
Linkages: Delta intakes through treatment plants
Outcomes
Disinfection byproducts at tap
Salinity at tap
Taste and odor at tap
Disinfection level/ type
Water quality for the tap

This conceptual model is used as a framework for identifying the data and processes that need to be analyzed to develop a full understanding of finished drinking water quality. This model was customized for regional conditions to help with the analysis of drinking water treatment in Chapter 6.

What have CALFED efforts done to solve the problem?

The programs initial efforts to fulfill the ROD Water Quality Program actions were described in the June CALFED 2005 Water Quality Program Assessment Report. This report provides an update of progress on these commitments. The majority of projects fall in the category of source control because of the requirements of the funding sources. While there has been progress (many more projects have been completed) a few key ROD commitments are behind schedule. The most important of these remaining program actions are development of a Central Valley Drinking Water Policy (now scheduled for completion in 2009) and development of a comprehensive monitoring and assessment program.

In addition to completing these outstanding ROD actions, the program is also moving towards a performance based management model. Recommendations for specific performance measures are provided in the report and summarized in Appendix C. A related recommendation is that, prior to directing significant additional funds to source improvement projects on a broad geographic scale, the program should conduct an experimental focused source improvement effort on a smaller watershed with appropriate monitoring and cost/benefit analyses.

What will conveyance projects do to solve the problem?

A number of different alternative configurations of channels and conveyance of water through (or around) the Delta have been proposed in the Delta Vision process and elsewhere. The primary drivers of these proposed conveyance changes are to reduce the conflict between water supply and ecosystem health, to provide a water supply that is more secure from levee failure and sea level rise, and to improve the quality of water diverted from the Delta. This report outlines the factors that should be considered and analyses that should be done when planning Delta conveyance alternatives. For drinking water supply purposes the most significant benefit of changed conveyance will likely be in the reduction in salinity and bromide concentrations although organic carbon concentrations could also be reduced. Most of the conveyance alternatives under consideration will have the effect of reducing the size of the Delta supply watershed. This could raise new water quality issues for both the water supplied from the system and for the water remaining in the Delta. A new set of monitoring and analysis tools will need to be developed to help in planning these alternatives and in assessing the effects of the chosen alternative.

How do recently identified future risks affect the problem?

In addition to the drivers mentioned above, climate change will continue to have a variety of effects on the quantity and quality of water available in the system. Population growth projections also point to a Delta system with more land use and water quality challenges. Proper analysis of conveyance alternatives and water quality program planning will require more definitive projections of these drivers and new modeling tools that will allow projections of water quality in a Delta that may be dramatically different from the existing configuration, hydrodynamics, and hydrology.

What are the priorities for Stage 2?

Recommendations for Stage 2 WQP priorities are summarized in Chapter 7 and include:

- Continuing to embrace the multiple barriers approach to drinking water protection.
- Review, refine, and possibly revise the program targets for organic carbon, bromide, and the "equivalent level of public health protection" goal
- Continue to support studies of organic carbon quality in DBP production.
- Reduce bromide concentrations in water supplied from the Delta.
- Focus watershed source reduction efforts to increase program performance.
- Continue to improve the programs understanding of treatment plant source water quality needs.
- Continue to work with regional groups and the IRWMP to protect and improve water quality "downpipe" from the Delta.
- Work with regional treatment technology research and demonstration projects to disseminate results.
- Develop, adopt and implement a comprehensive and integrated performance measurement system.
- Expand and integrate monitoring, assessment, and reporting of Delta water quality for all uses.

California Depart ent of Fish and a e
Bay Delta egion
P O Bo
O N E, CA,

California Endangered Species Act
Incidental Take Permit No. 2081-2009-013-03

CON A COS A WA E D S C
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Authority This California Endangered Species Act (CESA) Incidental Take Permit (ITP) is issued by the Department of Fish and Game (DFG) pursuant to Fish and Game Code section 2081, subdivisions (b) and (c), and California Code of Regulations, Title 14, section 783.0 et seq. CESA prohibits the take[1] of any species of wildlife designated as an endangered, threatened, or candidate species[2] by the Fish and Game Commission. DFG, however, may authorize the take of such species by permit if the conditions set forth in Fish and Game Code section 2081, subdivisions (b) and (c), are met. (See also Cal. Code Regs., tit. 14, § 783.4.)

Per ittee Contra Costa Water District CCWD

Na e and title of principal officer r Walter Bishop, eneral anager

Contact person Dr eah Orloff, Water esources anager

ailing address 1331 Concord Avenue
Post Office Box H20
Concord, CA 94524

Effective Date and E piration Date of the P

This ITP shall be executed in duplicate original form and shall become effective once a duplicate original is acknowledged by signature of the Permittee on the last page of the ITP and returned to DFG's Habitat Conservation Planning Branch at the address listed in the Notices section of this ITP. Unless renewed by DFG, this ITP's authorization to take the Covered Species shall expire on **Dece ber ,**

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[1]Pursuant to Fish and Game Code section 86, "'Take' means hunt, pursue, catch, capture, or kill, or attempt to hunt, pursue, catch, capture or kill."

[2]"Candidate species" are species of wildlife that have not yet been placed on the list of endangered species or the list of threatened species, but which are under formal consideration for listing pursuant to Fish and Game Code section 2074.2.

Scope of P and elationship to Prior e orandu of nderstanding anage ent Authori ation for the os a ueros Pro ect

This ITP addresses expected incidental take of and impacts of taking to the species listed below in the "Covered Species" section of this ITP, summarized as follows:

- Construction of the Alternative Intake Project (AIP) and Longfin smelt (*Spirinchus thaleichthys*): On August 3, 2007, DFG issued Consistency Determination 2080-2007-019-03 (hereafter, the 2007 Consistency Determination), in connection with a related federal approval authorizing incidental take of Sacramento winter-run and Central Valley spring-run Chinook salmon (*Oncorhynchus tshawytscha*)(hereafter, "Chinook salmon") and delta smelt (*Hypomesus transpacificus*) during construction of the AIP. (See Fish & G. Code, § 2080.1.) That Consistency Determination did not address longfin smelt because the species was not protected under CESA at that time. Longfin smelt are currently protected under CESA, [3] however, and this ITP authorizes incidental take of the species as set forth below during construction of the AIP.

- Operation and Maintenance of the AIP with respect to all Covered Species: DFG's 2007 Consistency Determination does not address or otherwise include post-construction operation and maintenance of the AIP. As set forth below, this ITP provides incidental take authorization to CCWD for post-construction operation and maintenance of the AIP, which CCWD intends to integrate with operation of the Los Vaqueros Project (LVP) to allow flexibility based on water quality and species considerations.

- Operation and maintenance of the LVP with respect to all Covered Species: On February 16, 1994, pursuant to former Fish and Game Code section 2081, DFG issued Memorandum of Understanding and Management Authorization (MOU/MA) No. 9339 to CCWD for construction and development of the LVP. (See Fish & G. Code, § 2081.1.) That MOU/MA authorizes incidental take of winter-run Chinook salmon and delta smelt expected to occur with construction of the Los Vaqueros Reservoir, construction of the Old River Intake, construction of LVP-associated water transfer and conveyance facilities, and maintenance and operation of the LVP facilities, including diversion and re-diversion at CCWD's existing Rock Slough and Mallard Slough Intakes and the proposed Old River Intake. This ITP supersedes all provisions of MOU/MA No. 9339 to avoid, minimize, and fully mitigate the incidental take and all impacts of the taking on winter-run Chinook salmon and delta smelt expected to occur with LVP maintenance and operation.

[3] Cal. Reg. Notice Register 2008, No. 9-Z, p. 308; Fish & G. Code, §§ 2080, 2085; see also Cal. Cal. Reg. Notice Register 2009, No. 19-Z, p. 699, No. 24-Z. p. 924.

DFG MOU/MA No. 9339 also includes a terrestrial component related primarily to construction of the Los Vaqueros Reservoir and incidental take of San Joaquin kit fox (*Vulpes macrotis mutica*). The MOU/MA addresses, among other things, temporary and permanent impacts of the taking to 2,804 acres of San Joaquin kit fox. This ITP does not supersede nor modify those provisions of MOU/MA No. 9339 related to San Joaquin kit fox, including but not necessarily limited to, the maintenance in perpetuity of habitat mitigation areas. This ITP also does not address any issues related to the proposed Los Vaqueros Expansion Project. If CCWD approves the Los Vaqueros Expansion Project and take of CESA protected species incidental to implementation of that project will occur, CCWD will need to request a new ITP or an amendment to this ITP from DFG, or obtain other appropriate coverage for such take as provided by the Fish and Game Code.

Pro ect ocation

The continued operation of the LVP and construction and operation of the AIP (hereafter, the Project) is located in Contra Costa County and San Joaquin County. The continued operation of the LVP includes a dam and reservoir in the Kellogg watershed in eastern Contra Costa County, and three existing water intakes and pumping stations, along with associated conveyance facilities, located in the Sacramento-San Joaquin Delta Estuary (Delta) at: Mallard Slough, Rock Slough and Old River in Contra Costa County. CCWD's Project also includes the construction, operation, and maintenance of a fourth intake and pumping station, the AIP, which will be located in the San Joaquin County portion of the Delta at Victoria Canal with conveyance infrastructure and facilities extending from the AIP intake and connecting to the existing Old River conveyance facility in Contra Costa County.

Pro ect Description

Background

CCWD operates untreated water distribution facilities, and water treatment and treated water distribution facilities. CCWD supplies treated or untreated water supplies to approximately 550,000 wholesale and retail customers throughout north-central Contra Costa County. CCWD's customers include urban residents, agricultural users, and various cities, districts, and industries.

CCWD's receives its primary source of water from the Central Valley Project (CVP) pursuant to a contract with the U.S. Bureau of Reclamation (BOR). CVP water is diverted or rediverted at the intake channel at Rock Slough and at the Old River intake for use by CCWD and its customers. The AIP, once constructed, will also be used to divert or redivert CVP water for use by CCWD and its customers. CCWD has a right under its existing BOR contract to 195,000 acre-feet of water per year (afa). CCWD's BOR water supply contract extends to 2045. CCWD also has a water right permit and a water right license to divert up to 26,780 afa from Mallard Slough; when CCWD uses its Mallard Slough supply, CCWD generally

reduces the use of its CVP supply by a like amount since CCWD's demand is less than the total supply available from both. The delivery capacity of the current CCWD facilities is adequate to fully utilize all of its CVP entitlements and Mallard Slough water rights (CCWD system capacity includes the Contra Costa Canal System, Multi-Purpose Pipeline Project, and the Los Vaqueros Reservoir).

The quality of water at Mallard Slough, Rock Slough and Old River are subject to substantial variations in salt and mineral concentrations and other water quality parameters. The new AIP intake will provide water quality benefits to CCWD by changing the location and timing of diversions, but will not increase CCWD's average annual Delta diversions. CCWD water supply and quality risks will be reduced with the inclusion of the AIP intake since water quality from this intake is expected to be significantly better during the summer and fall months than from CCWD's other intakes. This will allow the current LVP to be used less for blending in wetter years and will allow more blending water when it is needed in dry years and during extended droughts. The AIP will also allow CCWD to shift a portion of its diversions out of the fish-sensitive winter and spring period and into the late summer and fall, since water quality at that intake during summer and fall is generally much better than water quality at CCWD's existing intakes. Because the AIP is linked to the existing Old River conveyance facilities, CCWD does not increase the maximum diversion capacity of that system. However, at times, the AIP may be used concurrently with the Old River intake to a maximum combined capacity for the existing Old River and new AIP intakes of 320 cubic feet per second to allow reduced diversions at the currently unscreened Rock Slough intake. Integrated operation of the Project will allow CCWD the flexibility to switch between the Old River and the AIP intakes, based upon water quality and species considerations.

Water Transmission, Diversion, and Storage

The Old River intake has a capacity to divert 250 cubic feet per second (cfs) of water. The AIP will also have a capacity to divert 250 cfs of water. Water from the AIP intake is piped to the Old River pump station, where it ties into a pipeline to a transfer facility. This pipeline has a capacity of 320 cfs, so CCWD Old River and AIP intakes will have a combined capacity to divert 320 cubic feet per second (cfs) of water. From the transfer facility, water can either be pumped to the Los Vaqueros reservoir or conveyed by gravity flow to the Contra Costa Canal. Water released from the Los Vaqueros reservoir is conveyed by gravity flow to the Contra Costa Canal. The AIP intake will allow less water to be diverted at the unscreened Rock Slough intake, as described in the October 2006 final AIP Environmental Impact Report/Environmental Impact Statement (SCH No. 2005012101).

CCWD Water Rights

Implementation of the LVP required acquisition and modification of water rights by CCWD and BOR. CCWD and BOR pursued these actions with appropriate applications and petitions filed with the State Water Resources Control Board (SWRCB). CCWD's Application 20245 proposed diversion of unappropriated flows in Old River to storage in the Kellogg

Creek Watershed. CCWD also requested partial assignment of State Filed Application 25516, to use unappropriated flows in Kellogg Creek. The LVP is operated in conjunction with the CVP, and BOR petitioned the SWRCB to modify seventeen CVP permits to: add the Los Vaqueros intake(s) as a point of diversion or rediversion; modify the place of use of some permits to conform with Application 20245; and add municipal and industrial uses as permitted uses under some of the permits. CCWD and BOR also developed a draft contract to amend CCWD's existing BOR water supply contract for CVP water service to allow for integration of LVP operations with CVP operations. The amendatory contract contains a term which does not allow annual distribution for customers' use within CCWD's service area of more than 195,000 acre feet of CVP water and CCWD's Application 20245 water. The SWRCB granted the applications and petitions on June 2, 1994 in Decision 1629. The amendatory CVP contract, number I75r-3401, was executed on May 26, 1994. On May 10, 2005 amendatory contract number I75r-3401A-LTR1 between CCWD and BOR was executed, renewing contract I75r-3401 for a term of forty (40) years pursuant to the Central Valley Project Improvement Act of 1992 (Pub. Law No. 102-575).

In connection with the review of the water rights applications and petitions, the SWRCB and CCWD jointly requested consultation with DFG, by letter dated November 30, 1992, in accordance with former Fish and Game Code section 2090. Implementation of the AIP will require modification of CCWD's and BOR's existing water right permits. On August 9, 2007, CCWD and BOR filed petitions to add a point of diversion to CCWD's permit 20749 (Application 20245) and to the seventeen CVP permits that include the Old River intake as a place of diversion.

Covered Species

This ITP covers the following species:

Na e	**Status**
Fish	
Sacramento River winter-run Chinook salmon (*Oncorhynchus tshawytscha*)	Endangered
Central Valley spring-run Chinook salmon (*Oncorhynchus tshawytscha*)	Threatened
Delta smelt (*Hypomesus transpacificus*)	Threatened[5]

[4] Under CESA, a species may be on the list of endangered species, the list of threatened species, or the list of candidate species. All other species are "unlisted."

[5] Delta smelt are currently protected under CESA as a threatened species. (Cal. Code Regs., tit. 14, § 670.5, subd. (b)(2)(A); see also Fish & G. Code, § 2080.) On June 7, 2007, the California Fish and Game Commission accepted a petition to uplist Delta smelt as an endangered species and on August 7, 2008, the Commission made a finding that uplisting from threatened to endangered is warranted. (Cal. Reg. Notice Register 2007, No. 25-Z, p. 1090, and 2009, No. 3-Z, p. 111.) The Commission is currently engaged in related

Longfin smelt (*Spirinchus thaleichthys*) Candidate[6]

These species and only these species are hereinafter referred to as "Covered Species."

pacts to Covered Species

The Project will result in impacts to the longfin smelt associated with construction of the AIP, and to all Covered Species during ongoing operation and maintenance of the water diversion facilities. Project activities and the related impacts are expected to result in the incidental take of individual Covered Species and other impacts of the taking on such individuals. These impacts may be direct, in the form of capture, stranding, or mortality, or indirect, in the form of increased competition, increased predation, reduction of available habitat, increased habitat fragmentation, and other behavioral disruption resulting from ongoing Project water diversion activities. In particular, incidental take of individual Covered Species is expected to occur as a result of mortality due to operation and maintenance of Project water diversion and related facilities, including entrainment and impingement. Impacts of the taking on the Covered Species also include: (1) The reduction in quantity of available aquatic habitat, up to 171,000 acre feet annually, as water is diverted out of the system; (2) Disruption to movement caused by water diversions; (3) Disruption to ecosystems processes and loss of food web resources; and (4) Ongoing effect of up to 720 surface acres of aquatic habitat for the Covered Species affected by the water diversions before implementation of take minimization and mitigation measures. Modifications of flow patterns on the San Joaquin side of the Delta due to filling operations of the Project likely will result in a small increase in take of adults, juveniles, and larval delta smelt through displacement to areas less suitable for spawning and rearing. The Project also could increase adverse conditions for and during juvenile Chinook salmon migration through the Delta. Winter-run Chinook salmon juveniles migrate downstream during the winter through the early spring.

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rulemaking under the Administrative Procedure Act (APA) (Gov. Code, § 11340 et seq.) and, when complete, the legal status of Delta smelt under CESA will change from threatened to endangered. (Fish & G. Code, 2075.5(2); Cal. Reg. Notice Register 2009, No. 3-Z, p. 106; see also proposed Cal. Code Regs., tit. 14, § 670.5, subd. (a)(2)(O).) The species' change in legal status under CESA will not affect this ITP.

[6] Longfin smelt are currently protected under CESA as a candidate species. (Cal. Reg. Notice Register 2008, No. 9-Z, p. 308; Fish & G. Code, §§ 2080, 2085.) On March 4, 2009, the California Fish and Game Commission made a finding that listing longfin smelt as a threatened species under CESA is warranted. (Cal. Reg. Notice Register 2009, No. 24-Z, p. 924.) The Commission is currently engaged in related rulemaking under the APA and, when complete, the legal status of longfin smelt under CESA will change from a candidate to a threatened species. (Fish & G. Code, § 2075.5(2); Cal. Reg. Notice Register 2009, No. 19-Z, p. 699; see also proposed Cal. Code Regs., tit. 14, § 670.5, subd. (b)(2)(E).) The species' change in legal status will not affect this ITP.

ncidental ake Authori ation

This ITP authorizes incidental take of the Covered Species and only the Covered Species. With respect to incidental take of the Covered Species, DFG authorizes the Permittee, its employees, contractors, and agents to take Covered Species incidentally in carrying out the Project, subject to the limitations described in this section and the Conditions of Approval identified below. This ITP does not authorize take of Covered Species from activities outside the scope of the Project as described above, take of Covered Species resulting from violation of this ITP, or intentional take of Covered Species, except for intentional take as authorized by this ITP.

Conditions of Approval

Unless specified otherwise, the following measures shall pertain to all Project operations and maintenance activities described above, and to construction of the AIP with respect to longfin smelt. DFG's issuance of this ITP and the Permittee's authorization to take Covered Species are subject to Permittee's compliance with and implementation of the following Conditions of Approval:

1. Permittee shall comply with all applicable state, federal, and local laws in existence on the effective date of this ITP or adopted thereafter.

2. Permittee shall implement and adhere to the mitigation measures related to the Covered Species in the Biological Resources section of the Environmental Impact Report certified by the lead agency, CCWD, for the AIP under the California Environmental Quality Act (CEQA) on November 15, 2006. (SCH No. 2005012101.) Permittee shall also implement and adhere to the mitigation measures related to the Covered Species in the Biological Resources section of the Environmental Impact Report certified by the lead agency, CCWD, for the LVP under CEQA on October 27, 1993. (SCH No. 91063072.)

3. Permittee shall fully implement and adhere to the conditions of this ITP within the time frames set forth below and as set forth in the Mitigation Monitoring and Reporting Program (MMRP) included as Attachment 1 to this ITP.

eneral Provisions

Incidental take of Chinook salmon and delta smelt during construction of the AIP is addressed by the DFG 2007 Consistency Determination (2080-2007-019-03). AIP construction-related take of longfin smelt is not addressed by the 2007 Consistency Determination. AIP construction-related take of longfin smelt is addressed by this ITP and, as previously indicated, this ITP supersedes all provisions of the 1994 MOU/MA related to Chinook salmon and delta smelt. 1994 MOU/MA Conditions 20-32 on page 26-33 of the MOU/MA, and all other conditions in the 1994 MOU/MA and 2007

Consistency Determination related to Chinook salmon and delta smelt are superseded in their entirety and replaced by the Conditions of Approval set forth in this ITP:

4.1. Notwithstanding any expiration date on the take authorization provided by this ITP, Permittee's obligations under this ITP do not end until DFG accepts as complete the Permittee's Final Mitigation Report demonstrating compliance with minimization and mitigation measures for operation of the Project required by Condition 5.2 of this ITP.

onitoring, Notification, and eporting Provisions

5.1. Annual Status Report: Beginning with issuance of the ITP and continuing until DFG accepts the Final Mitigation Report identified below, Permittee shall provide DFG an Annual Status Report no later than October 31 of every year. Each Annual Status Report shall include, at a minimum: (1) results of the expanded monitoring program; (2) maximum instantaneous rate of diversion for each diversion point summarized monthly; (3) cumulative monthly diversion in acre feet at each point of diversion; (4) any fish rescue results; (5) a copy of the table in the MMRP with notes showing the current implementation status of each mitigation measure; and (6) an assessment of the effectiveness of each completed or partially completed mitigation measure in minimizing and compensating for Project impacts.

5.2. Final Mitigation Report: No later than ninety (90) days prior to expiration of this ITP, Permittee shall provide DFG with a Final Mitigation Report. The Final Mitigation Report shall include, at a minimum: (1) a copy of the table in the MMRP with notes showing when each of the mitigation measures was implemented; (2) all available information about Project-related incidental take of the Covered Species; (3) information about other Project impacts on the Covered Species; (4) construction dates; (5) an assessment of the effectiveness of the ITP's Conditions of Approval in minimizing and compensating for Project impacts; and (6) recommendations on how mitigation measures might be changed to more effectively minimize and mitigate the impacts of future projects on the Covered Species.

5.3. If a Covered Species is killed by Project-related activities during construction or operation and maintenance of the Project, or if a Covered Species is otherwise found dead within the Project boundary, Permittee shall immediately email the DFG Regional Office at swilson@dfg.ca.gov and kgeary@dfg.ca.gov or their designees. The initial notification to DFG shall include information regarding the location, species, number of animals injured or killed, and the ITP Number. Following the initial notification, Permittee shall send DFG a written report within seven (7) calendar days. The report shall include the date and time of the finding or incident, location of the carcass, and if possible provide a photograph, explanation as to cause of death, and any other pertinent information.

5.4. Monitoring: Permittee shall determine the effectiveness of the no-fill and no-diversion timing and conditions to protect delta smelt in their various life stages by implementing an expanded monitoring program. Permittee shall continue to utilize the DFG approved Rock Slough Expanded Monitoring Program (circa 2003), Revised Biological Monitoring Program for the Old River Fish Screen Facility (circa 2000), and the Proposed Program to Sample the Overflow Structure at the CCWD Mallard Slough Pumping Plant (circa 2000). Permittee shall monitor at the AIP in a manner consistent with the methods approved by DFG for the Old River Fish Screen Facility. Additionally, to provide an indication of the possible presence of larval longfin and delta smelt, the Permittee shall perform additional plankton net sampling at Old River, Rock Slough, and the AIP. To provide an indication of the presence of the estuarine food-chain Permittee shall begin a program of zooplankton net sampling at Old River, Rock Slough, and the AIP. Permittee shall provide to DFG a summary of the real time monitoring for adults, juveniles, and larvae present near Permittee intakes, and water quality data at the beginning and middle of each month. Permittee shall use the above monitoring information to determine diversion of water at the Rock Slough, Old River, AIP, and Mallard Slough intakes. Permittee may use monitoring information to recommend changes to Conditions 6.4, 6.5 or 6.6, or as a trigger for other measures such as diversion reductions for the protection of the Covered Species. Permittee shall submit to DFG an annual summary of all collected information by October 31 of each year, as described in Condition 5.1.

5.5. Study Plan: By August 1, 2010, and every three years subsequently, Permittee shall submit an updated study plan to DFG for approval. The purpose of the study plan shall be to determine the presence of Covered Species adults, juveniles, and larvae at all current Permittee intakes and at the AIP. DFG shall provide written comments and requested changes, if any, regarding the adequacy of the submitted study plan and its elements by September 1 of each year in which an updated study plan is submitted. If DFG has comments or requested changes, Permittee shall resubmit a revised study plan that addresses DFG's comments and requests by October 1. This study plan must be acceptable to and must be approved by DFG prior to November 1 of each year in which an updated study plan is submitted. Permittee shall not be in violation of this provision if DFG does not respond in writing regarding the acceptability of the latest study plan in accordance with this schedule, provided Permittee is implementing and adhering to the latest study plan submitted to DFG. This continuous study shall begin by November 1 and shall continue until June 30 unless an alternative schedule is agreed to by DFG. Permittee shall submit a summary of the results of each study to DFG in accordance with the schedule contained within the approved study plan. Permittee shall conduct fish sampling techniques and handling procedures in a manner that minimizes mortality to the Covered Species. Permittee shall coordinate with the ongoing Interagency Ecological Studies Program (IEP) and make the Project monitoring data available to IEP upon IEP's request.

5.6. Permittee shall transmit proposed monitoring plans, summaries of monitoring data, and other technical information required by this ITP to the Regional Representative identified by DFG in the Notices section of this ITP. A copy of such information shall also be transmitted to the:

Regional Manager
California Department of Fish and Game
Bay Delta Region
Post Office Box 47
Yountville, CA 94599

ake ini i ation easures

Avoidance of Covered Species is the first priority of this ITP. The second priority is the minimization of incidental take of Covered Species that are in the Project area during construction of the AIP and operation of the Project. Permittee shall implement and adhere to the following conditions to avoid or minimize take of Covered Species:

6.1 The total annual water deliveries by the Permittee of CVP water and water appropriated under Application 20245 shall not exceed 177,000 acre feet and the total diversion annually under all bases of rights shall not exceed 222,000 acre feet.

6.2 Permittee shall construct, operate, and maintain fish screens and fish screen cleaning systems at the Old River and AIP facilities that strictly conform to the fish screening system design criteria identified in Attachment 2 and as generally described by DFG's fish screen criteria included as Attachment 3 to this ITP. In addition, Permittee shall maintain an average approach velocity of 0.2 feet per second at the screen in accordance with the reasonable and prudent measures in the U.S. Fish and Wildlife Service's delta smelt Biological Opinions for the Los Vaqueros Project (U.S. Fish and Wildlife Service 1993a, as clarified and modified, U.S. Bureau of Reclamation 1993) and the AIP (U.S. Fish and Wildlife Service 2007). Permittee shall construct the AIP screened diversion and shall ensure the screen is continuously functioning prior to and during any diversion operation of the AIP.

6.3 Permittee shall collaborate with BOR to ensure that screening the intake at Rock Slough in accordance with the CVPIA is completed no later than:

a. The year in which Permittee total deliveries to its customers reaches 160,000 acre feet per year; or
b. Implementation of a subsequent project that would substantially change operations of the Los Vaqueros Project; or
c. By the end of 2018, if neither a or b above has occurred.

6.4 Permittee shall not divert water to storage in Los Vaqueros Reservoir from March 15 through May 31, except when reservoir storage is below emergency storage levels. For the purposes of this condition, the term "emergency storage" shall mean at least 70,000 af in storage in below normal years, above normal years, and wet years, and 44,000 af in dry years and critical years. Year types shall be as defined in the February edition of the California Department of Water Resources Bulletin 120 and the Four Basin Index defined by water right decision 1485. If the reservoir storage is below emergency storage levels, Permittee may fill the reservoir without the above restrictions only if (1) Permittee has provided DFG with notification that reservoir storage is below emergency storage level, and (2) Permittee notifies DFG of the intent to fill when filling would otherwise be restricted and DFG determines, in its sole discretion, that the filling can occur without exposing the Covered Species to an unacceptable level of risk.

6.5 Beginning in February following the first year of operation of the AIP, Permittee shall not divert water from any of its diversions to storage in Los Vaqueros Reservoir for 15 days from February 14 through February 28, provided that reservoir storage is at or above 90,000 af on February 1. If reservoir storage is at or above 80,000 af on February 1, but below 90,000 af, Permittee shall not divert water to storage in Los Vaqueros Reservoir for 10 days from February 19 through February 28. If reservoir storage is at or above 70,000 af on February 1, but below 80,000 af, Permittee shall not divert water to storage in Los Vaqueros Reservoir for 5 days from February 24 through February 28.

6.6 During the period April 1 to April 30, Permittee shall not divert water from the Delta unless Los Vaqueros Reservoir is below emergency storage levels as defined above and shall instead release up to 12,500 af of water from the Los Vaqueros Reservoir to meet demand in Permittee's service area. In those instances where such diversions are necessary due to emergency storage levels, Permittee may divert water from the Delta only for direct use within the Permittee's service area.

6.7 If DFG determines that a change in the periods described in Conditions 6.4, 6.5 and 6.6 would provide greater overall protection to the Covered Species, then DFG shall, no later than January 15 of any year, provide Permittee with a written request to modify one or more of those Conditions. Permittee shall notify DFG if it will implement the change.

6.8 Permittee may submit to DFG by January 1 of each year, a proposal to modify the dates of Conditions 6.4, 6.5, and 6.6 to better protect delta and longfin smelt. DFG may approve modification of the dates for the periods when reservoir filling is to be avoided and the periods when no diversion shall occur if DFG determines the proposed modification of dates will be more effective in minimizing take of delta and longfin smelt. If DFG provides no response to the Permittee's proposal, Permittee shall adhere to and implement Conditions 6.4, 6.5, and 6.6.

6.9 Permittee shall only perform in-channel maintenance and repair operations on the Old River and AIP intakes between September 1 and November 15 of each year, unless DFG approves a modification in writing. If emergency in-channel maintenance and repairs of the Old River or AIP intake are necessary, Permittee shall notify DFG within 48 hours of commencing emergency work. The Permittee shall only conduct in-channel AIP construction activities between September 1 and November 30.

6.10 Until the Rock Slough diversion is screened, Permittee shall minimize water diversions from Rock Slough from December 1 through June 30. Permittee shall maximize use of its screened intakes by diverting from the Old River and AIP intakes, and diverting from the Rock Slough intake only when demand cannot be fully met from the Old River and AIP intakes because Los Vaqueros Reservoir is being filled or because water quality at the Old River and AIP intakes does not meet the Permittee's delivered water quality criterion. When diversions to meet demand are being made at the screened intakes, Permittee may also make the minimum diversion at the Rock Slough intake which is necessary to prevent stagnation in the Canal. This condition shall not apply if monitoring at the intakes indicates, and DFG agrees in writing, that the incidental take of Covered Species adults, juveniles, or larvae would be less at Rock Slough than another intake, or that Covered Species are not present at Rock Slough.

6.11 Permittee shall ensure the following diversion requirements are met: maximum instantaneous rate of diversion for the Rock Slough Intake shall not exceed 350 cfs; maximum instantaneous rate of diversion for the Old River Intake shall not exceed 250 cfs; maximum instantaneous rate of diversion for the AIP shall not exceed 250 cfs; and maximum instantaneous rate of diversion for the Old River Intake and the AIP combined shall not exceed 320 cfs. The maximum instantaneous rate of diversion cumulatively for all diversion points shall not exceed: 540 cfs for the months of June, July, August, September and October; 410 cfs for the months of November, December, January, February and March; and 470 cfs for April and May.

6.12 To reduce turbidity in Victoria Canal during AIP-related construction activities (primarily excavation and cofferdam installation), Permittee shall: (1) install a silt curtain to reduce the dissipation of suspended sediments during dredging and cofferdam installation; and (2) install the cofferdam during the designated in-water work window between September 1 and November 30. In addition, successful AIP-related turbidity control shall be accomplished by installation and subsequent removal of the temporary cofferdam, while maintaining suspended sediment and turbidity levels within the water quality criteria established by the Regional Water Quality Control Board (RWQCB).

6.13 Permittee shall implement the following measures during AIP construction activities: (1) prohibit the discharge of petroleum products or other excavated materials to surface waters; (2) minimize substrate disturbance during AIP construction activities; (3) not cause turbidity increases in surface waters during AIP construction activities as follows: (a) where natural turbidity is between 0 and 5 Nephelometric Turbidity Units (NTUs), increases shall not exceed 1 NTU; (b) where natural turbidity is between 5 and 50 NTUs, increases shall not exceed 20%; (c) where natural turbidity is between 50 and 100 NTUs, increase shall not exceed 10 NTUs; and d)where natural turbidity is greater than 100 NTUs, increases shall not exceed 10%; (4) not cause settleable matter to exceed 0.1 ml/l in surface waters as measured in surface waters 300 feet downstream from the project during AIP construction activities; (5) not cause visible oil, grease, or foam in the work area or downstream during AIP construction activities; (6) protect all areas disturbed by AIP construction activities from washout or erosion; (7) in the event that AIP construction activities create a visible plume in surface waters, initiate monitoring of turbidity levels at the discharge site and 300 feet downstream, taking grab samples for analysis of NTU levels twice per day during the work period while the visible plume persists; (8) notify DFG immediately if the above criteria for turbidity, oil/grease, or foam are exceeded; and (9) notify DFG immediately of any spill of petroleum products or other organic or earthen materials.

6.14 Permittee shall prepare a soil erosion control plan and stormwater pollution prevention plan prior to AIP grading and excavation activities to minimize potential AIP construction-related silt from entering waterways and increasing turbidity. The plans shall include, at a minimum, the following measures to minimize AIP-related erosion and sedimentation: (1) use sedimentation basins and straw bales or other measures to trap sediment and prevent sediment and silt loads to waterways during project construction; (2) cover graded areas adjacent to levees and in other areas that may be subject to erosion (as appropriate) with protective material, such as mulch, and re-seed with adapted native plant species after project construction is complete; (3) incorporate bank stabilization (riprap) into the AIP design on both the east and west sides of the intake to minimize channel margin erosion of soils into Victoria Canal; (4) minimize AIP construction-related surface disturbance of soil and vegetation and restore terrestrial habitats immediately after construction to the extent feasible; (5) place any AIP construction-related stockpiled soil where it would not be subject to accelerated erosion; and (6) commence re-vegetation with grasses native to the Delta and placement of erosion control devices, such as crushed rock, as soon as a graded area has attained finish grade. Permittee shall ensure that a certified erosion control specialist or California-registered civil engineer prepares the plan and that an AIP field manager monitors implementation of the plan in accordance with established protocols/procedures.

6.15 Permittee shall implement measures to reduce and/or avoid underwater sound pressure impacts. Permittee shall avoid and minimize risk of adverse impacts and

incidental take of longfin smelt by installing the sheet pile cofferdam using a vibration hammer that minimizes underwater sound pressure levels to the greatest extent feasible. If Permittee determines that a higher intensity percussion hammer is required to install the cofferdam, Permittee shall consult with DFG to determine the appropriate actions to avoid or lessen adverse effects. Additional actions may include surveying Victoria Canal at the intake site to determine fish presence prior to installation, and possibly modifying the work window accordingly. Permittee shall not use a higher intensity percussion hammer without prior approval by DFG. Installation of the cofferdam, however, is expected to occur during the designated in-water work-window in summer and early fall when water temperatures within the central and south Delta are seasonally elevated and aquatic habitat in these areas is considered to be generally unsuitable for longfin smelt. Installation of the cofferdam using percussion hammers during summer would reduce and avoid potential adverse effects to these species.

6.16 Permittee shall prepare and implement a hazardous materials control and spill prevention and response plan prior to AIP construction. Measures in the plan to minimize AIP construction-related effects shall include the following: (1) a spill prevention and countermeasure plan that includes strict on-site handling rules to keep construction and maintenance materials out of drainages and waterways; (2) prevent AIP-related raw cement, concrete, concrete washings; asphalt, paint, or other coating material; oil or other petroleum products; or any other substances that could be hazardous to aquatic life from contaminating the soil or entering watercourses, including Victoria Canal; (3) clean up all AIP-related spills immediately according to the spill prevention and countermeasure plan, and notify RWQCB immediately of spills and cleanup procedures; (4) provide staging and storage areas for AIP-related equipment, materials, fuels, lubricants, solvents, and other possible contaminants away from watercourses and their watersheds; and (5) conduct periodic inspection during construction. Permittee shall provide DFG access to the Project site during construction to inspect construction activities to ensure compliance.

6.17 Permittee shall develop a fish rescue plan and shall obtain DFG approval of the plan prior to implementation of the Project. Installation of the cofferdam and dewatering a portion of the intake structure site during AIP fish screen construction may result in fish stranding. Permittee shall ensure that a qualified fishery biologist with a current DFG scientific collecting permit designs and conducts the fish rescue and relocation effort to collect fish from the area behind the cofferdam. The fish rescue effort shall be implemented during the dewatering of the area behind the cofferdam and shall include the capture and return of those fish to suitable habitat within Victoria Canal. To ensure compliance with this condition, a fisheries biologist shall be present on-site during initial dewatering activities.

6.18 Permittee shall monitor progress of installation of the cofferdam and the schedule for dewatering. Permittee shall coordinate the dewatering schedule with the construction contractor and fishery biologist to allow for the fish rescue to occur prior to completely closing the cofferdam and again when water depths are approximately two feet. Permittee shall notify DFG at least 48 hours prior to the fish rescue. Permittee shall record information on the species and sizes of fish collected in the rescue and estimates of survival immediately before release during fish rescue activities, and include this information in the next required report to DFG.

Full itigation for Authori ed ake

DFG has determined that the implementation of all three of the following measures will fully mitigate the impacts of the taking associated with this Project.

7.1 The implementation of Conditions 6.4, 6.5, and 6.6 above will minimize take and provide increased aquatic habitat during the time these Conditions are in place. Conditions 6.4, 6.5, and 6.6 shall be implemented to provide additional aquatic habitat and, in so doing, shall provide partial mitigation for Project impacts of taking on Covered Species.

7.2 As partial mitigation for the entrainment of delta smelt and longfin smelt, Permittee shall relocate one agricultural diversion from Victoria Canal to behind the AIP fish screen, thereby screening the one 16-inch agricultural diversion. This will reduce overall entrainment potential at the agricultural siphon.

7.3 Habitat Management Land Acquisition and Funding Assurances:
DFG has determined that permanent protection of compensatory habitat is necessary and required under CESA to mitigate the impacts of the taking on the Covered Species that will result with implementation of the Project.

Prior to initiating AIP operations, or no later than eighteen (18) months after the start of AIP operations if Security is provided pursuant to Condition 8 below, Permittee shall acquire, restore, enhance and permanently preserve 36 acres of tidal wetland habitat as Habitat Management Lands (HM Lands). The required acreage is based on an assessment of timing and quantity of the aquatic habitat impacted at the Project site and an assessment of the value of the other mitigation provided. A minimum of three months prior to acquisition of the HM Lands, Permittee shall submit to DFG for approval a formal Proposed Lands for Acquisition Form (see Attachment 4A) identifying the land to be purchased as mitigation for the Project's impacts on Covered Species. As part of this condition, the Permittee shall:

7.3.1 Transfer fee title to the HM Lands to DFG or another entity under terms approved by DFG. If fee title is held by an entity other than DFG, a conservation easement in a form approved by DFG shall be recorded on title of

the HM Lands. The grantee of the conservation easement may be DFG, a DFG-approved non-profit organization qualified pursuant to California Government Code section 65965, or a public agency approved by DFG and authorized to hold conservation easements. If a DFG-approved non-profit organization or approved public agency is grantee on a conservation easement, DFG shall be named third party beneficiary;

7.3.2 Provide a recent preliminary title report, initial hazardous materials survey report, and other necessary documents (see Attachment 4B). All documents conveying the HM Lands and all conditions of title are subject to the approval of DFG and if applicable, the Wildlife Conservation Board, and the Department of General Services;

7.3.3 Provide for the initial protection and enhancement of HM Lands as determined by DFG once Permittee identifies the HM Lands. DFG estimates that initial protection and enhancement will cost approximately $10,000.00/acre for 36 acres;

7.3.4 Conduct a Property Analysis Record (PAR) or PAR-like analysis once the HM Lands have been identified to determine the appropriate endowment amount to fund the in-perpetuity management of the 36 acres of required HM Lands. Permittee shall provide the required endowment to DFG after DFG reviews and approves the PAR using the Mitigation Payment Transmittal Form (Attachment 5). Permittee shall provide funding assurances for the endowment in the Security (see Condition 8 below). Interest from the endowment amount shall be available for reinvestment in the principal and for the long-term operation, management, and protection of the HM Lands, including reasonable administrative overhead, biological monitoring, improvements to biological carrying capacity, law enforcement measures, and any other action designed to protect or improve the habitat values of the HM Lands. Monies received by DFG pursuant to this Condition shall be deposited in a special deposit account established pursuant to Fish and Game Code section 13014. Alternatively, endowment funds may be held by a DFG-approved non-profit organization qualified to hold endowment funds. DFG may pool the endowment with other endowments for the operation, management and protection of HM Lands for local populations of the Covered Species; and

7.3.5 Reimburse DFG for reasonable expenses incurred during title and documentation review, expenses incurred from other state agency reviews, and overhead related to transfer of HM Lands to DFG. DFG estimates that this Project will create an additional cost to DFG of no more than $3,000 for every fee title deed or easement processed.

Perfor ance Security

8.1. Permittee may proceed with Project activities before completing all of the required mitigation (including acquisition of HM Lands), monitoring, and reporting activities only if Permittee ensures funding to complete those activities by providing to DFG at least thirty (30) days prior to commencing AIP operation an irrevocable letter of credit in the form of Attachment 6 or another form of security (Security) approved by DFG's Office of the General Counsel.[7] The Security shall allow DFG to draw on the principal sum if DFG, at its sole discretion, determines that Permittee has failed to comply with the Conditions of Approval of this ITP. The Security shall be in the amount of , based on the following estimated costs of implementing the ITP's mitigation, monitoring and reporting requirements:

8.1.1. Land acquisition costs for impacts to habitat, calculated at $5,000.00/acre for 36 acres: ,

8.1.2. Costs of initial protection and enhancement/restoration HM Lands, calculated at $10,000.00/acre for 36 acres: ,

8.1.3. Endowment estimate, estimated at $ 5,000.00/acre for 36 acres: ,

Even if the Security is provided, Permittee shall complete the required acquisition, protection and transfer of all HM Lands and record the required conservation easements in favor of DFG no later than eighteen (18) months after the start of AIP operation.

A end ent

This ITP may be amended as provided by California Code of Regulations, Title 14, section 783.6, subdivision (c), and other applicable law. This ITP may also be amended without the concurrence of the Permittee as required by law, including if DFG determines that continued implementation of the Project under existing ITP conditions would jeopardize the continued existence of the Covered Species or that Project changes or changed biological conditions necessitate an ITP amendment to ensure that impacts to the Covered Species are minimized and fully mitigated.

Stop-Work Order

DFG may issue Permittee a written stop-work order to suspend any activity covered by this ITP for an initial period of up to twenty-five (25) days to prevent or remedy a violation of ITP conditions (including but not limited to failure to comply with reporting, monitoring, or habitat

[7] Security for the performance of AIP construction-related mitigation was fulfilled by Bank of the West Letter of Credit No. MB60512988. Section 8 addresses security for the performance of Project maintenance and operations mitigation.

acquisition obligations) or to prevent the illegal take of an endangered, threatened, or candidate species. Permittee shall comply with the stop-work order immediately upon receipt thereof. DFG may extend a stop-work order under this provision for a period not to exceed twenty-five (25) additional days, upon written notice to the Permittee. DFG shall commence the formal suspension process pursuant to California Code of Regulations, Title 14, section 783.7 within five working days of issuing a stop-work order.

Co pliance with Other aws

This ITP contains DFG's requirements for the Project pursuant to CESA. This ITP does not necessarily create an entitlement to proceed with the Project. Permittee is responsible for complying with all other applicable state, federal, and local laws.

Notices

The Permittee shall deliver the fully executed duplicate original ITP by first class mail or overnight delivery to the following address:

Habitat Conservation Planning Branch
Attention: CESA Permitting Program
1416 Ninth Street, Suite 1260
Sacramento, CA 95814

Written notices, reports and other communications relating to this ITP shall be delivered to DFG by first class mail at the following addresses, or at addresses DFG may subsequently provide the Permittee. Notices, reports, and other communications shall reference the Project name, Permittee, and ITP Number (2081-2009-013-03) in a cover letter and on any other associated documents.

Original cover with attachment(s) to:

Regional Manager
Department of Fish and Game
Post Office Box 47
Yountville, CA 94599
FAX (707) 944-5563

Copy of cover without attachment(s) to:

Office of the General Counsel
Department of Fish and Game
1416 Ninth Street, 12th Floor
Sacramento, CA 95814

And:

Habitat Conservation Planning Branch
Department of Fish and Game
1416 Ninth Street, Suite 1260
Sacramento, CA 95814

Unless Permittee is notified otherwise, DFG's Regional Representative for purposes of addressing issues that arise during implementation of ITP conditions is:

Mr. Scott Wilson
Post Office Box 47
Yountville, CA 94599
(707) 944-5584 phone
(707) 944-5563 fax

Findings nder CESA

These findings are intended to document DFG's compliance with the specific findings requirements set forth in CESA and related regulations. (Fish & G. Code, § 2081, subs. (b)-(c); Cal. Code Regs., tit. 14, §§ 783.4, subds. (a)-(b), 783.5, subd. (c)(2).)

DFG finds that issuance of this ITP complies and is consistent with the criteria governing the issuance of ITPs under CESA:

(1) Take of Covered Species as defined in the ITP will be incidental to the otherwise lawful activities covered under the ITP;

(2) Impacts of the taking of the Covered Species will be minimized and fully mitigated through the implementation of measures required by this ITP and as described in the MMRP. Measures include: (1) The installation and proper maintenance of fish screens as described in the ITP; (2) Project operational restrictions including no-fill and no-diversion periods; (3) The screening of an additional agricultural diversion; (4) The acquisition, restoration and enhancement of tidal wetland habitat approved by DFG and maintained in perpetuity; and (5) An expanded monitoring and reporting program. DFG evaluated the quality and amount of aquatic habitat impacted by the Project, the scope and extent of direct impacts, the scope and extent of indirect impacts, and other relevant information available to DFG or provided by the Permittee. Based on this evaluation, DFG has determined that (1) the increased aquatic habitat provided during the no-fill and no-diversion periods; and (2) the acquisition, restoration, enhancement, protection and management in perpetuity of 36 acres of tidal wetland habitat, along with the minimization, monitoring, reporting, and funding requirements of this ITP fully mitigates the impacts of the taking on Covered Species expected to occur with the Project;

(3) The take avoidance and mitigation measures required pursuant to the conditions of this ITP and its attachments are roughly proportional to the impacts of the taking authorized by this ITP;

(4) The measures required by this ITP maintain Permittee's objectives to the greatest extent possible;

(5) All required measures are capable of successful implementation;

(6) The ITP is consistent with any regulations adopted pursuant to Fish and Game Code sections 2112 and 2114;

(7) Permittee has ensured adequate funding to implement the measures required by the ITP as well as for monitoring compliance with, and the effectiveness of, those measures for the Project; and

(8) Issuance of the ITP will not jeopardize the continued existence of the Covered Species based on the best scientific and other information reasonably available, and this finding includes consideration of the species' capability to survive and reproduce, and any adverse impacts of the taking on those abilities in light of (a) known population trends; (b) known threats to the species; and (c) reasonably foreseeable impacts on the species from other related projects and activities. Moreover, DFG's finding is based, in part, on DFG's express authority to amend the terms and conditions of the ITP without concurrence of the Permittee as required by law, including as necessary to avoid jeopardy to the Covered Species.

Attach ents

ATTACHMENT 1	Mitigation Monitoring and Reporting Program
ATTACHMENT 2	MOU/MA screening criteria
ATTACHMENT 3	General DFG fish screening criteria
ATTACHMENT 4A	Proposed Lands for Acquisition Form
ATTACHMENT 4B	Habitat Management Land Acquisition Checklist
ATTACHMENT 5	Mitigation Payment Transmittal Form
ATTACHMENT 6	Irrevocable Letter of Credit template

SS ED B E CA FO N A DEPA EN OF F S AND A E

on _____

_____

CHARLES ARMOR, Regional Manager
BAY DELTA REGION

APPROVED AS TO FORM:

_____

JOHN H. MATTOX
Senior Staff Counsel

AC NOW ED EN

The undersigned: 1) warrants that he or she is acting as a duly authorized representative of the Permittee, 2) acknowledges receipt of this ITP, and 3) agrees on behalf of the Permittee to comply with all terms and conditions of the ITP.

By _____ Date: _____

Printed Name: _____ Title _____

ISSUED BY THE CALIFORNIA DEPARTMENT OF FISH AND GAME

on Nov 5, 2009.

CHARLES ARMOR, Regional Manager
BAY DELTA REGION
APPROVED AS TO FORM:

JOHN H. MATTOX
Senior Staff Counsel

ACKNOWLEDGMENT

The undersigned: 1) warrants that he or she is acting as a duly authorized representative of the Permittee, 2) acknowledges receipt of this ITP, and 3) agrees on behalf of the Permittee to comply with all terms and conditions of the ITP.

By Walter J. Bishop Date: 11/9/09

Printed Name: Walter J. Bishop Title General Manager

APPROVED AS TO FORM

Robert B. Maddow
DISTRICT COUNSEL

ATTACHMENT 1

CALIFORNIA DEPARTMENT OF FISH AND GAME
MITIGATION MONITORING AND REPORTING PROGRAM (MMRP)
CALIFORNIA ENDANGERED SPECIES ACT

INCIDENTAL TAKE PERMIT NO. 2081-2009-013-03

PERMITTEE: **Contra Costa Water District**

PROJECT: **Los Vaqueros Project Maintenance and Operation**

PURPOSE OF THE MMRP

The purpose of the MMRP is to ensure that the impact minimization and mitigation measures required by the Department of Fish and Game (DFG) for the above-referenced Project are properly implemented, and thereby to ensure compliance with section 2081(b) of the Fish and Game Code and section 21081.6 of the Public Resources Code. A table summarizing the mitigation measures required by DFG is attached. This table is a tool for use in monitoring and reporting on implementation of mitigation measures, but the descriptions in the table do not supersede the mitigation measures set forth in the California Incidental Take Permit (ITP) and in attachments to the ITP, and the omission of a permit requirement from the attached table does not relieve the Permittee of the obligation to ensure the requirement is performed.

OBLIGATIONS OF PERMITTEE

Mitigation measures must be implemented within the time periods indicated in the table that appears below. Permittee has the primary responsibility for monitoring compliance of all mitigation measures and for reporting to DFG on the progress in implementing those measures. These monitoring and reporting requirements are set forth in the ITP itself and are summarized at the front of the attached table.

VERIFICATION OF COMPLIANCE, EFFECTIVENESS

DFG may, at its sole discretion, verify compliance with any mitigation measure or independently assess the effectiveness of any mitigation measure.

TABLE OF MITIGATION MEASURES

The following items are identified for each mitigation measure: Mitigation Measure, Source, Implementation Schedule, Responsible Party, and Status/Date/Initials. The Mitigation Measure column summarizes the mitigation requirements of the ITP. The Source column identifies the Permit document that sets forth the mitigation measure. The Implementation Schedule column shows the date or phase when each mitigation measure will be implemented. The Responsible Party column identifies the person or agency that is primarily responsible for implementing the mitigation measure. The Status/Date/Initials column shall be completed by the Permittee during preparation of each Status Report and the Final Mitigation Report, and must identify the implementation status of each mitigation measure, the date that status was determined, and the initials of the person determining the status.

	Mitigation Measure	Source	Implementation Schedule	Responsible Party	Status/Date/Initial
	Monitoring, Notification and Reporting				
1	Notwithstanding any expiration date on the take authorization provided by this ITP, Permittee's obligations under this ITP do not end until DFG accepts as complete the Permittee's Final Mitigation Report demonstrating compliance with minimization and mitigation measures for operation of the Project required by Condition 5.2 of this ITP.	ITP Condition 4.1	Entire Project	Permittee	
2	Permittee shall provide DFG an Annual Status Report no later than October 31 of every year. Each Annual Status Report shall include, at a minimum: (1) results of the expanded monitoring program; (2) maximum instantaneous rate of diversion for each diversion point summarized monthly; (3) cumulative monthly diversion in acre feet at each point of diversion; (4) any fish rescue results; (5) a copy of the table in the MMRP with notes showing the current implementation status of each mitigation measure; and (6) an assessment of the effectiveness of each completed or partially completed mitigation measure in minimizing and compensating for Project impacts.	ITP Condition 5.1	Beginning with issuance of the ITP and continuing until DFG accepts the Final Mitigation Report. Report due by October 31 of every year	Permittee	
3	Permittee shall provide DFG with a Final Mitigation Report. The Final Mitigation Report shall include, at a minimum: (1) a copy of the table in the MMRP with notes showing when each of the mitigation measures was implemented; (2) all available information about Project-related incidental take of the Covered Species; (3) information about other Project impacts on the Covered Species; (4) construction dates; (5) an assessment of the effectiveness of the ITP's Conditions of Approval in minimizing and compensating for Project impacts; and (6) recommendations on how mitigation measures might be changed to more effectively minimize and mitigate the impacts of future projects on the Covered Species.	ITP Condition 5.2	No later than ninety (90) days prior to expiration of the ITP	Permittee	
4	If a Covered Species is killed by Project-related activities during construction or operation and maintenance of the Project, or if a Covered Species is otherwise found dead within the Project boundary, Permittee shall immediately email the DFG Regional Office at swilson@dfg.ca.gov and kgeary@dfg.ca.gov or their designees. The initial notification to DFG shall include information regarding the location, species, number of animals injured or killed, and the ITP Number. Following the initial notification, Permittee shall send DFG a written report within seven (7) calendar days. The report shall include the date and time of the finding or incident, location of the carcass, and if possible provide a photograph, explanation as to cause of death, and any other pertinent information.	ITP Condition 5.3	Entire Project	Permittee	

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5	Permittee shall determine the effectiveness of the no-fill and no-diversion timing and conditions to protect delta smelt in their various life stages by implementing an expanded monitoring program. Permittee shall continue to utilize the DFG approved Rock Slough Expanded Monitoring Program (circa 2003), Revised Biological Monitoring Program for the Old River Fish Screen Facility (circa 2000), and the Proposed Program to Sample the Overflow Structure at the CCWD Mallard Slough Pumping Plant (circa 2000). Permittee shall monitor at the AIP in a manner consistent with the methods approved by DFG for the Old River Fish Screen Facility. Additionally, to provide an indication of the possible presence of larval longfin and delta smelt, the Permittee shall perform additional plankton net sampling at Old River, Rock Slough, and the AIP. To provide an indication of the presence of the estuarine food-chain Permittee shall begin a program of zooplankton net sampling at Old River, Rock Slough, and the AIP. Permittee shall provide to DFG a summary of the real time monitoring for adults, juveniles, and larvae present near Permittee intakes, and water quality data at the beginning and middle of each month. Permittee shall use the above monitoring information to determine diversion of water at the Rock Slough, Old River, AIP, and Mallard Slough intakes. Permittee may use monitoring information to recommend changes to Conditions 6.4, 6.5 or 6.6, or as a trigger for other measures such as diversion reductions for the protection of the Covered Species. Permittee shall submit to DFG an annual summary of all collected information by October 31 of each year, as described in Condition 5.1.	ITP Condition 5.4	Entire Project	Permittee	
6	By August 1, 2010, and every three years subsequently, Permittee shall submit an updated study plan to DFG for approval. The purpose of the study plan shall be to determine the presence of Covered Species adults, juveniles, and larvae at all current Permittee intakes and at the AIP. DFG shall provide written comments and requested changes, if any, regarding the adequacy of the submitted study plan and its elements by September 1 of each year in which an updated study plan is submitted. If DFG has comments or requested changes, Permittee shall resubmit a revised study plan that addresses DFG's comments and requests by October 1. This study plan must be acceptable to and must be approved by DFG prior to November 1 of each year in which an updated study plan is submitted. Permittee shall not be in violation of this provision if DFG does not respond in writing regarding the acceptability of the latest study plan in accordance with this schedule, provided Permittee is implementing and adhering to the latest study plan submitted to DFG. This continuous study shall begin by November 1 and shall continue until June 30 unless an alternative schedule is agreed to by DFG. Permittee shall submit a summary of the results of each study to DFG in accordance with the schedule contained within the approved study plan. Permittee shall conduct fish sampling techniques and handling procedures in a manner that minimizes mortality to the Covered Species. Permittee shall coordinate with the ongoing Interagency Ecological Studies Program (IEP) and make the Project monitoring data available to IEP upon IEP's request.	ITP Condition 5.5	By August 1, 2010 and every three years subsequently: August 1 update study plan; September 1 DFG Feedback; October 1 Revised Plan; November 1 DFG Approved Plan; Plan Implementation Nov 1-Jun 30.	Permittee & DFG	
7	Permittee shall transmit proposed monitoring plans, summaries of monitoring data, and other technical information required by this ITP to the Regional Representative identified by DFG in the Notices section of this ITP. A copy of such information shall also be transmitted to the: Regional Manager, California Department of Fish and Game, Bay Delta Region, Post Office Box 47, Yountville, CA 94599.	ITP Condition 5.6	Entire Project	Permittee	

	Take Minimization Measures				
8	The total annual water deliveries by the Permittee of CVP water and water appropriated under Application 20245 shall not exceed 177,000 acre feet and the total diversion annually under all bases of rights shall not exceed 222,000 acre feet.	ITP Condition 6.1	Entire Project	Permittee	
9	Permittee shall construct, operate, and maintain fish screens and fish screen cleaning systems at the Old River and AIP facilities that strictly conform to the fish screening system design criteria identified in Attachment 2 and as generally described by DFG's fish screen criteria included as Attachment 3 to this ITP. In addition, Permittee shall maintain an average approach velocity of 0.2 feet per second at the screen in accordance with the reasonable and prudent measures in the U.S. Fish and Wildlife Service's delta smelt Biological Opinions for the Los Vaqueros Project (U.S. Fish and Wildlife Service 1993a, as clarified and modified, U.S. Bureau of Reclamation 1993) and the AIP (U.S. Fish and Wildlife Service 2007). Permittee shall construct the AIP screened diversion and shall ensure the screen is continuously functioning prior to and during any diversion operation of the AIP.	ITP Condition 6.2	Entire Project	Permittee	
10	Permittee shall collaborate with BOR to ensure that screening the intake at Rock Slough in accordance with the CVPIA is completed no later than: (a) The year in which Permittee total deliveries to its customers reaches 160,000 acre feet per year; or (b) Implementation of a subsequent project that would substantially change operations of the Los Vaqueros Project; or (c) By the end of 2018, if neither a or b above has occurred.	ITP Condition 6.3	No later than the end of 2018	BOR & Permittee	
11	Permittee shall not divert water to storage in Los Vaqueros Reservoir from March 15 through May 31, except when reservoir storage is below emergency storage levels. For the purposes of this condition, the term "emergency storage" shall mean at least 70,000 af in storage in below normal years, above normal years, and wet years, and 44,000 af in dry years and critical years. Year types shall be as defined in the February edition of the California Department of Water Resources Bulletin 120 and the Four Basin Index defined by water right decision 1485. If the reservoir storage is below emergency storage levels, Permittee may fill the reservoir without the above restrictions only if (1) Permittee has provided DFG with notification that reservoir storage is below emergency storage level, and (2) Permittee notifies DFG of the intent to fill when filling would otherwise be restricted and DFG determines, in its sole discretion, that the filling can occur without exposing the Covered Species to an unacceptable level of risk.	ITP Condition 6.4	Entire Project	Permittee	
12	Beginning in February following the first year of operation of the AIP, Permittee shall not divert water from any of its diversions to storage in Los Vaqueros Reservoir for 15 days from February 14 through February 28, provided that reservoir storage is at or above 90,000 af on February 1. If reservoir storage is at or above 80,000 af on February 1, but below 90,000 af, Permittee shall not divert water to storage in Los Vaqueros Reservoir for 10 days from February 19 through February 28. If reservoir storage is at or above 70,000 af on February 1, but below 80,000 af, Permittee shall not divert water to storage in Los Vaqueros Reservoir for 5 days from February 24 through February 28.	ITP Condition 6.5	Entire Project	Permittee	

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13	During the period April 1 to April 30, Permittee shall not divert water from the Delta unless Los Vaqueros Reservoir is below emergency storage levels as defined above and shall instead release up to 12,500 af of water from the Los Vaqueros Reservoir to meet demand in Permittee's service area. In those instances where such diversions are necessary due to emergency storage levels, Permittee may divert water from the Delta only for direct use within the Permittee's service area.	ITP Condition 6.6	Entire Project	Permittee	
14	If DFG determines that a change in the periods described in Conditions 6.4, 6.5 and 6.6 would provide greater overall protection to the Covered Species, then DFG shall, no later than January 15 of any year, provide Permittee with a written request to modify one or more of those Conditions. Permittee shall notify DFG if it will implement the change.	ITP Condition 6.7	By January 15th each year	DFG & Permittee	
15	Permittee may submit to DFG by January 1 of each year, a proposal to modify the dates of Conditions 6.4, 6.5, and 6.6 to better protect delta and longfin smelt. DFG may approve modification of the dates for the periods when reservoir filling is to be avoided and the periods when no diversion shall occur if DFG determines the proposed modification of dates will be more effective in minimizing take of delta and longfin smelt. If DFG provides no response to the Permittee's proposal, Permittee shall adhere to and implement Conditions 6.4, 6.5, and 6.6.	ITP Condition 6.8	January 1 each year	DFG & Permittee	
16	Permittee shall only perform in-channel maintenance and repair operations on the Old River and AIP intakes between September 1 and November 15 of each year, unless DFG approves a modification in writing. If emergency in-channel maintenance and repairs of the Old River or AIP intake are necessary, Permittee shall notify DFG within 48 hours of commencing emergency work. The Permittee shall only conduct in-channel AIP construction activities between September 1 and November 30.	ITP Condition 6.9	September 1 - Nov 15th of each year except during emergencies	Permittee	
17	Until the Rock Slough diversion is screened, Permittee shall minimize water diversions from Rock Slough from December 1 through June 30. Permittee shall maximize use of its screened intakes by diverting from the Old River and AIP intakes, and diverting from the Rock Slough intake only when demand cannot be fully met from the Old River and AIP intakes because Los Vaqueros Reservoir is being filled or because water quality at the Old River and AIP intakes does not meet the Permittee's delivered water quality criterion. When diversions to meet demand are being made at the screened intakes, Permittee may also make the minimum diversion at the Rock Slough intake which is necessary to prevent stagnation in the Canal. This condition shall not apply if monitoring at the intakes indicates, and DFG agrees in writing, that the incidental take of Covered Species adults, juveniles, or larvae would be less at Rock Slough than another intake, or that Covered Species are not present at Rock Slough.	ITP Condition 6.10	Until Rock Slough is Screened	Permittee	

18	Permittee shall ensure the following diversion requirements are met: maximum instantaneous rate of diversion for the Rock Slough Intake shall not exceed 350 cfs; maximum instantaneous rate of diversion for the Old River Intake shall not exceed 250 cfs; maximum instantaneous rate of diversion for the AIP shall not exceed 250 cfs; and maximum instantaneous rate of diversion for the Old River Intake and the AIP combined shall not exceed 320 cfs. The maximum instantaneous rate of diversion cumulatively for all diversion points shall not exceed: 540 cfs for the months of June, July, August, September and October; 410 cfs for the months of November, December, January, February and March; and 470 cfs for April and May.	ITP Condition 6.11	Entire Project	Permittee	
19	To reduce turbidity in Victoria Canal during AIP-related construction activities (primarily excavation and cofferdam installation), Permittee shall: (1) install a silt curtain to reduce the dissipation of suspended sediments during dredging and cofferdam installation; and (2) install the cofferdam during the designated in-water work window between September 1 and November 30. In addition, successful AIP-related turbidity control shall be accomplished by installation and subsequent removal of the temporary cofferdam, while maintaining suspended sediment and turbidity levels within the water quality criteria established by the Regional Water Quality Control Board (RWQCB).	ITP Condition 6.12	During Construction	Permittee	
20	Permittee shall implement the following measures during AIP construction activities: (1) prohibit the discharge of petroleum products or other excavated materials to surface waters; (2) minimize substrate disturbance during AIP construction activities; (3) not cause turbidity increases in surface waters during AIP construction activities as follows: (a) where natural turbidity is between 0 and 5 Nephelometric Turbidity Units (NTUs), increases shall not exceed 1 NTU; (b) where natural turbidity is between 5 and 50 NTUs, increases shall not exceed 20%; (c) where natural turbidity is between 50 and 100 NTUs, increase shall not exceed 10 NTUs; and d)where natural turbidity is greater than 100 NTUs, increases shall not exceed 10%; (4) not cause settleable matter to exceed 0.1 ml/l in surface waters as measured in surface waters 300 feet downstream from the project during AIP construction activities; (5) not cause visible oil, grease, or foam in the work area or downstream during AIP construction activities; (6) protect all areas disturbed by AIP construction activities from washout or erosion; (7) in the event that AIP construction activities create a visible plume in surface waters, initiate monitoring of turbidity levels at the discharge site and 300 feet downstream, taking grab samples for analysis of NTU levels twice per day during the work period while the visible plume persists; (8) notify DFG immediately if the above criteria for turbidity, oil/grease, or foam are exceeded; and (9) notify DFG immediately of any spill of petroleum products or other organic or earthen materials.	ITP Condition 6.13	During Construction	Permittee	

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21	Permittee shall prepare a soil erosion control plan and stormwater pollution prevention plan prior to AIP grading and excavation activities to minimize potential AIP construction-related silt from entering waterways and increasing turbidity. The plans shall include, at a minimum, the following measures to minimize AIP-related erosion and sedimentation: (1) use sedimentation basins and straw bales or other measures to trap sediment and prevent sediment and silt loads to waterways during project construction; (2) cover graded areas adjacent to levees and in other areas that may be subject to erosion (as appropriate) with protective material, such as mulch, and re-seed with adapted native plant species after project construction is complete; (3) incorporate bank stabilization (riprap) into the AIP design on both the east and west sides of the intake to minimize channel margin erosion of soils into Victoria Canal; (4) minimize AIP construction-related surface disturbance of soil and vegetation and restore terrestrial habitats immediately after construction to the extent feasible; (5) place any AIP construction-related stockpiled soil where it would not be subject to accelerated erosion; and (6) commence re-vegetation with grasses native to the Delta and placement of erosion control devices, such as crushed rock, as soon as a graded area has attained finish grade. Permittee shall ensure that a certified erosion control specialist or California-registered civil engineer prepares the plan and that an AIP field manager monitors implementation of the plan in accordance with established protocols/procedures.	ITP Condition 6.14	During Construction	Permittee	
22	Permittee shall implement measures to reduce and/or avoid underwater sound pressure impacts. Permittee shall avoid and minimize risk of adverse impacts and incidental take of longfin smelt by installing the sheet pile cofferdam using a vibration hammer that minimizes underwater sound pressure levels to the greatest extent feasible. If Permittee determines that a higher intensity percussion hammer is required to install the cofferdam, Permittee shall consult with DFG to determine the appropriate actions to avoid or lessen adverse effects. Additional actions may include surveying Victoria Canal at the intake site to determine fish presence prior to installation, and possibly modifying the work window accordingly. Permittee shall not use a higher intensity percussion hammer without prior approval by DFG. Installation of the cofferdam, however, is expected to occur during the designated in-water work-window in summer and early fall when water temperatures within the central and south Delta are seasonally elevated and aquatic habitat in these areas is considered to be generally unsuitable for longfin smelt. Installation of the cofferdam using percussion hammers during summer would reduce and avoid potential adverse effects to these species.	ITP Condition 6.15	During Construction	Permittee	

23	Permittee shall prepare and implement a hazardous materials control and spill prevention and response plan prior to AIP construction. Measures in the plan to minimize AIP construction-related effects shall include the following: (1) a spill prevention and countermeasure plan that includes strict on-site handling rules to keep construction and maintenance materials out of drainages and waterways; (2) prevent AIP-related raw cement, concrete, concrete washings; asphalt, paint, or other coating material; oil or other petroleum products; or any other substances that could be hazardous to aquatic life from contaminating the soil or entering watercourses, including Victoria Canal; (3) clean up all AIP-related spills immediately according to the spill prevention and countermeasure plan, and notify RWQCB immediately of spills and cleanup procedures; (4) provide staging and storage areas for AIP-related equipment, materials, fuels, lubricants, solvents, and other possible contaminants away from watercourses and their watersheds; and (5) conduct periodic inspection during construction. Permittee shall provide DFG access to the Project site during construction to inspect construction activities to ensure compliance.	ITP Condition 6.16	During Construction	Permittee	
24	Permittee shall develop a fish rescue plan and shall obtain DFG approval of the plan prior to implementation of the Project. Installation of the cofferdam and dewatering a portion of the intake structure site during AIP fish screen construction may result in fish stranding. Permittee shall ensure that a qualified fishery biologist with a current DFG scientific collecting permit designs and conducts the fish rescue and relocation effort to collect fish from the area behind the cofferdam. The fish rescue effort shall be implemented during the dewatering of the area behind the cofferdam and shall include the capture and return of those fish to suitable habitat within Victoria Canal. To ensure compliance with this condition, a fisheries biologist shall be present on-site during initial dewatering activities.	ITP Condition 6.17	During Construction	Permittee	
25	Permittee shall monitor progress of installation of the cofferdam and the schedule for dewatering. Permittee shall coordinate the dewatering schedule with the construction contractor and fishery biologist to allow for the fish rescue to occur prior to completely closing the cofferdam and again when water depths are approximately two feet. Permittee shall notify DFG at least 48 hours prior to the fish rescue. Permittee shall record information on the species and sizes of fish collected in the rescue and estimates of survival immediately before release during fish rescue activities, and include this information in the next required report to DFG.	ITP Condition 6.18	Entire Project	Permittee	
	Compensation for Take				
26	The implementation of Conditions 6.4, 6.5, and 6.6 above will minimize take and provide increased aquatic habitat during the time these Conditions are in place. Conditions 6.4, 6.5, and 6.6 shall be implemented to provide additional aquatic habitat and, in so doing, shall provide partial mitigation for Project impacts of taking on Covered Species.	ITP Condition 7.1	Entire Project	Permittee	
27	As partial mitigation for the entrainment of delta smelt and longfin smelt, Permittee shall relocate one agricultural diversion from Victoria Canal to behind the AIP fish screen, thereby screening the one 16-inch agricultural diversion. This will reduce overall entrainment potential at the agricultural siphon.	ITP Condition 7.2	Prior to start of Project Operations	Permittee	

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28	Prior to initiating AIP operations, or no later than eighteen (18) months after the start of AIP operations if Security is provided pursuant to Condition 8 of the ITP, the Permittee shall acquire, restore, enhance and permanently preserve 36 acres of tidal wetland as Habitat Management Lands (HM Lands). The required acreage is based on an assessment of timing and quantity of the aquatic habitat impacted at the Project site and an assessment of the value of the other mitigation provided. The HM Lands shall be protected and managed in accordance with condition 7.3 of the ITP.	ITP Condition 7.3	Prior to AIP operation or no later than 18 months from the effective ITP date	Permittee	
	Performance Security				
34	Permittee may proceed with Project activities before completing all of the required mitigation (including acquisition of HM Lands), monitoring, and reporting activities only if Permittee ensures funding to complete those activities by providing to DFG at least thirty (30) days prior to commencing AIP operation an irrevocable letter of credit in the form of Attachment 6 or another form of security (Security) approved by DFG's Office of the General Counsel. The Security shall allow DFG to draw on the principal sum if DFG, at its sole discretion, determines that Permittee has failed to comply with the Conditions of Approval of this ITP. The Security shall be in the amount of $720,000.00 based on the following estimated costs of implementing the ITP's mitigation, monitoring and reporting requirements: (1) Land acquisition costs for impacts to habitat, calculated at $5,000.00/acre for 36 acres: **$180,000.000;** (2) Costs of initial protection and enhancement/restoration HM Lands, calculated at $10,000.00/acre for 36 acres: **$360,000.00;** and, (3) Endowment estimate, estimated at $ 5,000.00/acre for 36 acres: **$180,000.00** Even if the Security is provided, Permittee shall complete the required acquisition, protection and transfer of all HM Lands and record the required conservation easements in favor of DFG no later than eighteen (18) months after the start of AIP operation.	ITP Condition 8.1	30 days prior to AIP operation	DFG & Permittee	

ATTACHMENT 2

TABLE I-5
OLD RIVER FACILITY
DESIGN CRITERIA FOR INTAKE AND PUMPING PLANT

Old River Water Levels	
Maximum water surface	Elevation +8 ft (100-year *flood)*
Minimum water surface	Elevation -2 ft (extreme low water)
Design *low* water	Elevation -0S ft (MLLW)
Normal high water	Elevation +2.5 ft (MHHW)
General Intake Criteria	
Number of intake bays	5
Width of bays	15 ft
Top of intake. structure deck	Elevation +11 ft
Top of screen opening	Elevation -06 ft
Intake sill elevation	Elevation -125 ft
Intake side water depth	20 ft, maximum 10 ft, minimum 11.5 to 14.5 ft, normally
Fish Screens	
Screen material	Type 304 stainless steel
Maximum screen approach velocity	033 fps
Minimum gross wetted screen area	750 square ft
Minimum screen open area	50% of gross wetted screen area
Screen height	11.5 ft, vertical
Screen inclination	I (horizontal):6(vertical)
Maximum screen opening	3/32 inch, oriented vertically
Screen flatness tolerance	1/16 inch per panel 1/16 inch between panels 1/8 inch diagonally from corner to corner
Screen squareness tolerance	5 ft by 12 ft deep, not including transition plate 3
Panel size	per bay: 15 total
Number of panels	1
Standby panel	300 pounds per linear foot at panel midline
Panel design loading	1/8 inch
Maximum deflection at design load	Steel tube and plate sections acting as guide rails
Panel support system	Lifting eyes on each panel
Screen removal	
Screen Cleaning and Debris Removal System	
Number of cleaning rake units	2 units on a single rail system
Maximum screen cleaning interval	40 minutes (1 unit operating)
Normal screen cleaning interval	20 minutes (2 units operating)
Screen cleaning rake operation	Single stroke vertical scraping cycle at each position along screen face
Debris removal operation	Single continuous operation along the intake face to the end of the structure into a debris box
Basis of design	Hercules Hydrorake System by Atlas Polar Co., Ltd., Toronto, Ontario

(continued)

ATTACHMENT 2

TABLE 1-5
OLD RIVER *FACILITY*
DESIGN CRITERIA FOR INTAKE AND PUMPING PLANT
(continued)

Screen Cleaning and Debris Removal System	*(cont.)*
Required lifetime	5 years before major component overhaul or replacement 16
Debris box area	ft by 10 ft, based on a 20 cubic yard dumpster Redundant
System backup	rake machines and 5 scrapers/rakes for manual cleaning
Miscellaneous Intake Criteria	Provide slots for future flow control louvers
Screen flow control	Provide stoplog slots at each bay and 5 aluminum stoplog panels stored on site
Dewatering and Intake bay isolation	Provide 15 solid panels fated for screen slots to isolate bays during extended facility down time
Inlet Channel and Wet Well"	03 fps
Pump approach velocity	5.0 fps (to be selected by pump manufacturer)
Pump inlet bell velocity	15 ft clear between splitter walls
Pump bay width	3 ft from centerline of pumps to back wall
Back wall distance	1.8 ft from bottom of sump floor to inlet bell
Distance from floor to inlet bell	6.7 ft from bottom of inlet bell to extreme low water surface in Old River
Submergence	Use corner fillets (1.8 ft fillet leg) at all wetted wall and floor
Miscellaneous criteria	intersections; use rounded wall ends in wet well
Pumping Plant Criteria	250 cfs
Total capacity	5 vertical turbine pumps with wet well suction
Number and type of pumps	4 kV, three-phase induction motors, with power factor
Type of motor	correction capacitors operated at 4.16 kV
Horsepower	[2],000 hp each pump motor
Pump design point	Flow per pump: 50 cfs TDH: 273 ft with 5 pumps operating Minimum pump efficiency: 85%

ATTACHMENT 3

GENERAL FISH SCREENING CRITERIA[1]

1. Structure Placement

A. Streams and Rivers (flowing water):

The screen face shall be parallel to the flow and adjacent bankline with the screen at or streamward of the annual low flow water's edge. The bankline shall be warped to match the screen structure, eliminating eddies in front, upstream, and downstream of the screen.

Intake structures shall not be constructed shoreward from the normal bankline in locations where parallel velocities past the screen cannot be provided.

B. Lakes and Reservoirs (non-flowing waters):

Diversion structures and/or intakes shall be constructed offshore to minimize fish contact with the diversion. Velocity from any direction toward the screen shall not exceed the approach velocities in No. 2 below.

2. Approach Velocity (Local velocity component perpendicular to screen face)

A. The approach velocity shall not exceed 0.33 feet/second.

B. The approach velocity shall be uniformly distributed across the face of the screen.

C. The actual wetted screen area, excluding area affected by structural components, required at the minimum stream stage is calculated by dividing the maximum diverted flow by the allowable approach velocity.

D. Fish screens shall be considered continually cleaned when a cleaning cycle can be completed and continues at 5 minute intervals or less.

E. Fish screens shall be cleaned as frequently as necessary to prevent impedance of flow and violation of the approach velocity criteria.

F. Screens which are not continually cleaned shall be designed with an= approach velocity of 0.0825 feet/second and shall be cleaned when the approach velocity becomes 0.33 feet/second.

3. Velocities Past Screens

In flowing streams, the component of the velocity parallel and adjacent to the screen face shall be at least two times the allowable approach velocity. Screen faces shall be placed flush with any adjacent screen bay piers or walls to allow an unimpeded flow of bypass water parallel to the screen face.

[1]Criteria developed pursuant to Fish and Game Code sections 1600, 5900, and 6100.

ATTACHMENT 3

4. Screen Openings

A. Continually cleaned screens shall have a minimum-open area of 1½ square feet per cubic foot/second. Screens not continually cleaned shall have a minimum open area of 6 square feet per cubic foot/second.

B. Round openings in screening shall not exceed 5/32 inch.

C. Square openings in screening shall not exceed 5/32 inch measured diagonally.

D. Slotted openings in screening shall not exceed 3/32 inch.

E. Orientation of the long axis of slot or rectangular openings shall be vertical when installed in flowing water.

5. Screen Construction

A. Screens may be constructed of any rigid material, perforated or woven, that provides water passage while physically excluding fish.

B. Corrosion resistant screening material is recommended for the screening material to reduce opening clogging due to corrosion blocking.

C. Plans shall be provided to the Department which show that all the applicable screening criteria have been met before written approval can be granted by the Regional Manager.

D. All fish screens constructed after 1982 shall be designed and constructed to satisfy these criteria. Owners of existing screens approved by the Department prior to 1982 shall be required to upgrade their facilities to satisfy the revised criteria as: 1) the screen components deteriorate and require replacement (i.e., change mesh size or mesh orientation when the mesh on panels or rotary drum sections needs replacing), or 2) during modification/reconstruction of the intake facilities (i.e., change screen alignment or increase screen area to satisfy approach velocity requirement), or 3) when the owner proposes to increase the rate of diversion which would result in violation of the approach velocity criteria without the construction of additional screen area.

E. Supplemental criteria may be issued by the Department in the future to accommodate new fish screening technology which may be developed or to modify these "Screening'Criteria" if new scientific data warrants revision.

F. Written variances to these screening criteria may be granted with the approval of the Regional Manager and concurrence of Environmental Services Division and Inland Fisheries Division chiefs.

ATTACHMENT 4A

Proposed Land for Acquisition Form ("PLFAF")

Date: _____

TO:

Facsimile:

FROM:

Applicant proposes that the following parcel(s) of land be considered for approval by the Department as suitable for purposes of habitat management lands to compensate for the adverse environmental impacts of the Project:

Section (s)	Township	Range	County	Acres

Current Legal Owner(s), include Parcel Number(s):

General Description of Location of Parcel(s):

Land value: $

For Region Use Only

APPROVED ____ By: _____ Date: _____

REJECTED _____ Region:

Explanation:

ATTACHMENT 4B

DEPARTMENT OF FISH AND GAME
HABITAT MANAGEMENT LAND ACQUISITION PACKAGE CHECKLIST
FOR PROJECT APPLICANTS

The following checklist is provided to inform you of what documents are necessary to expedite Department processing of your Habitat Management Land acquisition proposal. Any land acquisition processing requests which are incomplete when received, will be returned. The Region contact will review and approve the document package and forward it to the Habitat Conservation Branch, Senior Land Agent with a request to process the land acquisition for formal acceptance.

To: _____
Regional Manager, Region Name

From: _____
Project Applicant

Phone: _____

Tracking #: _____
CDFG assigned permit or agreement #

Project Name: _____

Enclosed is the complete package for the ☐ Conservation Easement OR ☐ Grant Deed

Documents in this package include:

☐ Fully executed, approved as to form Conservation Easement Deed or Grant Deed.
Date executed: _____

☐ Proposed Lands for Acquisition Form (PLFAF)

☐ Phase I Environmental Site Assessment Report Date on report: _____
(An existing report may be used, but it must be less than two years old.)

☐ Preliminary Title Report(s) for subject property is enclosed and has been reviewed for encumbrances and other easements. The title report must be less than six months old when final processing is conducted. Included are additional documents:

☐ Copies of document(s) to title exceptions identified in Schedule B of the Preliminary Title Report.

☐ Williamson Act Contract, if any.

☐ A plot or map of easements/encumbrances on the property

☐ County Assessor Parcel Map(s) for subject property

☐ Site Location Map (Site location with property boundaries outline on a USGS 1:24,000 scale topo)

☐ Final Permit or Agreement (or other appropriate instrument)
Type of agreement: ☐ Bank Agreement ☐ Mitigation Agreement
☐ Permit _____ Other: _____

(write in type of permit)

☐ Biological Resources Survey (may be an attachment to Permit or Agreement or separate document)

☐ Final Management Plan (if required prior to finalizing permit or agreement or if this package is for a Grant Deed)

☐ Draft Summary of Transactions ☐ hard copy ☐ electronic copy (both are required)

ATTACHMENT 5

California Department of Fish and Game

Mitigation Payment Transmittal Form

Project Applicant Instructions: Please fill out and attach this form to payment. For conservation banks, also attach the Bill(s) of Sale for credits sold. One form may be used for multiple transactions, **BUT YOU MUST USE A SEPARATE FORM FOR EACH CHECK YOU TRANSMIT.** Make sure to include Project Name, Project Tracking Number, and ASB Mitigation Tracking Number (if available) on the attached payment type.

(1) **DATE:** _____

TO: _____
[CDFG Regional Manager]

_____
[CDFG Region Office Address]

(2) **FROM:** _____
Name

_____
Mailing Address

_____
City, State, Zip

_____
Telephone Number/FAX Number

(3) **RE:** _____
[Project Name as appears on permit/agreement]

(4) **AGREEMENT/ACCOUNT INFORMATION:**
(Check the applicable type)

□ 2081 Permit □ Conservation Bank □ 1802 Agreement

□ 2835 NCCP □ Other _____

_____
[Project Tracking Number]

_____
[ASB Mitigation Tracking Number (if available)]

Index _____ PCA _____

(5) PAYMENT TYPE (One check per form only): The following funds are being remitted in connection with the above referenced project:

Check information:

Total $_____ Check No. _____

Account No. _____ Bank Routing No. _____

a. Endowment: for Long-Term Management Subtotal $_____

b. Habitat Enhancement Subtotal $_____

c. Security:

1. Cash Refundable Security Deposit Subtotal $_____

2. Letter of Credit Subtotal $_____

1. Financial Institution: _____

2. Letter of Credit Number: _____

3. Date of Expiration: _____

ATTACHMENT 6

IRREVOCABLE STANDBY LETTER OF CREDIT NO. [*number*]

Issue Date: [***date***]

Beneficiary:

Department of Fish and Game
1416 Ninth Street, 12th Floor
Sacramento, CA 95814
Attn: Office of the General Counsel

Amount: U.S. $[***dollar number***] [(***dollar amount***)]

Expiry: [***Date***] at our counters

Dear Sirs:

1. At the request and on the instruction of our customer, [***name of applicant***] ("Applicant"), we, [***name of bank***] ("Issuer"), hereby establish in favor of the beneficiary, the California Department of Fish and Game ("Department"), this irrevocable standby letter of credit ("Credit") in the principal sum of U.S. $[***dollar number***] [(***dollar amount***)] ("Principal Sum").

2. We are informed this Credit is and has been established for the benefit of the Department pursuant to the terms of the incidental take permit for the [***name of project***] issued by the Department to the Applicant on [***date***] (No. [***number***]) ("Permit").

3. We are further informed that pursuant to the Permit, the Applicant has agreed to complete certain mitigation requirements, as set forth in Conditions [***numbers***] in the Permit ("Mitigation Requirements").

4. We are finally informed that this Credit is intended by the Department and the Applicant to serve as a security device for the performance by the Applicant of the Mitigation Requirements.

5. The Department shall be entitled to draw upon this Credit only by presentation of a duly executed Certificate for Drawing ("Certificate") in the same form as

ATTACHMENT 6

Attachment A, which is attached hereto, at our office located at [***name and address of bank***].

6. The Certificate shall be completed and signed by an "Authorized Representative" of the Department as defined in paragraph 12 below. Presentation by the Department of a completed Certificate may be made in person or by registered mail, return receipt requested, or by overnight courier.

7. Upon presentation of a duly executed Certificate as above provided, payment shall be made to the Department, or to the account of the Department, in immediately available funds, as the Department shall specify.

8. If a demand for payment does not conform to the terms and conditions of this Credit, we shall give the Department prompt notice that the demand for payment was not effected in accordance with the terms and conditions of this Credit, state the reasons therefore, and await further instruction.

9. Upon being notified that the demand for payment was not effected in conformity with the Credit, the Department may correct any such non-conforming demand for payment under the terms and conditions stated herein.

10. All drawings under this Credit shall be paid with our funds. Each drawing honored by us hereunder shall reduce, *pro tanto*, the Principal Sum. By paying to the Department an amount demanded in accordance herewith, we make no representations as to the correctness of the amount demanded.

11. This Credit will be cancelled upon receipt by us of Certificate of Cancellation, which: (i) shall be in the form of Attachment B, which is attached hereto, and (ii) shall be completed and signed by an Authorized Representative of the Department, as defined in paragraph 12 below.

12. An "Authorized Representative" shall mean either the Director of the Department of Fish and Game, the General Counsel of the Department of Fish and Game, or a Regional Manager of the Department of Fish and Game.

13. This Credit shall be automatically extended without amendment for additional periods of one year from the present or any future expiration date hereof, unless at least sixty (60) days prior to any such date, we notify the Department in writing

ATTACHMENT 6

by registered mail, return receipt requested, or by overnight courier that we elect not to consider this Credit extended for any such period.

14. Communications with respect to this Credit shall be in writing and addressed to us at [***name and address of bank***], specifically referring upon such writing to this credit by number. The address for notices with respect to this Credit shall be: (i) for the Department: Department of Fish and Game, Office of the General Counsel, 1416 Ninth Street, 12th Floor, Sacramento, California 95814-2090 Attn: General Counsel; and (ii) for the Applicant: [***name and address of Applicant***].

15. This Credit may not be transferred.

16. This Credit is subject to the International Standby Practices 1998 ("ISP 98"). As to matters not covered by the ISP 98 and to the extent not inconsistent with the ISP 98, this credit shall be governed by and construed in accordance with the Uniform Commercial Code, Article 5 of the State of California.

17. This Credit shall, if not cancelled, expire on [***expiration date***], or any extended expiration date.

18. We hereby agree with the Department that documents presented in compliance with the terms of this Credit will be duly honored upon presentation, as specified herein.

19. This Credit sets forth in full the terms of our undertaking. Such undertaking shall not in any way be modified, amended or amplified by reference to any document or instrument referred to herein or in which this Credit is referred to or to which this Credit relates and any such reference shall not be deemed to incorporate herein by reference any document or instrument.

[***Name of bank***]

By: _____
Name: _____
Title: _____

ATTACHMENT 6

ATTACHMENT A

IRREVOCABLE STANDBY LETTER OF CREDIT NO. [***number***]
CERTIFICATE FOR DRAWING

To:

[***Name and address of bank***]

Re: Incidental Take Permit No. [***permit number***]

The undersigned, a duly Authorized Representative of the Department of Fish and Game ("Department"), as defined in paragraph 12 in the above-referenced Irrevocable Standby Letter of Credit ("Credit"), hereby certifies to the Issuer that:

1. [***Insert one of the following statements:*** "In the opinion of the Department, the Applicant has failed to complete the Mitigation Requirements referenced in paragraph 3 of the Credit." ***or*** "As set forth in paragraph 13, the Issuer has informed the Department that the Credit will not be extended and the Applicant has not provided the Department with an equivalent security approved by the Department to replace the Credit."]

2. The undersigned is authorized under the terms of the Credit to present this Certificate as the sole means of demanding payment on the Credit.

3. The Department is therefore making a drawing under the Credit in amount of U.S. $_____.

4. The amount demanded does not exceed the Principal Sum of the Credit.

Therefore, the Department has executed and delivered this Certificate as of the ___day of _____, _____.

CALIFORNIA DEPARTMENT OF FISH AND GAME

BY: _____
[Insert one of the following: "DIRECTOR" ***or*** "GENERAL COUNSEL" ***or*** "REGIONAL MANAGER, [***NAME OF REGIONAL OFFICE***]"]

ATTACHMENT 6

ATTACHMENT B

IRREVOCABLE LETTER OF CREDIT NO. [***number***]
CERTIFICATE FOR CANCELLATION

To:

[***Name of bank and address***]

Re: Incidental Take Permit No. [***permit number***]

The undersigned, a duly Authorized Representative of the California Department of Fish and Game ("Department"), as defined in the paragraph 12 in the above-referenced Irrevocable Standby Letter of Credit ("Credit"), hereby certifies to the Issuer that:

1. [***Insert one of the following statements:*** "The Applicant has presented documentary evidence of full compliance with the Mitigation Requirements referenced in paragraph 3 of the Credit." ***or*** "The natural expiration of this Credit has occurred."]

2. The Department therefore requests the cancellation of the Credit.

Therefore, the Department has executed and delivered this Certificate for Cancellation as of the ____ day of _____, _____.

CALIFORNIA DEPARTMENT OF FISH AND GAME

BY: _____
[Insert one of the following: "DIRECTOR" ***or*** "GENERAL COUNSEL" ***or*** "REGIONAL MANAGER, [***NAME OF REGIONAL OFFICE***]"]

CALIFORNIA FARM BUREAU FEDERATION
NATURAL RESOURCES AND ENVIRONMENTAL DIVISION
2300 River Plaza Drive, Sacramento, CA 95833-3293 · Phone (916) 561-5655 · Fax (916) 561-5691

January 28, 2010

Via First-Class Mail & Email
karen.scarborough@resources.ca.gov
beth.gerbutavicius@resources.ca.gov

Karen Scarborough
Under Secretary
NATURAL RESOURCES AGENCY
1416 Ninth Street, Suite 1311
Sacramento, CA 95814

Re: Bay Delta Conservation Plan;
January 29, 2010 Decisions Regarding Near- and Long-term Operations.

Dear Ms. Scarborough:

Three years ago, the California Farm Bureau Federation ("Farm Bureau") requested a seat on the BDCP Steering Committee. Farm Bureau's executive leadership and staff have devoted considerable time and effort to the process because we recognize that the Delta is a linchpin not only for California's agricultural industry, but also for the whole of the State's economy. Areas south of the Delta simply cannot persist without an adequate and reliable supply from the Delta and such a supply will not exist until we have improved the water conveyance system in the Delta and put in place a robust and effective plan to stabilize Delta species and the Delta ecosystem.

A unique confluence of disparate interests have come together in the BDCP, making it perhaps the best hope of a broadly-supported, comprehensive solution today. As a statewide leadership organization, Farm Bureau recognizes that the status quo concerning the Delta is unacceptable. This is why we remain at the table, fully engaged and desirous to see the process through to a successful conclusion.

Notwithstanding the foregoing, and notwithstanding our general support for the BDCP to date, we do not come to the process without certain hopes and expectations, as well as certain duties to the various segments of our diverse statewide membership. In particular, one expectation that we have striven to articulate throughout the process is that a long-term conveyance solution in the BDCP should not be the cause of any substantial deterioration in water quality conditions in Delta that would preclude much of the existing agriculture in the Delta from coexisting in the future alongside the various conveyance or habitat improvements being currently considered.

At the BDCP Steering Committee's January 29, 2009 meeting, our understanding is that BDCP Steering Committee members will be asked to tentatively approve certain specific parameters for use in the "full effects analysis" process that will begin in March and run through June. Among these parameters are a set of proposed near- and long-term operations and a package of proposed conservation measures including a potential "isolated facility" and some 65,000 acres of restored tidal marsh over the 50-year term of the BDCP. The consensus which may be reached on the 29th is not intended to be a final decision; however, it does represent a significant step in the process, as we understand it, to the extent these decisions will determine the outlines of a general project description that will form the basis of the detailed effects and impacts analyses to be undertaken over the next several months, as the next important step in the BDCP process.

Construction and operation of an isolated facility and proposed tidal marsh restoration in the BDCP are activities that have potential to significantly alter existing flow and salinity patterns in the Delta. This could in turn impact the quality of the Delta's waters as a perennial irrigation water supply upon which several hundreds of thousands of acres of existing farmland in the Delta currently rely. Presumably, even if the BDCP were implemented in full, much of this existing farmland would continue to be farmed in the future—provided that such lands remain economically viable, unflooded, unimpaired by restoration actions, infrastructure, or other land use changes, and so long as they have access to a sufficiently fresh supply of water from adjacent Delta channels and waterways. Water quality in the Delta, however, is an especially important ingredient for Delta agriculture, since Delta farmland without an adequately fresh supply of in-Delta water is land lacking an essential resource for its continued viability. With respect to a supply of water meeting adequate quality standards therefore, Farm Bureau's position has been and remains that the BDCP process must make every effort to accurately predict and fully disclose potential adverse salinity impacts on Delta farmers and then take all feasible and necessary steps within the program's control to avoid and minimize the same.

Farm Bureau appreciates the DWR's, the BDCP Management Team's, and the BDCP modelers' scheduling of a recent "Modeling for Modelers" technical briefing held on January 20, 2010, of a previous technical workshop for modelers held October 28, 2010, in addition to numerous prior briefings related to water quality (for example, in the HOTT, Integration, and Conveyance Workgroup meeting in 2008). Also, particularly where we cannot know with any greater certainty what impacts may occur until a more complete analysis is completed, Farm Bureau appreciates the need to press ahead at this point with the full effects analysis of a straw proposal that can in turn serve as a basis for an eventual proposed project and project description. At the same time, however, many aspects of the BDCP's operations, hydrodynamic and water quality modeling to date remain in flux, while the totality of water quality and hydrodynamic information provided in BDCP to date remains too general and too preliminary to support any definite conclusions at this juncture.

To ensure a package that is reasonably protective of the legitimate interests of parties outside of the BDCP, there remains much uncertainty. Defensible answers to these questions will be important, not only from the perspective of a statewide agricultural organization such as Farm Bureau, but also in a broader political, legal and public relations sense. As noted, even as the BDCP Steering Committee is being asked to approve various elements of a proposed project for completion of the BDCP's full effects analysis by early summer 2010, the sheer number of unknowns make any definitive judgment or approval at this stage impossible. Final approval, however, is quite different from the kind of interim direction the Steering Committee is being asked to provide at this point, based on a tentative consensus of the parties in light of the draft plan elements discussed to date and the as yet incomplete body of information we have available to us at this time. Quite distinct from any sort of definitive approval, then, we believe such a tentative consensus to be both possible and appropriate at this time—at least, with the clear understanding that additional briefings (Steering Committee, technical, small group, or otherwise) will be needed as the BDCP's effects and impacts analyses progress and as more definitive modeling results are developed this spring.

Lastly, in regard to irrigation and potential salinity impacts in the Delta specifically, Farm Bureau's tentative consent at this time is premised on a reasonable expectation that the process will ultimately produce and make available at least following information, as specified:

Minimum Information Specifically Required in the BDCP Process to Support Eventual Policy Decisions Related to In-Delta Salinity:

1. Capturing different year types and different sequences of years (as opposed to mere historic averages):

    - Run the proposed project for all water year types individually (wet, above normal, below normal, dry, critical dry).

    - Run the proposed project showing multi-year trends for representative sequences of different year types (for example, 1987-1992 for a multi-year drought pattern, 1995-1999 as a series of wet years, and 1963-1969 as a series alternating wet and dry years).

    - Modeling results should incorporate effects of embedded tidal marsh restoration and climate change assumptions that would apply at each stage of implementation (i.e., near-term, early long-term, and late long-term).

2. Capturing the full range of different year types and different sequences of years (as described above) for each implementation period compared to existing and pre-BO conditions:

   Run the above for (a) the pre-BO D-1641 condition, (b) the existing RPA condition, (c) the proposed project in the near-term implementation period, (d) the proposed project in the early long-term implementation period, (e) the proposed project in the late long-term implementation period.

3. Distinguishing effects of operations from effects of tidal marsh restoration and long-term sea level rise:

   In addition to potential major operational changes associated with the BDCP's proposed project, proposed tidal marsh restoration and projected effects of future sea level rise in the early and late long-term implementation periods could also have significant hydrodynamic and salinity-related impacts in the Delta. The combined effect of these three factors, however, could potentially confound or mask the relative incremental impact of each individual factor in relation to the whole. For example, there is some potential for the "tidal dampening" effect of proposed tidal marsh restoration in the BDCP to act as a hydrologic buffer to some saltwater intrusion into the central and eastern Delta. Depending on the physical location of restored tidal marsh however, this new tidal marsh habitat could also alter the tidal prism, net salt transport and the like, in potentially unpredictable ways.

   Similarly, proposed operations in the future could alter and affect salinity and flow patterns in the Delta, detrimentally, neutrally, or beneficially, depending on the location. Operational adjustments could mitigate some adverse effects, while others could be beyond the control of any operational response. Future sea level rise, for example, catastrophic levee failure, natural saltwater intrusion, upstream storage constraints, or limited inflow could potentially overwhelm any viable operational response.

   At a minimum, to clearly distinguish and characterize the relative effect of these three important variables of proposed operations, proposed tidal marsh restoration, and projected future sea level rise, it will be necessary to carry out a series modeling runs that layers and clearly shows the incremental effect of each, as follows:

   - Show results of the proposed project for each water year type for the early and late long-term implementation periods without tidal marsh or sea level rise/climate change.

- Compare to the above results for the proposed project in each water year type for the early and long-term implementation periods with tidal marsh, but without sea level rise/climate change.

- Compare to the first two runs, the results of the proposed project in each water year type for the early and long-term implementation periods with tidal marsh and sea level rise/climate.

4. Ease of comparison among differing conditions:

   To be useful and easily understandable to technical and non-technical audiences alike, modeling results should be visually presented in graphs, graphics, and bar charts as appropriate to clearly, visually, and meaningfully facilitate:

   - Cross-comparison of month-to-month trends and changes among differing years and scenarios, in addition to trends and changes within each individual year, for all years and conditions.

   - Side-by-side comparison of conditions among differing year types (wet, above normal, below normal, dry and critical dry).

   - Side-by-side comparison of conditions across different implementation periods relative to pre-BO and current RPA conditions.

   - Visual references to facilitate comparison among differing salinities relative to existing regulatory standards.

   - Clear delineation and visual presentation of relative salinities during the Delta's core irrigation season, from roughly April through September.

   - Comparison of incremental and cumulative effects of operations, tidal marsh restoration and sea level rise/climate change in different year types and across all implementation periods.

5. Water levels & net flows:

   In addition to salinity, water levels and lack of circulation have been cited as two significant problems for Delta farmers in certain years, certain months and certain locations in the South Delta in particular. Operations of the CVP and SWP export pumps in the South Delta have been identified by the State Water Resources Control Board in Water Rights Decision 1641 and elsewhere as one factor that can potentially

affect water levels and flow patterns in the South Delta (along with inflow on the San Joaquin River and the tides). It follows that altering CVP and SWP operations in the South Delta as part of a long-term dual-conveyance regime could affect water levels and flow patterns in the South Delta (negatively, positively, or neutrally), which could in turn affect local agricultural diversions and South Delta concentrations of salt. From a regional and also a statewide agricultural standpoint, it is therefore important to get a fair and complete assessment of the potential effects of the proposed project on water levels and flows, during the traditional April-September irrigation season in particular, in different year types and sequences of years. As with salinity effects, as described above, this should include:

- Water level and flow results for the South Delta in all year types (W, AN, BN, D, C), with a particular focus on relative effects during the relevant period of the Delta's traditional irrigation season from roughly April through September.

6. South Delta and San Joaquin River Flow Assumptions:

From a regulatory and environmental effects standpoint, unless and until the regulatory or environmental baseline changes, BDCP modeling and BDCP planning must assume existing San Joaquin River flow criteria and existing D-1641 and contractual M&I and agricultural standards will apply not only now, but in the future as well. On a parallel track, however, as part of the current periodic review of the Bay-Delta Water Quality Control Plan, the State Water Board has initiated an on-going review of the existing South Delta and San Joaquin River flow standards in D-1641, which *could* lead to potential modification and revision of one or both standards. Something to be considered in the BDCP process is the potential for these possible changes in the regulatory and environmental baseline to alter or affect the body of modeling results, operations assumptions, effects and impact analyses that will have supported or formed the basis for various decisions up to the point at which such changes might occur.

7. Verification and Third-Party Review of BDCP Modeling Assumptions:

If implemented, the proposed project would represent a fairly radical departure from all past experience. Changes associated with the addition of up to five, preferentially operated diversion points in the North Delta, with a combined peak diversion capacity of 15,000 cfs, and a significant reduction in current pumping from the South Delta, would alter current conditions in the Delta considerably. These substantial changes then present a special challenge for BDCP modelers attempting to accurately predict these potential changes by adapting existing tools. In addition, the hydrodynamic and water quality effects of the phased restoration of some 65,000 acres of tidal marsh and up to a foot and a half of projected long-term sea level rise will make the BDCP modelers' task that much more complex.

The BDCP's modelers engaged in this task are no doubt among the best and most qualified in the state. Precisely because of the above mentioned uncertainties however, various interests have now expressly requested access to the "recalibrated" and "retrained" models and model outputs being developed as part of the BDCP process. As we have been informed, whether to release this information is ultimately a management, lead agency and policy-level call. On one hand, some hesitancy to release detailed modeling results that are, at this stage, perhaps still very preliminary and incomplete, is understandable. On the other hand, precisely because of the tremendous importance of the BDCP process, there may be a need for some higher standard of transparency in this case, to more solidly establish the integrity of the process and perhaps even partially overcome what has in various quarters amounted to a considerable amount of counterproductive anxiety, controversy, misinformation, and speculation.

Short of providing preliminary review of on-going modeling outputs then, there is at least an interim need for more meaningful, comprehensive, and detailed information, as described above, and for on-going third-party review of the BDCP modeler's technical memoranda as these are ready. In addition, all of the BDCP's core modeling outputs and assumptions should be ultimately included a technical appendix to the BDCP's Draft and Final EIR/EIS documents.

Conclusion:

In closing, Farm Bureau congratulates the BDCP Steering Committee and Management Team in anticipation of the attainment of this new milestone in the planning process. We have offered the foregoing observations and suggestions in the best spirit of collaboration and look forward to continued meaningful participation on these and other issues as the BDCP process moves forward.

Sincerely,

CHRISTIAN C. SCHEURING
Managing Counsel

CCS\mmm

cc: (See next page)

cc: *(Via Email)*

Kenny Watkins, Committee Member & First Vice President (CFBF):	*kwatkins@cfbf.com;*
Ann Hayden, Environmental Defense Fund:	*ahayden@environmentaldefense.org;*
Anthony Saracino, The Nature Conservancy:	*asaracino@tnc.org;*
Brent Walthall, Kern County Water Agency:	*bwalthall@kcwa.com;*
Ara Azhderian, San Luis Delta-Mendota Water Authority:	*ara.azhderian@sldmwa.org;*
Federico Barajas, U.S. Bureau of Reclamation:	*fbarajas@mp.usbr.gov;*
Dan Castleberry, U.S. Fish and Wildlife Service:	*dan_castleberry@fws.gov*
Dan Nelson, San Luis Delta-Mendota Water Authority:	*dan.nelson@sldmwa.org;*
Carl Wilcox, California Department of Fish and Game:	*cwilcox@dfg.ca.gov;*
Gary Bobker, The Bay Institute:	*bobker@bay.org;*
Greg Gartrell, Contra Costa Water District:	*ggartrell@ccwater.com;*
Greg Thomas, Natural Heritage Institute:	*gat@n-h-i.org;*
Greg Zlotnick, Santa Clara Valley Water District:	*GZlotnick@valleywater.org;*
Jill Duerig, Zone 7 Water Agency:	*jduerig@zone7water.com;*
Joe Grindstaff, California Bay-Delta Authority:	*jgrindstaff@calwater.ca.gov;*
John Chillemi, Mirant Delta:	*john.chillemi@mirant.com;*
Kim Delfino, Defenders of Wildlife:	*kdelfino@defenders.org;*
Jerry Johns, California Department of Water Resources:	*jjohns@water.ca.gov;*
Maria Rea, NOAA National Marine Fisheries Service:	*maria.rea@noaa.gov;*
Melinda Terry, North Delta Water Agency:	*Melinda@northdw.com;*
Paul Robershotte, U.S. Army Corps of Engineers:	*paul.j.robershotte@usace.army.mil;*
Richard Roos-Collins, American Rivers:	*rrcollins@n-h-i.org;*
Roger Patterson, Metropolitan Water District:	*rpatterson@mwdh2o.com;*
Steve Ottemoeller, Friant Water Authority:	*sottemoeller@friantwater.org;*
Jason Peltier, Westlands Water District:	*jpeltier@westlandswater.org;*
Tom Howard, State Water Resources Control Board:	*thoward@waterboards.ca.gov.*

CALIFORNIA natural resources AGENCY

EDMUND G. BROWN JR., Governor
JOHN LAIRD, Secretary for Natural Resources

September 11, 2013

Dear Chair Wornham and Ms. Stapleton:

Working together, California stands at a precipice not reached in more than 40 years: decisions in the California Delta that will stabilize our water reliability for generations to come. I want to thank the San Diego County Water Authority (SDCWA) for its considerable contribution to that progress, and, in the spirit of transparent and informed public policy, I would also like to detail a framework of issues and processes that yet remain before us.

In January of this year, the SDCWA along with other water agencies and environmental groups asked that a proposal containing a wide variety of elements be considered as an alternative to the proposed Bay Delta Conservation Plan (BDCP). Please find attached an evaluation of the potential of such a concept to meet the co-equals of water supply reliability and ecosystem restoration in the Delta established by the California Legislature in 2009.

While there are many areas of agreement in regard to local water supply development, water use efficiency, storage, and other essential water management strategies, the fundamental premise that cost savings from building a smaller facility could generate funding for substantial and adequate investments in other regional and local water supply to meet California's future water needs does not bear out. That said, the portfolio of water management strategies you identified in January will be the foundation upon which my agency, in collaboration with the California Environmental Protection Agency, and California Department of Food and Agriculture will embark on the development of a broad water action strategy for California. This is also described in more detail in the attached document.

I want to thank the ratepayers, board, and professional staff of the San Diego County Water Authority, for their ongoing financial, policy and technical support of the BDCP and its environmental review documents. After six years of study, and hundreds of millions of dollars of sound science, evaluation, assessment and collaboration, the BDCP has seen its first public release – and is several weeks away from initiating formal public review of a draft proposed plan for environmental actions and infrastructure investments needed to reach the twin goals.

Please do not hesitate to contact me with further questions. I look forward to continuing our work together to meet California's water needs in an efficient and sustainable way.

Sincerely,

John Laird
California Secretary for Natural Resources

1416 Ninth Street, Suite 1311, Sacramento, CA 95814 Ph. 916.653.5656 Fax 916.653.8102 http://resources.ca.gov

Portfolio Approach to Statewide Water Management
and the Bay Delta Conservation Plan

September 11, 2013

The Bay Delta Conservation Plan (BDCP) is one effort among many others aimed at developing a broad and sustainable water portfolio for California's water future. The California Natural Resources Agency (CNRA), the California Environmental Protection Agency (Cal EPA) and the California Department of Food and Agriculture (CDFA) are collaborating to develop a statewide approach that identifies specific actions to most efficiently and sustainably manage our water resources statewide.

There are key integrated water management elements that help achieve the co-equal goals of the BDCP, but which are not within the BDCP's specific scope, including:

- Increased water use efficiency and conservation (as mentioned above).
- Increased water supply through storage, desalination, water recycling, and groundwater management.
- Improved operational efficiency through other water conveyance projects, increased Central Valley Project and State Water Project operational efficiencies, and voluntary water transfers/exchanges.
- Ecosystem enhancements throughout California watersheds.

The BDCP is governed by the legislatively-mandated co-equal goals to restore the ecosystem of the Delta and determine what water can be exported in a way that's environmentally sustainable and reliable in the face of an extreme event or disaster made more likely by climate change. The ability of the BDCP to meet these coequal goals is the lynchpin for broader, statewide integrated water management. Without a successful BDCP, the effectiveness of local efforts to improve groundwater management, maintain and improve water quality, and develop recycled water supplies to meet California's water future will be greatly diminished.

The BDCP is significant, because for the first time, and as a direct result of the co-equal goals provided by the Legislature, biological objectives will help determine water deliveries. The water project will meet the stringent requirements of the Endangered Species Act and Natural Community

Conservation Planning Act. State and federal agencies have been working together to define a project that can be permitted within these laws.

The BDCP will be one of the largest and most complex water supply and habitat conservation plans in the nation. Hundreds of millions of dollars have gone into its planning in the form of engineering work, biological studies, economic analyses and water supply modeling. The state Department of Water Resources (DWR) has worked in close partnership with water agencies, environmental groups, scientists, and state and federal fish and wildlife experts to move the plan forward. If the BDCP is to be approved by state and federal fish agencies, the plan must meet the stringent environmental standards of both state and federal law. The current "proposed project" includes, among other things, a new 9,000 -cubic feet per second (cfs) north Delta export facility (three intake structures and two parallel tunnels from near Hood to the state and federal pumps in the South Delta) and 65,000 acres of restored tidal marsh habitat.

Response to the January, 2013 Portfolio Concept

In January, 2013, some environmental groups and water agencies asked that a proposal containing a wide variety of elements be considered as an alternative concept to the proposed BDCP project. This "portfolio" proposal includes a new 3,000- cfs north Delta water export facility (one intake structure and a single tunnel), reduced habitat restoration, increased water storage and conservation around the state, funds for Delta levee repairs, and other elements. The proponents of this statewide proposal suggest that it might save the water exporters money, which could be used for more diverse water sources, such as water conservation, wastewater recycling, and other types of water management.

Although the portfolio proposal, with its emphasis on conservation, diversification, and improved storage, has considerable merit from a policy standpoint, the proposal as a package is not practical as an alternative to the BDCP proposed project. The portfolio alternative has four premises. The first two are explicit, while the second two are implicit.

1. It would be cheaper and more cost-effective to build a 3,000- cfs north Delta water export facility with a single tunnel than to build a 9,000- cfs facility with two parallel tunnels.

2. The 3,000- cfs facility, combined with the existing south Delta facilities, could export annually about 1 million acre feet less water than is being exported today. This lost water would be

made up by other water management techniques such as water conservation, wastewater recycling, groundwater management, and additional water storage that are more cost-effective and more protective of the environment than the BDCP proposed project.

3. The biological goals and objectives of BDCP could be met by the "portfolio" alternative, thus fulfilling the requirements of both a Habitat Conservation Plan (HCP) under the federal Endangered Species Act, and a Natural Community Conservation Plan (NCCP) under the California Natural Community Conservation Planning Act. These stringent goals and objectives would be met despite continued very heavy reliance on exports from the south Delta.

4. A smaller Delta water export facility would provide adequate protection against a prolonged inability to export water from the South Delta due to the flooding of Delta islands following an earthquake or major storm.

Each of these premises are examined below.

1. Premise: It would be cheaper and more cost-effective to build a smaller Delta water export facility.

From an engineering point of view, redundancy in underground water systems (tunnels) is highly desirable to allow for maintenance and unforeseen outages. The BDCP proposed 9,000- cfs project includes two tunnels in order to provide this redundancy. The portfolio proposal does not provide the desired infrastructure redundancy. If the project were to include two tunnels the cost would be about $1 billion more than the single bore version.

The cost of a 3,000- cfs tunnel would be $8.5 billion. The cost of the 9,000- cfs tunnels would be $14.5 billion. Based on Chapter 9 of the BDCP, water supply from a 3,000- cfs tunnel project would be an average of 4.2 million acre- feet per year. Water supply from a 9,000- cfs project, in contrast, would average at least 4.7 million acre-feet per year.

The substantial reduction in water supply provided by the 3,000- cfs facility would result in a large reduction in economic benefits compared to the larger facility. The economic analysis performed in BDCP Chapter 9 shows that most alternatives to the proposed project have positive benefit cost ratios. But the 3,000- cfs tunnel has a negative benefit cost ratio, largely because the cost of the 3,000- cfs tunnel is approximately two thirds of building the proposed 9,000- cfs twin tunnels but the water yield is much smaller. (Right-of-way and equipment mobilization costs are not much smaller for a small project than for a large one.)

The proposed project would increase the reliability of exports by allowing more flexibility to deliver water from the north Delta when environmental conditions are appropriate, while increasing total average annual exports from 3.5 million acre feet per year (with no project) to 4.7 million acre feet per year even if very high Delta outflows are required to protect sensitive fish species.

Conclusion: Building a 3,000- cfs tunnel has a benefit/cost ratio of less than 1, and results in a reduction in the Delta water supply of 500,000 acre- feet per year compared to the 9,000- cfs tunnels.

2. Premise: spending the money saved on the smaller facility to develop water supply alternatives would be more cost effective than building the larger facility.

DWR believes that Delta improvements and a wide variety of water supply alternatives will be needed to meet California's future water needs. This is particularly true because climate change will adversely impinge on existing water supplies in a several ways:

• Snowfall in the Sierra will gradually be replaced by rain. The slow and steady snowmelt will be somewhat replaced by immediate rain runoff. The rain will come when reservoirs must be drawn down for flood control, whereas snowmelt allows reservoirs to fill gradually after the flood season is over. These changes will make storage of the rain runoff difficult.

• Less reliable and more variable water supplies will lead to greater demand for groundwater, increasing groundwater overdraft. This trend will gradually lead to a greater demand for surface water supplies as groundwater becomes less affordable.

• The water supply from the Colorado River to Southern California may decline due to climate change and the increasingly erratic precipitation pattern in the Colorado River watershed. Also, demand for Colorado River water by other states in the watershed is increasing.

• If increased rainfall leads to higher peak winter flows in the Central Valley rivers, the U.S. Army Corps of Engineers may increase the flood reservation requirements in the major reservoirs. Such a change in reservoir operations could reduce the water supply, hydroelectric, recreational, cold water pool, and other benefits of the reservoirs.

These impacts, along with increased water demand to relieve groundwater overdraft and to accommodate economic and population growth, are challenges that transcend the BDCP. For that reason, as mentioned above, CNRA, Cal EPA, and CDFA are working to develop a broader statewide action plan. The action plan will also be designed to contribute to achieving the goal of the Delta Reform Act to reduce future reliance on the Delta by making the most efficient use of the existing Delta system.

The portfolio plan calls for a $2 billion investment in water recycling and a $3 billion investment in urban conservation. The proposal also calls for unspecified investments in agricultural conservation. As described above, reducing the size of the tunnels from 9,000 cfs to 3,000 cfs only saves $5 billion while producing less water for export, a lack of redundancy, and fewer economic benefits. Also, many statewide conservation, efficiency, recycling and other water management programs are underway, and while they are not part of the BDCP, they were studied at length in the BDCP Appendix 1C (Demand Management Measures). These water management strategies are already anticipated to contribute to the success of the BDCP and will be addressed in the water action plan.

Investing $3 billion in the most cost effective forms of water conservation and wastewater recycling would not come close to replacing the water supply lost as a result of reducing the size of the tunnels. Water recycling costs are often in the range of $1,000 - $1,500 per acre-foot per year, and sometimes much higher. Conservation is often somewhat less expensive than recycling, but in most urban areas served by the SWP, has a cost of $1,000 per acre-foot and above. Indeed, reviewing the actual costs of recent water recycling projects in California, it is doubtful that a $3 billion investment would produce even 100,000 acre-feet of reliable new water supply in urban areas, and would do nothing for agricultural users. Further, investing $3 billion in conservation and recycling to make up for the smaller tunnel size would use up the most cost effective water conservation and wastewater recycling opportunities, making it more expensive to implement water conservation and wastewater recycling in the future.

The portfolio proposal includes development of new surface or groundwater storage south of the Delta. DWR agrees such new storage should be part of an overall water supply program for California in coming decades, this is made clear in BDCP Appendix 1B (Water Storage).

In the past two decades, significant new water storage space in the form of reservoirs and groundwater storage banks has been created south of the Delta. Improving the Delta conveyance

system will increase the ability to use this new storage space and set the stage for additional future storage investments.

Conclusion: California will need investment in all alternatives due to increasing demand for water, especially since existing supplies will be reduced by climate change. Many such investments should occur independent of, and parallel to, the BDCP. But investment in protecting the supply of water from the Delta is the most cost effective way to protect an important source of California water supply from disruption. A more detailed discussion of water supply management alternatives is in Appendix 1C (Demand Management Measures) of the BDCP administrative draft EIR/EIS.

3. Premise: The biological goals and objectives of BDCP could be met by the "portfolio based" alternative, thus fulfilling the requirements of both a Habitat Conservation Plan under the federal Endangered Species Act, and a Natural Community Conservation Plan under the California Natural Community Conservation Planning Act.

The portfolio alternative reduces by one-third (from 65,000 acres down to 40,000 acres) the amount of tidal marsh habitat that would be restored. This reduction would save money, but would also reduce the environmental benefits of BDCP. The BDCP is an ecosystem-based plan designed to restore fish and wildlife species while also providing a more reliable water supply. The goal is to do more, not less, to help the environment. The proposed project includes a tidal habitat restoration target of 65,000 acres because tidal marsh habitat may contribute to the recovery of some critical fish species, and will surely provide a wide variety of other environmental benefits. There appears to be sufficient land available to achieve this goal over the first 40 years of BDCP implementation. Adaptive management could allow for subsequent adjustment of this program. DWR looks forward to working with the portfolio signatories through the adaptive management process to make adjustments as necessary to achieve BDCP biological goals and objectives.

According to the analysis contained in Chapter 9 of the BDCP, 72 percent of mean total CVP and SWP deliveries would be diverted through south Delta intakes with the 3,000- cfs proposal, compared with 51 percent under the BDCP proposed action's 9,000- cfs project. The south Delta is where fish species are most at risk from pumping. When more water is diverted through the south Delta intakes, such action increases the potential for take of aquatic species from entrainment and predation. Thus, the reduced opportunity to divert from the north Delta when environmental

conditions are appropriate represents a reduced opportunity to address existing, ongoing adverse environmental conditions in the south Delta. Under both scenarios, pumping is maximized during wet periods, and minimized during dry periods.

Conclusion: Based on the best available science restoration of tidal marsh is an important habitat for some species and DWR is committed to doing more, not less to meet the biological goals and objectives of the plan. The portfolio plan may undermine this biological objective.

4. Premise: A smaller Delta water export facility would provide adequate protection against a prolonged inability to export water from the south Delta due to the flooding of Delta islands following an earthquake or major storm.

The United States Geological Survey has stated that, in the next 40 years, there is a high likelihood of a major earthquake that will collapse from several to many Delta islands. (Appendix 3E of the 2nd Administrative Draft discussed Seismic Risk and Climate Change in the Delta). Another likely event is a major storm that would cause the same result. If many Delta islands fail, sea water will enter the Delta, replacing fresh water in the Delta and greatly reducing water exports. It may take from one to 10 years to rebuild enough Delta levees to once again allow substantial exports from the south Delta. It may even be impossible to fully restore enough islands to allow export from the south Delta to resume on a reliable basis. The Delta is currently nearly one fifth of the state's water supply. Large regions in the Bay Area (e.g., the Silicon and Livermore valleys, and the Contra Costa Water District), Central Valley, and Southern California rely on the Delta for 25 percent to 100 percent of their water supply. Delta exports averaged 5.3 million acre-feet per year over the last 20 years. If it appears that Delta exports are not possible for several to many years, a tunnel project would likely have to be built to provide water as soon as possible to prevent an economic catastrophe. Statewide economic impacts of a multi-year Delta outage could be as high as $10 billion per year, and job losses could be as high as 40,000 per year. In this scenario, a 3,000- cfs facility would be insufficient to meet the State's water needs and avert huge economic losses. Adding an additional 6,000 cfs under urgent conditions to avert this disaster would cost more than $11 billion (in addition to the $9 billion of building the 3,000- cfs facility initially). The portfolio concept includes $1 billion in levee improvements in the Delta to address seismic risks. While this level of investment in Delta levees may be appropriate for the long term, it will not prevent the type of levee collapse that is threatened by earthquake, major storm events,

and sea level rise. Nor can it substitute for the type of protection against levee collapse that the 9,000- cfs tunnels would provide.

> *Conclusion: building a 3,000- cfs tunnel would leave California dangerously exposed to a 75 percent reduction in Delta water supply after a major earthquake or storm. Building an emergency facility in the event of a major Delta island failure would cost more than building the 9,000- cfs tunnels now and would have to be done under enormous pressure to restore water supply reliability.*

Conclusion

This analysis indicates that while the portfolio approach includes many worthwhile elements, it ultimately is not a viable solution for meeting the state's co-equal goals for restoration of the Delta ecosystem and a more reliable water supply. Moreover, integrating activities beyond the Delta into the permit process would be legally challenging and substantially increase the complexity of complying with the legal requirements of an NCCP, and is therefore not a practical alternative to the BDCP proposed project. But the proposed approach helpfully draws attention to the larger statewide policies that will contribute to the success of the BDCP and are needed as we plan for more sustainable water management. DWR is committed to working with the portfolio proponents to ensure that the elements identified in the portfolio approach are part of a broader statewide effort to manage water resources more efficiently and sustainably.

RESOLUTION NO. 88-45

A RESOLUTION OF THE BOARD OF DIRECTORS OF CONTRA COSTA WATER DISTRICT AFFIRMING THE CONTRA COSTA WATER DISTRICT'S GOALS AND OBJECTIVES FOR THE LOS VAQUEROS RESERVOIR PROJECT

WHEREAS, the Contra Costa Water District (CCWD) has always sought to improve the quality and reliability of its water supply, and

LOS VAQUEROS RESERVOIR PROJECT

WHEREAS, the primary purposes of the Los Vaqueros Reservoir Project are to improve water quality by minimizing seasonal quality changes and to provide emergency and drought storage, and

WHEREAS, additional purposes of the Los Vaqueros Reservoir Project are to provide flood control benefits, to maintain and enhance fish and wildlife resources and to provide recreational opportunities consistent with the primary water quality purpose, and

WATER QUALITY

WHEREAS, CCWD is committed to reducing the concentration of sodium and chloride in the District's water, thereby reducing household and landscape irrigation concerns and industrial and manufacturing costs caused by the fluctuating sodium and chloride levels of the District's Delta source, and

WHEREAS, results of studies conducted by water resource engineers have determined that water quality and emergency storage objectives will be reasonably met with a reservoir of approximately 100,000 acre-feet, and

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EMERGENCY STORAGE

WHEREAS, CCWD has only a three-day supply at Contra Loma Reservoir during peak demand periods, and

WHEREAS, East Bay Municipal Utility District (EBMUD) has 120 days of storage and the City of San Francisco 260 days, and

WHEREAS, in cases of disaster such as oil spills, Delta levee breaks, chemical spills, drought or other emergency conditions, a three-day backup supply is insufficient for a district serving water to more than 350,000 customers and fifteen major industries, and

ENVIRONMENTAL

WHEREAS, CCWD has completed its Stage I Environmental Impact Report (EIR) in compliance with the California Environmental Quality Act (CEQA) and the State CEQA guidelines, and

WHEREAS, CCWD is implementing all of the mitigation measures adopted in the Stage I EIR, and

WHEREAS, CCWD has been conducting extensive studies of wildlife, botanical, archeological, and historical resources in the watershed to provide adequate understanding of these resources, and

WHEREAS, CCWD is committed to fully evaluate all potential environmental impacts of the project and to implement adequate mitigation measures to reduce impact severity to less than significant levels, and

WHEREAS, CCWD has begun the preparation of a Stage 2 EIR to described and evaluate such environmental impacts and mitigation measures, and

WHEREAS, CCWD is coordinating with state and federal wildlife agencies to develop mitigation plans to offset potential adverse impacts of the project, and

OPEN SPACE MANAGEMENT

WHEREAS, CCWD has committed to carefully manage the watershed lands to allow agriculture and ranching to continue, and to maintain appropriate wind farm operations while developing and maintaining a balance between the project, current land uses and the environment as provided in its Interim Land Management Plan adopted in September 1987, and

WHEREAS, CCWD is committed to preparing a long-term watershed management plan to continue to manage the watershed to maintain the balance between the project, public recreation, environmental protection, and agricultural uses following project construction, and

GROWTH

WHEREAS, CCWD currently has a contract for 195,000 acre-feet of water each year, uses only 100,000 to 110,000 acre-feet, and has an adequate supply to meet anticipated service area needs, and

COSTS

WHEREAS, the proposed reservoir project will have a cost to the District of about $350 million in 1988 dollars.

THEREFORE, BE IT RESOLVED by the Board of Directors that, it is the policy of the Contra Costa Water District that the implementation and financing of the Los Vaqueros Reservoir Project under the authority to be secured from the voters of the District will meet the following goals and objectives:

WATER QUALITY

1) CCWD has set long-term goals of stabilizing sodium levels at 50 parts per million (ppm) sodium and 65 ppm chloride. These goals will be met by capturing Delta flows, through the purchase of Mokelumne River water from EBMUD, or by securing other Sierra sources for storage in the Los Vaqueros Reservoir, or by a combination of these sources.

2) CCWD will build a reservoir for its own purposes with approximately 100,000 acre feet of storage to be operated to meet its water quality goals.

EMERGENCY STORAGE

1) Los Vaqueros will be operated in combination with water quality goals to provide approximately six months of storage.

ENVIRONMENTAL

1) CCWD will prepare the Stage 2 EIR addressing environmental impacts, adopting mitigation measures, and entering into agreements with federal and state resource agencies regarding the mitigation of impacts before construction.

2) CCWD will prepare a long-term watershed management plan integrating protection of reservoir water quality, protection of environmental resources, provision of appropriate public recreation, operation of wind farms as appropriate, continuation of agricultural production, and other appropriate land uses.

GROWTH

1) CCWD will implement and operate its interests in the project for water quality, emergency storage and drought protection.

LOCAL CONTROL

1) CCWD will own, operate and control Los Vaqueros to keep water in Northern California.

2) The District shall not operate the project in conjunction with a Peripheral Canal or to increase the export of Delta water from Northern California without additional voter approval.

3) CCWD will explore partnership arrangements for a larger project with other regional agencies with the following stipulations:

a) Partners must have objectives in common with CCWD: water quality and reliability (emergency storage and drought protection).

b) Participation must not unreasonably delay the project.

c) Participation must result in significant cost savings to CCWD's customers.

d) Participation does not introduce environmental issues at the Los Vaqueros site or within the service area of the participants that are unacceptable to CCWD.

RECREATION

1) Guided by environmental considerations, the District will pursue recreation opportunities consistent with its water quality and emergency storage objectives, protection of the watershed and preservation of the watershed's unique features.

2) CCWD will develop a recreation plan for the project as a part of the Stage 2 EIR.

COSTS

1) Costs will be recovered through rates and charges for services to cities, districts, industries, other wholesale customers, retail customers, and other beneficiaries of the project.

2) CCWD is committed to managing its operations efficiently to keep the cost of an improved water supply to a minimum. The District estimates that once the facility is operating, only 15 percent of its retail customers' bills will be directly related to the cost of water stored in Los Vaqueros.

TIME LINE

The District has chosen to move forward with Los Vaqueros quickly and carefully to make higher quality water and a sufficient emergency supply available to its customers as soon as possible. If kept on its current track, high-quality Los Vaqueros water could be available in 1995.

* * * * * * * * * * *

I hereby certify that the foregoing is a true and complete copy of a resolution duly and regularly adopted by the Board of Directors of Contra Costa Water District at a regular meeting thereof held on July 27, 1988, by the following vote:

AYES: Directors Freitas, Boatmun, Butler, Pellegrini, and Hughey

NOES: None

ABSENT: None

Dated: July 27, 1988

Janice N. Harski

Janice N. Harski, Secretary
Contra Costa Water District

CONTRA COSTA
WATER DISTRICT

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September 16, 2009

Directors
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President

Karl L. Wandry
Vice President

Elizabeth R. Anello
Bette Boatmun
John A. Burgh

Walter J. Bishop
General Manager

Bay-Delta Conservation Plan Steering Committee
c/o Hon. Karen Scarborough, Undersecretary of Resources
1416 Ninth Street, Suite 1311
Sacramento, CA 95814

Subject: **BDCP Operational Parameters and Effects Analysis**
Follow-up to September 10, 2009, Steering Committee Meeting

Dear Members of the Steering Committee:

Contra Costa Water District (CCWD) would like to take this opportunity to offer comments on the BDCP operational parameters and effects analysis, as presented in the September 10, 2009 Steering Committee meeting. We have three areas of concern, as follows:

- **Evaluation and verification of modeling tools.**
  Models used for operations, hydrodynamics, and water quality have been extensively modified for BDCP studies. Before model results are relied upon to guide important BDCP decisions, the modified models must be carefully evaluated and verified. Furthermore, to provide context for model results, CCWD recommends that the historical data, as well as the pre-BO (i.e. D-1641) modeling results, and the current BO modeling results, be displayed together with results of BDCP proposed operations.

- **X2 requirements.**
  The use of a 5-month average for compliance with X2 requirements could have problematic results, such as a decrease in the temporal variability in salinity that historical conditions and the current standard provide.

- **Limitations on South Delta exports to prevent salvage.**
  The proposed Old and Middle River flow limits should be reviewed; preliminary analysis indicates the levels may be overly restrictive and not supported by the smelt or salmon data. Furthermore, installation of positive barrier fish screens at the south Delta export facilities will allow increased pumping of about 1,000 cfs or more while still protecting covered fish species.

More detailed discussion of the above-listed concerns is given below and in the attachments to this letter.

Evaluation and Verification of Modeling Tools

Modeling tools used in the BDCP analysis need to be verified and should be compared to historical data for context. The models have been modified extensively in the last year to calibrate for salinity and to incorporate new operational changes reflecting the current Biological Opinions (BOs) for the Central Valley Project (CVP) and State Water Project (SWP). They are being modified and the calibrations adjusted to reflect the proposed actions in the draft BDCP. These are not easy tasks.

The preliminary results of the long-term effects analysis presented to the Steering Committee on September 10 include some questionable results, especially the water quality results on slide 22 (see Attachment A). Before the modeling tools can be used to develop, analyze and refine BDCP proposed operations, there must be a demonstration that the models are behaving in a reasonably accurate manner.

The Reasonable and Prudent Alternatives (RPAs) in the current BOs are anticipated to alter upstream storage patterns as well as hydrodynamics and salinity within the Delta, creating a new baseline that is significantly different from the pre-2007 conditions. Monitoring data that represent the conditions anticipated under the current BOs is limited to the last one to two years, when operations included restrictions similar to some of the RPAs. Additionally, the VAMP period each year provides relevant data on expected flows and salinity within the Delta. Monitoring during these periods indicates that water quality in the Central and South Delta is likely to deteriorate during periods of low exports from the existing South Delta facilities. These conditions are unlike those we have seen in the past under prior BOs, but they are the current conditions.

To ensure a common understanding of *current* conditions, as opposed to pre-2007 conditions, CCWD suggests the following approach.

To provide context to the analyses to be presented to the Steering Committee and its subcommittees, CCWD recommends that the historical data, as well as the pre-BO (i.e. D-1641) modeling results, and the current BO modeling results, be displayed together to provide a general understanding of where we are now and what has changed. The modeling results for the proposed BDCP operations can then be compared to these results so that there is a complete understanding of where the system was and what is proposed.

Unfortunately, the modeling tools have previously performed poorly in simulating salinity within the Central and South Delta under conditions with low export pumping from the South Delta, such as imposed by the current BOs and anticipated in the BDCP long-term operations. Also, two years ago CCWD pointed out that the water quality model also has some accuracy problems in the Central and South Delta during periods of seawater intrusion. When these inaccuracies are trained into CALSIM, the degree of

error introduced is compounded. CCWD is hopeful that the modifications made to the models have corrected these problems; however, this has yet to be demonstrated. CCWD recommends that the California Water and Environmental Modeling Forum (CWEMF) perform an independent verification of the modeling tools.

Finally, the additional tidal marsh to be created within the Restoration Opportunity Areas (ROAs) is likely to have significant affects on tidal stage, flow, and salinity. For instance, the preliminary results shown on September 10 (slide 8) seem to indicate that over 2,000 acres of existing intertidal habitat within Suisun Marsh will become subtidal and an additional 500 acres of existing intertidal habitat within Suisun Marsh will no longer be inundated with the tides. Combined with the additional proposed tidal marsh areas, the subsequent effect on water quality within the Delta is likely to be substantial and we must have confidence the models are correctly predicting the effects. As mentioned above, the current preliminary water quality results are suspect. Clearly, incorporation of the ROAs cannot be compared to historical data (the areas have not been inundated historically); therefore, the modeling tools must be carefully validated, and the results carefully evaluated at incremental steps by adding portions of the proposed tidal marsh individually and then evaluating the subsequent incremental change in hydrodynamics and water quality. As recommended above, an independent analysis by CWEMF would be appropriate given the level of uncertainty in modeling a completely new environment without any historical context.

X2 Requirements

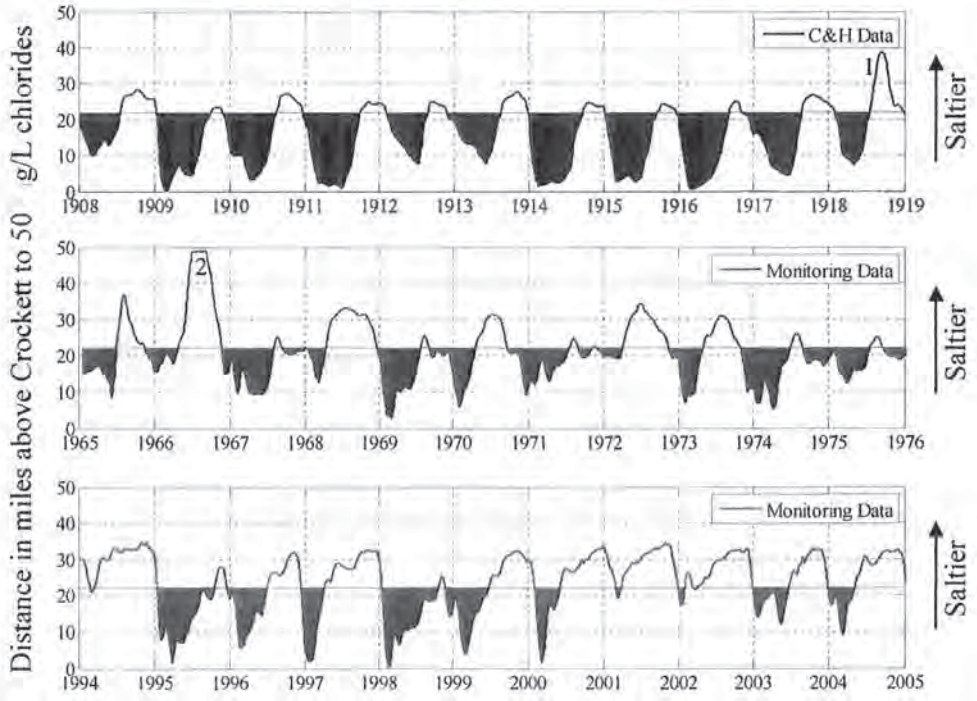
CCWD questions the implementation of the X2 requirement using a 5-month (February through June) average for several reasons. The current implementation of X2, including three methods to comply with the regulation, was carefully developed to avoid unnecessary water supply impacts, while providing water quality conditions at a level of the late 1960s through early 1970s, when fish populations were generally much healthier. Changes to this methodology are fraught with problems and can have unintended consequences. For example, an average may not provide the temporal variability in salinity that the current standard provides.

The X2 target levels (late 1960's to early 1970's) were chosen after consideration of a wide range of potential levels going back to the 1920's. As an illustration of how salinity variability has changed in the estuary, historical data, using three different decadal time periods with similar hydrological variability, are provided here.

Seasonal Variability

Observations from the California & Hawaiian Sugar Refining Corporation (C&H) and more recent monitoring data from two time periods of similar hydrology show how seasonal salinity fluctuations have changed since the early 1900s. The shading represents the amount of fresh water, with less than 0.2 ppt salinity, that is available below the confluence of the Sacramento and San Joaquin Rivers at Collinsville (approximately 22 miles above Crockett). While hydrological conditions were similar in the three periods, the sequence of wet and dry periods differs.

Fresh water was available below the confluence for a longer time period each year during the early 1900s. The period 1965-1976 is the period targeted by the X2 standard. The post-Accord period (1994-2005) shows overall similar winter and spring conditions, indicating some of the effect of the X2 standards. From 2001 to 2005, the initial POD years, fresh water was seldom available below the confluence. The change in summer and fall conditions is readily apparent.



1 During August and September 1918, average water quality obtained by C&H exceeded 110 mg/L chlorides.

2 Salinity intrusion during 1966 is likely an overestimate due to inadequate spatial coverage of monitoring stations.

To evaluate the effect of the proposed BDCP operations, simulated salinity variability should be compared to the historical data presented above. A presentation of this sort makes both the average conditions and the variability readily apparent. The time period of 1965-1976 would be of particular interest.

Limitations on South Delta Exports to Prevent Direct Mortality (Salvage)
CCWD understands that the proposed restrictions on net flow in Old and Middle River represent the "mid-range" of the RPAs in the current BOs. However, these values are more restrictive than necessary based on the available data, and could be further modified with implementation of additional conservation measures in the South Delta including installation of positive barrier fish screens.

Limitations on net flow in Old and Middle River are based on the observations of increased salvage at the export facilities with large southerly monthly average net flow in Old and Middle River. The net flow in Old and Middle River is predominantly driven by the export pumping and the San Joaquin River inflow to the Delta at Vernalis. In fact, CCWD has shown that salvage at the export facilities is directly related to pumping at the export facilities and San Joaquin River inflow (Attachment C).

As previously stated in earlier comments, fish do not experience the net monthly average flow at two combined locations, but rather respond to the instantaneous velocity at the location of the fish. The correlation between net flow in Old and Middle River and salvage at the export facilities, therefore, cannot be a causal relationship, but simply represent two parameters that appear to co-vary. The cause of increased salvage is actually the elimination of the ebb (downstream) flow (Attachments C and D). The fundamental reason that salvage of delta smelt increases when exports exceed about 5,000 cfs plus half the San Joaquin flow (Attachment C, Figure 2), and salvage of salmon increases when exports exceed 7,000 cfs (Attachment C, Figure 3) is that the ebb tides begin to be lost at that level (Attachment C, Figure 4).

Relationships between salvage and export pumping are further complicated by whether the fish are present in the region in which the export pumping diminishes the ebb tide. Distribution of fish is dependent on a number of water quality parameters, including turbidity, temperature, and salinity. A recent paper by Gartrell and Herbold (Attachment D) examines the effect of flow and salinity on salmon migration.

All these factors come together to determine the effect of pumping on salvage. CCWD is currently evaluating relationships for salvage at the export facilities; preliminary results indicate the restrictions on Old and Middle River are possibly overly restrictive.

Furthermore, salvage can be reduced by the implementation of positive barrier fish

screens at the export facilities. Similar screens have been proven effective at the CCWD Old River intake and will work in the south Delta if the exports are constrained (as required under current BOs and proposed in the long-term BDCP operations) to moderate levels, such that the ebb tide is maintained.

Ensuring the Delta is tidal (with flows reversing naturally approximately every six hours) will ensure that flows are available to transport fish away from the screens. Low, but still substantial, pumping rates allow modest screen sizes that will work with ebb tides to transport aquatic species away. Implementation of positive barrier fish screens would allow pumping to be increased by about 1,000 cfs or more while still ensuring protection of covered fish species.

The BDCP includes a conservation measure to install fish screens on agricultural intakes within the Delta. If implemented, the only intakes without fish screens will be the SWP and CVP export facilities in the South Delta. But with the low pumping rates proposed, screens will work and there is no reason not to install them, especially when they allow improved fishery protection and water supply reliability.

Thank you for you attention to these comments. If you have any questions, please call me at (925) 688-8100.

Sincerely,

Greg Gartrell
Assistant General Manager

Attachments:

A Comparison of Preliminary BDCP Water Quality Results with Historical Data
B Limitations on Exports to Prevent Direct Mortality (Salvage) at the South Delta Facilities
C The Effect of Export Pumping on South Delta Flows
D Flow, Salinity and Migration of Salmon (G. Gartrell and B. Herbold)

Comparison of Preliminary BDCP Water Quality Results with Historical Data

Preliminary results of water quality modeling presented to the Steering Committee on September 10, 2009, contain some questionable results (Figure 1):

1. Salinity in the Sacramento River at Emmaton is typically the same order of magnitude as salinity in the San Joaquin River at Jersey point. However, the modeling indicates Emmaton is approximately 20 times saltier than Jersey Point.

2. Salinity within the Delta is seldom less than 200 umohms/cm, yet the modeling results indicate average salinities as low as 50 umohms/cm.

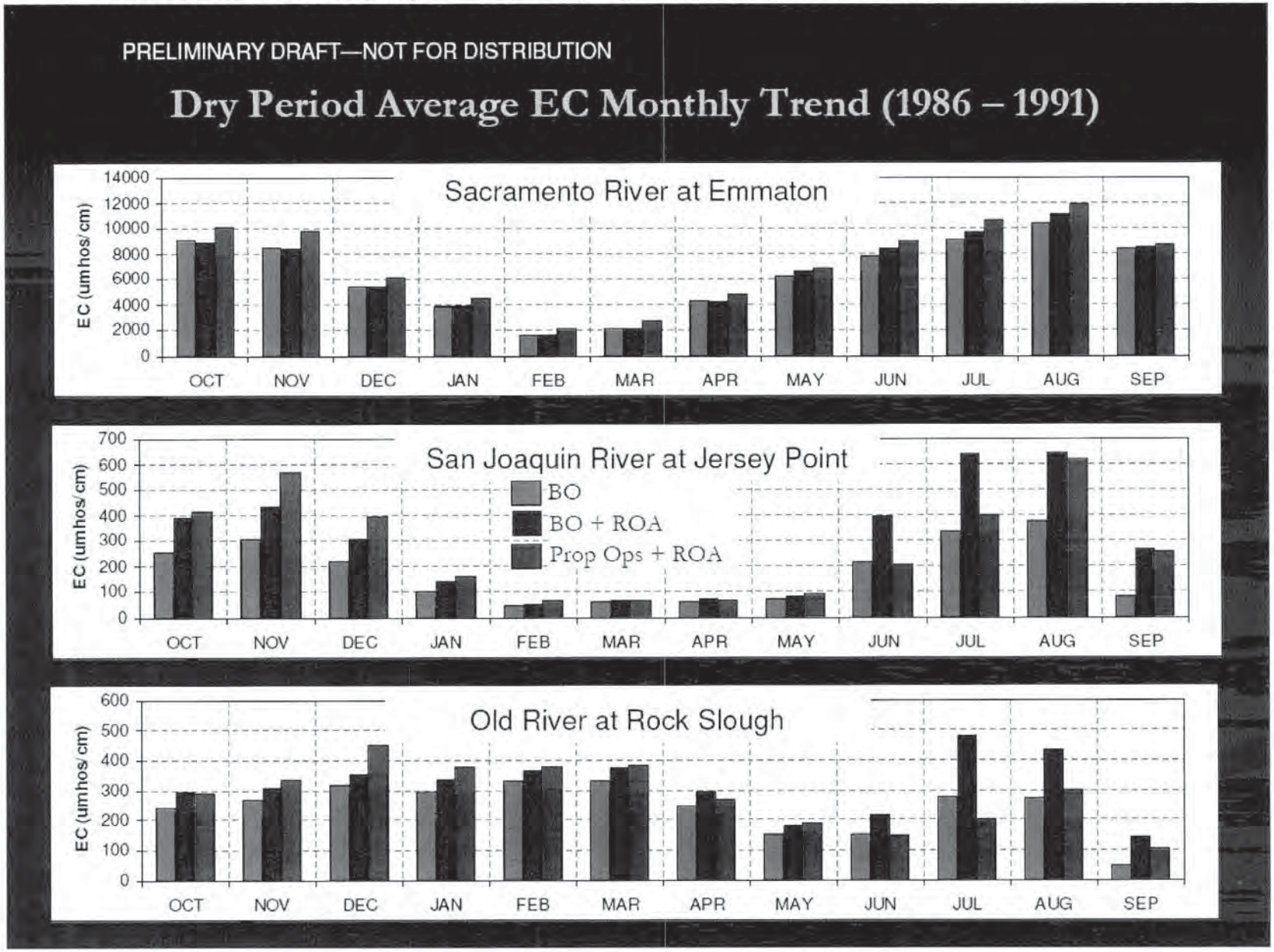
3. Historically, when seawater intrusion is significant, Rock Slough salinity is generally about 40% of that found at Jersey Point (EC). This ratio does not hold in the modeling results shown.

4. Significant freshening (lower salinity) in September relative to August (at all stations) is counter-intuitive for dry years (Fall X2 measure is likely to reduce September salinity in wet and above normal water years).

These inconsistencies would certainly have been caught during the review process. However, this example illustrates the need for a historical reference to provide context for the modeling results. Figure 2 shows the average historical salinity at the same locations as the modeling results, for an historical period as close as possible to the modeling conditions (dry hydrologic period with current BO RPAs). The most recent three water years (October 1, 2006 to September 15, 2009) have been dry with some restrictions on exports, similar to the FWS RPAs.

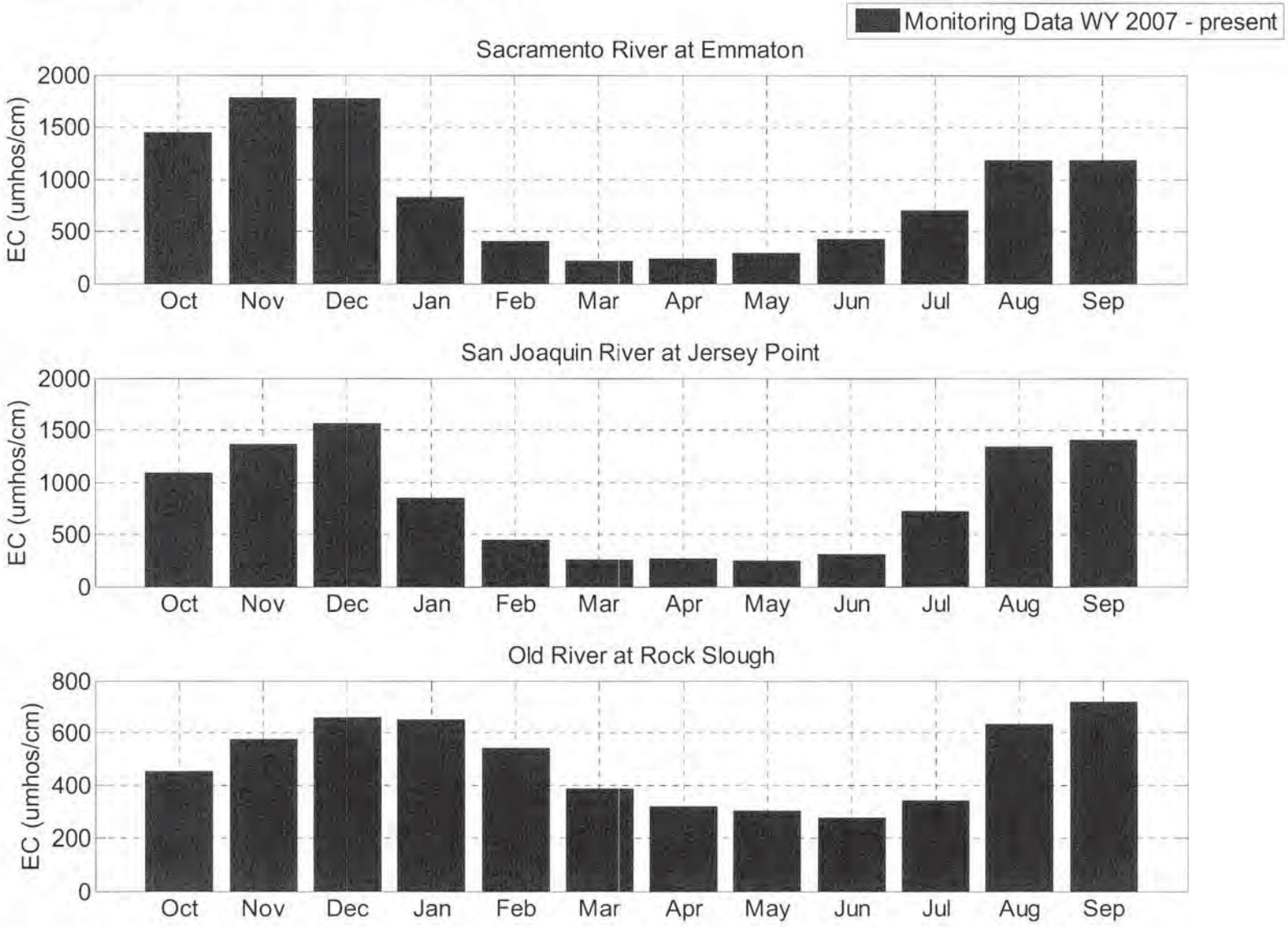
Providing historical context is necessary to evaluate the effect of the new BO RPAs as well as the proposed BDCP habitat changes and operations. Additionally, historical context is helpful for individuals who are unfamiliar with the historical salinity patterns.

Figure 1: Preliminary water quality results presented to Steering Committee on September 10, 2009
Slide 22 from "Preliminary Physical Preliminary Physical Modeling off BDCP Proposed Project – Early Long-Term"



BDCP1563.

Figure 2: Historical water quality results to provide context for modeling results
Closest period within historical record to a "Dry Period" BO baseline is water year 2007 to present (October 1, 2006 through September 15, 2009)



BDCP1563.

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Limitations on Exports to Prevent Direct Mortality (Salvage) at the South Delta Facilities

The current BO RPAs restrict South Delta exports to meet net flow requirements in Old and Middle River (OMR), which is based on correlations between salvage of fish and monthly average instream flows. Figure 1 shows a typical relationship for salvage of adult delta smelt during January and February as a function of the average flow in Old and Middle River during each 2-month period. CCWD confirms a similar correlation (with a slightly better fit) between winter salvage at the export pumps and the quantity: one-half of the San Joaquin River inflow minus total exports (Figure 2). Likewise, for Chinook salmon, Dr. Wim Kimmerer found a similar relationship between total exports and percent salvage (Figure 3). The underlying physical basis for the relationships between export levels and salvage is that export pumping alters tidal flows in the South Delta (as manifested by OMR changes) by eliminating and reversing the ebb flows that normally exist (Figure 4). As flow becomes unidirectional, fish find it increasingly difficult to escape the influence of the pumps, leading ultimately to increased entrainment and salvage.

Figure 1: Salvage of adult delta smelt as a function of average Old and Middle River flow in January and February

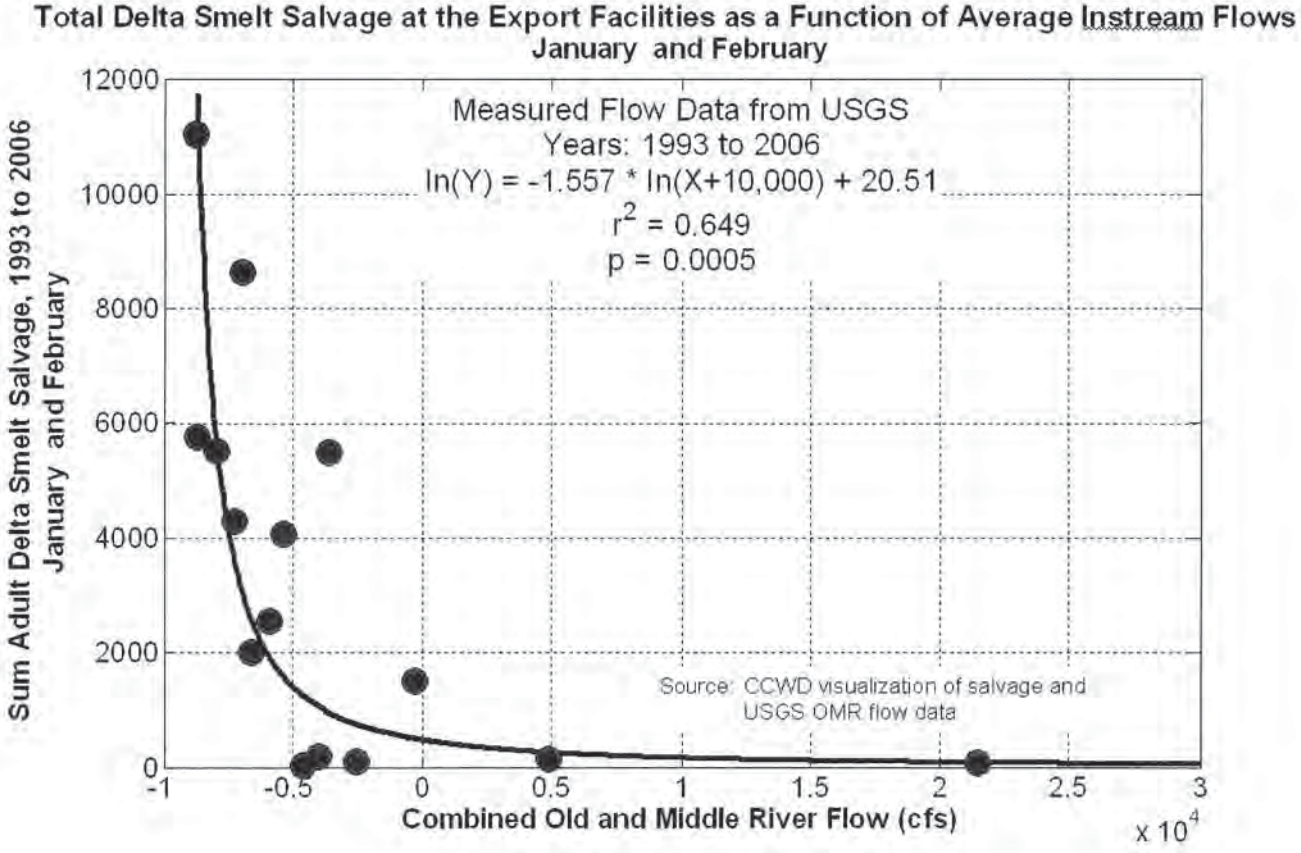


Figure 2: Salvage of adult delta smelt as a function of total exports (Banks and Jones) and San Joaquin River inflow into the Delta at Vernalis in January and February

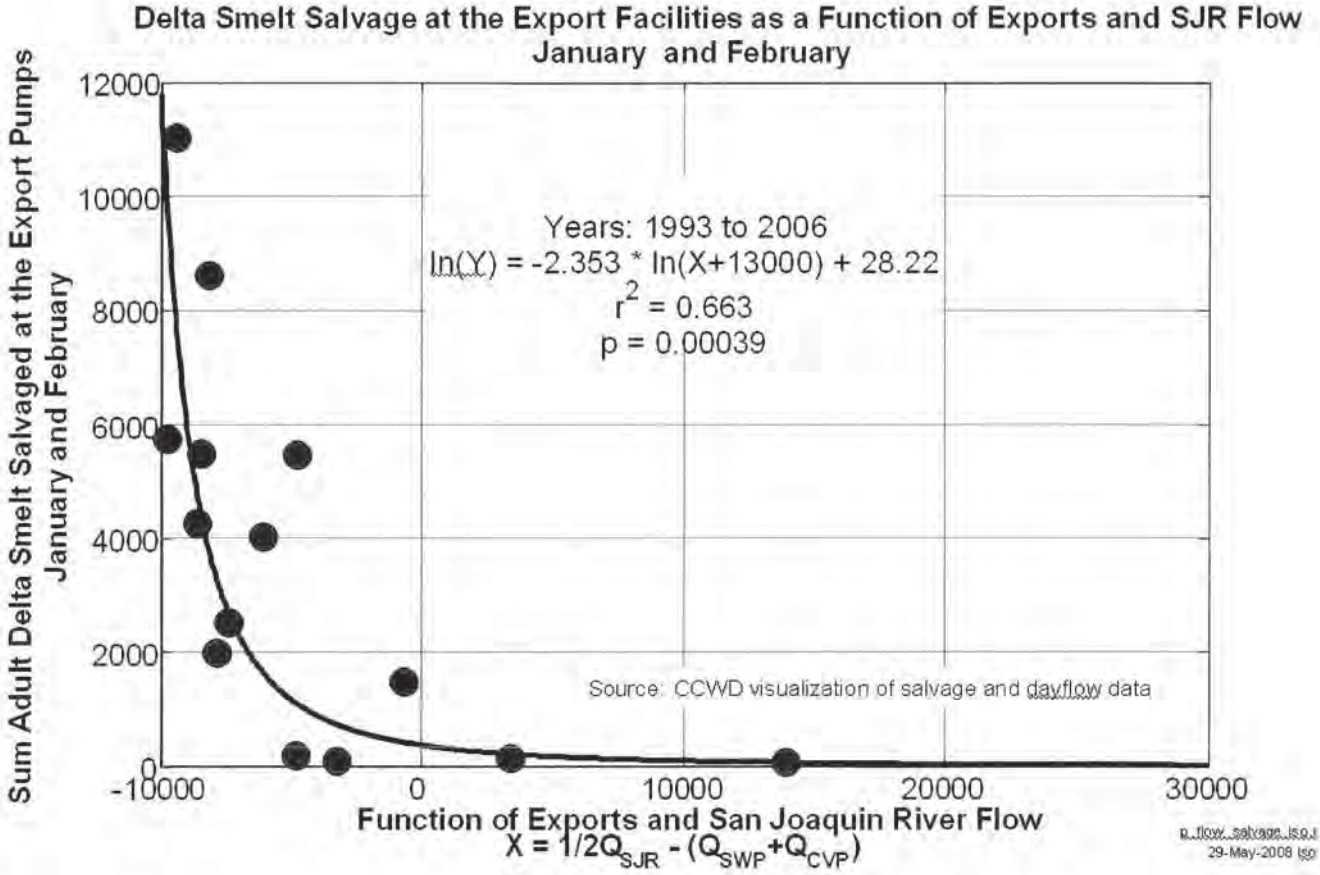


Figure 3: Salvage of Chinook salmon from the Livingstone Stone National Fish Hatchery (LSNFH) and the Coleman National Fish Hatchery (CNFH) as a function of total exports (from Kimmerer, W.J. 2008, "Losses of Sacramento River Chinook Salmon and Delta Smelt to Entrainment in Water Diversions in the Sacramento-San Joaquin Delta")

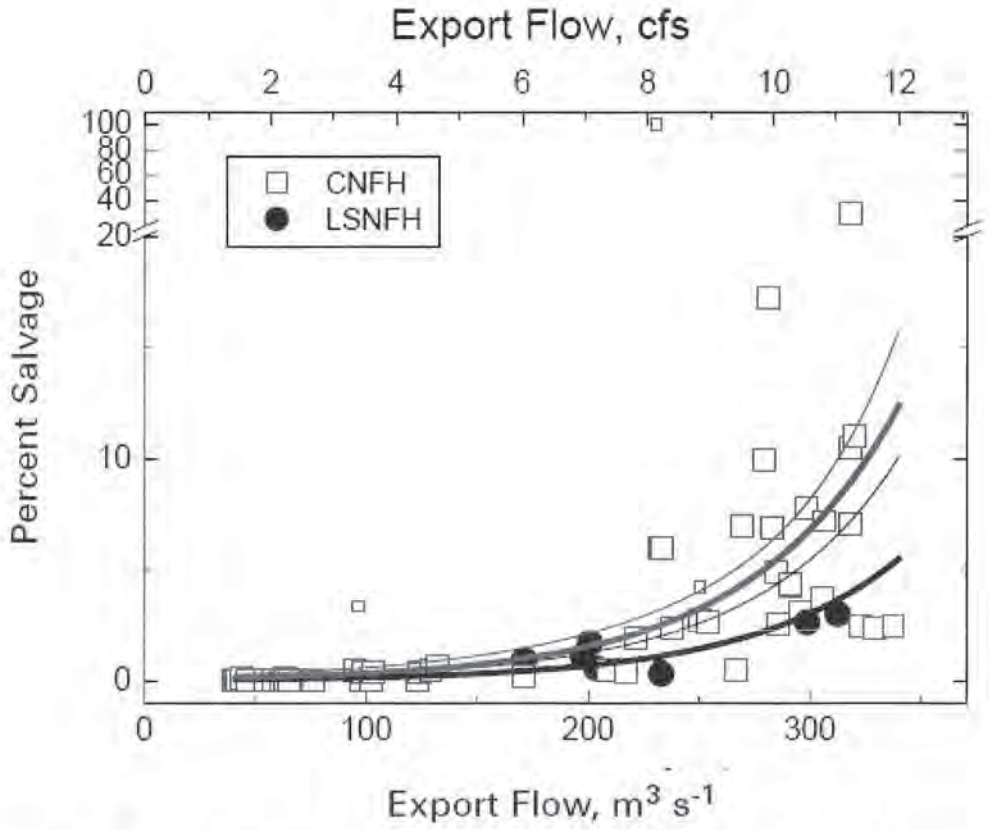
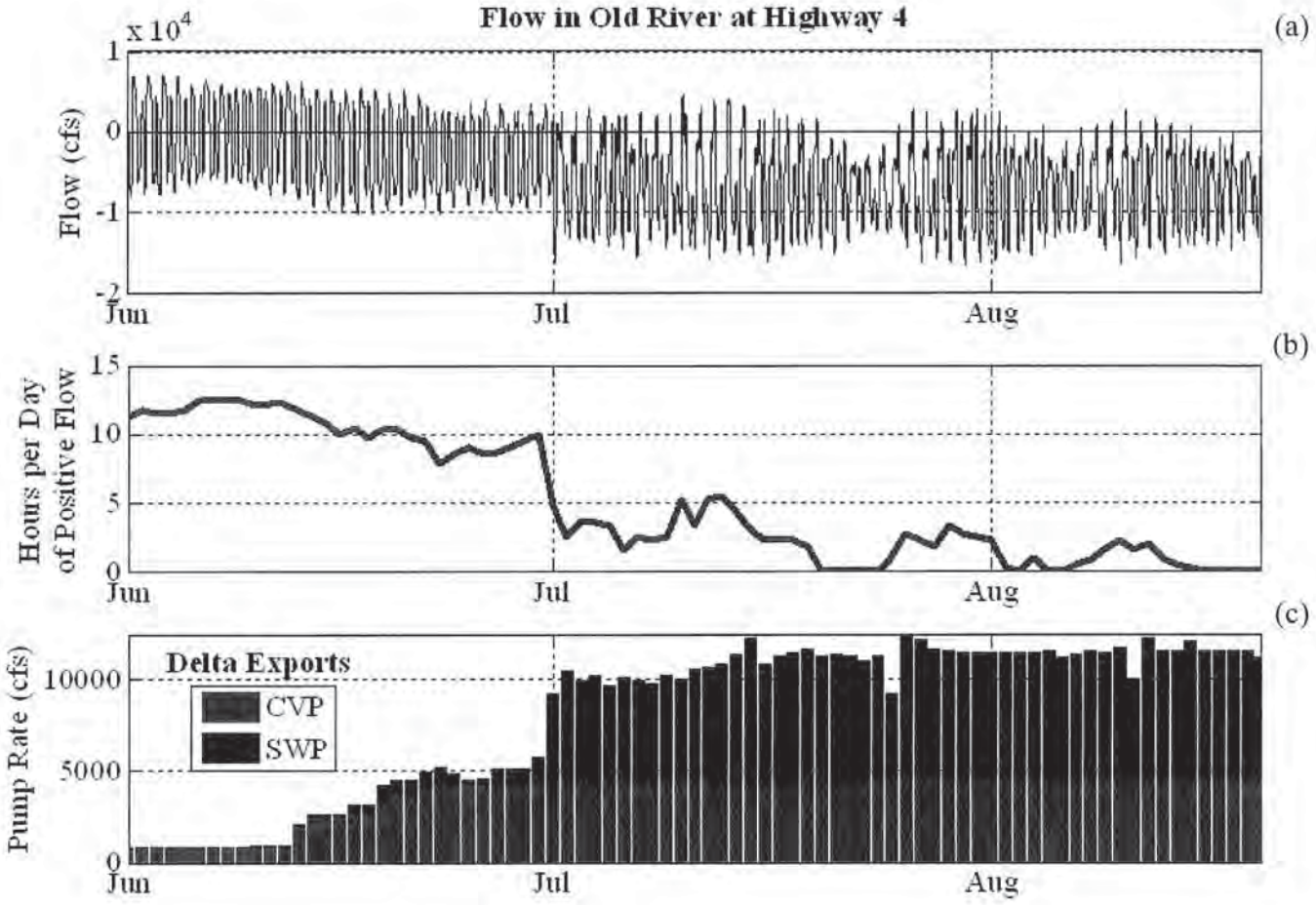


Figure 9. Chinook salmon. Relationship of estimated proportional salvage of tagged smolts at the fish facilities, P_S, to export flow. Small symbols represent data based on six or fewer fish caught, which were not used in determining the line. Lines are from a generalized linear model with log link function and variance proportional to the mean ($p < 0.0001$, 57 df), with source of fish as a categorical variable. Thick lines are predictions for fish from each hatchery; thin lines are upper 90% confidence limits of the predicted mean values.

Figure 4: Tidal flow in Old River as influenced by export pumping

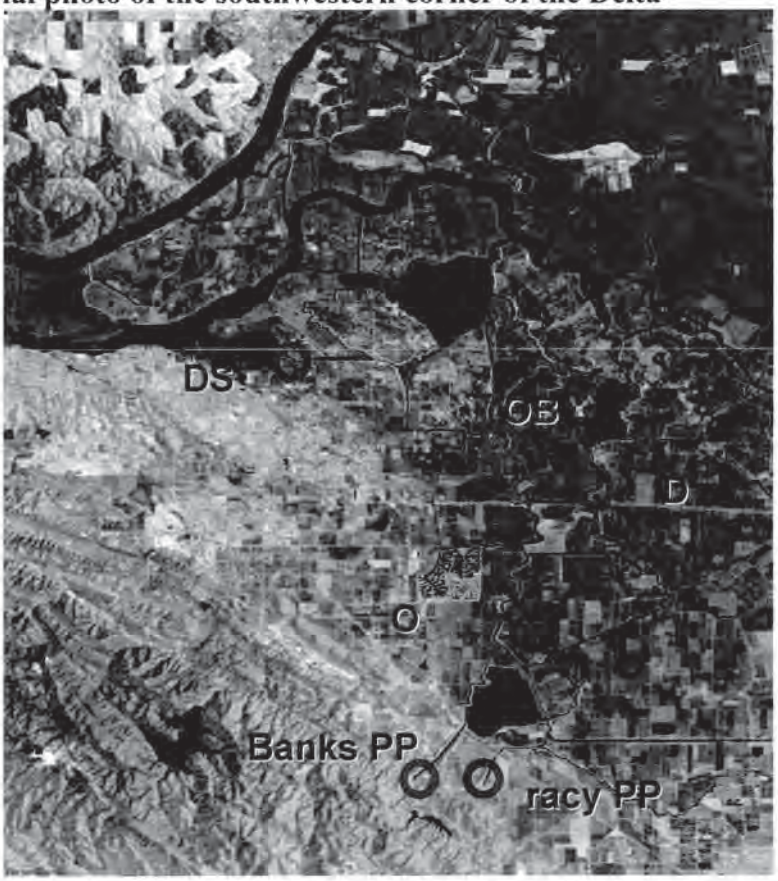
At Old River at Highway 4, just a few miles north of the export facilities, the effect of export levels on tidal flow in the river is evident. In early June 2007, when export levels were low, the flow was dominantly tidal, with both positive (flow to the north) and negative (flow to the south) oscillations of similar magnitudes with the tides, averaging to a net flow of approximately zero (top panel). As exports increase from mid- to late-June, the oscillations shift such that the net flow becomes negative (to the south), and the number of hours each day when the flow moves to the north is reduced to about 9 hours each day when exports are approximately 5,000 cfs (middle panel). This is followed by another drop to less than 5 hours of positive flow in the first part of July as exports are significantly ramped up. Then, from mid-July through August, when total exports continuously exceed 10,000 cfs, the flow becomes primarily to the south, effectively eliminating the ebb tidal flow, such that waters no longer oscillate between north and south, but simply flow constantly to the south, first fast, then slow.



The Effect of Export Pumping on Flows in the Delta

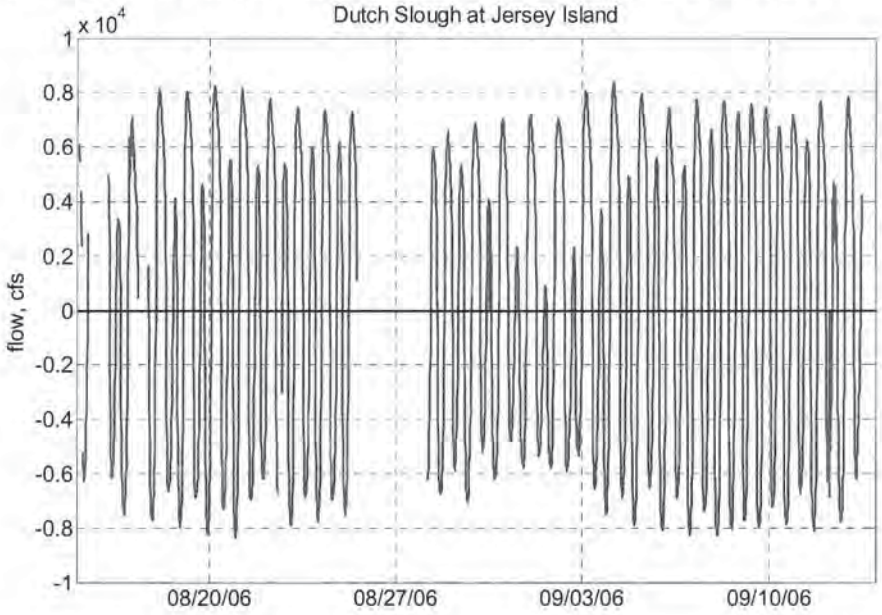
Flows in the San Francisco Bay and Sacramento-San Joaquin Delta are strongly influenced by ocean tides. The tides result in the typical two flood-ebb tidal cycles per day in the Delta, with a small net flow west towards the ocean due to river flows. Export pumping at Banks and Tracy Pumping Plants affects tidal flows in the South Delta by reducing ebb tides and increasing flood tides as will be seen below. The effect is clearly seen through visual inspection of the flow data from various stations in the Delta, available from the California Data Exchange Center (http://cdec.water.ca.gov). For example, we can look at data from four representative locations over the period August 15 to September 14, 2006. During this period, export pumping was high, with combined Tracy and Banks Pumping Plants averaging 11,500 cfs. The relevant locations are indicated in the map in Figure 1.

Figure 1. Aerial photo of the southwestern corner of the Delta



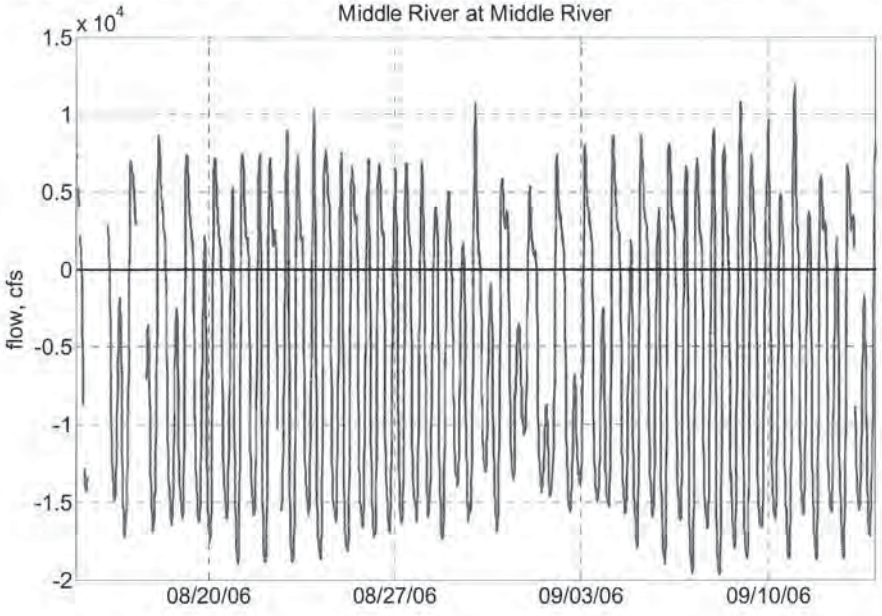
At Dutch Slough at Jersey Island (CDEC station DSJ), located near the western end of the Delta, flows are roughly centered around 0 cubic feet per second (cfs), with the ebb flows generally being of the same magnitude but in opposite direction as the flood flows (Figure 2). Flows at this location are not visibly affected by the export pumping.

Figure 2. Flow in Dutch Slough, 1 = 10,000 cubic feet per second



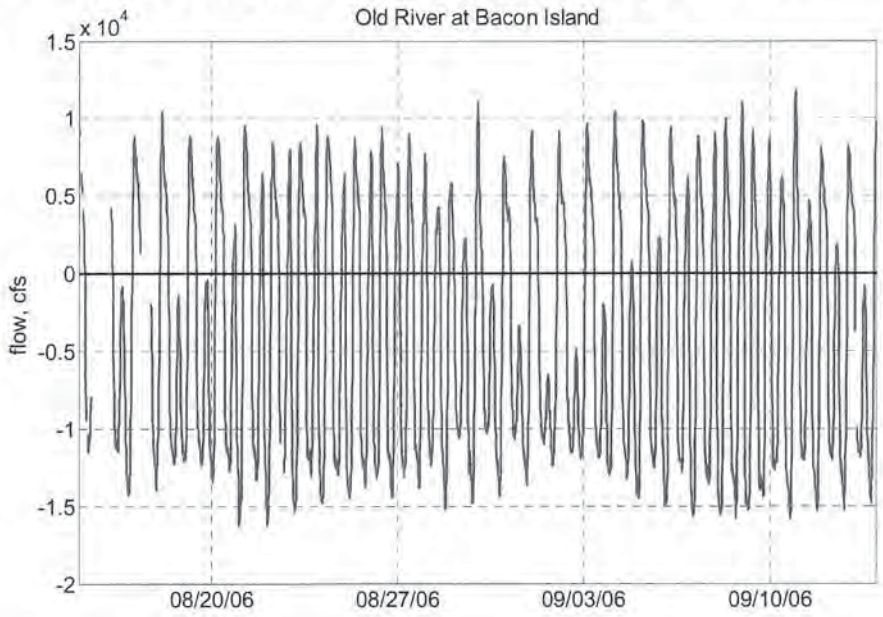
In the northern part of Middle River near the southeast corner of Bacon Island (CDEC station MDM), the flow still reflects the influence of the tides, but flows are stronger to the south than to the north, with negative values indicating southward flows (figure 3). The magnitude of ebb tides are significantly reduced while those of flood tides are magnified.

Figure 3. Flow in Middle River, 1 = 10,000 cubic feet per second



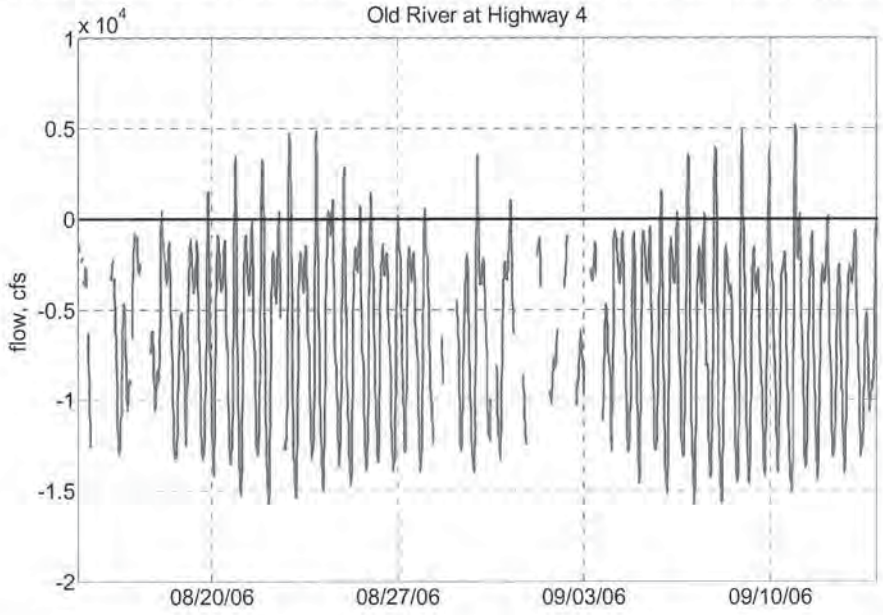
A similar shift in the net flow is observed at Old River at Bacon Island near Rock Slough (CDEC station OBI), which is also closer to the export pumps than the Dutch Slough station (figure 4). Again, a substantial reduction of the ebb tide and concurrent increase in flood tide is apparent.

Figure 4. Flow in Old River. 1 = 10,000 cubic feet per second



Finally, farther south at Old River at Highway 4 (CDEC station OH4), which is only a few miles north of the export pumps, the flow is almost always to the south (Figure 5). Instead of reversing direction on ebb tides, the flow merely transitions to being more or less southward, except when the tides are greatest.

Figure 5. Flow in Old River at Highway 4, 1 = 10,000 cubic feet per second



These results indicate that, not surprisingly, the export pumps have a greater influence on the direction of flow in areas that are geographically closer to the pumps in the South Delta. Of the four stations examined here, export pumping nearly eliminates flows in the

ebb direction completely at Old River near Highway 4, while flows in Dutch Slough at Jersey Island are not visibly affected by even the high rates of export pumping that occurred during the period.

What is critical to the survival of aquatic organisms as they get closer to the export pumps is the magnitude of ebb flow and its duration in the vicinity of the pumps. The magnitude and duration of ebb flow in Old and Middle Rivers are determined primarily by a few parameters (the tidal cycle—which is predictable, exports from Banks and Tracy, San Joaquin River inflow, and barrier operations).

It is important to note that at about 5,000 to 6,000 cfs export pumping, the ebb tide actually begins to be lost near the pumps. It is no coincidence that at this same pumping level, adult delta smelt salvage starts to become significant in the January-February time period. Kimmerer also found that salvage of tagged salmon started to increase at export levels around 7,000 cfs. This threshold effect occurs for the same reason as with delta smelt: the ebb tides become weak at this level of pumping. When ebb tides are sufficiently large, fish have a chance to move out of the area. When ebb tides are small or nonexistent, fish must swim against a strong flood tide (strengthened by the exports) and do not get any real assistance from the weakened ebb tide.

Flow, Salinity and Migration of Salmon

Greg Gartrell[1] and Bruce Herbold[2]

This is a brief discussion of how flow and salinity likely affect salmon outmigration. The first section discusses the difference between average flow and tidal flow, and how the "net flow model" leads to incorrect conclusions. The second section applies a tidal view to salinity gradients to provide an alternative explanation of observations.

1) Net flow models versus a tidal view of the Delta

Net flow (whether QWEST or OMR net flow or any other net flow) in channels influenced by tides is a mathematical construct, not a physical factor felt by fish. QWEST was first used in an old "Carriage Water model" that attempted to describe how the outflow required to meet a given salinity level in the Delta increased with increasing exports. That model failed miserably: the hydrodynamics were wrong, the outflow levels the model predicted were wrong and the shape of the curve relating exports and outflow was backwards (predicting a monotonically increasing curve when the actual curve has a minimum value before increasing).

Net flows are averages of flows measured at a point (an Eulerian view), effectively the view of water movement from the river bank. This is not something that fish experience. This mathematical construct simplifies a complex flow field, and in the case of fish movement, confuses the picture just as the old Carriage Water Model confused the understanding of salinity in the Delta. Fish experience local velocity[3] as they move around (the fish-eye or Lagrangian view). Of course, to the extent that fish move with the flow, they experience no change in velocities any more than we sense the movement of the Earth through space, except that they feel accelerations due to factors like turbulence, fish body motion or changes in channel shape. However, the movement of water and fish with flow is very different when viewed without the averaging needed to calculate net flows. To give an idea of how badly a model based on average flows (Eulerian or Lagrangian average) in a tidal environment can be, consider the following:

a) Tagged salmon released north of Rio Vista have been caught after just a few days at Chipps Island where tidal flows are very high but net flows are very small. If the fish moved with the average flow, it would take them one to two months to arrive.

b) A salmon could start the day in Old River, travel with the instantaneous local flow down the river on the flood tide towards the export pumps, move across Woodward Cut and travel up Middle River on the ebb tide. The daily average flow (in this case Lagrangian average) would be pointing from Old River to Middle River, leading to the false conclusion that the salmon walked across the island. All information about the intermediate movement of the salmon is

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[1] Contra Costa Water District

[2] U.S. Environmental Protection Agency

[3] Flow in a channel is the average velocity times the cross-section. The velocity in a channel varies across the width and depth of the channel. Fish will experience the local velocity (in space and time), not the cross-sectionally averaged velocity, nor the overall flow in the channel.

lost in the averaging. On the other hand, using the (Eulerian) average of the measured water velocity at one location in the channel (the USGS velocity meter for example) could give an average velocity of a few millimeters per second (or about 300 meters per day), an equally false conclusion.

Two problems with net flows prevent them from reflecting conditions that directly affect fish: they throw out important information in the process of averaging and they are derived variables (not independent variables) both mathematically and physically.

The following graphs illustrate these problems. The graphs show instantaneous flows.

Figure 1 shows Delta flows with the ebb and flood flows generally of the same magnitude in opposite directions. The average net flow is much smaller than any flow affecting the fish at a given moment.

Figure 1. Flow with flood and ebb nearly balanced, 1 = 10,000 cubic feet per second

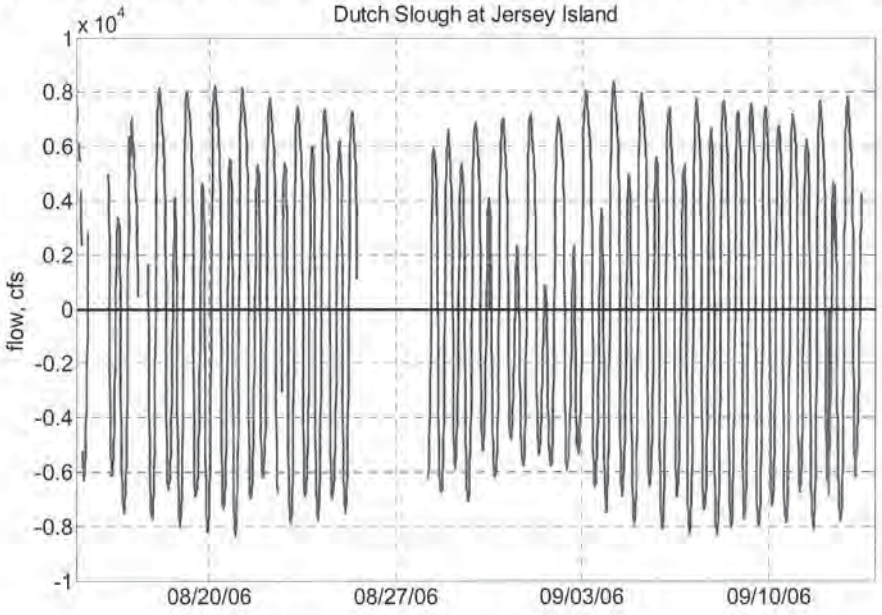
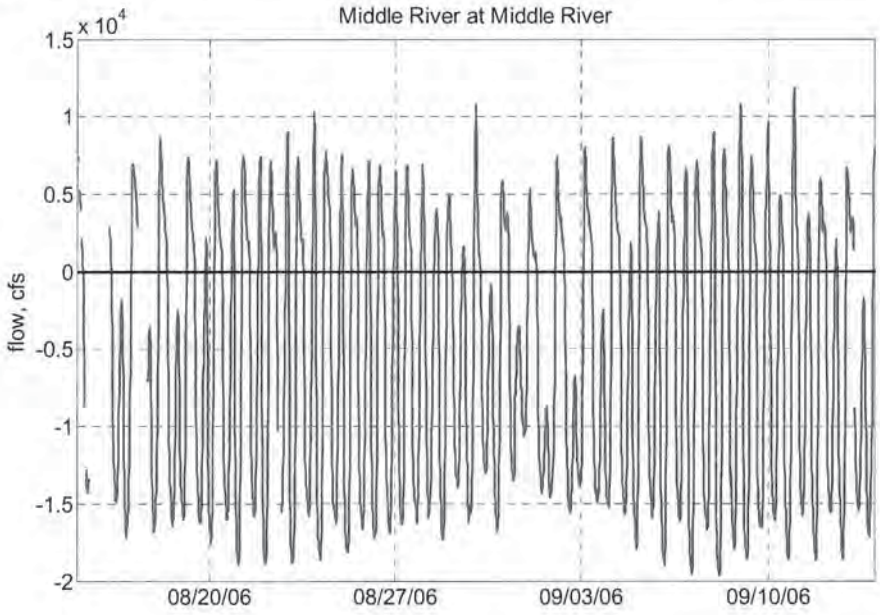


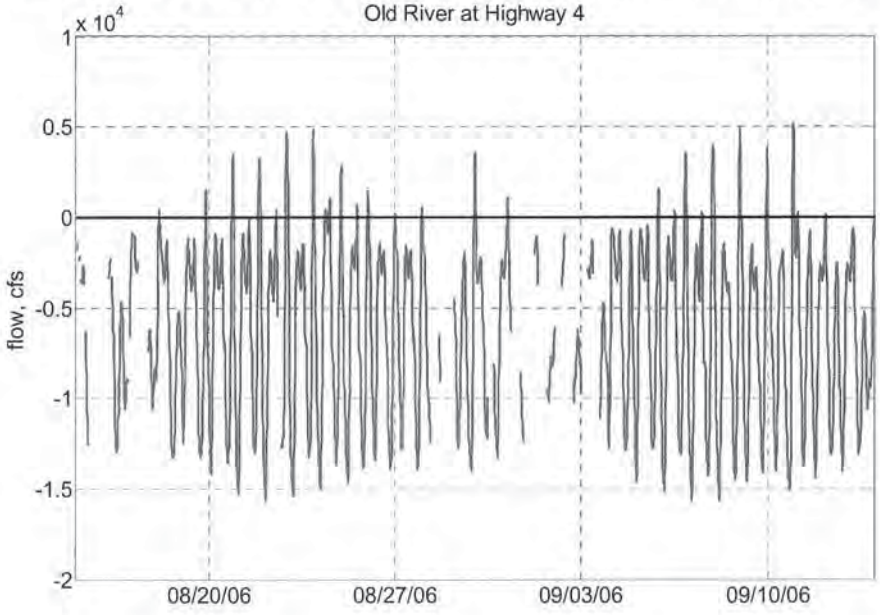
Figure 2 shows tidal flows with a stronger flood than ebb. While the direction of the average is obvious, the magnitude of the average is not. A fish experiencing this still has a chance to move in the opposite direction from the average if it uses the tides correctly (i.e., if it gets into the high velocity part of the channel on the ebb, and stays near the channel sides on the flood). Salmon clearly have the ability to pick the right tide based on cues, or they could not get from north of Rio Vista to Chipps Island in a few days.

Figure 2. Flow with strong flood tide compared to ebb, 1 = 10,000 cubic feet per second



Finally, Figure 3 shows a tidal flow where, at times, the ebb and flood are both less than zero. In this case, a salmon trying to surf the ebb will have a rough time of it. In fact, one can find no ebb tide at all for days at a time. This is a not a good situation if, in one flood tide, the salmon can end up in Clifton Court Forebay.

Figure 3. Flow in Old River at Highway 4, 1 = 10,000 cubic feet per second



Clearly, the situation in Figure 3 is going to result in high entrainment of fish: the export flows are so big that the ebb tide is lost and it is a one-way trip south, with tidal excursions double the normal 4 or 5 miles. When does this situation occur? It starts when exports are 5000 cfs to 7000 cfs. The Bay Institute argued in the OCAP lawsuit that high entrainment of salmon occurs when exports are over 7000 cfs: that is when the ebb tide is lost. That level of exports is also when delta smelt entrainment is high in January and February.[4] An examination of Figures 1 through 3 tells the story very quickly: this is about tides and export levels, not net flows. It is not the "net flow"; it's the "no ebb flow".

What about entrainment that occurs when net flows are small (or even positive)? The net flow view of the world fails completely (just like the old Carriage Water model) in this situation. When viewed with the tides in mind, the picture becomes clear, as the examples in the next section illustrate.

2) Salmon movement in a tidal environment

Consider salmon moving down the Sacramento River into the Delta. Some will make it to Chipps Island and beyond, but some will end up in the Lower San Joaquin River, via Georgiana Slough, through Three-Mile Slough or around Sherman Island. In this central delta area their advective (i.e. non-swimming) movement would be governed by tidal flows. Some will, even when export pumping is low and net flows are positive, go through False River into Franks Tract, where they (the survivors, anyway) have a good chance of being discharged out into Old River. Others can get sloshed into Middle River. This is their starting point for the scenarios that are described below.

For San Joaquin Salmon, the starting point for the scenarios below will be the San Joaquin River at the Head of Old River.

Scenario 1: High exports, typical San Joaquin River flow and salinity (i.e., low flow, high salinity).
In this case, exports are high and the ebb tide is very small or non-existent. It is a short trip down the river (the salmon simply cannot swim against 1 to 2 fps currents for long) to the export pumps for Sacramento salmon. San Joaquin salmon have two likely fates: those entering Old River have a quick trip to the export pumps; those moving down the San Joaquin River get to the Lower San Joaquin River and then some will make it to Chipps Island and some will move into Old and Middle Rivers and thence to the export pumps. In all cases salmon entrainment will be high.

Scenario 2: Low exports, typical San Joaquin River flow and salinity (i.e., low flow, high salinity).

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[4] Pete Smith used OMR net flow to show this, but OMR net flow is a dependent, not independent variable. Exports and San Joaquin inflow are independent variables, and the correlation between delta smelt entrainment and exports/San Joaquin flows is better than the correlation between entrainment and OMR flows for the same time period.

Sacramento salmon coming from the north experience substantial ebb and flood tides. However, one thing is peculiar in the central and south Delta compared to what should be found in an estuary: San Joaquin River salinity (generally as much as 1 mS/cm, with chloride levels over 150 mg/l) is much higher than Sacramento River salinity (about 0.15 mS/cm with chloride levels around 10 mg/l).[5] An obvious cue in a tidal system for the ocean is salinity (electrical conductivity or specific ions; two obvious ions would be sodium and chloride). What salmon in the central and south Delta see is a reverse salinity gradient because of high San Joaquin salinity and saline discharges (ag and urban) within the Delta. Salmon attempting to follow the salinity gradient to the ocean would jump into the high velocity zone on the flood, rather than ebb. That takes them the wrong way, and exposes them to entrainment at the export pumps. (Even if export rates are very low, there is a good chance to get into the pumps).

The situation for San Joaquin salmon is probably very much worse: arriving in a low flow with high salinity and entering a reverse salinity gradient, the chances of a bad ending would lead one to wonder how any salmon at all find their way out. This is consistent with the extremely low survival rates reported by USFWS under all but flood conditions in the delta

In this case it is neither the "net reverse flow", nor the "no ebb tide"; it is the "reverse salinity gradient".

Scenario 3: Low exports, typical San Joaquin River flow and salinity (i.e., low flow, high salinity) with an Isolated Facility.
This case is little different from Scenario 2, except that the exports are liable to be less and the water quality situation could easily be worse. With apologies to our friends who authored the PPIC reports, it is likely to create an "Arkansas cesspool" from the "Arkansas Lake". With drainage (from the San Joaquin River and in-Delta ag) and urban discharges ringing the area (clockwise: Sacramento Regional, Stockton, Manteca, Tracy, Discovery Bay, Ironhouse SD, Delta Diablo SD, Central Contra Costa SD), and little inflow, the central and south Delta are likely to become (with apologies to Thomas Friedman) "Hot (warm SJR water), Flat (gradients) and Crowded (with non-natives)". Entrainment, in the absence of screens will be high at both export pumps and ag intakes (you only have to see the vortex spinning above a siphon to realize just how fast the velocity is in the siphon), and confusion will be high. The number of fish orienting correctly to the ocean would be very small and even for them the very long transit time would probably subject them to extremely high mortality rates within the delta.

Scenario 4: Good flows and high quality on the San Joaquin River. Salinity gradients are not reversed and fish orient correctly to the tidal salinity gradient and tidal flows. This is totally different from Scenario 1, 2 or 3. The key is improved San Joaquin River flow and salinity.

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[5] As an example, with flows increasing during the VAMP period, SJR salinity is currently about 0.4 mS/cm today (April 20, 2009). That level is also found near Collinsville today, but in between it is as low as 0.2 mS/cm (Jersey Point area).

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May 14, 2009

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Subject: Revised Notice of Preparation (February 13, 2009) of the Environmental Impact Report/Environmental Impact Statement (EIR/EIS) for the Bay Delta Conservation Plan (BDCP)

Dear Ms. Brown:

Contra Costa Water District (CCWD) appreciates this opportunity to provide these comments in response to the recently revised Notice of Preparation (NOP) of the Environmental Impact Report/Environmental Impact Statement (EIR/EIS) for the Bay Delta Conservation Plan (BDCP) dated February 13, 2009. CCWD supports efforts to resolve many long-standing and mounting technical and policy issues regarding water quality, the ecosystem, and water supply reliability associated with the Bay-Delta. CCWD provides these comments with the hope that your endeavor will become a constructive step in that effort.

The enclosed comments from CCWD cover (1) the development of reasonable alternatives and (2) potential environmental impacts. To avoid confusion, CCWD's prior comments (submitted May 30, 2008) regarding the previous NOP (dated March 17, 2008) have been incorporated with our current comments.

CCWD is concerned, however, that the process being followed is confusing to the general public and even to those involved more directly. The Lead Agencies have filed multiple Notices of Preparation and Notices of Intent, and they are also participating in a concurrent process, the BDCP, that is both highly related and at the same time separate from this EIR/EIS. A major source of concern and confusion is that the BDCP management continues to narrow projects (indeed, it has recently excluded all options but one for evaluation) while claiming that the EIR/EIS will consider a wide range of options. It has never been made clear, however, what would occur if the outcome of the EIR/EIS analysis is inconsistent with the BDCP management decisions already made.

These processes (EIR/EIS and BDCP) are now the subject of litigation (Central Delta Water Agency and South Delta Water Agency vs. United States Fish and Wildlife Service, *et al.*, Eastern District of California, No. 2:09-CV-01003-JAM-GG). The

outcome of that litigation is not clear and may not be settled for many months. CCWD provides these comments without making assumptions concerning the outcome of that litigation, in order to help the Lead Agencies develop the best possible document consistent with California Environmental Quality Act (CEQA) and National Environmental Policy Act (NEPA) guidelines.

Because of the controversy surrounding the issues raised in this EIR/EIS, it is imperative that solutions with wide support that will provide immediate improvements in the Delta ecosystem and water supplies be adopted as soon as possible. CCWD encourages the Lead Agencies to evaluate immediate, interim, and near-term projects, including the 2-Gates Demonstration Project, pilot fish screens at Clifton Court Forebay, ecosystem restoration projects, and reoperation of the Delta Cross Channel. These projects will allow critical issues to be addressed in a timely manner and lay a foundation for any long-term projects by including a monitoring component, thus expanding the scientific knowledge base of how various projects and management actions affect the environment. Each of these vital projects is described within the "Interim and Near-term Actions" section of our comments.

If you have any questions regarding CCWD's comments, please contact Leah Orloff at (925) 688-8083.

Sincerely,

FOR Greg Gartrell
Assistant General Manager

GG/DS:wec

Attachments:

A. CCWD Comments (May 14, 2009) in Response to Revised BDCP NOP dated February 13, 2009.
B. CCWD letter to the U.S. Fish and Wildlife Service and the National Marine Fisheries Service (March 24, 2008) submitted in response to the first NOI dated January 24, 2008.
C. CCWD Facilities and Operations.
D. CCWD letter to the State Water Resources Control Board (Feb 13, 2007) regarding relaxation of water quality standards and anti-degradation policies.
E. Gartrell, G. and B. Herbold. April 27, 2009. Flow, Salinity and Migration of Salmon.

cc: Ms. Lori Rinek, FWS
Ms. Rosalie del Rosario, NMFS
Ms. Patti Idlof, USBR

Contra Costa Water District (CCWD) provides the following comments in response to the revised Notice of Preparation (NOP) for the Environmental Impact Report / Environmental Impact Statement (EIR/EIS) for the Bay Delta Conservation Plan (BDCP) dated February 13, 2009, concerning (1) the development of reasonable alternatives and (2) potential environmental impacts.

Develop ent of easonable Alternatives

The NOP appears to have restricted the EIR/EIS to a narrow set of solutions and alternatives that are likely to result in a flawed set of environmental documents and an equally flawed plan. Failure to consider the full range of reasonable alternatives will also affect the ability of lead agencies to approve and of responsible agencies to permit any projects, potentially resulting in delays and even failure of the process to meet its goals and schedule. The full range of reasonable alternatives that could feasibly attain all or most of the BDCP's basic objectives (including but not limited to those which could avoid and/or substantially lessen significant effects of the proposed action or actions) should be considered and evaluated.

CCWD makes the following recommendations regarding (1) through Delta conveyance alternatives; (2) dual conveyance alternatives; and (3) interim and near-term actions that should be incorporated into all alternatives.

hrough Delta Conveyance Alternatives

A number of proposals have been presented that do not require relocation of intakes to the north Delta, nor require construction of pipelines or canals. The following alternatives, which have been presented to the Delta Vision Blue Ribbon Task Force[1], may meet the BDCP goals without building a new conveyance around the Delta: (1) "A Long Term Vision for the Sacramento-San Joaquin Delta: A Work in Progress", submitted by: The Bay Institute, Natural Heritage Institute, Natural Resources Defense Council, The Nature Conservancy, Planning and Conservation League, California Water Impact Network and Environmental Defense; (2) "A Water Plan for the 21st Century", submitted by: In-Delta Group; and (3) "Delta Corridors", submitted by: Russ Brown.

Exclusion of such alternatives is ultimately likely to result in a flawed environmental document and in vulnerability of any project decisions based on those documents. CCWD therefore requests that these alternatives be thoroughly considered and that at least one through-Delta conveyance alternative be evaluated in the EIR/EIS in accordance with CEQA and NEPA.

[1] Descriptions of these alternatives may be downloaded from the Delta Vision website: http://deltavision.ca.gov/DeltaVisionVisions.shtml

Dual Conveyance Alternatives

The most recent NOP (dated February 13, 2009) indicates the dual conveyance alternative may include "use of existing points of diversion during some circumstances and potential new points of diversion at various locations in the North Delta, as well as facilities to move water from new points of diversion to the existing SWP and CVP pumping facilities in the South Delta". CCWD requests the dual conveyance alternatives in the EIR/EIS (1) include an alternative with a 2,500 cfs pipeline and another alternative with a 5,000 cfs canal; (2) explicitly define the range of anticipated operations, and include analysis of operations under the higher bypass flow scenario proposed by the California Department of Fish and Game; and (3) include modification of existing South Delta export facilities. Each of these requests is described in the following sections.

New Physical Conveyance Facility

2,500 cfs Pipeline

The EIR/EIS should evaluate a dual conveyance alternative with a 2,500 cubic feet per second (cfs) pipeline to move water from the new North Delta diversion(s) to the SWP and CVP export facilities in the South Delta. While meeting water supply reliability goals, the smaller capacity facility would leave more water in the river system to benefit the environment and maintain or improve water quality (see environmental impacts section). Additionally, the facility should be constructed as a pipeline, which has a number of benefits over an open canal for each of the following issues:

Issue	Discussion
Seismic Stability	Since the conveyance facility will likely be crossing liquefiable soils in a seismically active region, seismic stability is a key issue. A pipeline, or a series of pipelines, would reduce risk of failure and shorten the time period the facility would be out-of-service for repair following a seismic failure in comparison to an open canal built of earthen levees. The existing Delta levees are currently being evaluated for risk to seismic events as part of the Delta Risk Management Strategy. Given the potential risk, it is difficult to justify building another 80 miles of levees associated with an unlined canal (the embankments) on top of liquefiable soils. Removal, replacement, and compaction of those soils, along with the cost of damage to existing drainages and associated land uses are likely to make a pipeline cost-effective compared to a properly designed canal capable of providing a secure water supply.
Maintenance	Plant growth within earthen canals inhibits flow and contributes to levee instability. However, the use of chemical herbicides is increasingly problematic due to regulatory constraints.

	Earthen canals leak, both into and out of the canal. Canal levees are also subject to erosion from wind waves. For certain storm events, the proposed canal alignments will have very long fetch, which would produce large wind waves within the canal, potentially causing significant erosion and overtopping. Using rip-rap or other means to resist the action of wind waves will increase head losses along the canal, resulting in larger cross-sections and larger environmental impacts. Flooding of an island upon which a canal is constructed will subject the external canal levees to wave action, erosion and seepage. A levee break on a river near a canal will subject the canal to potential failure from the erosive forces of the floodwaters filling the island. Either situation will potentially disable all supplies through the canal for an extended period. In contrast, a pipeline, or series of pipelines, would not be subject to routine damage and maintenance associated with plant growth or wind waves and would provide protection from erosive forces of a flooded island.
Physical Barrier	Canals, in general, create a migration corridor barrier for terrestrial species. Canals will sever many large tracts of agricultural land, and create severe drainage issues that will be very expensive to mitigate, if mitigation is at all possible. These impacts would be reduced or completely eliminated by constructing a buried pipeline rather than a canal.
Contamination / Security Risk	Open canals are vulnerable to contamination from runoff, spills, and intentional acts. Securing the water supply in a pipeline would alleviate this risk.

CCWD's experience with a much smaller and shorter unlined canal has led CCWD to a decision to replace it with a pipeline. It is likely that a complete evaluation of the benefits of a small pipeline will show it to be a better alternative than an unlined, vulnerable canal. The EIR/EIS should include a dual conveyance alternative consisting of a screened intake and pipeline (instead of a canal) with a capacity of approximately 2,500 cfs.

5,000 cfs Canal

The EIR/EIS should evaluate a second dual conveyance alternative with a 5,000 cfs canal to move water from the new North Delta diversion(s) to the SWP and CVP export facilities in the South Delta.

A recent study[2] by the Department of Water Resources (DWR) compared the water supply benefit of three canals of different capacity, diverting water from the North Delta, and operated in a dual conveyance scenario with existing South Delta facilities. Results indicate essentially no water supply benefit of a larger capacity facility (10,000 cfs or 15,000 cfs) relative to a smaller capacity facility (5,000 cfs). For example, the DWR study indicates that a new 5,000 cfs isolated facility operated with priority over the existing South Delta facilities would yield a combined 6,440 thousand acre-feet per year (TAF/year) and the 15,000 cfs isolated facility operated in similar fashion would yield an additional 90 TAF/year on average, less than 1.5% increase in water supply. During drought periods, the 15,000 cfs facility actually yields 10 TAF/year less than the 5,000 cfs facility.

Additionally, the larger facility will reduce Delta inflow by a larger amount, causing larger impacts on Delta water quality and fisheries (see environmental impacts section). Since a 5,000 cfs capacity canal could feasibly attain the same level of water supply reliability, while substantially lessening the significant effects of the isolated facility, the EIR/EIS should evaluate a dual conveyance alternative with a 5,000 cfs canal.

Operation of New and Existing SWP and CVP Facilities

Operation of the new and existing SWP and CVP facilities will greatly affect the potential impacts; therefore, the EIR/EIS must fully disclose and analyze the full range of anticipated operations of each conveyance alternative.

BDCP modeling studies[3] to date have shown that the new isolated facility being considered is clearly oversized. Oversizing the facility implies that the operational constraints that were modeled might be changed or relaxed, allowing the facility to be used more often than evaluated within the EIR/EIS and/or that additional facilities are anticipated but not included in the environmental documentation.

For example, BDCP studies evaluating the 15,000 cfs capacity isolated canal, operated in a dual conveyance scheme with preferential use over the existing South Delta export facilities, have shown that much of the capacity of the facility would be seldom used,

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[2] California Department of Water Resources. 2008. An Initial Assessment of Dual Delta Water Conveyance.

[3] All references to BDCP modeling studies and results provided within these comments refer to the most recently distributed modeling report: Bay Delta Conservation Plan Integration Team. February 2009. "Draft Technical Memorandum: Summary of Preliminary Modeling of Draft BDCP Conservation Strategy – Core Elements". Assumptions of this modeling are further described in the BDCP "Overview of the Draft Conservations Strategy for the Bay Delta Conservation Plan" (revised January 12, 2009).

creating an under-performing asset. As illustrated in Figure 1, the modeling results for "Scenario 1"[4] indicate that 80% of the time, the canal would carry less than 10,000 cfs; 50% of the time, the canal would carry less than 4,500 cfs; and 12% of the time, the canal would carry no water at all (the equivalent of one year in eight, the canal would be empty).

The frequency that the isolated facility would be used depends on the operational constraints for the facility, such as the amount of water that must be allowed to stay in the Sacramento River, passing the North Delta intakes (i.e. "bypass flows"), the water quality standards within the Delta and Suisun Bay, and the amount of storage in the system. Figure 1 indicates that the isolated facility would be slightly fuller if the restrictions for bypass flows are lowered ("Scenario 2"[5] has lower bypass flow requirements than "Scenario 1"; all other assumptions are equal between the two scenarios). Similarly, the isolated facility would likely be slightly less full (i.e. emptier) if higher bypass flows are required.

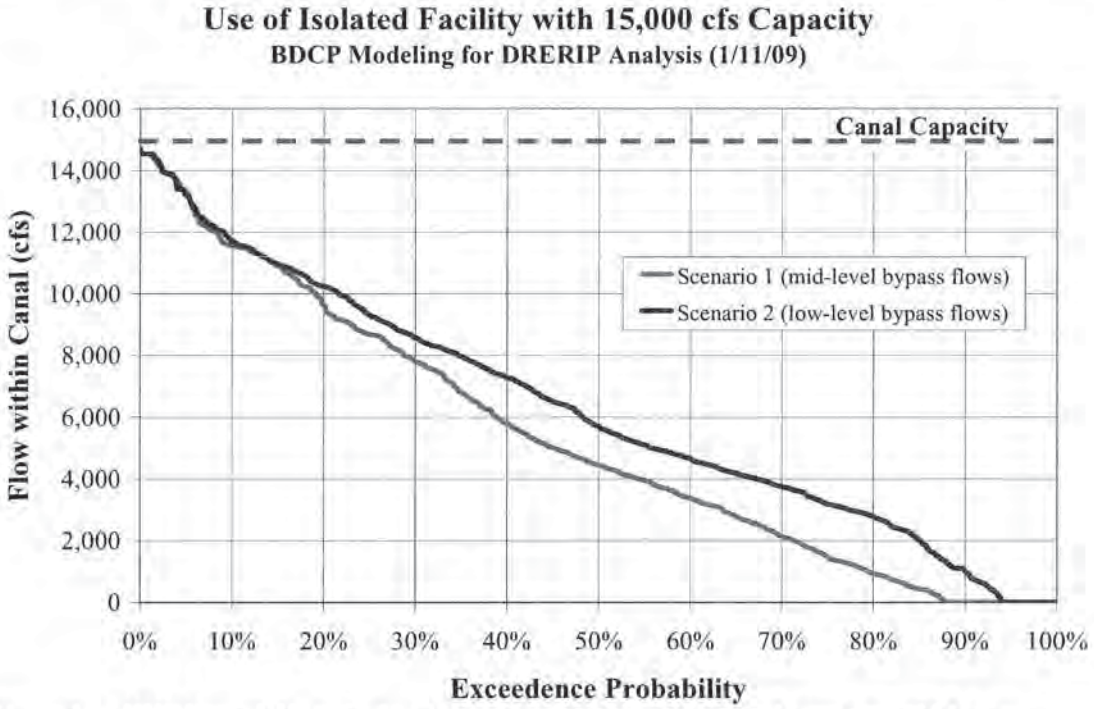


Figure 1 – BDCP modeling studies indicate a 15,000 cfs isolated canal would be an under-performing asset.

[4] Assumptions used in modeling "Scenario 1" include (1) increased frequency and duration of diversion through Yolo Bypass; (2) a 15,000 cfs canal with diversion locations in the North Delta near Hood; (3) mid-level bypass flow requirements at the North Delta diversion location of 11,000 cfs during winter-spring; (4) Restrictions on South Delta exports to maintain net flow in Old and Middle River greater (more positive) than -3,500 cfs from December through June and greater than -5,000 cfs from July through November; (5) Closure of Delta Cross Channel gates for all months except July and August and half of September and October; and (6) large-scale tidal marsh restoration in Cache Slough.

[5] Assumptions used in modeling "Scenario 2" are the same as "Scenario 1" (listed above), with the following exception: "Scenario 2" assumes a low-level bypass flow requirement of 5,000 cfs in the winter-spring period.

A higher bypass flow scenario proposed by the California Department of Fish and Game (CDFG) has not been examined by the BDCP. The high bypass flow scenario should be analyzed in the EIR/EIS along with the low and mid-level bypass flow scenarios and the environmental impacts of each examined.

Draft BDCP documents[6] recognize that water supply is limited by South of Delta storage facilities and that "[s]ome combination of improved operations of existing storage, new surface storage, and expanded groundwater storage is likely to occur in the future", and BDCP modeling indicates little dry year improvement in water supplies (Figure 2).

On several occasions in the BDCP Steering Committee, in its workgroups and in discussions led by BDCP consultants, new storage facilities have been cited as the primary reason for oversizing the facility. In addition, there has been discussion on the sharing of CVP and SWP storage in San Luis Reservoir to improve deliveries from the SWP and CVP with an isolated facility. The under-use of the proposed 15,000 cfs facility in BDCP analyses, combined with discussions about the improvement in use of the facility with new storage or operations, indicates that other options not being considered in the analyses are in fact being considered for the future by the Lead Agencies and others. Otherwise, there would be no reasonable basis for constructing the large facility currently under consideration.

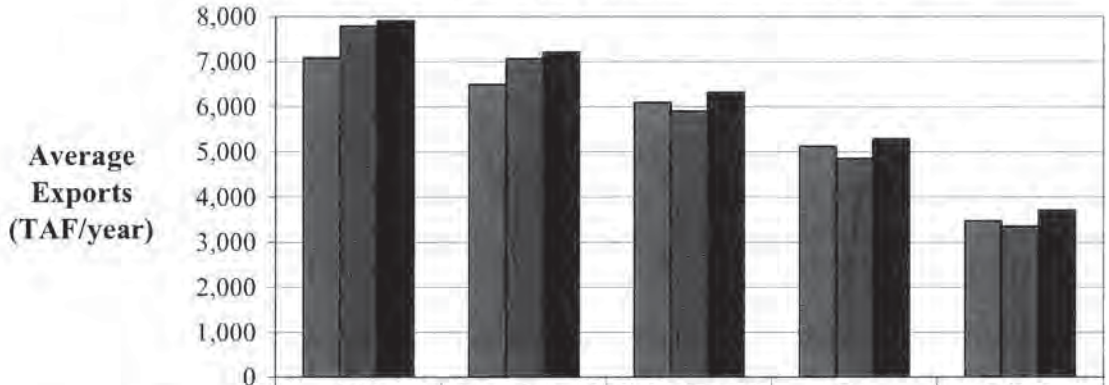
If operations to work around shortages, such as flexibility in San Luis Reservoir operations (e.g., lending storage capacity between the CVP and SWP), are anticipated, the operations must be fully described and analyzed within the EIR/EIS, with full disclosure of potential impacts. Similarly, if construction of additional storage is the basis for the physical conveyance capacity of the isolated facility, future operation of the isolated facility in coordination with the additional storage must be fully described and analyzed within the EIR/EIS, with full disclosure of potential impacts. Failure to do so would be evidence of piecemealing.

The BDCP modeling studies described herein have been used by various BDCP workgroups to evaluate possible benefits and impacts of the proposed project (e.g. the DRERIP evaluation) and to recommend changes in operation of the isolated facility. Those studies are the basis of this revised NOP. Therefore, all BDCP studies, reports and analyses to date must be included in the administrative record.

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[6] Bay Delta Conservation Plan. 2009. Overview of the Draft Conservation Strategy for the Bay Delta Conservation Plan (January 12, 2009)

Comparison of Water Supply for Different Hydrological Conditions
BDCP Modeling for DRERIP Analysis (1/11/09)



	Wet	Above Normal	Below Normal	Dry	Critical
D-1641 Reference Case	7091	6496	6102	5130	3473
Scenario 1 (mid-level bypass flows)	7791	7068	5906	4852	3350
Scenario 2 (low-level bypass flows)	7906	7214	6321	5292	3703

Hydrological Conditions

Figure 2 – BDCP modeling studies indicate little improvement in water supplies during relatively dry hydrological periods

Modification of Existing South Delta Export Facilities

BDCP modeling to date has demonstrated the necessity of continued reliance on existing South Delta export facilities. Even with the proposed 15,000 cfs isolated conveyance facility operated preferentially over the South Delta export facilities, the South Delta export facilities would average between 900 cfs and 4,500 cfs seasonally over a long period (82 years) of hydrological variability (Figure 3). The percentage of total exports taken from the South Delta facilities would be largest during dry periods, averaging between 74% for mid-level bypass flow requirements in critically dry years (Figure 4) and 40% for low-level bypass flows requirements in dry years (Figure 5). The percentage of total exports taken from the South Delta facilities would be even higher for the high bypass flow case proposed by CDFG that must be included in the analysis for full disclosure.

Due to the continued reliance on existing South Delta export facilities, the EIR/EIS should include measures to reduce direct mortality of fish at these facilities in each of the dual conveyance alternatives and the through Delta conveyance alternatives. Measures to reduce direct mortality at the existing South Delta facilities would work towards the stated project objectives, specifically "to be granted incidental take permits for the covered species that authorize take related to … operation of existing State Water Project Delta facilities".

The EIR/EIS should examine fully screening all intakes at export facilities, including the existing export intakes in the South Delta, with positive barrier fish screens. An examination of the salvage and fish population data shows strong correlations between winter salvage at the existing SWP facilities and reduced Fall Mid-Water Trawl population numbers for several species, including delta smelt. Screening these facilities to eliminate salvage and loss of adult delta smelt would improve fish population numbers and avoid a number of significant impacts associated with large canals.

Alternatives that would also reduce take in the South Delta, such as use of bypass flows, barriers and separation of Old and Middle Rivers to provide a habitat corridor, were developed in the Delta Vision process and should be evaluated in detail in the EIR/EIS. Failure to consider measures to reduce take at the existing South Delta facilities would render the document incomplete and inadequate.

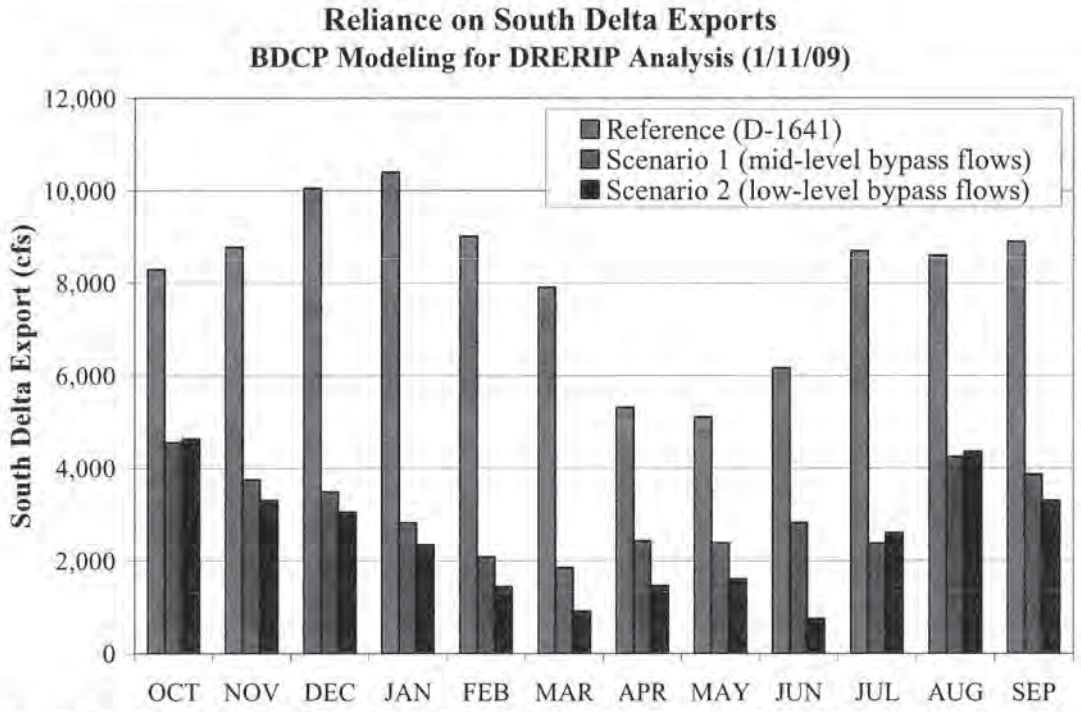


Figure 3 – Even with a 15,000 cfs North Delta diversion facility and isolated conveyance, operated preferentially over South Delta exports, South Delta exports would still be necessary to meet water supply goals, averaging between 900 cfs and 4,500 cfs seasonally.

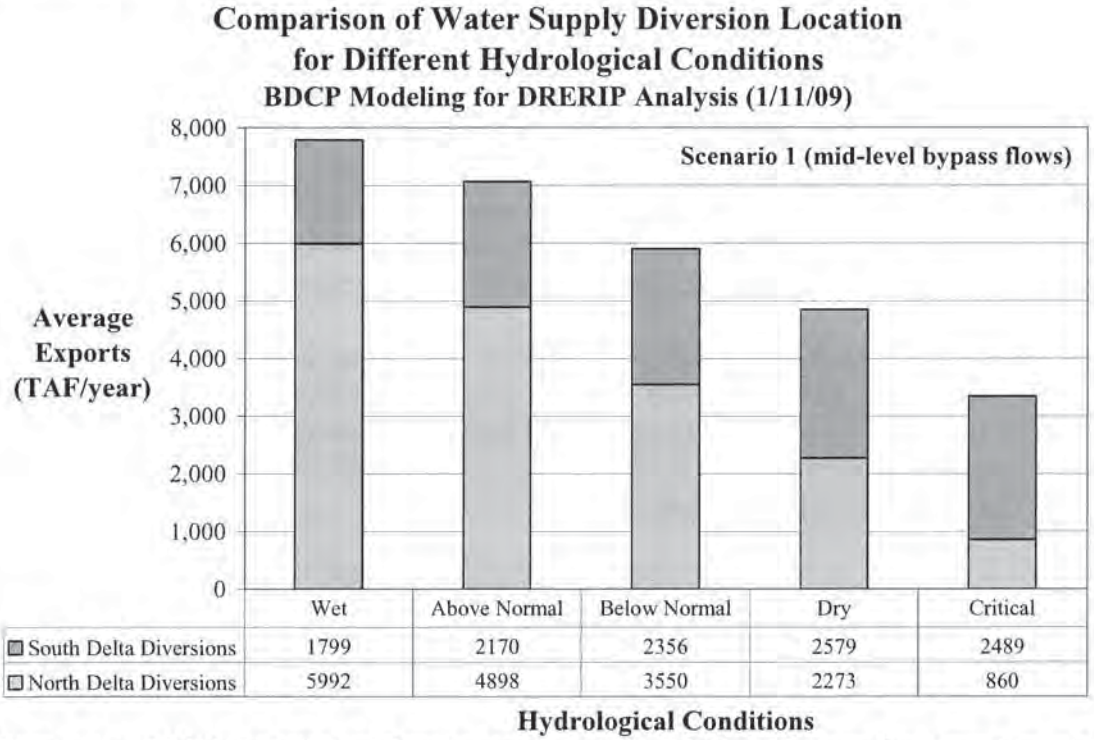


Figure 4 – BDCP modeling of dual conveyance with mid-level bypass flow requirements in the North Delta would rely on South Delta diversions for approximately 2,500 TAF/year during dry and critical years.

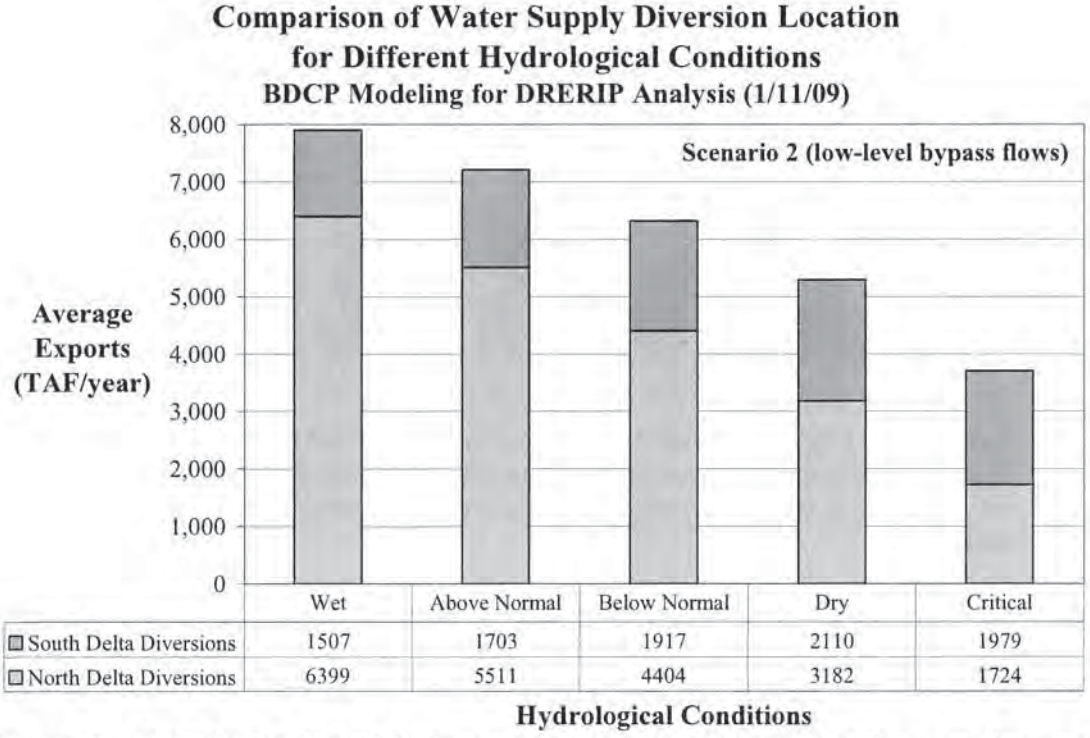


Figure 5 – BDCP modeling of dual conveyance with low-level bypass flow requirements in the North Delta would rely on South Delta diversions for approximately 2,000 TAF/year during dry and critical years.

nteri and Near-ter Actions

Interim and near-term actions will allow critical issues to be addressed in a timely manner and lay a foundation for any long-term projects by expanding the scientific knowledge base of how various projects and management actions affect the environment.

These projects are vital to the health of the Delta ecosystem and reliability of the SWP and CVP water supply. Therefore, they should be considered as components in each of the EIR/EIS alternatives or they should be started separately immediately.

Such projects could have immediate benefits and provide valuable data to assist in the operation of a dual conveyance facility. Project-level evaluation of these near-term solutions could be undertaken concurrently with a programmatic evaluation of the longer-term dual conveyance facility to enable these near term improvements to be done separately on an accelerated schedule where necessary.

Central Delta Pilot Projects

A number of potential pilot projects, with goals similar to the BDCP effort, have been proposed in the central Delta. The projects could provide protection to Delta fish by impeding migration toward the South Delta export facilities (thus reducing take) and improve water quality by reducing salinity intrusion in the fall. For instance, Metropolitan Water District of Southern California, a potentially regulated entity of the BDCP, has proposed various barrier configurations and operational modifications[7] to provide for protection of delta smelt equivalent to the operational restrictions mandated by the 2008 U.S. Fish and Wildlife Biological Opinion[8], while reducing the water supply impacts and Delta water quality degradation resulting from implementation of the same Biological Opinion.

If these projects are not started immediately on their own, then the EIR/EIS should incorporate similar near-term actions in each of the alternatives, designed with an integral monitoring component to evaluate the effects of these barriers on multiple species of concern.

Fish protection screens at Clifton Court Forebay

Implementation of pilot screens at or near Clifton Court Forebay could immediately reduce the loss of fish by predation in the Clifton Court Forebay and through salvage operations. Bond funding is already available for this project. This should be examined and environmental documentation completed on its own accelerated schedule. Information from such a pilot project will provide valuable information for the EIR/EIS,

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[7] The "2-Gates Demonstration Project" involves the placement of temporary barriers along Old River and Connection Slough to demonstrate and validate the value of proposed modifications to the flow patterns in the Sacramento-San Joaquin River Delta with regard to the protection of sensitive species and management of water supply. An Administrative Draft of the Biological Assessment was provided for DWR review in April 2009.

[8] U.S. Fish and Wildlife Service (USFWS). 2008. Biological Opinion on the Coordinated Operations of the Central Valley Project (CVP) and State Water Project (SWP). Final. December 15, 2008.

as each of the EIR/EIS alternatives should include measures to reduce take at the South Delta facilities, including the installation of positive barrier fish screens.

Ecosystem Habitat Improvements

A number of ecosystem habitat improvements could be incorporated into the near-term actions of the BDCP. Many projects have been proposed and advanced to various levels, but have not yet produced environmental documents. By incorporating these habitat improvement projects into the EIR/EIS, the projects would contribute to species recovery in the near-term and provide additional information for subsequent habitat improvement projects. Examples of such projects include:

- Restoration of floodplain habitat and salmon migration through the Yolo Bypass;
- Brackish tidal marsh habitat development in Meins Landing in Suisun Marsh; and
- Freshwater tidal marsh habitat development on Decker Island or Liberty Island.

These projects can increase evapo-transpiration over existing levels, and can affect water supplies and water quality. Such projects should be included in the EIR/EIS, with full evaluation and disclosure of potential impacts, including impacts to water supplies and water quality so that adequate mitigation measures can be developed to reduce any impacts to insignificance.

Delta Cross Channel Operations

Alternative operation of the Delta Cross Channel (DCC) was proposed as part of the North/Central Delta Salmon Out-migration Study, coordinated by the Department of Water Resources[9]. Based on the results of previous studies, the principal investigators hypothesize that the DCC "gates could be operated with respect to the diel cycle to minimize fish movements into the central Delta while at the same time minimizing water quality impacts in the central Delta. These observations motivate the idea of closing the gates at night, presumably a period when salmon outmigrants are more vulnerable to entrainment into the DCC. Using this operational strategy, the DCC would be allowed to convey water into the central Delta during the day (and recreational boaters could move freely from the central to northern Delta through the DCC), where it would presumably alleviate water quality concerns and allow increased exports over fully closed conditions."[10]

The EIR/EIS should incorporate modifications to the DCC operations as a near-term action in each of the through Delta alternatives and dual conveyance alternatives, designed with an integral monitoring component to evaluate the effects of the barrier operations on multiple species of concern. Reoperation of the DCC could have immediate benefits and provide valuable data to assist in the long-term operation of a through Delta or dual conveyance project.

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[9] Study proposal and review documents are available on the DWR project website: http://baydeltaoffice.water.ca.gov/ndelta/salmon/index.cfm

[10] Burau, Jon, Aaron Blake, and Russell Perry. 2007. Sacramento/San Joaquin River Delta Regional Salmon Outmigration Study Plan: Developing Understanding for Management and Restoration.

Potential Environmental Impacts to be addressed

CCWD comments on potential environmental impacts focus primarily on the quality of water necessary to support existing beneficial uses and the regulatory and legal framework that prohibits degradation of water quality and on water supplies. This section is concluded with some additional comments concerning the potential impacts of a new conveyance facility.

Water Quality and water supply

Delta waters support multiple beneficial uses, and Delta water quality and water supply is protected by regulatory policies and federal and state laws. The project effect on Delta water quality and water supply must be fully evaluated and disclosed and mitigation measures proposed and adopted to reduce significant impacts to insignificance.

Fisheries Impacts

Scientific research concerning the current pelagic organism decline (POD) has highlighted the importance of water quality in ecosystem function. The basic conceptual model[11] for the POD identifies the following relevant physical and chemical water quality parameters that determine the habitat suitability: salinity, temperature, turbidity, contaminants, disease, and toxic algae.

The salinity gradient as indexed by the position of X2[12] is correlated to the abundance of numerous species[13], indicating that population levels increase as the salinity gradient is pushed seaward. Although the relationships between populations and X2 have changed with the introduction of the invasive clam *Corbula amurensis* and, more recently, for certain species during the POD years, freshwater flow continues to be an important requirement for a healthy ecosystem. Therefore, the EIR/EIS should analyze the impacts to X2, listing the average monthly value and maximum daily change in X2 from the baseline conditions. If the EIR/EIS proposes changes to the existing X2 standards, the EIR/EIS must demonstrate that the changes benefit the fish populations for which the standards were developed, including the new X2 requirement imposed by USFWS[14] for implementation in the fall months following wet and above normal water years.

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[11] Interagency Ecological Program for the San Francisco Estuary (IEP). January 2008. Pelagic Organism Decline Progress Report: 2007 Synthesis of Results. Available at http://www.science.calwater.ca.gov/pdf/workshops/POD/IEP_POD_2007_synthesis_report_031408.pdf.

[12] X2 is the distance from the Golden Gate to the location of the 2 psu isohaline measured near the bottom of the water column.

[13] Jassby, A. D., W. J. Kimmerer, S. G. Monismith, C. Armor, J. E. Cloern, T. M. Powell, J. R. Schubel, and T. J. Vendlinski. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological Applications 5: 272-289.

[14] U.S. Fish and Wildlife Service (USFWS). 2008. Biological Opinion on the Coordinated Operations of the Central Valley Project (CVP) and State Water Project (SWP). Final. December 15, 2008.

Similarly, The Bay Institute has developed a Delta flow index that shows strong correlations to a composite Delta fish abundance index[15]. The Delta flow index should also be used to evaluate impacts of alternatives.

Additionally, analysis by CCWD shows that the abundance of juvenile delta smelt in summer (as measured by the Summer Townet Survey, TNS) is significantly correlated with the salinity in the Western Delta during the previous fall, a finding that has been confirmed by peer review[16]. This relationship is strengthened further when the analysis is expanded to account for the number of adult delta smelt available to reproduce (as measured by the Fall Midwater Trawl survey, FMWT). A multiple regression analysis of fall salinity, FMWT, and TNS for the following summer yields one of the strongest predictors for delta smelt abundance.[17] The POD years appear as anomalies in this relationship likely due to the exceptionally low population levels and a significant stock-recruitment relationship.

This research is consistent with analysis of habitat environmental quality by the DWR[18], which found a long-term environmental quality decline for delta smelt characterized by increases in fall salinity and decreases in fall turbidity. The recent synthesis of POD research[19] suggests the decline in environmental quality has had "population-level consequences for delta smelt".

Due to this evidence that salinity is an important indicator of population abundance for a number of species, and fall salinity is particularly important for delta smelt, the EIR/EIS should assess the project's effect on salinity at multiple locations in Suisun Bay and within the Delta. The salinity regime under project conditions should be compared to the salinity regime under current conditions and compared to the observed salinity regime at different time periods in history (e.g. 1910's, 1960's, 1970's, 1980's). The impact of changes in salinity should be discussed in terms of the potential impact to the covered species resulting from direct changes to habitat environmental quality and resulting from indirect changes due to the likely effect on distribution of invasive species, such as the overbite clam *Corbula amurensis* and aquatic water weed *Egeria densa*, which could have a subsequent impact to fisheries.

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[15] The Bay Institute. June 19, 2007. Presentation to the State Water Resources Control Board: Recommendations to Improve Fishery Resources, Slow or Stop the Decline of Delta Smelt, and Improve Water Quality Conditions in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. Available at: http://www.waterrights.ca.gov/baydelta/docs/pelagicorganism/tbi_swanson_ppt_061907.pdf

[16] Manly, Bryan F. J. 2006. Review of Analyses Presented at the Environmental Water Account Meeting, December 7-8, 2005.

[17] The Bay Institute, 2007. Petition to the State of California Fish and Game Commission and supporting information for listing the delta smelt (*Hypomesus transpacificus*) as an endangered species under the California Endangered Species Act. Available online at: http://www.bay.org/delta.smelt.petition.pdf. Equation 3 ($p = 0.004$; $p<0.05$ is significant).

[18] Feyrer, F., M. Nobriga, and T. Sommer. 2007. Multi-decadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences 64:723-734

[19] Interagency Ecological Program for the San Francisco Estuary (IEP). Pelagic Organism Decline Progress Report: 2007 Synthesis of Results. January 2008. Available at http://www.science.calwater.ca.gov/pdf/workshops/POD/IEP_POD_2007_synthesis_report_031408.pdf.

In addition to salinity, the BDCP has the potential to change the residence times in the Delta in significant ways, thus impacting temperature, turbidity, and contaminant concentrations. Assumptions regarding contaminant loads from the San Joaquin River must be realistic and cover a range of future scenarios, and disclose the potential impacts of any long residence times in the South Delta that could adversely affect sensitive species.

Any assumptions regarding efficacy of existing contaminant source control programs must recognize the risk that if those programs do not meet targets then the project analysis may be flawed, and may fail to meet conservation goals. Therefore, the project should analyze impacts of contaminant residence times (such as selenium) at current and future levels, without always assuming the contaminant is removed by other projects.

Temperature is recognized to be an important water quality factor for fish. High temperatures will increase mortality of juvenile salmon and delta smelt. The proposed project alternatives can affect Delta temperatures in significant and adverse ways, increasing residence times and raising temperatures. The effects of alternatives on temperatures and the effects of temperature on migratory and resident species should be examined in the EIR/EIS.

The potential for increased temperature and increased nutrient concentrations are likely to effect algal growth patterns in the Delta. Certain algal species (e.g. microcystis) are known to be detrimental to sensitive aquatic species. The EIR/EIS should analyze any potential changes to algal growth, including the frequency and location of large, toxic algal blooms and the effects of such algal blooms on migratory and resident species should be examined in the EIR/EIS.

Drinking Water Impacts

Increased algal growth within the Delta will cause adverse effects for drinking water supplies due to the release of organic chemicals from algal cells either during normal metabolic processes or following rupture of algal cells after the algae die. The most common of these problems are taste and odor and the potential for increased formation of trihalomethanes during the water treatment process. Additionally, hepatotoxins from blue-green algae are increasingly recognized as a potential health hazard in drinking water supplies, potentially causing acute or chronic liver injury, with the possibility of enhanced susceptibility to, and growth of, liver tumors. The EIR/EIS should analyze the effect of increased algal growth on drinking water beneficial uses.

Delta water is subject to large variations in salinity and mineral concentrations, which may be altered by project operations. The EIR/EIS should analyze the changes caused by the project on a daily basis for chloride, bromide, and organic carbon concentrations at all existing and planned drinking water intakes in the Delta and provide for mitigation where appropriate. Bromide and organic carbon are precursors that can result in production of bromate, trihalomethanes, and other disinfection byproducts with potential public health impacts.

CCWD has relied on the Delta as a drinking water source since 1940 (see Attachment C). Through changes to water quality within the Delta (described above) and the timing of Delta "surplus" conditions, the project may have a significant impact on CCWD operations. Therefore, the EIR/EIS must fully analyze and disclose the changes to Delta water quality, including chloride, bromide, and organic carbon concentrations on a daily basis, and the timing of Delta surplus to allow a complete evaluation on the potential economic impacts to CCWD operations.

Regulatory and Legal Constraints

A recent report by DWR prepared for the Delta Vision Blue Ribbon Task Force indicates the BDCP Steering Committee may propose relaxing one or more water quality standards.[20] However, numerous regulatory policies and federal and state laws are intended to prevent degradation of water quality. This section is only a brief summary of some relevant regulatory and legal constraints.

CCWD has observed that federal and state anti-degradation policies seriously constrain, if not outright prohibit, the relaxation of water quality standards. At the request of the State Water Resources Control Board, CCWD prepared a letter summarizing the legal obstacles to relaxation of the southern Delta salinity standards, which is applicable to the relaxation of any water quality standards. This February 13, 2007 letter is enclosed and herein incorporated into CCWD's scoping comments (see Attachment D).

Regardless of action by the State Water Resources Control Board, federal law (P.L. 99-546) requires that the CVP be operated to meet water quality standards at the intake of the Contra Costa Canal on Rock Slough, as established in 1978 in Water Right Decision 1485.

> "The Secretary is further directed to operate the Central Valley Project, in conjunction with the State Water project, so that water supplied at the intake of the Contra Costa Canal is of a quality equal to the water quality standards contained in the Water Right Decision 1485 of the State of California Water Resources Control Board, dated August 16, 1978, except under drought emergency water conditions pursuant to a declaration by the Governor of California. Nothing in the previous sentence shall authorize or require the relocation of the Contra Costa Canal intake." [21]

Furthermore, the Delta Protection Act requires that substituting a water supply in lieu of meeting the required salinity and water supply requirements of Delta water users be done without imposition of any financial burden on said Delta water users.

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[20] California Department of Water Resources. 2008. An Initial Assessment of Dual Delta Water Conveyance. p. 34.

[21] Public Law 99-546, enacted October 27, 1986. This Federal legislation approved the Coordinated Operations Agreement between the Bureau of Reclamation and the Department of Water Resources.

> "If it is determined to be in the public interest to provide a substitute water supply to the users in said Delta in lieu of that which would be provided as a result of salinity control no added financial burden shall be placed upon said Delta water users solely by virtue of such substitution."[22]

Any proposals to change current water quality standards must be thoroughly evaluated and, regardless of whether such changes are assumed to be lawful, the impacts on all beneficial uses of Delta water must be disclosed.

Direct fish ortality due to entrain ent

Previous research[23] showed correlations between winter exports and salvage levels at the export pumps, although the authors used Old and Middle River flows as a surrogate for the effect of export pumping. More recent work by CCWD confirms a stronger correlation between winter salvage at the export pumps and the quantity: exports minus one-half of the San Joaquin River flow. CCWD has also found that winter exports, as well as winter salvage at the SWP intake, are both strongly correlated with subsequent Fall Mid Water Trawl indices (increased salvage correlates with decreased FMWT).

Inasmuch as exports and San Joaquin River flow are independent (physically and mathematically) variables[24], impacts should be analyzed against unscreened export levels and San Joaquin River flows. Furthermore, in order to avoid this impact and meet project objectives, the plan should examine the benefits of installing positive barrier fish screens on reducing salvage and potentially increasing FMWT indices, and the additional benefits on through-Delta flows, fisheries and water quality levels. The EIR/EIS should examine using positive barrier fish screens on all export facilities in order to achieve the project goal of obtaining a take permit for operation of existing and future facilities,.

Additional potential i pacts associated with proposed new conveyance facilities and operations

The EIR/EIS should fully evaluate and disclose potential impacts, and propose mitigation measures where appropriate, of new conveyance facilities and operations, including, but not limited to, the following:

Landscape and Drainage Obstruction

The canal will sever property, disrupt island drainage, and create a barrier to migration corridors, just as the existing Delta-Mendota Canal and California Aqueducts created a major migration barrier for the San Joaquin Kit Fox, cutting off the northern habitat in Alameda and Contra Costa Counties from the San Joaquin Valley. Additionally, the

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[22] California Water Code, Section 12202.
[23] Smith, P., J. Simi, C. Ruhl, and J. Donovan. October 24, 2006. Presentation at CALFED Science Conference. Hydrodynamic Influence on Historical Patterns in Delta Smelt Salvage.
[24] Conversely, Old and Middle River flows are dependent variables and influenced by a number of factors totally unrelated to salvage at the export pumps.

existing irrigation and drainage ditches that the canal will sever may be considered as habitat for various special status species. The EIR/EIS should fully evaluate and disclose these potential impacts. The EIR/EIS also should evaluate the alternative of a pipeline conveyance system in order to avoid this impact.

Seepage from Isolated Canal to Adjacent Lands

If the water level in the isolated canal is expected to be above the surrounding land surface elevation for large sections of the canal route, the seepage from the unlined canal would impact land use adjacent to the canal as well as water quality in adjacent channels. The EIR/EIS should fully evaluate and disclose impacts associated with seepage and provide for mitigation where appropriate. The EIR/EIS also should evaluate the alternative of a pipeline conveyance system in order to avoid this impact.

Water flows and Migration of Aquatic Species

New facilities and operations may alter flows in the Delta, and could disrupt aquatic migration corridors for resident and migrating fish. All impacts of changed flows must be thoroughly evaluated and disclosed.

Bypass flows near intakes are important to adequately protect fisheries. At the same time, relocating existing intakes and diverting water at new locations may limit diversion of flows that are needed for bypass flows or preclude diversion of flows that come from other parts of the system and are not available at the new intakes. Consequently, there may be a reduction in supplies available for export while, at the same time, those changes result in water quality degradation in other areas of the Delta. These potential impacts should be fully evaluated and disclosed.

Recent studies within the Delta indicate that certain life stages of sensitive fish species respond to the local tidal velocity (including secondary currents at river bends) the amount of daylight, and local turbidity and salinity gradients. The EIR/EIS should rely on the best available science, including the behavioral models discussed below, to evaluate the potential impacts of changes in tidal velocity, turbidity, and salinity.

Sacramento River and Mokelumne River Salmonids

Results from a pilot study of salmon outmigration in the North Delta[25] indicate that survival of juvenile salmonids decreased with decreasing net flow. In other words, the probability that a given fish will survive migration through a specific channel reach was increased as the net flow in the channel reach was increased. Therefore, reducing the net flow through a migratory pathway has the potential to reduce survival of fish through that pathway (i.e. increase indirect mortality due to predation or toxics).

Proposed diversions in the North Delta would reduce net flow along the Sacramento River below the diversion locations, reduce net flow in Sutter, Steamboat, and Georgiana Sloughs, and potentially reduce net flow on the lower Mokelumne River system,

[25] Results of the pilot study are presented in Burau et. al. 2007. Sacramento/San Joaquin River Delta Regional Salmon Outmigration Study Plan: Developing Understanding for Management and Restoration.

dependent on the operation of the Delta Cross Channel (DCC) gates (see below). Based on the pilot study cited above, this reduction in net flow throughout the North Delta is likely to reduce survival of outmigrating juvenile salmonids. The EIR/EIS must fully evaluate the increased indirect mortality of juvenile salmonids as a result of North Delta diversions.

Similarly, increased closure of the DCC gates is likely to impact juvenile salmonids emigrating from the Mokelumne and Consumnes River systems. Since closure of the DCC gates reduces net flow on the lower Mokelumne system, it is likely that survival on these reaches is also reduced. Preliminary review of the timing of the proposed increase in DCC closure periods in relation to the timing of outmigranting populations, indicates that the proposed closures have the potential to affect a larger fraction of the population for Mokelumne River salmonids, impacting an additional 15% of fry, 37% of sub-yearling smolts, and 27% of yearling fall run Chinook salmon smolts and impacting an additional 36% of fry, 49% of sub-yearling smolts, and 33% of yearling steelhead smolts. Furthermore, some emigrating steelhead smolts are known to outmigrate through the DCC and down the Sacramento River; extended DCC closures would reduce potential use and increase mortality for this migratory pathway. The EIR/EIS must fully evaluate the increased indirect mortality of juvenile salmonids as a result increased DCC closure periods.

Preliminary BDCP modeling utilized the Delta Simulation Model II – Particle Tracking Model (DSM2-PTM) to examine travel time (time for a certain percent of particles to travel a particular reach) and particle fate (percent of particles to reach a particular boundary location). The DSM2-PTM model assumed the particles were neutrally buoyant and did not exhibit any swimming behavior[26]. However, a study in the North Delta revealed that secondary circulation patterns influenced the spatial distribution of fish near a bend in the Sacramento River near Clarksburg[27]. Additionally, research by Blake and Horn[28] has shown that juvenile salmon approaching channel junctions are not split into each of the channels at the same ratio as the net flow split. These results indicate that juvenile salmon should not be modeled as neutrally buoyant particles; rather, a model of salmon behavior must be utilized to effectively asses the potential impacts to outmigrating salmonids.

Changes in hydrodynamics in the North and Central Delta have the potential to affect both the distribution of salmon (through route selection) and the survival of salmon (through changes to the travel time and exposure to toxics and predators). The overall survival of juvenile salmonids emigrating from the Sacramento River is determined by the probability of route selection at each river junction combined with the probability of survival through each individual river reach - the North/Central Delta Salmon Out-

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[26] Bay Delta Conservation Plan Integration Team. 2009. Draft Technical Memorandum: Summary of Preliminary Modeling of Draft BDCP Conservation Strategy – Core Elements.

[27] Preliminary results of the Clarksburg Bend January 2007 study are presented in Appendix C of Burau et. al. 2007. Sacramento/San Joaquin River Delta Regional Salmon Outmigration Study Plan: Developing Understanding for Management and Restoration.

[28] Blake, A. and M.J. Horn. In Press, "Acoustic Tracking of Juvenile Chinook Salmon Movement in the Vicinity of Georgiana Slough, Sacramento River, California – 2003 Study Results." – USGS SIR-XXXX

migration Study is designed to estimate these probabilities in response to a range of river flows and DCC operations. The EIR/EIS should incorporate results from this study to evaluate impacts on juvenile salmonids.

San Joaquin River Salmonids

Relatively high salinity along the San Joaquin River and within the South Delta creates an inverse salinity gradient within the South and Central Delta (Figure 6), with salty bay water to the west and salty San Joaquin River water to the south. In this situation, fish in the Central Delta may not be able to determine an out-migratory pathway towards the ocean based on local salinity conditions; in other words, if fish utilize salinity gradients to migrate toward the ocean, the fish could get turned around in the Central Delta.



Figure 6 – Typical spatial distribution of salinity. High salinity on the San Joaquin River and within the South Delta creates an inverse salinity gradient, which could be detrimental to aquatic species.

Transport in the South and Central Delta, including the lower San Joaquin River, Old River, and Middle River, is largely influenced by the tidal dynamics and pumping at the South Delta export facilities. Fish react to their local environment, including the tidal velocity and the local salinity gradient. Fish do not react to daily average flows, which depend not only on the local tidal velocity near the fish, but the tidal velocity in areas where the fish is not present and the geometry of the channel cross-section (a

mathematical value the fish cannot measure). Gartrell and Herbold (2009)[29] discusses the difference between average flow and tidal velocity, and how the "net flow model" leads to incorrect conclusions; the paper also presents a tidal perspective of salinity gradients to provide an explanation of observations. The EIR/EIS should consider the effects of project alternatives on salinity gradients in the Delta and the subsequent effect on aquatic species.

Delta Smelt

Resource Management Associates, Inc. (RMA) has developed a particle tracking model that incorporates behavior related to turbidity and salinity gradients to simulate the distribution of adult delta smelt and entrainment by export pumps. Model results compare favorably with the timing of historical salvage at the South Delta export facilities; additionally, the author hypothesizes that reductions in South Delta exports may actually increase salvage during certain time periods due to the potential collapse of the low turbidity zone in the Central Delta[30]. The EIR/EIS should evaluate potential impacts to direct mortality of adult delta smelt at the South Delta export facilities using the best available scientific tools and provide for mitigation, including the use of positive barrier fish screens, where appropriate.

Sediment and Nutrient Load Reduction

By diverting a large fraction of the flow on the Sacramento River, the canal will remove a similar fraction of the sediment and nutrient load, potentially effecting turbidity and nutrients within the Delta. As discussed above, turbidity has been identified as an important factor in the environmental quality for delta smelt. Any changes to turbidity and nutrients should be fully evaluated and disclosed, with proposed mitigation measures, where appropriate.

Flood Risk

An unlined canal will create new flood risks. An unlined canal crossing liquefiable soils will be subject to failure in seismic events and allow disruption of vital water supplies for long periods. The EIR/EIS must fully evaluate and disclose these impacts of using an unlined canal for transport of water supplies. The EIR/EIS also should evaluate the alternative of a pipeline conveyance system in order to avoid this impact.

Operation and Maintenance Practices

Since the NOP indicates operation and maintenance of the proposed facilities will be a covered action, the EIR/EIS must evaluate the impacts associated with anticipated operation and maintenance activities, including:

- aquatic weed management and the potential use of herbicides or physical clearing of vegetation that will be necessary along, and in, any canal, especially during the long winter periods in dry years when the canal is not used.

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[29] Gartrell, G. and B. Herbold. April 27, 2009. Flow, Salinity and Migration of Salmon. (Attachment E)

[30] "Particle Modeling of Adult Delta Smelt with Behavior based on EC and Turbidity Distributions" presented by John DeGeorge (RMA) at California Water and Environmental Modeling Forum 2009 Annual Meeting.

- levee maintenance, and
- facility security.

The potential impact of maintenance activities on the habitat within the canal as well as downstream beneficial uses, such as recreational use in reservoirs, agricultural irrigation, and drinking water must be considered.

Oversizing the canal may lead to additional operating expenses and maintenance-related impacts. For instance, vegetation is likely to establish within the open canal during low flows. The vegetation would need to be cleared before the canal can carry high flows during the peak diversion periods. The EIR/EIS must fully evaluate the additional aquatic weed management activities associated with sub-optimal flows within the canal.

Historical Fresh Water and Salinity Conditions in the Western Sacramento-San Joaquin Delta and Suisun Bay

A summary of historical reviews, reports, analyses and measurements

Water Resources Department

Contra Costa Water District

Concord, California

February 2010

Technical Memorandum WR10-001

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Foreword - *Establishing the Historical Baseline*

The watershed of the Sacramento–San Joaquin Delta (Delta) provides drinking water to more than 23 million Californians as well as irrigation water for millions of acres of agriculture in the Central Valley. The Delta itself is a complex estuarine ecosystem, with populations of many native species now in serious decline. The Delta estuary as we know it began to form about 6,000 years ago, following the end of the last ice age. Because the estuary is connected to the Pacific Ocean through San Francisco Bay, seawater intrusion causes the salinity of Suisun Bay and the Delta to vary depending on hydrological conditions. This seawater intrusion into the Delta affects estuarine species as well as drinking water and irrigation water supplies.

Successful restoration of the Delta ecosystem requires an understanding of the conditions under which native species evolved. Contra Costa Water District's report on "Historical Fresh Water and Salinity Conditions in the Western Sacramento-San Joaquin Delta and Suisun Bay" presents a detailed review of more than 100 years of studies, monitoring data, scientific reports, and modeling analyses that establish an historical record of the salinity conditions in the Western Delta and Suisun Bay.

Executive Summary

The historical record and published studies consistently show the Delta is now managed at a salinity level much higher than would have occurred under natural conditions. Human activities, including channelization of the Delta, elimination of tidal marsh, and water diversions, have resulted in increased salinity levels in the Delta during the past 150 years.

Eighty years ago, Thomas H. Means wrote ("*Salt Water Problem, San Francisco Bay and Delta of Sacramento and San Joaquin Rivers*," April 1928, pp 9-10):

> "Under natural conditions, Carquinez Straits marked, approximately, the boundary between salt and fresh water in the upper San Francisco Bay and delta region of the two tributary rivers—the Sacramento and San Joaquin. Ordinarily salt water was present below the straits and fresh water was present above. Native vegetation in the tide marshes was predominately of salt water types around San Pablo Bay and of fresh water types around Suisun Bay....
>
> The definite statement that salt water under natural conditions did not penetrate higher upstream than the mouth of the river, except in the driest years and then only for a few days at a time, is warranted....
>
> At present [1928] salt water reaches Antioch every year, in two-thirds of the years running further [sic] upstream. It is to be expected that it will continue to do so in the future, even in the years of greatest runoff. In other words, the penetration of salt water has become a permanent phenomenon in the lower river region.
>
> The cause of this change in salt water condition is due almost entirely to the works of man."

In 1928, Thomas Means had limited data over a short historical period from which to draw these conclusions. Nonetheless, his conclusions remain accurate and have been confirmed by numerous subsequent studies, including paleosalinity records that reveal salinity conditions in the western Delta as far back as 2,500 years ago. The paleosalinity studies indicate that the last 100 years are among the most saline of periods in the past 2,500 years. Paleoclimatology and paleosalinity studies indicate that the prior 1,500 years (going back to about 4,000 years ago) were even wetter and less saline in San Francisco Bay and the Delta. The recent increase in salinity began after the Delta freshwater marshes had been drained, after the Delta was channelized and after large-scale upstream diversions of water, largely for agricultural purposes, had significantly reduced flows from the tributaries into the Delta. It has continued, even after the construction of reservoirs that have been used in part to manage salinity intrusion.

Increased Salinity Intrusion into the Delta

Studies and salinity measurements confirm that despite salinity management efforts, Delta salinity is now at or above the highest salinity levels found in the past 2,500 to 4,000 years. Under equivalent hydrological conditions, the boundary between salt and fresh water is now 3 to 15 miles farther into the Delta than it would have been without the increased diversions of fresh water that have taken place in the past 150 years.

Reservoir operations artificially manage salinity intrusion to conditions that are saltier than had been experienced prior to the early 1900's. While these managed conditions are certainly fresher than would occur in today's altered system if operated without any salinity management, they are still saltier than what the Delta experienced under similar hydrological conditions in the past. While the Delta is being managed to a somewhat acceptable saline condition to meet many beneficial uses, it is still managed at a more saline condition than would have occurred prior to the anthropogenic changes of the past 150 years.

For example, the 1928-1934 drought was one of the driest periods in the past 1,000 years (Meko *et al.*, 2001a), and occurred after tidal marshes within the Delta had been reclaimed and water diversions began removing substantial amounts of fresh water from the Bay-Delta system. Nonetheless, the Delta freshened during the winter in those drought years. This winter freshening of the Delta has not occurred during recent droughts. While salinity intrusion into the Delta was previously only seen in the driest years, significant salinity intrusion now occurs in nearly every year – exceptions are only found in the wettest conditions.

Changed Variation in Salinity

The variability of fresh and saline conditions in the Delta has considerably changed because of upstream and in-Delta water diversions and water exports (Enright and Culberson, 2009). This change in variability results largely from the lack of fresh conditions in Suisun Bay and the western Delta, especially in the winter and spring. Restoring a variable salinity regime that more closely approximates conditions prior to the early 1900's would require much higher flows and much fresher conditions than current management practices provide, with larger outflows in the fall in most years and much larger outflows in the late winter and spring in all years.

Key Conclusions

The major conclusions of this study are:

1. Salinity intrusion during the last 100 years has been among the highest levels over the past 2,500 years. The Delta has been predominantly a freshwater tidal marsh for the last 2,500 years.
2. Human activities during the last 150 years, including channelization of the Delta, elimination of tidal marsh, construction of deep ship channels, and diversion of water, have resulted in the increased salinity levels in the Delta.

3. Conditions in the Delta during the early 1900's were much fresher than current conditions for hydrologically similar periods. Salinity typically intrudes 3 to 15 miles farther into the Delta today.
4. The historical record and published studies uniformly demonstrate and conclude the Delta is now managed at a salinity level that is much higher than would have occurred under pre-1900 conditions. Operation of new reservoirs and water diversion facilities for salinity management reduces salinity intrusion somewhat, but the levels still exceed pre-1900 salinities.
5. Seasonal and inter-annual variation in salinity has also been changed; however, this change is largely the result of reduced freshwater flows into the Delta. At any given location in the western Delta and Suisun Bay, the percentage of time during the year when fresh water is present has been greatly reduced or, in some cases, largely eliminated.

Background

Flows and water quality in the Sacramento-San Joaquin Delta (Delta) are strongly influenced by freshwater inflow from the rivers, by the tides in San Francisco Bay and by salinity from Bay waters. Prior to human influence, the historical distribution of salinity in the Delta was controlled primarily by the seasonal and inter-annual distribution of precipitation, the geomorphology of the Bay and Delta, daily tides, the spring-neap[1] tidal cycle, and the mean sea level at Golden Gate. Extended wet and dry periods are both evident in the historical record. Since about 1860, a number of morphological changes to the Delta landscape and operational changes of reservoirs and water diversions have affected flows and the distribution of salinity within the Delta.

Between 1860 and 1920, there was significant modification of the Delta by humans:
(i) marsh land was reclaimed,
(ii) hydraulic mining caused extensive deposition and then erosion of sediment, and,
(iii) Delta channels were widened, interconnected and deepened.

Large-scale reservoir construction began in about 1920 and continued through the 1970's, changing the timing and magnitude of flows to the Delta. Large volumes of water began to be diverted for agricultural use upstream of and within the Delta in the same time period. In more recent times, California's Delta water resources have been extensively managed to meet the water supply needs of the State's municipal, industrial, and agricultural water users, with attempts made to also provide flow and water quality conditions to meet fishery needs.

Proposals for significant additional alteration of the Delta and of flows within the Delta are currently being developed as part of the Bay-Delta Conservation Plan process[2]. To

[1] During a spring tide, the gravitational forces from the sun and moon are largely the same direction and the high-low tidal range is greatest. During a neap tide, the gravitational forces sun and moon are largely not aligned and the tidal range is the lowest. The spring-neap tidal cycle, from strong spring tides through weak neap tides and back to spring tides, in San Francisco Bay has a period of about 14 days.
[2] www.baydeltaconservationplan.com

understand the effect of those proposals, it is important to accurately establish historical conditions. For example, for ecological restoration to be successful, it is necessary to establish and understand the conditions to which native species have previously adapted and survived in order to predict their response to future changes in climate or water management. This report uses available data and modeling to examine the consequences of structural changes in the Delta (channelization, channel dredging), increased diversions of water upstream of the Delta, reservoir operations, climate and sea level effects, and other factors on Delta salinity.

Objective

The objective of this report is to answer two major questions regarding the historical extent of fresh water and salinity in the western Delta and Suisun Bay:

I. What was the extent of fresh water and what were the salinity conditions prior to large-scale reservoir operations and water diversions (i.e., prior to early 1900's) and prior to structural changes in the Delta (i.e., prior to the 1860's)?

II. What are the effects of large-scale water management practices (reservoir operations and diversions) on salinity conditions in the western Delta and Suisun Bay?

Approach

Available data were used to characterize historical and present-day fresh water extent and salinity intrusion into the Delta. The data examined in this report include paleohistorical records (over geologic time scales) of river flow and salinity (Section 2), instrumental observations of hydrology and salinity (Section 3), and literature reports on the extent of fresh water in the Delta (Section 4). Additional details and supplemental information are presented in the Appendices to this report.

Historical Fresh Water and Salinity Conditions in the Western Sacramento-San Joaquin Delta and Suisun Bay

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Acrony s

C&H	California and Hawaiian Sugar Refining Corporation
CCWD	Contra Costa Water District
CDEC	California Data Exchange Center
Cl	Chloride concentration
CVP	Central Valley Project
DPW	Department of Public Works
DSM2	Delta Simulation Model 2
DWR	California Department of Water Resources
DWSC	Deep water ship channel
EC	Electrical conductivity
ENSO	El Niño/Southern Oscillation
ESA	Endangered Species Act
IEP	Interagency Ecological Program
M&I	Municipal and Indutrial
NDO	Net Delta Outflow
PDO	Pacific Decadal Oscillation
PPIC	Public Policy Institute of California
SWRCB	State Water Resource Control Board
SRI	Sacramento River Index
STORET	Storage and Retrieval
SWP	State Water Project
TBI	The Bay Institute
TDS	Total Dissolved Solids

Units

AF	Acre-feet
MAF	Million acre-feet
TAF	Thousand acre-ft
µS/cm	MicroSiemens per centimeter, a measure of EC
cfs	Cubic feet per second
mg/L	Milligrams per liter
ppm	Parts per million
ppt	Parts per thousand

ntroduction

1.1. Background

The Sacramento-San Joaquin River Delta (Delta) is fed by fresh water from the Sacramento River and the San Joaquin River basins (Figure 1-1). The Delta is connected to the San Francisco Bay through Suisun and San Pablo Bays, and the movement of water back and forth between the Delta and the Bay results in mixing between saline water from the Pacific Ocean and fresh water from the rivers flowing into the Delta. The extent to which salty ocean water intrudes into the Delta is a function of natural processes such as ocean tides and precipitation and runoff from the upstream watersheds. It has also been greatly influenced by anthropogenic activities (e.g. construction of artificial river channels, removal of tidal marsh, removal of floodplain connections to channels, deepening of channels for navigation purposes, reservoir storage and release operations, and water diversions).

Proposals for significant additional alteration of Delta channels and marshland, of flows within the Delta, and of reoperation of upstream reservoirs are currently being developed as part of the Bay-Delta Conservation Plan, which builds upon earlier work by the Delta Vision Blue Ribbon Task Force[3], and others (e.g., see Lund *et al.,* 2007). To understand the context and effect of those proposals, it is important to accurately understand the historical conditions previously experienced by Delta species.

An analysis of the salinity trends and variability in northern San Francisco Bay since the 1920's and the factors controlling those salinity trends has recently been published (Enright and Culberson, 2009), with a focus on a comparison of pre-1968 salinity and flows with post-1968 conditions. This report includes analysis and review of reports, data and information from the period prior to Enright and Culberson's analysis, and includes the review of salinity trends using paleohistorical data.

Historically, reproduction of most species in the Bay-Delta (biotic production phase) occurred during the high-flow periods (winter and spring) and biotic reduction occurred in the low-flow periods (summer and fall) (Baxter *et al.,* 2008). Multi-year wet periods most likely resulted in population increases, whereas drought periods likely resulted in reduced reproduction and increased predation. The recent report on Pelagic Organism Decline (POD, Baxter *et al.,* 2008) indicated that reduced flow variability under the current water management conditions may have exacerbated the effects of predation on the population abundance of pelagic fish species in the Bay-Delta estuary. Native species of the Bay-Delta system adapted to the historical salinity conditions that occurred prior to large-scale water management practices and physical changes in the Delta. The historical salinity conditions in the Delta provide insight into the response of fish species to proposed ecosystem restoration actions, and the response of species to future changes in climate or water management.

[3] Delta Vision Blue Ribbon Task Force was appointed by California Governor Arnold Schwarzenegger in February 2007 and adopted the Delta Vision Strategic Plan in October 2008.

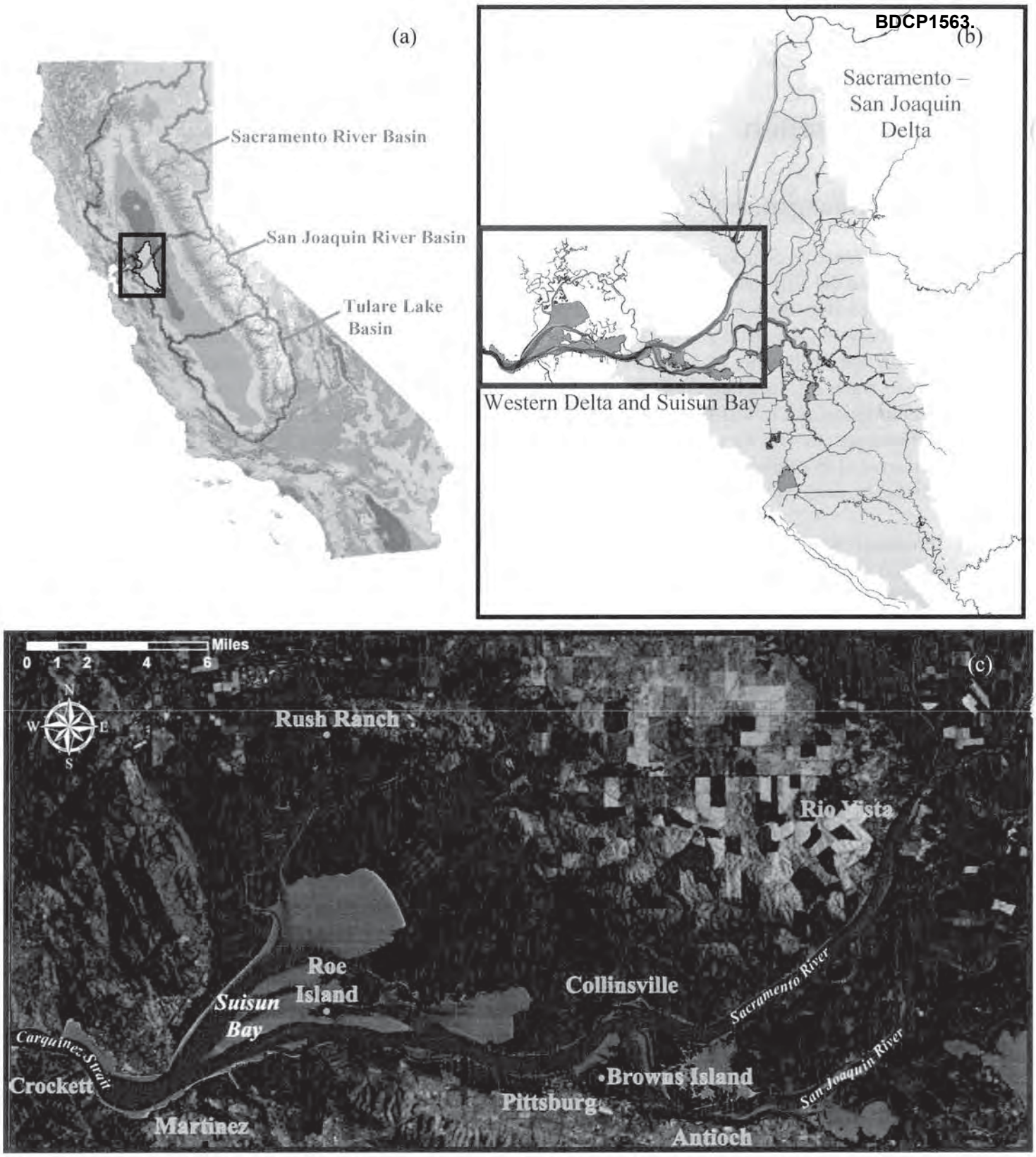


Figure 1-1 – Map

(a) Topographical map of California, with outlines of the Sacramento River, San Joaquin River, and Tulare Lake basins; purple rectangle indicates the extent of the inset in panel (b). (b) Sacramento – San Joaquin Delta and Suisun Bay region; green rectangle indicates the extent of the Western Delta and Suisun Bay enlarged in panel (c). (c) Extent of salinity evaluations considered within this study, including names of locations referenced throughout this report.

The salinity concentrations in San Francisco Bay and the Delta are the result of tides that move seawater into the system and are controlled in large part by the amount of fresh water passing through the system (Denton, 1993; Uncles and Peterson, 1996; Knowles *et al.*, 1998). The salinity distribution is driven by the motion of the tides, which convey ocean water into the system on the flood tide and draw a mixture of ocean and river water back out again on the ebb tide. These tides act on natural diurnal (repeating twice per day) and spring-neap (repeating every 14 days) cycles driven by the gravitational forces of the sun and moon (Oltmann and Simpson, 1997; Burau *et al.*, 1999).

Other factors affecting Bay-Delta salinity (discussed in Appendix A) may be smaller but are not insignificant. When comparing historical salinity conditions in the Bay-Delta watershed, it is often helpful to compare periods with similar hydrological conditions so that the changes due to other factors can be discerned. This will reveal if there is an anomalous change in salinity, even if the specific cause of that change in salinity is not known.

Major anthropogenic modifications to the Delta that affect salinity intrusion began with the European settlement of the region and can be classified into two categories: physical modifications of the landscape (e.g., removal of tidal marsh, separation of natural floodplains from valley rivers, construction of permanent artificial river channels, and land-use changes) and water management activities (e.g. diversion of water for direct agriculture, municipal, or industrial use, and reservoir storage and release operations).

As shown in Figure 1-2, tidal marsh acreage in the Delta decreased significantly from nearly 346,000 acres in the 1870's to less than 25,000 acres in the 1920's and has since continued to decrease. Even after hydraulic mining for gold was banned in California in 1884, large quantities of mining debris continued to be carried by runoff into the Delta, where it was deposited as sediment, filling channels in the Delta and Suisun Bay. Between 1887 and 1920, Suisun Bay became an erosional environment and continued to lose sediment through 1990. Enright and Culberson (2009) discuss the effects of the changes in Suisun Bay bathymetry on salinity intrusion. Major dredging projects on the main Delta channels to create the Stockton and Sacramento Deep Water Ship Channels (DWSC) have also changed how flows and, therefore, salinity are distributed throughout the Delta.

Each of these factors has changed the salinity regime: loss of tidal marsh lands has allowed increased tidal energy deeper into the Delta, increasing tidal flows and salinity dispersion (Enright and Culberson, 2009), net erosion and increasing depth within Suisun Bay likely increased dispersive transport of salt up the estuary (Enright and Culberson, 2009), and deeper channels allow increased salinity intrusion due to increased baroclinic circulation and increased tidal flow and dispersion..

However, these physical modifications generally have had less effect on salinity intrusion in the Delta than the major water management activities that have resulted in large-scale diversion of water for reservoir storage and agricultural, domestic, and industrial water use (Nichols *et al,* 1986; Knowles, 2002). As will be seen in data presented in this document, early diversions before large-scale storage projects resulted in greatly increased salinity intrusion, especially in the summer irrigation season, peaking in September. Later, reservoir operations reduced salinity intrusion in the summer and fall, but increased it in the winter and

spring, up until the mid-1980's. Subsequent water operations have resulted in increased salinity intrusion year round.

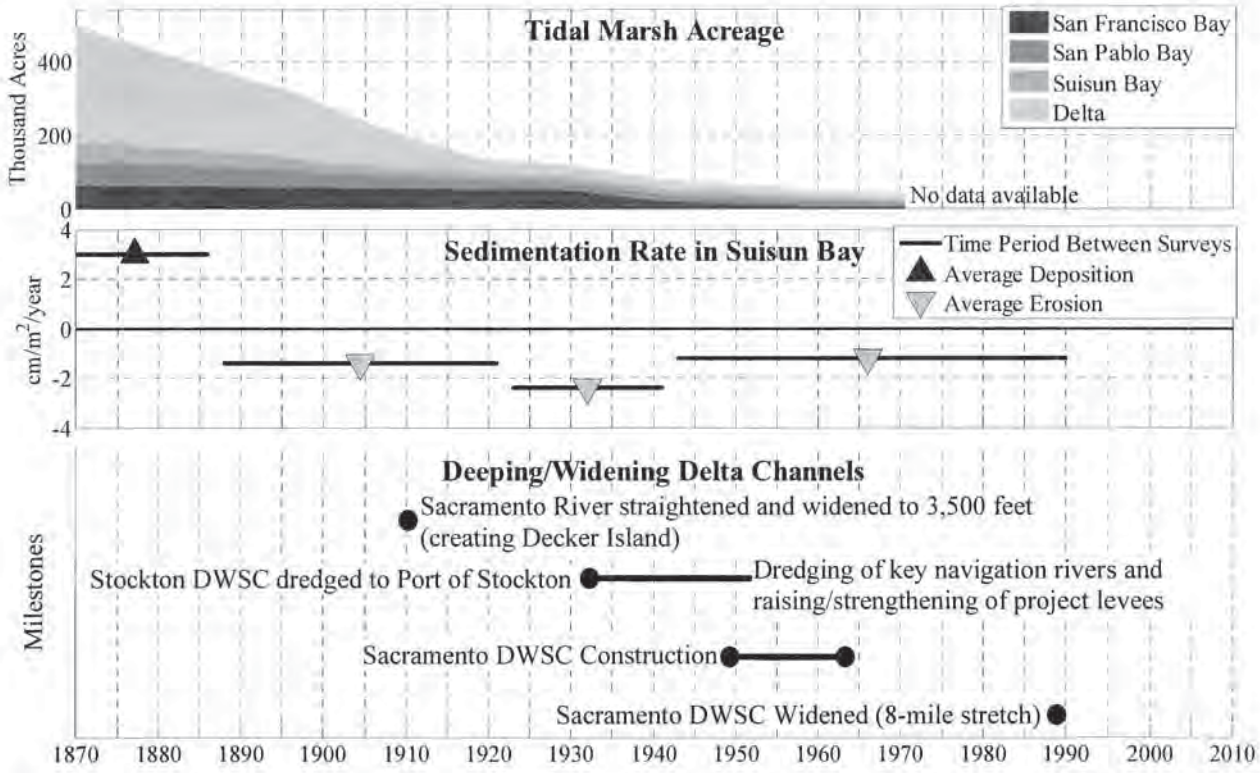


Figure 1-2 – Chronology of anthropogenic modifications to the Bay-Delta landscape

Bay-Delta landscape has undergone significant changes since the mid-1800's. Tidal marsh acreage (top panel) has been significantly reduced (data from Atwater, et al., 1979). Suisun Bay received a pulse of sediment from hydraulic mining in the late 1800's (middle panel), but lost sediment from 1887 to 1990 (data from Cappiella et al., 1999). Numerous efforts to widen and deepen the main channels within the Delta have occurred throughout the 20th Century (bottom panel).

The largest reservoir of the federal Central Valley Project (CVP), Lake Shasta, was completed in 1945, and the largest reservoir of the State Water Project (SWP), Lake Oroville, was completed in 1968. Total upstream reservoir storage capacity increased from 1 MAF in 1920 to more than 30 MAF by 1979. The CVP began exporting water from the southern Delta through Jones Pumping Plant (formerly known as the Tracy Pumping Plant) in 1951, and the SWP began exports through Banks Pumping Plant in 1968. By 1990, the combined export of water from the southern Delta through the Banks and Jones Pumping Plants was about 6 MAF per year.

Figure 1-3 shows that the greatest increase in upstream reservoir storage occurred from the 1920's through the 1960's. Prior to the construction of major water management reservoirs, irrigated acreage grew to about 4 MAF. The construction of the reservoirs allowed irrigated acreage to increase to about 9 MAF. Since 1951, when the first south Delta export facility was completed, annual diversions from the Delta have increased to a maximum of about 8 MAF; total annual diversions from the system are estimated at up to 15 MAF.

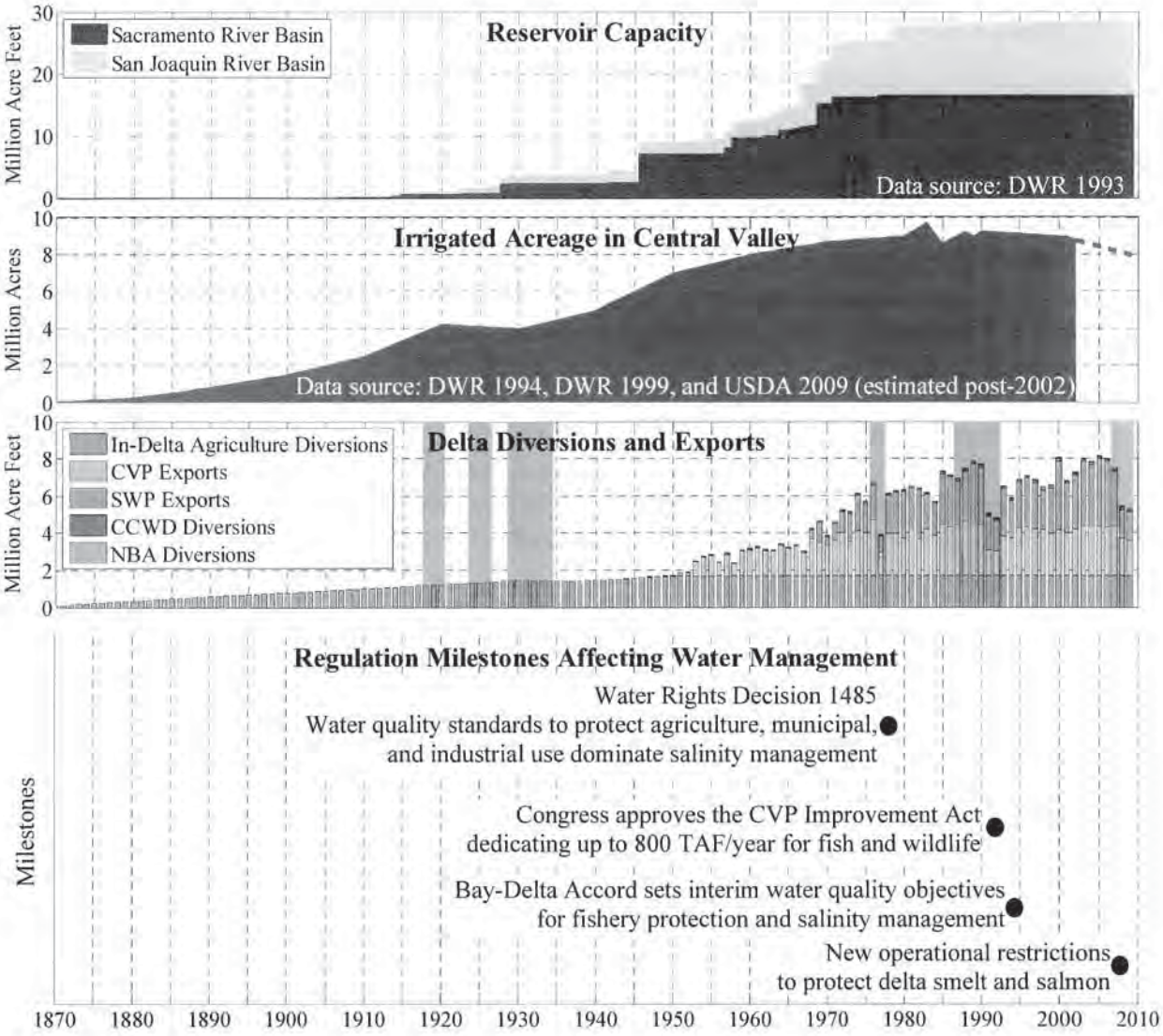


Figure 1-3 – Chronology of anthropogenic activities that affect water management

Reservoirs (top panel) and irrigated crops in the Central Valley (second panel) alter the timing and magnitude of water flow to reach the Delta. Diversions and exports within the Delta (third panel) further reduce the amount of water to flow through the Delta to Suisun Bay. Regulations (bottom panel) require modifications to water management activities to meet specific flow and water quality objectives.

Figure 1-3 also presents the timeline for recent regulatory milestones that have affected Delta water quality. Salinity management was dominated by water quality standards to protect Delta agriculture and municipal and industrial (M&I) uses in the 1978 Water Quality Control Plan and State Water Resources Control Board (SWRCB) Decision 1485. The Bay-Delta Accord of 1994 and subsequent SWRCB Water Rights Decision 1641 made fishery protection the dominant factor for salinity management with new estuarine habitat or "X2 Standards"[4] from February through June, with minimum outflows for the remainder of the

[4] X2 is the distance, in kilometers from the Golden Gate, to the location of the 2 part per thousand salinity line. A larger X2 means salinity has intruded farther into the Delta.

year. The relationship between X2 and estuarine habitat is discussed in detail in Jassby *et al.* (1995).

These regulations apply throughout the year and have modified how the large-scale water management reservoirs and export facilities are operated. For instance, delta smelt was listed as a threatened species under the federal Endangered Species Act in 1993, and Sacramento River winter-run salmon was listed as endangered in 1994. The subsequent biological opinions, 1994 Bay-Delta Accord, and the adoption of a new water quality control plan by the State Water Resources Control Board in 1995, required increased reservoir releases in some months for temperature control in the Sacramento River below Shasta and for salinity control in Suisun Bay. They also applied additional limits on pumping at the export facilities in the south Delta.

Changes in water diversions and reservoir operations have altered the magnitude and timing of river flows to the Delta, and anthropogenic modifications to the Delta landscape have altered the interaction of fresh water from the rivers with salt water from the ocean, thus changing patterns of salinity intrusion into the Delta.

1.2. Comparing Historical Conditions

Flow and salinity conditions prior to human interference varied according to seasonal and annual hydrological conditions, short-term and long-term drought cycles and other natural changes, so "natural" conditions include variability that must be considered in any analysis. Hydroclimatic variability is described by "unimpaired" runoff, which represents the natural water production of a river basin, unaltered by water diversions, reservoir storage and operation, and export of water to or import of water from other basins.

As discussed above, large-scale water management operations during the last 100 years superimposed on the anthropogenic modifications to the Delta landscape have significantly changed Delta conditions. It is possible to remove the effect that water management operations have had on flows and generate a corresponding set of unimpaired flows. However, it is not possible, without complex assumptions and modeling, to also remove the additional effect of the land use, channel and tidal marsh modifications to the Delta.

The historical conditions presented in this report have been determined from records in paleoclimatic fossils and measured directly with various scientific instruments. The paleoclimatic data start well before human influence, but continue through the 20th Century when anthropogenic modifications became significant.

Because of the natural hydroclimatic variability, no past historical period may fully represent "natural" conditions. Therefore, this report summarizes the available historical salinity information with reference to the time period of the observations, and then compares each period to the salinity regime during present day periods with similar upstream unimpaired hydrology. Where there are significant changes in salinity, despite similar upstream unimpaired hydrology, other factors such as landscape modifications and water management operations must be contributing factors.

1.3. Objective

The objective of this report is to answer two major questions regarding the historical extent of fresh water and salinity in the western Delta and Suisun Bay:

I. What was the extent of fresh water and what were the salinity conditions prior to large-scale reservoir operations and water diversions (i.e., prior to early 1900's) and prior to structural changes in the Delta (i.e., prior to the 1860's)?

II. What are the effects of large-scale water management practices (reservoir operations and diversions) on salinity conditions in the western Delta and Suisun Bay?

1.4. Report Structure

The remainder of this report is organized as follows:

Section 2: Paleoclimatic Evidence of the Last 10,000 Years

Estimated river flow data and salinity records for the past several thousand years have been obtained from paleoclimatic records, such as tree rings and sediment cores. These records capture the hydroclimatic variations over decadal and centennial time scales and are useful tools in understanding the freshwater flow and salinity regimes before modern instrumentation.

Section 3: Instrumental Observations of the Last 140 Years

Long-term precipitation and river runoff records from the 1870's to the present provide context for the salinity observations. Climatic variability of precipitation and runoff in the upper watershed has a significant influence on salinity intrusion, with greater salinity during dry periods and lower salinity during wet periods. If, for example, the salinity is greater or less than what would be expected based on the natural climatic variability, as measured by unimpaired runoff, other factors must be influencing salinity intrusion.

Reservoir operations, diversions and consumptive use (collectively termed "water management") alter the amount of runoff from the upper watershed that actually flows out of the Delta. Observations and common computer models are used to assess the effects of this water management on Net Delta Outflow (the net quantity of water flowing from the Delta to the Suisun Bay) and on salinity in the western Delta and Suisun Bay. Observations include measurements of salinity indicators by the California & Hawaiian Sugar Refining Corporation (C&H) from the early 1900's and long-term monitoring data from the Interagency Ecological Program (IEP). Modeling tools include the DAYFLOW program from IEP, the DSM2 model from the California Department of Water Resources, the X2[5]

[5] X2 is defined as the distance from the Golden Gate to the 2 part-per-thousand isohaline (equivalent to a salinity of 2 grams of salt per kilogram of water), measured along the axis of the San Francisco Estuary. X2 is often used as an indicator of freshwater availability and fish habitat conditions in the Delta (Jassby *et al.*, 1995; Monismith, 1998).

equation (Kimmerer and Monismith, 1992) and Contra Costa Water District's salinity outflow model (also referred to as the G-model) (Denton, 1993; Denton and Sullivan, 1993).

Section 4: Qualitative Observations of Historical Freshwater Flow and Salinity Conditions

Qualitative observations on salinity conditions in the western Delta and Suisun Bay from an early water rights lawsuit and from various literature reports are discussed to provide a perspective of the salinity conditions prevailing in the late 1800's and early 1900's. The 1920 lawsuit filed by the Town of Antioch against upstream irrigation districts alleged that the upstream water diversions were causing increased salinity intrusion at Antioch (Town of Antioch v. Williams Irrigation District, 1922). Briefings and testimony from the legal proceedings are indicative of the salinity conditions prevailing in the early 1900's, as are literature reports of conditions in the western Delta and Suisun Bay. These reports contain both qualitative observations and anecdotal information regarding historical salinity conditions. Because the proceedings were adversarial in nature, this report focuses on the testimony of the upstream interests, who were trying to demonstrate the extent of salinity intrusion in the Delta prior to their diverting water. Note that the Supreme Court did not base its final decision on the evidence of whether or not Antioch had continuous access to fresh water. The Court's decision was based on the State policy to irrigate as much land as possible for agriculture; the Court did not pass judgment on the accuracy of the testimony of either side.

Section 5: Conclusions

This section synthesizes the findings from Sections 2 through 4 and presents the overall conclusions regarding trends in the historical Delta salinity.

Paleocli atic Evidence of the ast , ears

Paleoclimatic evidence from the watershed of San Francisco Bay (Bay) and Sacramento-San Joaquin Delta (Delta), obtained from proxy information such as tree rings and sediment deposits, provides a history of conditions before modern direct instrumental observations. Evidence of major regional climatic events that represent long-term wet period and drought cycles will be discussed, followed by discussions of Delta watershed runoff and Delta salinity, as measured by flow and electrical conductivity instrumentation.

2.1. Major Regional Climatic Events

The modern Bay-Delta is relatively young in terms of geologic timescales. The estuary started forming around 8,000 to 10,000 years ago (Atwater *et al.* 1979), when rapid sea level rise allowed the ocean to enter the Golden Gate. At this time, there was no Bay or Delta, but simply river valleys. Rapid sea level rise continued, such that approximately 6,000 years ago, the outline of San Francisco Bay, including San Pablo Bay and Suisun Bay, resembled the modern extent. At about the same time, sea level rise slowed to a more moderate pace, allowing tidal marshes to begin to form.

Malamud-Roam *et al.* (2007) review paleoclimate studies in the Bay-Delta watershed, summarizing evidence of climate variability through the development of the present day Bay-Delta system (Table 2-1).

Table 2-1 – Climate during the evolution of the Bay-Delta estuary

Overview of precipitation, temperature, and sea level conditions during the last 10,000 years based on data from Malamud-Roam et al. (2007) and Meko et al. (2001). Time periods are given in terms of number of years ago (represented as age, a; or ka for 1,000 year ago) and the Common Era (BCE/CE) calendar system. The shading indicates relatively dry periods.

Approximate Time Period	*Prevailing Climate and Geomorphology*
10 ka to 8 ka 8000 BCE to 6000 BCE	▪ Rapid sea level rise ▪ Ocean enters Golden Gate ▪ San Francisco Bay is just a river valley ▪ Cooler than 20th Century, but becoming warmer and drier
6 ka to 5 ka 4000 BCE to 3000 BCE	▪ Sea level rise slows to more moderate pace ▪ Outline of San Francisco Bay resembles modern extent ▪ Tidal marsh begins to form in the Delta ▪ Temperature reaches a maximum of the last 10,000 years ▪ Relatively dry conditions ▪ Central Valley floodplain system began to develop

Approximate Time Period	*Prevailing Climate and Geomorphology*
4 ka to 2 ka 2000 BCE to 1 CE	▪ Cooling trend with increased precipitation ▪ Large flood occurred ~ 3,600 years ago (1600 BCE)

2 ka to 0.6 ka
1 CE to 1400 CE
	▪ Trend to more arid, dry conditions
	▪ Severe droughts:
	  ▪ 1,100 to 850 years ago (900 CE to 1150 CE)
	  ▪ 800 to 650 years ago (1200 CE to 1350 CE)

0.6 ka to 0.2 ka 1400 CE to 1800 CE	▪ Relatively cool and wet conditions ▪ Numerous episodes of extreme flooding ▪ Includes "Little Ice Age" (1400 CE to 1700 CE)

90 a to 50 a
1910 CE to 1950 CE
	▪ Dry period in the Sacramento River Basin.
	  ▪ Longest dry period in the last 420 years (34 years centered on the 1930's)
	  ▪ Driest 20-year period in the last 370 years (1917 CE to 1936 CE)

A number of scientific studies have used paleo-reconstruction techniques to obtain long-term (decadal, centennial and millennial time scale) records of river flow (e.g., Earle, 1993; Meko *et al.*, 2001) and salinity of the Bay and Delta (e.g., Ingram and DePaolo, 1993; Wells and Goman, 1995; Ingram *et al.*, 1996; May, 1999; Byrne *et al.*, 2001; Goman and Wells, 2000; Starratt, 2001; Malamud-Roam and Ingram, 2004; Malamud-Roam *et al.*, 2006; Malamud-Roam *et al.*, 2007; and Goman *et al.*, 2008). The reconstructions described in the following sections focus on the 2,000 years before present. As indicated in Table 2-1, this period was relatively dry with two extreme regional droughts, followed by relatively cool and wet conditions during the "Little Ice Age," then by a return of dry conditions at the early part of the 20th Century.

2.2. Reconstructed Unimpaired Sacramento River Flow

Meko *et al.* (2001a,b) used tree-ring chronologies in statistical regression models to reconstruct time series of annual unimpaired Sacramento River flow[6] for approximately the past 1,100 years (for the period 869 CE – 1977 CE). As discussed in Section 1.2, unimpaired flow is an estimate of the flow that would occur in the basin without the effects of water management activities.

The 1,100-year record shows strong variability between individual water years (Figure 2-1), with annual flow ranging from approximately 8% of average to 265% of average, where average is defined here for practical purposes as the average observed unimpaired flow from

[6] Meko *et al.* (2001a) used the annual unimpaired flow record for the Sacramento River provided by the Department of Water Resources, which is the sum of the following: flow of the Sacramento River at Bend Bridge, inflow of the Feather River to Lake Oroville, flow of the Yuba River at Smartville, and the flow of the American River to Folsom Lake. This definition is consistent with the definition typically used in hydro-climatic studies of this region (e.g., http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST)

1906 to 2009 of 18 million acre-feet per year (MAF/yr). The reconstructed record shows alternating periods of wet and dry conditions and is consistent with historical droughts (such as the drought in the Mono Lake region of California in the medieval period, around 1150 CE) reported by other paleoclimate studies (Malamud-Roam *et al.*, 2006).

As indicated by the shading in Figure 2-1, the driest long-term drought in the Sacramento River basin in the last 1,100 years occurred from approximately 1130 CE to 1415 CE when the 50-year average flow was seldom above normal for nearly 300 years. Following this drought, conditions were relatively wet (from approximately 1550 CE to 1900 CE). The timing of these droughts and wet periods will be compared to paleosalinity records in the following section.

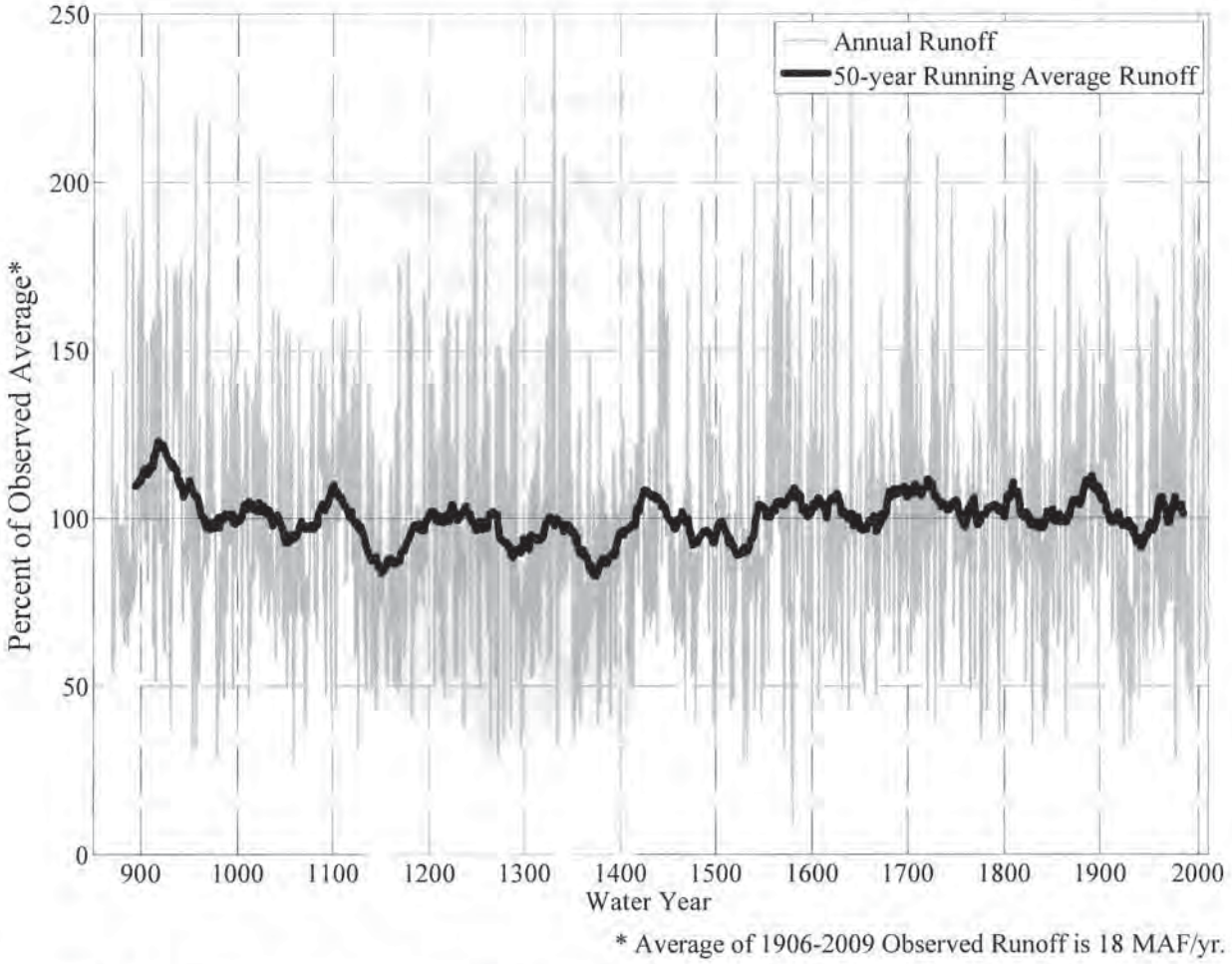


Figure 2-1 – Reconstructed annual unimpaired Sacramento River flow 869 CE to 2009 CE

Annual reconstructed unimpaired Sacramento River flow (grey line) as a percentage of the average annual observed runoff from 1906 to 2009 shows strong variability between years. The 50-year running average (thick black line) illustrates there were extended periods of above-normal and below-normal runoff conditions. The orange shading highlights an extended dry period in the reconstructed unimpaired Sacramento River data when the 50-year average flow is seldom above normal for nearly 300 years. Data for 869 CE to 1905 CE were reconstructed by Meko et al. (2001b); data for 1906 CE to 2009 CE are observed records from the California DWR (2009).

Meko *et al.* (2001a) indicated that for their 1,100-year reconstructed period, the 1630-1977 data are more reliable than the earlier time period, because of better availability of tree-ring information and superior regression model statistics. Figure 2-2 shows the reconstructed time series of annual unimpaired Sacramento River flow from 1630 to 1977 from Meko *et al.* (2001b). The inset in Figure 2-2 shows there is a good match between the reconstructed flows (grey line) and the observed annual flows (red line) during the period of overlap between the reconstructed and observed records (from 1906 to 1977).

Multi-decadal periods of alternating wet and dry conditions are pervasive throughout the reconstructed record. The wet conditions of the late 1800's and early 1900's, which were followed by severe dry conditions in the 1920's and 1930's, are consistent both with observed precipitation and estimated Sacramento River runoff for these time periods (see Section 3) and with literature reports of historical conditions (see Section 4).

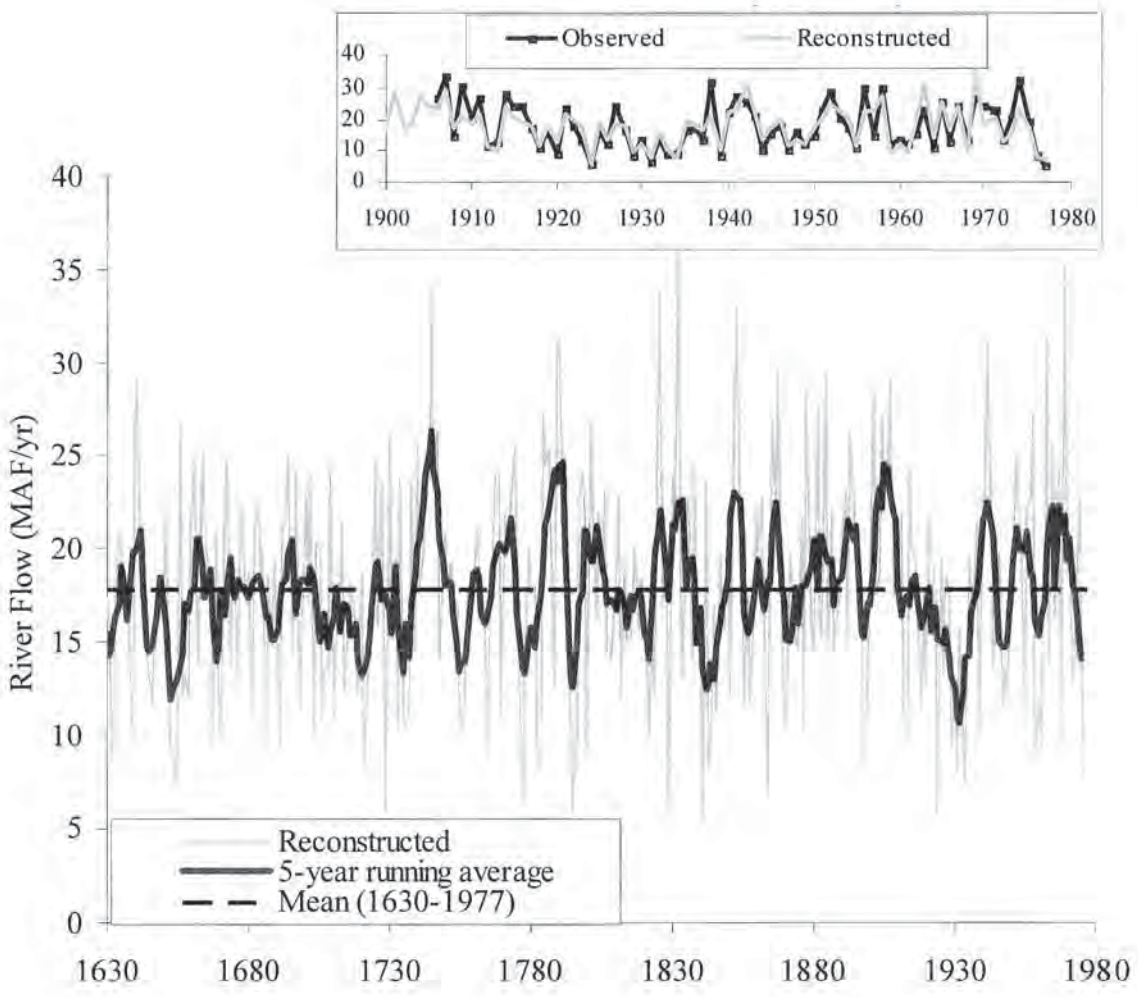


Figure 2-2 – Reconstructed annual unimpaired Sacramento River flow from 1630-1977.

Annual reconstructed unimpaired Sacramento River flow (grey line in main panel and inset) for the 1630 to 1977 time period was identified by Meko et al. (2001a) as the most accurate period of reconstruction. Inset panel illustrates the comparison between observed (red) and reconstructed (grey) unimpaired flows during the overlap period. The mean of the reconstructed unimpaired flow for 1630-1977 is 17.7 MAF/yr (dashed horizontal line in main panel). The 5-year centered running average (thick solid blue line in main panel) illustrates the decadal trends.

Meko *et al.* (2001a) identified the severe drought periods in the reconstructed Sacramento River flow record (1630-1977) by computing the lowest *n*-year moving average. For instance, to determine the most severe 6-year drought, Meko *et al.* calculated the moving average using a 6-year window for the entire data set and then identified the lowest 6-year average. Meko *et al.* found that the period from the early 1920's to late 1930's experienced the lowest 6-year, 10-year, 20-year, and 50-year averages (or droughts), both in the reconstructed and observed records. The observed droughts in Table 2-2 have been updated through present (1906-2009) using the same analysis; this update did not change the drought time periods identified by Meko *et al.* The reconstructed record of unimpaired Sacramento River flow shows the period from early 1920's to late 1930's experienced some of the worst drought conditions since 1630. Additional data are presented in Appendix B.

Table 2-2 – Periods of drought from the reconstructed and observed records of unimpaired Sacramento River flow

Severe drought periods in the reconstructed Sacramento River flow record (1630-1977) were determined by Meko et al. (2001a) by computing the lowest n-year moving average of the reconstructed annual unimpaired Sacramento River flow. The same method was used to determine the most severe droughts of the observed record (1906-2009).

	Period of lowest *n*-Year moving average Sacramento River flow					
	1-Year	3-Year	6-Year	10-Year	20-Year	50-Year
Reconstruction (1630-1977)	1924	1775 to 1778	1929 to 1934	1924 to 1933	1917 to 1936	1912 to 1961
Observations (1906-2009)	1977	1990 to 1992	1929 to 1934	1924 to 1933	1918 to 1937	1917 to 1966

Conclusions

Reconstruction of unimpaired Sacramento River flow indicates:

- Annual precipitation is highly variable. Even during long dry periods, individual years can be very wet.
- The Sacramento River basin experienced a multi-century dry period from about 1100 C.E. to 1400 C.E.
- The drought period in the 1920's and 1930's represents some of the worst drought conditions in the last 400 years.

2.3. Reconstructed Salinity in the Bay-Delta Estuary

Tree Ring Data

The interaction between saline ocean water from the Pacific Ocean and fresh water from the rivers flowing into the Delta determines the ambient salinity conditions in the Delta and the Bay. Estimates of historical precipitation derived from tree ring data can therefore be used to estimate the corresponding salinity conditions in the Delta.

Stahle *et al.* (2001) used tree ring chronologies from blue oak trees located in the drainage basin to San Francisco Bay to reconstruct salinity at the mouth of San Francisco Bay. Recognizing that a number of factors influence salinity other than precipitation (estimated from tree rings), the authors chose a time period prior to substantial water development when the salinity data were fairly constant in mean and variance. During the calibration period (1922-1952), annual tree ring growth correlates well with average salinity near the Golden Gate Bridge (r^2=0.81). Using this transfer function, Stahle *et al.* (2001) reconstructed annual average January to July salinity for all years 1604 to 1997.

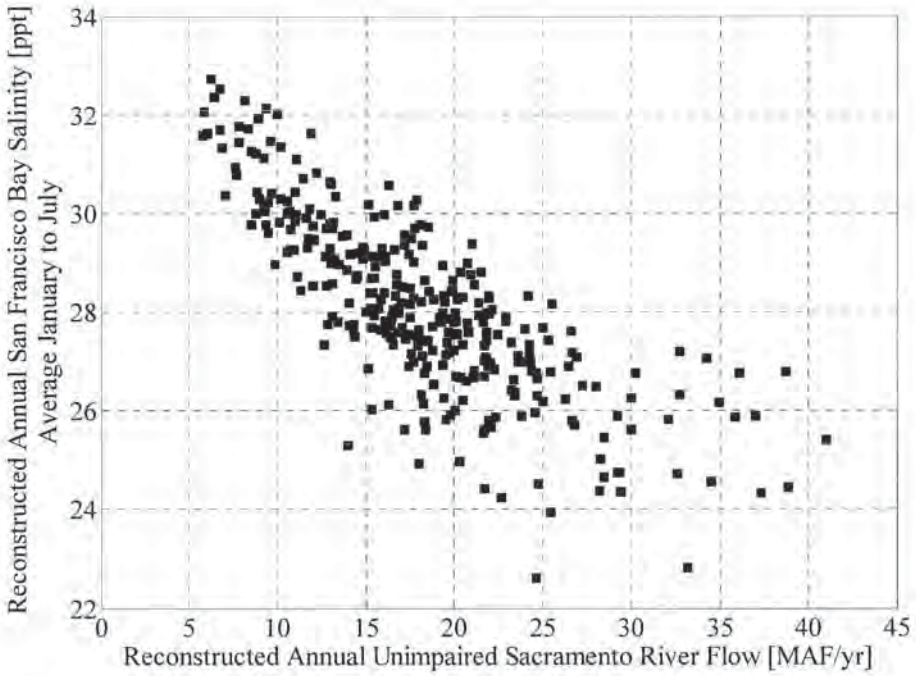


Figure 2-3 – Reconstructed salinity near the mouth of San Francisco Bay compares well with reconstructed unimpaired Sacramento River flow in the upper watershed
For each year from 1630 to 1952, the annual unimpaired Sacramento River flow (from Meko et al., 2001b) is plotted against the annual average salinity at Fort Point (from Stahle et al., 2001).

As shown in Figure 2-3, the salinity reconstruction by Stahle *et al.* (2001) compares well with the unimpaired flow reconstruction by Meko *et al.* (2001b). The data follow the expected inverse exponential relationship between flow and salinity. Over the period from

1630 to 1952, reconstructed salinity increases as reconstructed unimpaired Sacramento River flow decreases. The agreement is strongest in dry years. The increased scatter in wet years may reflect the limitations in the tree ring methods.

Stahle *et al.* (2001) identified an increasing divergence of observed salinity relative to predicted (reconstructed) salinity after 1952 (Figure 2-4) and suggested that the majority of differences are due to increased water diversions. During the calibration period (1922-1952), the observed salinity is typically within +/- 5% of the reconstructed salinity. However, from 1953-1994, the data show an increasing trend for observed salinity to be greater than predicted, exceeding reconstructed salinity by over 15% in 1978, 1979, 1991, and 1993. Since 1969, observed salinity has exceeded reconstructed salinity in all years except the extremely wet years of 1982 and 1983.

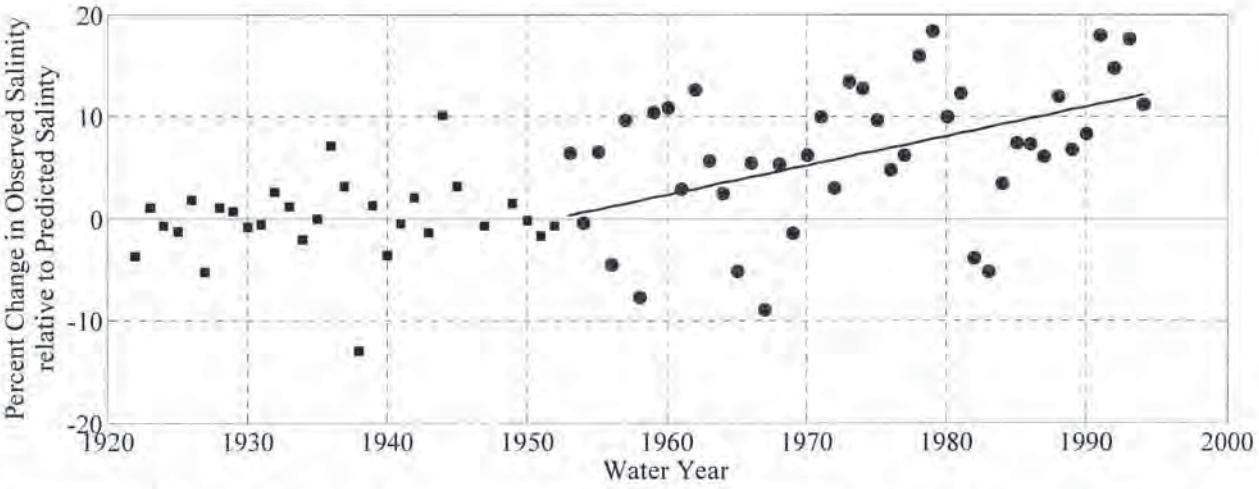


Figure 2-4 – Percent change in observed salinity relative to predicted (reconstructed) salinity for the period 1922 to 1994

The reconstructed salinity record by Stahle et al. (2001) overlaps with the observed salinity record from 1922 to 1994. During this period, the percent change of observed salinity relative to predicted salinity is determined as (observed salinity – reconstructed salinity) divided by reconstructed salinity, with positive values indicating when observed salinity exceeded the reconstructed salinity prediction. The calibration period is indicated with black squares, with the period outside the calibration window indicated by red circles. The straight red line is the linear trend in the post-calibration period, indicating observed salinity is increasingly diverging from predicted (reconstructed) salinity.

These data suggest that since the 1950's, water management operations have increased salinity, with an escalating effect over the period of record. In addition, it is worth noting that significant anthropogenic modifications to the landscape and water usage had already occurred prior to the 1922-1953 calibration period (see Figure 1-2 and Figure 1-3). Although this study is unable to evaluate the effect of anthropogenic modifications prior to 1953, the following section examines salinity prior to human interference at multiple sites in the Bay-Delta.

Tree ring reconstructions such as Meko *et al.* (2001a) and Stahle *et al.* (2001) have the advantage of providing high temporal resolution (i.e. annual) over approximately the last 1,000 years. However, a possible disadvantage of this method is the age of trees, limiting

high accuracy estimates to approximately the last 400 years. A second possible disadvantage of using tree ring reconstructions for paleosalinity is the remote location of the trees relative to the estuary. Paleosalinity estimates from tree rings in the upper basin necessarily assume that the precipitation patterns archived in the tree rings are representative of the quantity of water that reaches the estuary. However, as observed by Stahle *et al.*, anthropogenic water management affects the amount of water that flows through the estuary.

Sediment Core and Fossil Data

Because of uncertainties in estimates of precipitation and salinity derived from tree ring data, other paleosalinity methods that rely on local fossils to determine local salinity have also been explored. Organic deposits accumulated in the sediments contain signatures of the ambient conditions that can be used to infer the variations in salinity over geologic time scales. Although reconstructions from sediment cores have a coarser temporal resolution than tree rings, the variations in climate and landscape responses to change are better defined geographically because the evidence of localized climate change is preserved as a time series *in situ*, at the site of interest.

The San Francisco Bay-Delta has been the focus of several paleoclimatic reconstructions from sediment cores. Changes in wetland plant and algae communities are the dominant response in the Bay and Delta to climate change and associated fluctuations in temperature and precipitation. Proxies of plant and algae response to environmental conditions are preserved in the sediment cores and determined by:

- quantification and taxonomic identification of
  - (i) diatom frustules (Byrne *et al.*, 2001; Starratt, 2001; Starratt, 2004),
  - (ii) plant seeds and roots (Goman *et al.*, 2008),
  - (iii) plant pollen (May, 1999; Byrne *et al.*, 2001; Malamud-Roam and Ingram, 2004), and,
- measurement of peat carbon isotope ratios (Byrne *et al.*, 2001; Malamud-Roam and Ingram, 2004).

Results from plant pollen identification for three sites in the western Delta and Suisun Bay and Marsh are summarized below in Figure 2-5. The data indicate that Browns Island tidal marsh, near the confluence of the Sacramento and San Joaquin Rivers in the western Delta (Figure 2-5) was predominately a freshwater system for 2,500 years, even during century-long droughts. This condition prevailed until the early 1900's. The shading in Figure 2-5 corresponds to the nearly 300-year dry period identified in the reconstructions of annual unimpaired Sacramento River flow (Figure 2-1). Although salinity intrusion occurred during this period in Suisun Bay at Roe Island, and during earlier long drought periods, salinity did not affect the western Delta to the same degree. This suggests a change in spatial salinity gradient characteristics, and is possibly due to the effect on salinity intrusion of the vast tidal marshes that existed in the Delta until the early 20th Century.

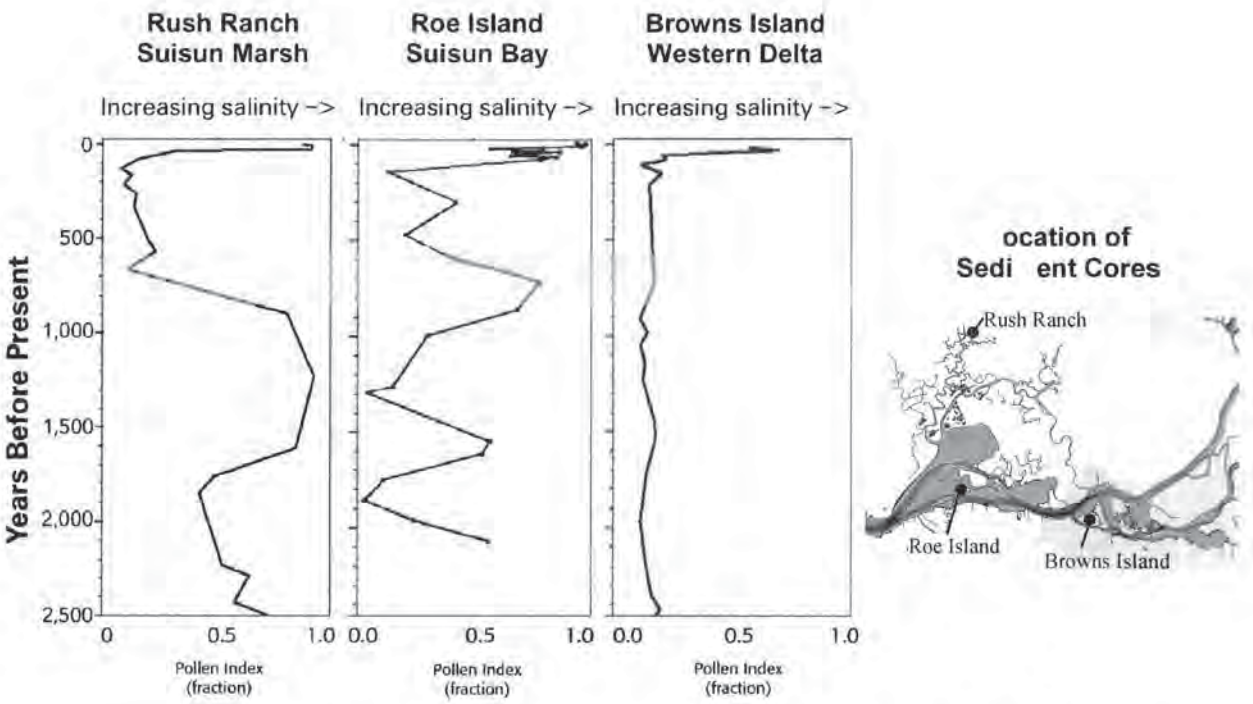


Figure 2-5 – Paleosalinity evidence derived from pollen data

Salinity variability over the last 2,500 years at Rush Ranch in Suisun Marsh (left panel), Roe Island in Suisun Bay (center panel), and Browns Island in the Western Delta (right panel). Data are reproduced from Malamud-Roam and Ingram (2004). Orange shading across each panel corresponds to the nearly 300-year dry period identified in the annual unimpaired Sacramento River flow reconstruction (see Section 2.2) Locations of each of the sediment cores are illustrated in the map on the right.

Malamud-Roam *et al.* (2006) attributed the differences between sites to a combination of methodological issues (such as sampling frequency and core chronology) and site-specific ecological differences (such as site elevation, location relative to channel and sedimentation rates over time). However, all of the paleosalinity reconstructions based on pollen, diatoms and carbon isotopes are in general agreement and suggest that salinity increased abruptly about 100 years ago, reaching or exceeding salinity levels at any other time in the 2,500 years of reconstructed records.

This increase in salinity may correspond to the reduction in unimpaired Sacramento River flow evidenced in the tree ring reconstructions by Meko *et al.* (2001a), which determined that the 1920's and 1930's experienced the worst droughts in the last 400 years. However, the droughts in the 1920's and 1930's do not appear to be as severe as the droughts between 1100 CE to 1400 CE (600 to 900 years ago), as categorized by unimpaired Sacramento River flow. Yet salinity in Suisun Bay and the western Delta appears to meet or exceed the level of the medieval droughts, indicating factors besides natural precipitation and runoff patterns have affected salinity in the last 100 years.

Conclusions

Reconstructions of salinity in the Bay and Delta indicate:

- Precipitation in the drainage basin for San Francisco Bay (as recorded in tree rings) is a good indicator of salinity near the mouth of the Bay for the period 1922-1953; however, since 1953, increased water diversions have increased observed salinity above the level predicted from precipitation estimates.
- The Delta was a predominately freshwater system for 2,500 years, until the early 1900's, even during century-long droughts.
- The multi-century dry period identified in unimpaired Sacramento River flow reconstruction is evident in Suisun Bay sediments but not in Delta sediments, indicating that salinity did not intrude as far into the Delta during past droughts as it has during the last 100 years.
- The evidence from most sites suggests that current salinity levels are as saline as, or more saline than, previous historical conditions.

nstru ental Observations of the ast ears

Field measurements of rain and snow have far greater accuracy and resolution than the paleoclimate records of precipitation; similarly, field measurements of salinity have far greater accuracy and resolution than the paleosalinity records from sediment cores. These instrumental observations will be used to analyze in more detail the salinity increase identified in the paleoclimate records approximately 100 years ago and determine if the increase in salinity has persisted.

The first sub-section presents observations of precipitation and unimpaired runoff in the upper basin, indicating the natural climatic variability and amount of fresh water available within the Bay-Delta watershed. The second sub-section examines Net Delta Outflow (NDO), which is the amount of water flowing through the Delta into Suisun Bay, directly affecting the level of salinity intrusion into the Delta. NDO is analyzed under both unimpaired (without water diversions and reservoir storage and releases) and historical (actual) conditions; comparison between unimpaired and actual conditions reveals the effect of water management practices. The third sub-section presents field measurements and model-based estimates of salinity at various locations within the Delta and Suisun Bay.

3.1. Precipitation and Unimpaired Flow in the Upper Basin

Precipitation in the Bay-Delta watershed indicates the amount of water available within the system, which could ultimately reach the Bay and affect salinity conditions. However, since precipitation falls as both rain and snow, the timing of runoff to the river channels is often lagged a few months due to snow melt conditions. For this reason, estimates of unimpaired flow (runoff) are generally used to characterize hydrological variability. Unimpaired runoff represents the natural water production of a river basin, unaltered by water diversions, reservoir storage and operation, and export of water to or import of water from other basins.

Figure 3-1 illustrates the total annual precipitation at Quincy[7] in the northeastern Sierra, the total annual unimpaired Sacramento River flow[8] and total unimpaired San Joaquin River flow[9]. Figure 3-2 shows the locations of the eight precipitation stations in northern California used to compute the Sacramento eight-station precipitation index (left panel) and the measurement locations of eight flow gages used to calculate the Sacramento and San Joaquin unimpaired flow data (right panel). Additional information on the annual unimpaired flows is provided in Appendix C.

As discussed in Section 2.2, the total annual unimpaired Sacramento River flow exhibits strong variability between years, both in the reconstructed and observed data. Figure 3-1

[7] Precipitation data are from Menne *et al.* (2009)

[8] "Unimpaired Sacramento River flow" is defined as the sum of the "full natural flows" from the Sacramento River at Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, and the American River inflow to Folsom Lake. (http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST)

[9] "Unimpaired San Joaquin River flow" is defined as the sum of the full natural flows from the Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River inflow to Millerton Lake (http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST)

indicates that the trends revealed in the total annual unimpaired Sacramento River flow (middle panel) are also evident in the total annual precipitation at Quincy (top panel) and the total annual unimpaired San Joaquin River flow (bottom panel). Alternating periods of wet and dry conditions are evident in both river basins. These data indicate there were wetter than normal conditions in the late 1800's and early 1900's, followed by severe dry conditions in the 1920's and 1930's. These were then followed by generally wetter conditions until the mid-1970's.

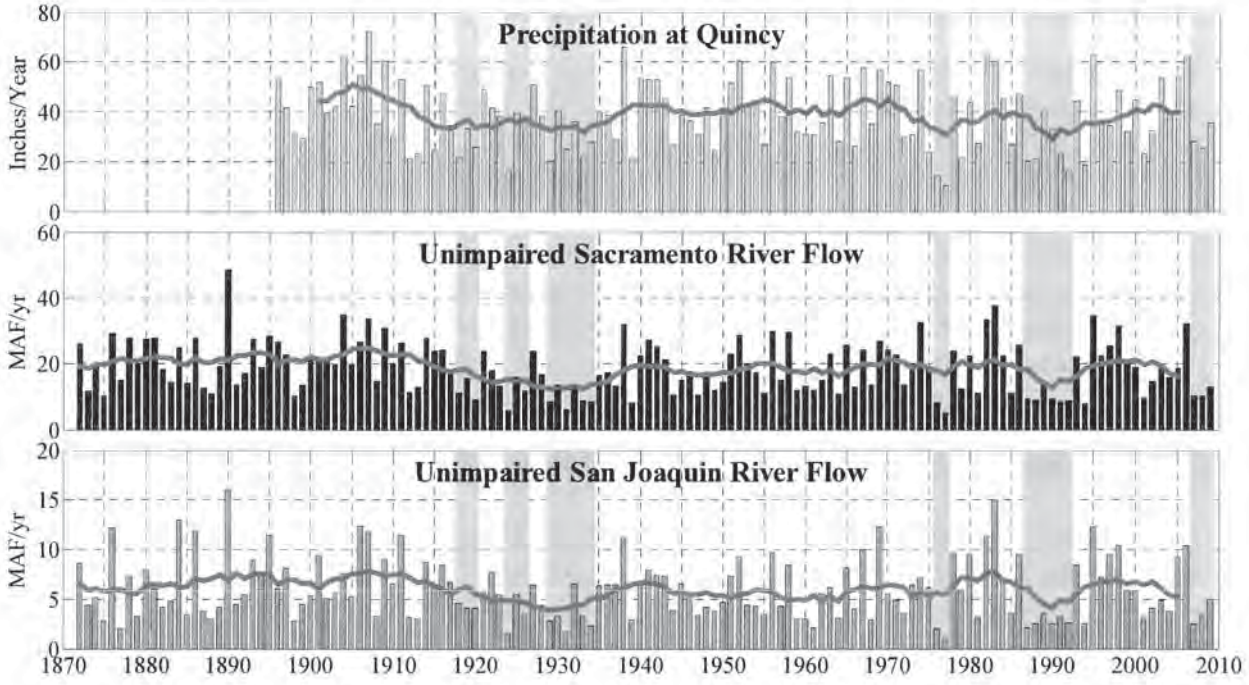


Figure 3-1 – Total annual precipitation and unimpaired flow in the upper Sacramento and San Joaquin River basins (1872-2009)

Total annual precipitation at Quincy in the northeastern Sierra (top panel), total annual unimpaired Sacramento River flow (middle panel), and total annual unimpaired San Joaquin River flow (bottom panel). Bar color on each panel indicates the regional location of the measurements, reflected in the remaining figures of this section (Figure 3-2, Figure 3-3 , and Figure 3-4). Grey line within each panel is the 10-year moving average for each parameter.

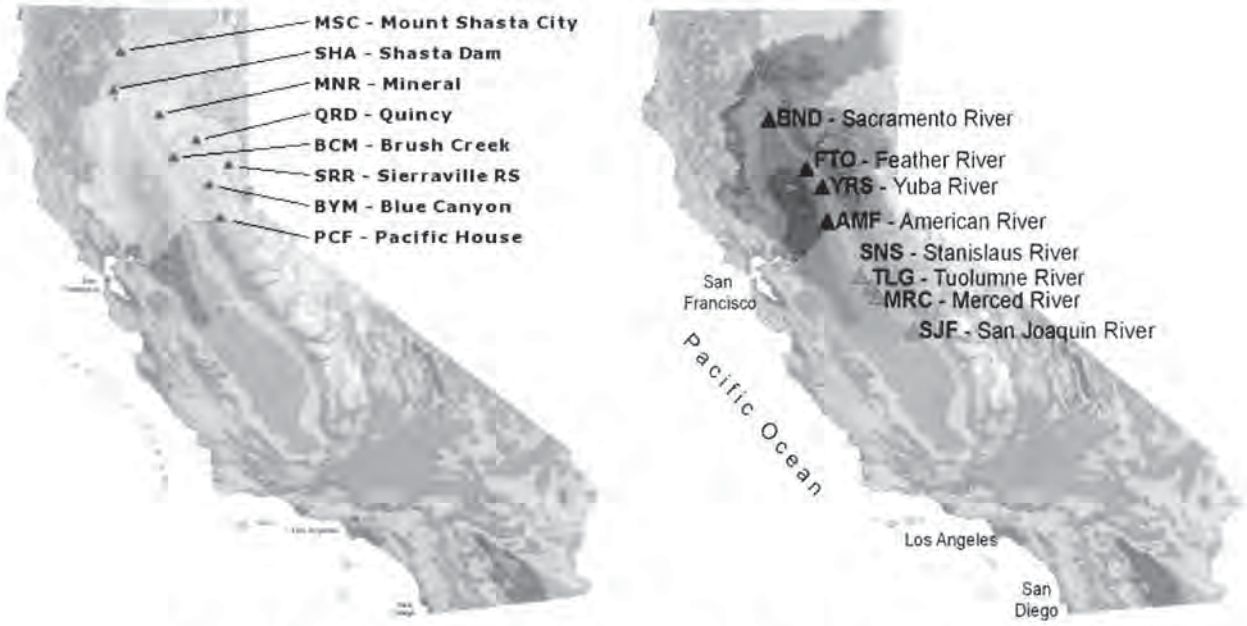


Figure 3-2 – Locations of Precipitation and Runoff Measurements

Location of stations used in the determination of the 8-station precipitation index for northern California (left map), including the location of Quincy (QRD), and the unimpaired Sacramento River flow (red stations, right map) and unimpaired San Joaquin River flow (orange stations, right map).

Knowles (2000) illustrated that the seasonal timing of runoff can significantly alter salinity intrusion without any change to the total annual runoff. For this reason, it is critical to examine the monthly variability in precipitation and unimpaired runoff. Monthly precipitation and unimpaired flow values are available for a shorter time period (generally 1921 to present) than the total annual values (generally 1870's to present).

The monthly distribution of the Sacramento eight-station precipitation index[10] indicates that most of the precipitation in northern California occurs during November through March (Figure 3-3). The variability between years, represented by the vertical bars and '+' marks, shows the distribution is positively skewed, i.e., excessively high precipitation occurs in relatively few years.

Figure 3-4 presents the monthly distribution of unimpaired flow for both the Sacramento and San Joaquin River basins. River flow lags precipitation by about two months because of storage of some precipitation in the form of snow and subsequent snowmelt in the spring. Most of the unimpaired inflow to the Delta originates from the Sacramento Basin, although the contributions from the two basins are approximately the same during the months of late-spring and early-summer snow melt, when unimpaired runoff from the San Joaquin Basin peaks.

[10] Data from 1921 through 2008, downloaded from http://cdec.water.ca.gov/cgi-progs/precip1/8STATIONHIST

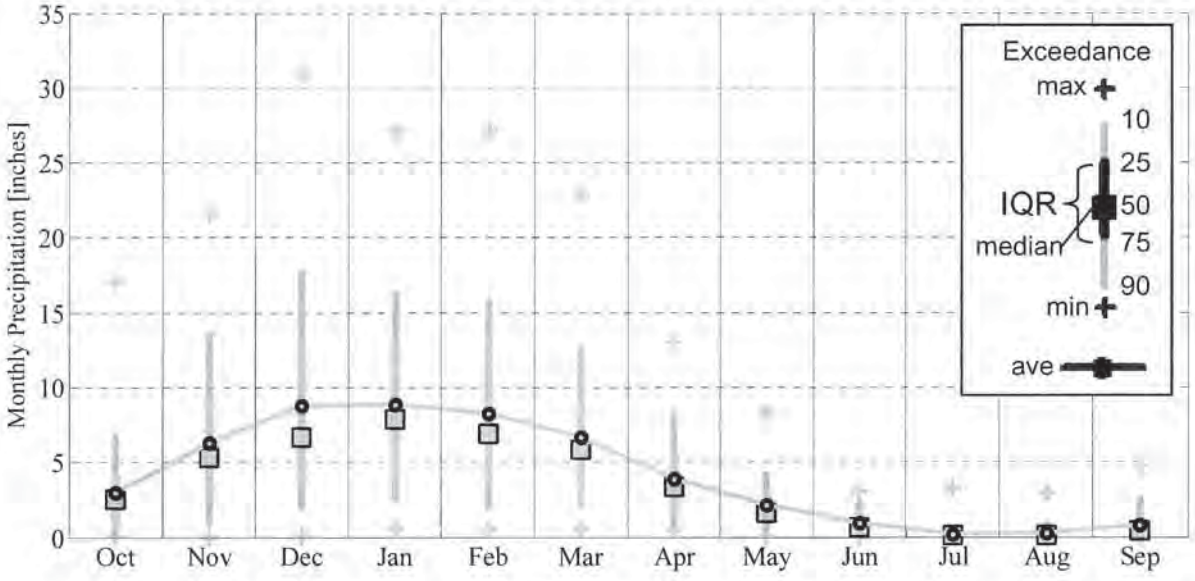


Figure 3-3 – Monthly Distribution of Precipitation in the Sacramento River Basin

Distribution of monthly precipitation for water years 1921 through 2008. Monthly averages are indicated by the blue line with black circles. Monthly median is given by the blue squares, while the interquartile range is indicated by the vertical blue line for each month and the vertical grey line extends to the 10th and 90th percentiles. Maximum and minimum values are indicated by '+' marks.

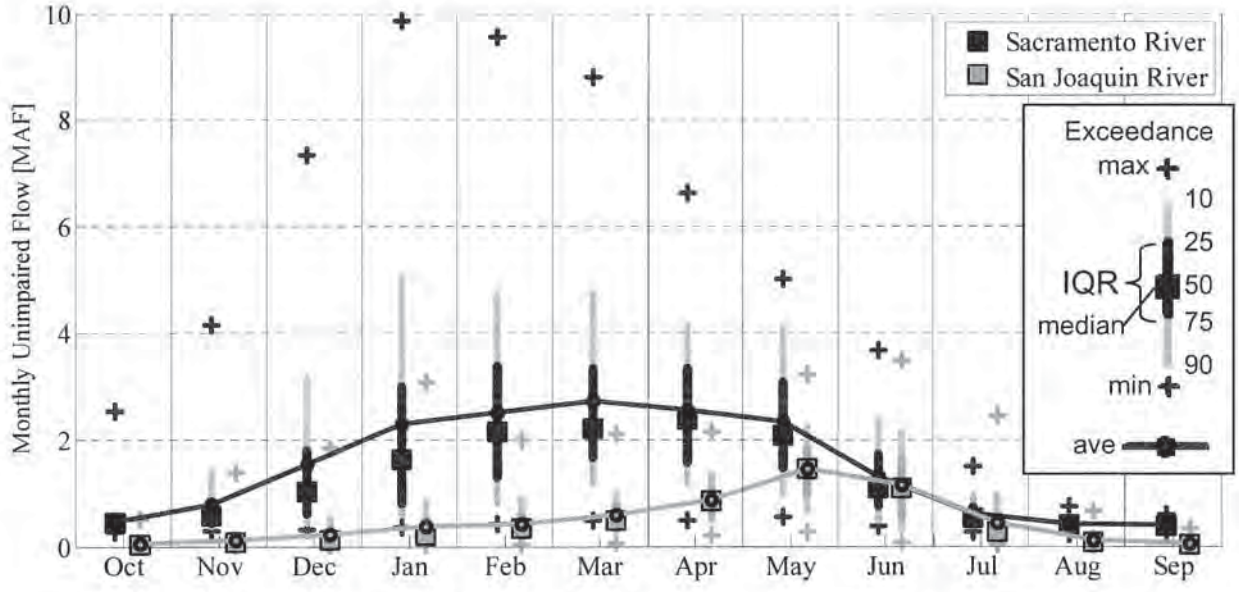


Figure 3-4 – Monthly distribution of unimpaired flow in the Sacramento and San Joaquin River basins

Distribution of monthly unimpaired flows for water years 1921 through 2008. Monthly averages are indicated by the lines with black circles. Monthly median is given by the squares, while the interquartile range is indicated by the vertical line for each month and the vertical grey line extends to the 10th and 90th percentiles. Maximum and minimum values are indicated by '+' marks.

Conclusions

The long-term observations of precipitation and unimpaired flow indicate:

- Relatively wet conditions occurred in the late 1880's to about 1917 in both the Sacramento and San Joaquin River watersheds prior to large-scale water management operations.
- Unusually dry conditions occurred from about 1918 through the late 1930's; these persistent dry conditions are not representative of the average conditions over the last 130 years.
- Precipitation in Sacramento River watershed peaks between December and March; the unimpaired river flow lags by about 1 to 2 months because of snow melt.

3.2. Net Delta Outflow

The quantity of water flowing from the Delta into Suisun Bay, defined as Net Delta Outflow (NDO), is the primary factor in determining salinity intrusion in Suisun Bay and the western Delta. Unimpaired NDO is calculated using unimpaired flow in the Sacramento and San Joaquin Rivers (Section 3.1) as well as contributions from other minor tributaries.[11] Unimpaired NDO is the hypothetical Delta outflow that would occur in the absence of any upstream diversion or storage, but with the existing Delta channel and upstream channel configuration.

Because the outflow from the Delta at the wide and deep entrance to Suisun Bay cannot be measured accurately, the parameter of historical (actual) NDO is estimated from a daily mass balance of the measured river inflows to the Delta, measurements of water diversions at major pumping plants in the Delta, and estimates of net within-Delta consumptive use (including Delta precipitation and evaporation).

The effect of anthropogenic water management on NDO is illustrated below by comparing monthly estimates of unimpaired NDO[12] and historical (actual) NDO[13] (Figure 3-5). Since unimpaired flow estimates also assume the existing Central Valley and Delta landscape (reclaimed islands, no natural upstream flood storage, current channel configuration, etc.), this comparison reveals the net effect of water management only. This analysis does not address the change due to physical modification to the landscape or sea level rise.

For the period of joint record, when both unimpaired and historical NDO values are available (water year 1930 through 2003), historical NDO decreased even though unimpaired NDO increased slightly. The long-term (74-year) linear trend in monthly unimpaired NDO (the black dashed line in top panel of Figure 3-5) increased on average 0.49 MAF/month; thus, by 2003, the average annual unimpaired NDO had increased 5.9 MAF/year since 1930. In contrast, the long-term linear trend in monthly historical NDO (the black dashed line in middle panel of Figure 3-5) decreased on average -0.29 MAF/month, totaling a decrease in historical (actual) NDO of -3.5 MAF/year. This corresponds to a net increase in diversion of 9.4 MAF/year of water from the Delta upstream watershed relative to the 1930 level[14].

Increased diversion and export of water have decreased historical NDO (middle panel of Figure 3-5), but this has been partially offset by a natural increase in unimpaired NDO (top panel). The difference between historical and unimpaired NDO (bottom panel) is due to the cumulative effects of upstream diversions, reservoir operations, in-Delta diversions, and

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[11] Unimpaired NDO does not include water imported from the Trinity River system, which is outside the Delta watershed.

[12] Unimpaired NDO data was obtained from Ejeta (2009), which is an updated version of DWR (1987).

[13] Historical NDO data was obtained from the IEP's DAYFLOW program (http://www.iep.ca.gov/dayflow/index.html).

[14] This is consistent with current estimates of approximately 15 MAF/year total diversion from the system, which includes the 4-5 MAF/year diversions established prior to 1930 and approximately 1 MAF/year additional water supply imported from the Trinity River system.

south-of-Delta exports. During most months, water management practices have historically resulted in historical (actual) NDO that is less than unimpaired conditions, indicated by a negative value for the quantity (historical NDO – unimpaired NDO).

Because the difference between monthly historical and unimpaired NDO has become more negative over time, the periods of excess conditions (when historical NDO exceeds unimpaired NDO) have become very infrequent. The only occurrences are now following the wettest years, primarily due to releases from reservoirs in the fall to make room for winter flood control storage.

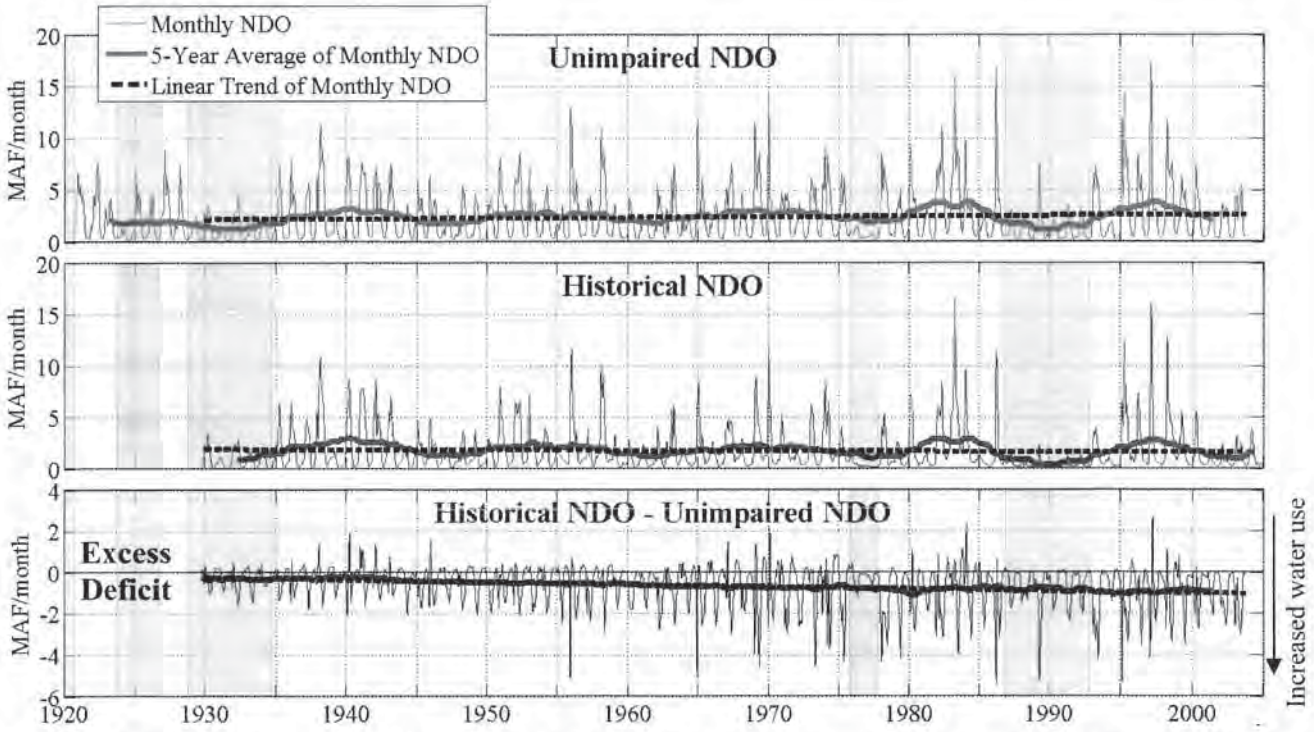


Figure 3-5 – Time series of Monthly Net Delta Outflow under unimpaired conditions and historical (actual) conditions

The thin color line on each panel indicates the monthly NDO, the thick color line indicates a running 5-year average of the monthly NDO, and the dashed black line indicates the linear long-term trend.

The monthly distribution (Figure 3-6) of unimpaired NDO and historical NDO for water years 1930 to 2003 reveals that for all months except September and October (when NDO is low), average unimpaired NDO is greater than average monthly historical NDO. The tendency in the average historical NDO toward greater flow in September and October is influenced strongly by the period prior to about 1975 when reservoir operations resulted in more flow in those months (see Figure 3-7 and related discussion below). On average from 1930-2003, water management practices reduced Delta outflows in the months of November through August (and in all months since about 1975, see Figure 3-7). The greatest reduction in Delta outflow relative to unimpaired conditions occurs in the months of March through June, when spring snow melt is captured in reservoirs and a portion of the river flow is diverted for direct use.

As also shown in Figure 3-6, water management practices also shift the peak flow periods to earlier in the year. The unimpaired NDO hydrograph peaks in May when snow melt contributes to high river flows, with at least 4.1 MAF in May in 50% of the years (averaging 4.2 MAF in May over all years). The historical NDO peaks in February with at least 2.9 MAF/month in 50% of the years (averaging 3.7 MAF/month over all years). The variability between years, represented by the vertical bars and '+' marks, indicates the distribution is positively skewed, which means a relatively few years have excessively high flows.

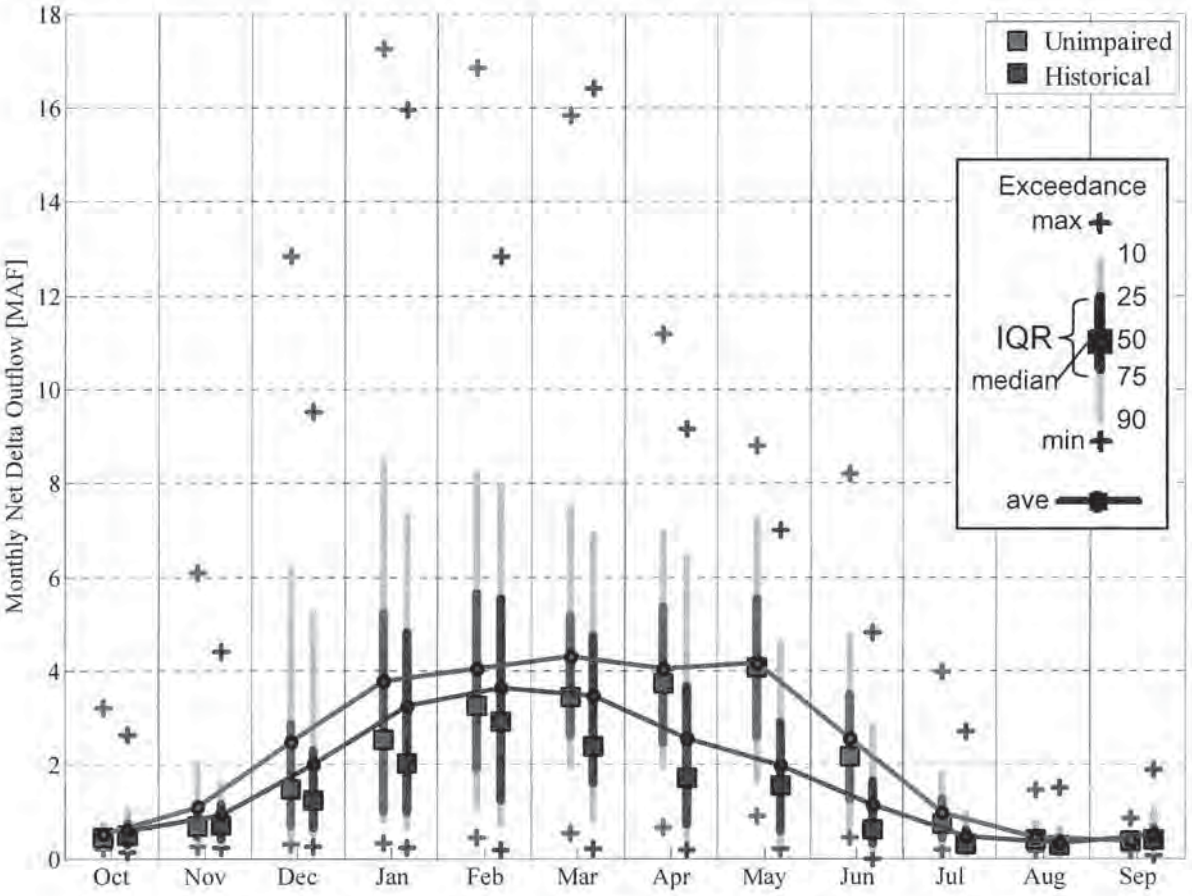


Figure 3-6 – Monthly distribution of Net Delta Outflow

Distribution of monthly NDO for water years 1930 through 2008. Monthly averages are indicated by the lines with black circles. Monthly median is given by the squares, while the interquartile range is indicated by the vertical line for each month and the vertical grey line extends to the 10th and 90th percentiles. Maximum and minimum values are indicated by '+' marks.

Figure 3-7 shows the long-term trends in the difference between historical (actual) monthly NDO and unimpaired monthly NDO. Increased water usage and increased diversion of water to storage has reduced historical NDO relative to unimpaired NDO in most months of the year. In July (and August, not shown in Figure 3-7), the deficit is reduced, likely due to reservoir releases which provide a portion of the water diverted by upstream users prior to reservoir construction. The 1994 Bay-Delta Accord called for higher minimum Delta outflows in July and August to protect Delta fish species, which should also serve to reduce the deficit. However, historical (actual) NDO still remains less than unimpaired NDO.

In September (and October, not shown in Figure 3-7), historical (actual) NDO exceeded unimpaired NDO from about 1945 to 1975, with an increasing trend in the percent change. Since 1975, the percent change has shown a downward trend with a deficit (historical NDO less than unimpaired NDO) during most years since 1975.

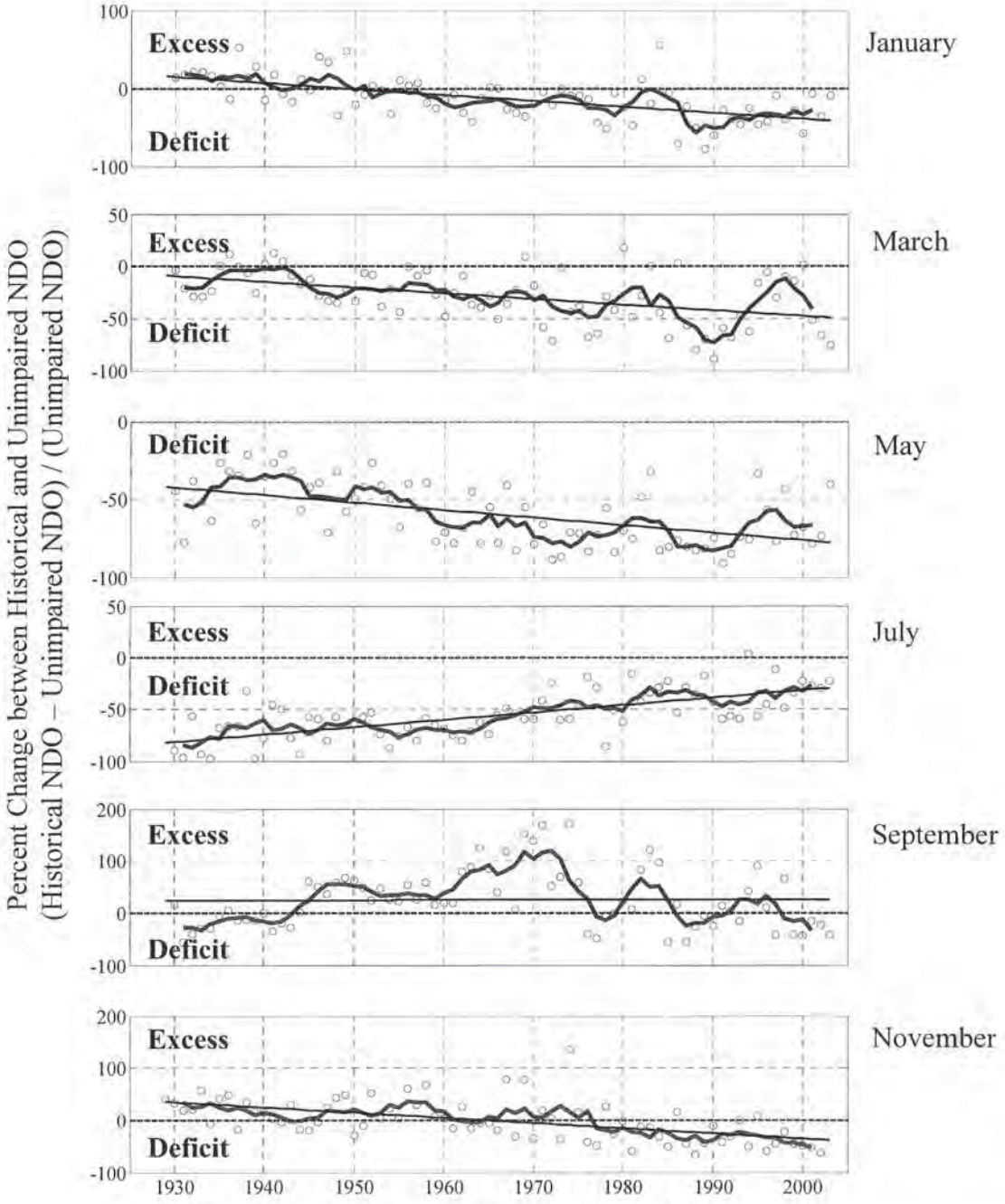


Figure 3-7 – Long-term trends in monthly NDO

Percent change of NDO relative to unimpaired conditions. Circles indicate the percent change for each month of the period of record. The red line indicates a moving 5-year average of the percent change, while the black line indicates the long-term linear trend over the entire period of record.

Conclusions

Anthropogenic water management practices have altered NDO in the following ways:

- Long-term data demonstrate that the difference between historical (actual) NDO and unimpaired NDO is increasing over time, indicating that water management actions have reduced Delta outflow significantly.
- During most months, water management practices have reduced Delta outflow relative to unimpaired conditions. From the mid-1940's to the mid-1980's, reservoir operations resulted in historical (actual) NDO slightly greater than unimpaired NDO slightly in a number of months, largely in the fall. However, since 1985, reservoir operations have resulted in increased NDO only in the wettest years, and NDO has declined in all other months.
- On average, water management practices have resulted in reduced Delta outflows in all months except September and October. The greatest reduction in Delta outflow relative to unimpaired conditions occurs in the months of March through June, when spring snow melt is captured in reservoirs and some of the remaining river flows are diverted for direct use.

3.3. Salinity in the Western Delta and Suisun Bay

Observations and model-based estimates can be used to examine historical variations in salinity in the western Delta and Suisun Bay. The observations examined in this section include records from the early 1900's from the California & Hawaiian Sugar Refining Corporation in Crockett (C&H) and long-term monitoring data published online by the Interagency Ecological Program (IEP). Estimates of salinity intrusion were obtained using the Kimmerer-Monismith equation describing X2 (Kimmerer and Monismith, 1992).

Section 3.3.1 addresses the importance of consistency among salinity comparisons. The spatial variability of a specific salinity level is examined in Section 3.3.2 and Section 3.3.3, while the temporal variability of salinity at specific fixed locations is explored in Section 3.3.4 and Section 3.3.5.

3.3.1. Importance of Consistency among Salinity Comparisons

Water salinity in this report is specified either as electrical conductivity (EC) or as a concentration of chloride in water. EC is a measure of the ability of an aqueous solution to carry an electric current and is expressed in units of microSiemens per centimeter (μS/cm)[15]. Chloride concentration is specified in units of milligrams of chloride per liter of water (mg/L). Conversion between EC and chloride concentration can be accomplished using site-specific empirical relationships such as those developed by Kamyar Guivetchi (DWR, 1986).

Previous studies have evaluated the level of salinity in the Bay and Delta, using a variety of salinity units (e.g. EC, chloride concentration, or concentration of total dissolved solids in water) and various salinity parameters (e.g. annual maximum location 1,000 μS/cm EC, monthly average location of 50 mg/L chloride, or daily average EC at a specific location). Therefore, when comparing studies, it is critical to use consistent salinity units, parameters, and timing, including the phase of tide and time of year. These concepts are discussed further in Appendix D.

3.3.2. Distance to Fresh Water from Crockett

The California & Hawaiian Sugar Refining Corporation (C&H) is located in Crockett, near the western boundary of Suisun Bay (see Figure 3-8). C&H either obtained its freshwater supply in Crockett, or, when fresh water was not available at Crockett, from barges that traveled upstream on the Sacramento and San Joaquin Rivers. The barges generally travelled upstream twice a day beginning in 1908 (DPW, 1931). C&H recorded both the distance traveled by its barges to reach fresh water and the quality of the water they obtained. This provides the most detailed quantitative salinity record available prior to the initiation of salinity monitoring by the State of California in 1920. The distance traveled by the C&H barges serves as a surrogate for the prevailing salinity conditions in the western Delta and

[15] The reported EC values are actually specific conductance, i.e., the electrical conductivity of the water solution at a reference temperature of 25° centigrade, as is standard practice.

Suisun Bay. Operations by C&H required water with less than 50 mg/L chloride concentration.[16] Additional detail on C&H operations and the detailed barge travel data are included in Appendix D.



Figure 3-8 – Map of Suisun Bay and Western Delta with locations of continuous monitoring stations

C&H barges traveled up estuary from Crockett (yellow star). Locations of IEP continuous monitoring stations are shown in red. Scale in miles is indicated in the upper left corner of the map.

[16] In comparison, the 50 mg/L concentration required for C&H operations is one-third the concentration of the industrial water quality standard under current conditions in the Delta.

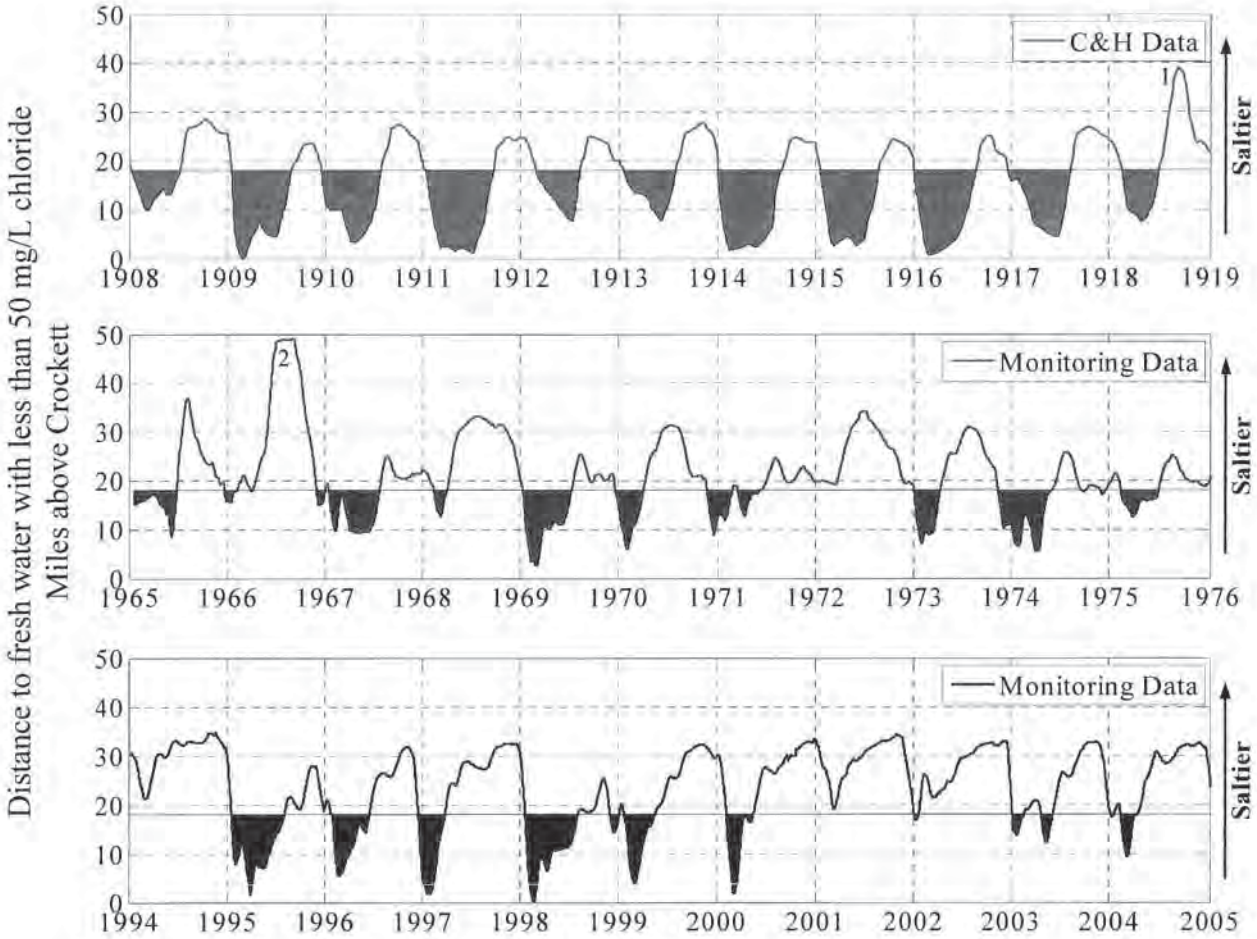


Figure 3-9 – Distance to fresh water from Crockett

"Distance to fresh water" is defined as the distance in miles upstream of Crockett to water with less than 50 mg/L chloride concentration. The horizontal line, at approximately 18 miles, is the distance from Crockett to the Delta. The shading represents the spatial extent and duration of the presence of fresh water within Suisun Bay, downstream of the Delta.

Data notes: (1) During August and September 1918, average water quality obtained by C&H exceeded 110 mg/L chlorides; (2) Salinity during 1966 is likely an overestimate due to relatively sparse spatial coverage of IEP monitoring stations. During 1966, salinity at Emmaton (28 miles from Crockett) exceeded 3,000 µS/cm; the nearest station upstream of Emmaton is near Courtland (58 miles from Crockett) and had a salinity of ~ 300 µS/cm. Location of 350 µS/cm isohaline based on data interpolation between these two stations (which are 30 miles apart) is not likely to be representative of the true location.

Figure 3-9 compares surface[17] salinity data from C&H with estimates derived from a network of continuous surface salinity monitoring stations (Figure 3-8) within Suisun Bay and the western Delta dating back to 1964. The monitoring data are published online by the Interagency Ecological Program (IEP, see http://iep.water.ca.gov/dss). The location of the 350 µS/cm EC isohaline, which approximately coincides with the C&H criterion of 50 mg/L chloride concentration, was estimated from the IEP measurements by linear interpolation between the average daily values at IEP monitoring stations.

[17] Due to the method of collection, C&H water samples are assumed to be from near the water surface.

As a cautionary note, depending on the source of information, the C&H barges are said to have traveled with the tide, indicating they either took water at high tide (moving up river on the flood and down on the ebb) or at low tide (traveling against the tide, but moving a shorter distance). Thus, the C&H records either represent the daily maximum or daily minimum distance traveled. In contrast, the distances to fresh water calculated from recent monitoring data are based on the average daily values of EC measured at fixed locations. The difference between daily average distance and daily minimum or maximum is approximately 2 to 3 miles. However, since the difference between the data from the early 1900's and the more recent time periods exceed this 2 to 3 mile uncertainty, the conclusions of this section remain unchanged regardless of the specific barge travel timing.

From 1908 through 1918, C&H was able to collect fresh water for a large portion of the year within Suisun Bay, without having to travel all the way from Crockett to the Delta. However, as can be seen in Figure 3-9, that would no longer be possible in many years (e.g., 2001-2004).

Figure 3-10 shows the monthly distribution of distance traveled by C&H barges during water years 1908 through 1917, and the equivalent distance from determined from observed data for water years 1966 through 1975 (top panel) and water years 1995 through 2004 (bottom panel). These two latter periods have similar hydrologic characteristics to the period of the C&H data.[18] The monthly distribution for each dataset illustrates the seasonal fluctuations of the salt field as well as the variability between years for each month.

During the early 1900's, the median distance traveled by C&H barges to procure fresh water was less than 8 miles in the spring (March-June) and about 25 miles (between Collinsville and Emmaton) in the fall (September-October). In contrast, due to water management conditions from 1995 to 2005, the equivalent distances would be 13 to 23 miles in the spring and up to 30 miles in the fall. It is worth noting that from 1966 to 1977, the distance to fresh water in the fall and early winter months (September through January) was generally less than the equivalent distance in the early 1900's, indicating that large-scale water management operations circa 1970 tended to reduce salinity in the fall and early winter. However, this trend has reversed in the more recent water management period (1995-2005), with salinity intrusion significantly increased over levels in the early 1900's during all months.

Figure 3-10 also shows that the range of the average annual distance from Crockett to fresh water from 1995 to 2005 was approximately 15 miles (from about 13 to 30 miles), while the range during the early 1900's was approximately 20 miles (from 6 to 25 miles). This analysis indicates that large-scale water management activities limit the fluctuating nature of the salt field by preventing fresh water from reaching as far downstream as it did in the early 1900's.

Finally, Figure 3-10 indicates that salinity intrusion in the Delta occurred later in the year (beginning in July) in the early 1900's than under more recent time period conditions (beginning in March).

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[18] This similarity in hydrological characteristics between the periods was established by approximately matching the distribution of annual Sacramento River flow during these periods (see Appendix E).

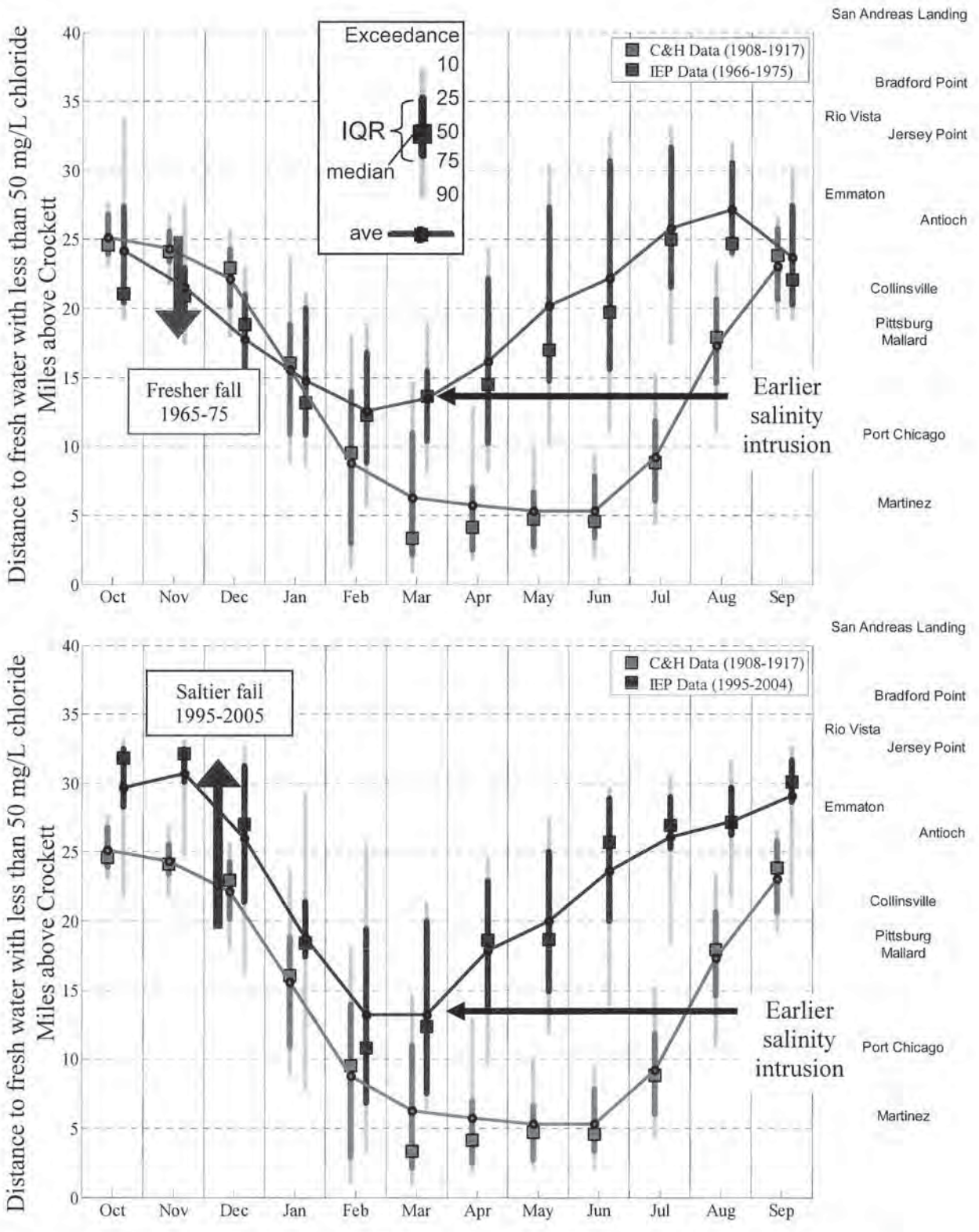


Figure 3-10 – Monthly distribution of distance to fresh water from Crockett

These comparisons (and other relevant comparisons in Appendix D) show that, on average, C&H barges would have had to travel up to 19 miles farther to procure fresh water under recent large-scale water management conditions than in the early 1900's. These comparisons also indicate that fresh water was present for significantly longer time periods, and over a larger area of the western Delta, in the early 1900's than during similar hydrological periods under current water management conditions. Abrupt changes in salinity just prior to 1920 caused C&H to abandon the Sacramento and San Joaquin Rivers and switch to a water supply contract with Marin County beginning in 1920 (Appendix D).

The distance to fresh water during individual wet years and during individual dry years is presented in Appendix D. The data in Appendix D also show that salinity has been generally higher in recent times than in the early 1900's and that water management has restricted the range in salinity experienced during a water year. The periods when fresh water is present at given locations have been reduced, or, in some cases, eliminated.

Conclusions

The records of the distance traveled upstream from Crockett by C&H barges to procure fresh water and estimates of this distance under large-scale water management conditions (reservoir operations and water diversions) show that:

- Fresh water was present farther downstream and persisted for longer periods of time in the western Delta in the early 1900's than under recent time periods with similar hydrologic conditions;
- Water management practices result in greater salinity intrusion in the western Delta for most months of the year; and,
- Salinity intrusion begins earlier in the year, extends farther upstream, and persists for a longer period each year.

3.3.3. X2 Variability

An often-used indicator of fresh water availability and fish habitat conditions in the Delta is a metric called X2. X2 is defined as the distance from the Golden Gate to the 2 part-per-thousand isohaline (equivalent to a salinity of 2 grams of salt per kilogram of water), measured near the channel bed along the axis of the San Francisco Estuary. Higher values of X2 indicate greater salinity intrusion. Monthly values of X2 are estimated in this report using the monthly regression equation from Kimmerer and Monismith (1992):

Monthly $X2(t) = 122.2 + 0.3278*X2(t-1) - 17.65*\log_{10}(NDO(t))$

The K-M equation expresses X2 (in units of kilometers) in terms of Net Delta Outflow (NDO, see Section 3.2) during the current month and the X2 value from the previous month. The monthly K-M equation was based on a statistical regression of X2 values (interpolated from EC measurements at fixed locations) and estimates of NDO from IEP's DAYFLOW computer program. Hence, the K-M equation is only valid for the existing Delta channel configuration and existing sea level conditions.

The K-M equation can be used to transform unimpaired and historical NDO data into the corresponding X2 values for unimpaired (without reservoir operations or water diversions) and historical (with historical water management) conditions, respectively.

The seasonal and annual variations of X2 are dependent on the corresponding variations of NDO under both historical and unimpaired flow conditions (Figure 3-11). X2 under historical flow conditions is shifted landward relative to unimpaired conditions by approximately 5 km. During the 1930's, historical NDO was often negative, sometimes averaging approximately -3,000 cfs for several months. This was due to relatively low runoff and significant upstream water diversions. Unfortunately, the K-M equation, which includes the logarithm (base 10) of NDO, is unable to account for negative values of NDO. In the case of historical flow conditions, this results in high variability of X2 in the 1930's. The values of X2 under historical flow conditions during 1930's in Figure 3-11 are likely underestimated.

Figure 3-12 compares X2 under unimpaired and historical conditions for the period from 1945-2003, following initiation of the Central Valley Project (i.e., after the completion of the Shasta Reservoir of the CVP). Figure 3-12 shows that, compared to unimpaired conditions, X2 under historical conditions was higher by about 10 km during April-July and by about 5 km during the rest of the year.

Salinity intrusion under historical water management conditions is, therefore, greater (higher X2) than the intrusion that would occur under unimpaired conditions. Moreover, the switch from declining X2 values during fall and winter months to increasing X2 values (increasing salinity intrusion) occurs in March under historical water management conditions and in June under unimpaired conditions. Thus, recent water management practices have resulted in a saltier Delta with earlier occurrence of salinity intrusion in the year.

Although current water management practices operate to provide salinity control, both the extent and duration of salinity intrusion are greater under current water management practices than under historical conditions. Likewise, current water management practices have changed the overall annual range in salinity (i.e., the difference between the highest and lowest salinity values during the year).

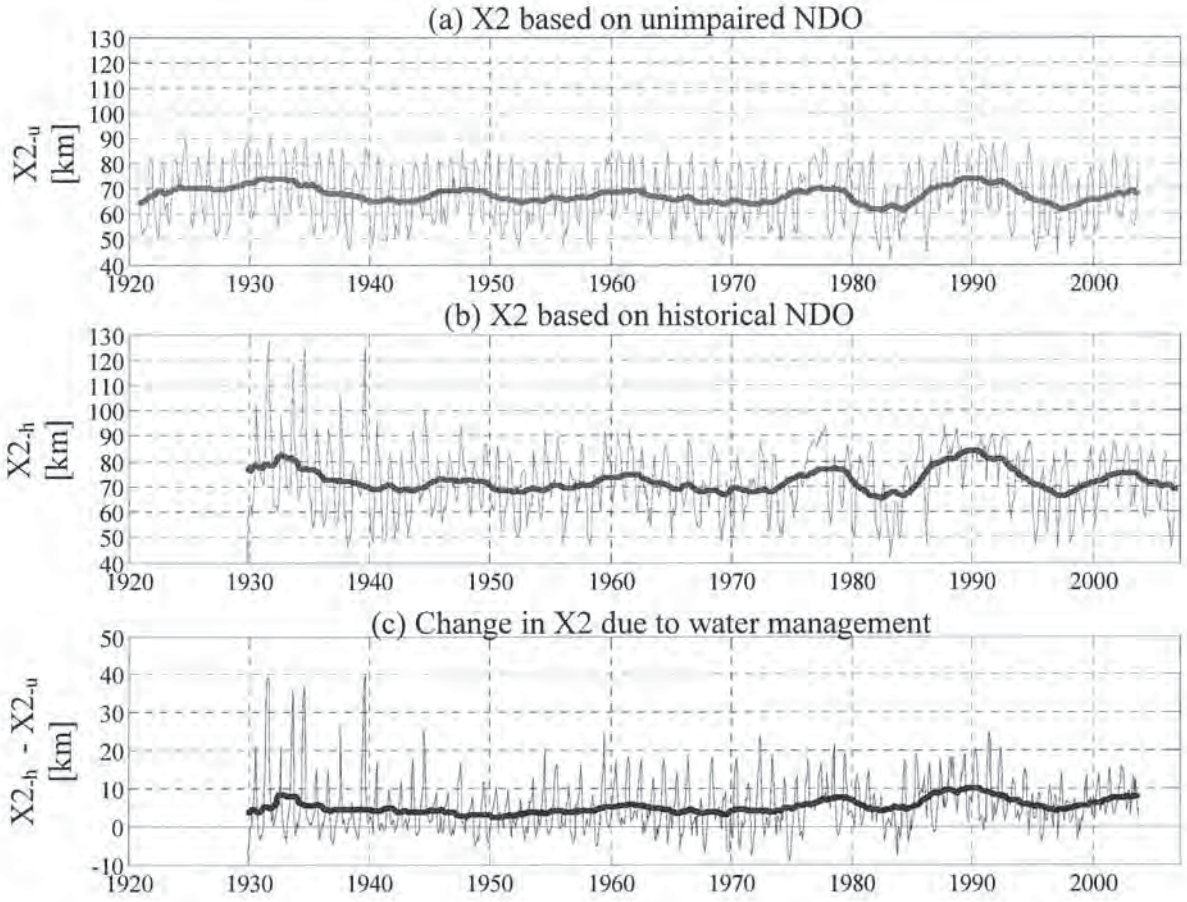


Figure 3-11 – Location of X2 under unimpaired and historical conditions

X2 has a strong seasonal and decadal variability under both unimpaired (top panel) and historical (middle panel) flow conditions reflecting the strong seasonal and decadal variability of NDO. The difference between historical and unimpaired conditions (bottom panel) illustrates the net effect of water management activities.

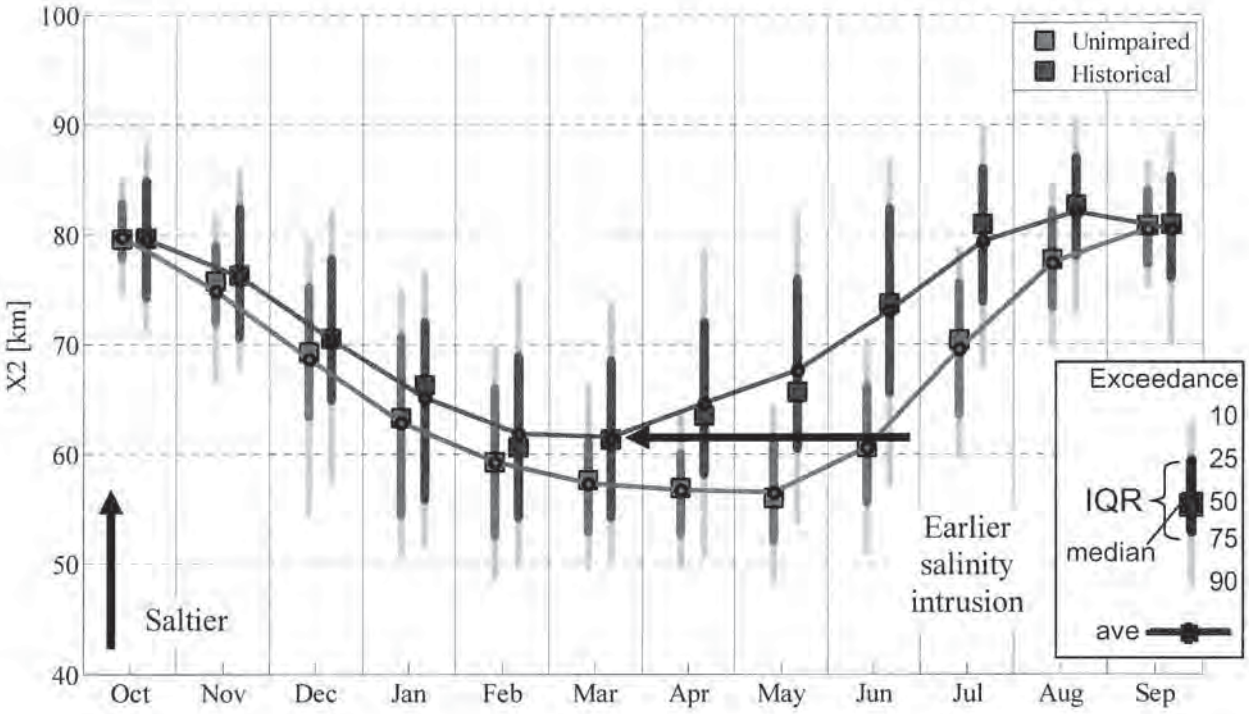


Figure 3-12 – Monthly distribution of X2 from 1945 through 2003

Figure 3-13 presents a comparison of unimpaired X2 and historical X2 during the 10 driest and the 10 wettest years of the CVP period (1945-2006).[19] During dry years (top panel), X2 is substantially greater under historical water management conditions than under unimpaired conditions (i.e., without water management); these effects are less dramatic but still occur during the wet years (bottom panel). Additionally, the annual range in salinity variability is significantly reduced under dry conditions (from approximately 22 km with unimpaired flows to 14 km with historical flows), but not wet conditions. The result of water management practices is a saltier Delta during both wet and dry years, with the greatest amount of salinity intrusion and reduced seasonal variability occurring in dry years.

Conclusions

The analysis of X2 (a measure of salinity intrusion in the Delta) shows that:

- Water management practices (reservoir operations and water diversions) result in a saltier Delta, with earlier salinity intrusion in the year.
- Water management practices result in a saltier Delta during both wet and dry years, but the effect is more pronounced in the dry years when the seasonal variability of salinity is also significantly reduced.

[19] Determination of the ten wettest and driest years is based on the total annual unimpaired Net Delta Outflow. The ten wettest years are 1952, 1956, 1958, 1969, 1974, 1982, 1983, 1986, 1995, and 1998. The ten driest years are 1947, 1976, 1977, 1987, 1988, 1990, 1991, 1992, 1994, and 2001.

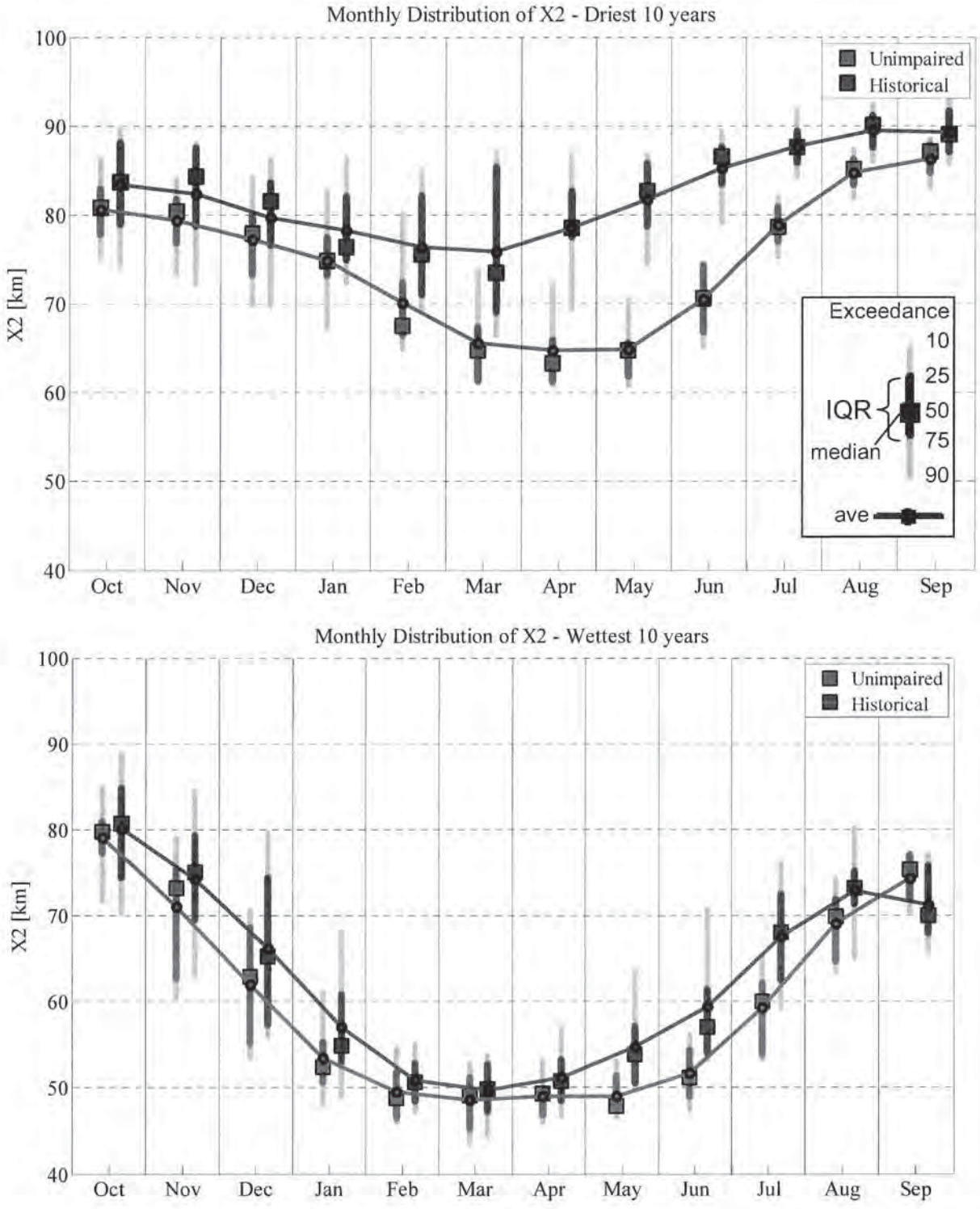


Figure 3-13 – Monthly X2 variability during wet and dry years (1945-2003)

Determination of the ten wettest and driest years is based on the total annual unimpaired Net Delta Outflow. The ten wettest years are 1952, 1956, 1958, 1969, 1974, 1982, 1983, 1986, 1995, and 1998. The ten driest years are 1947, 1976, 1977, 1987, 1988, 1990, 1991, 1992, 1994, and 2001.

3.3.4. Salinity at Collinsville

Collinsville, near the confluence of the Sacramento and San Joaquin Rivers, was one of the first long-term sampling locations implemented by the State of California. The Suisun Marsh Branch[20] of the DWR estimated monthly average salinity at Collinsville for the period 1920-2002, using a combination of 4-day TDS (total dissolved solids) grab samples from 1920-1971 and EC measurements from 1966-2002. Data from the overlap period of 5 years between the TDS grab samples and EC measurements were used in a statistical regression model, and the monthly averaged 4-day TDS samples were converted to monthly average EC (Enright, 2004). The result of this regression analysis was a time series of monthly EC values at Collinsville for the period of 1920-2002.

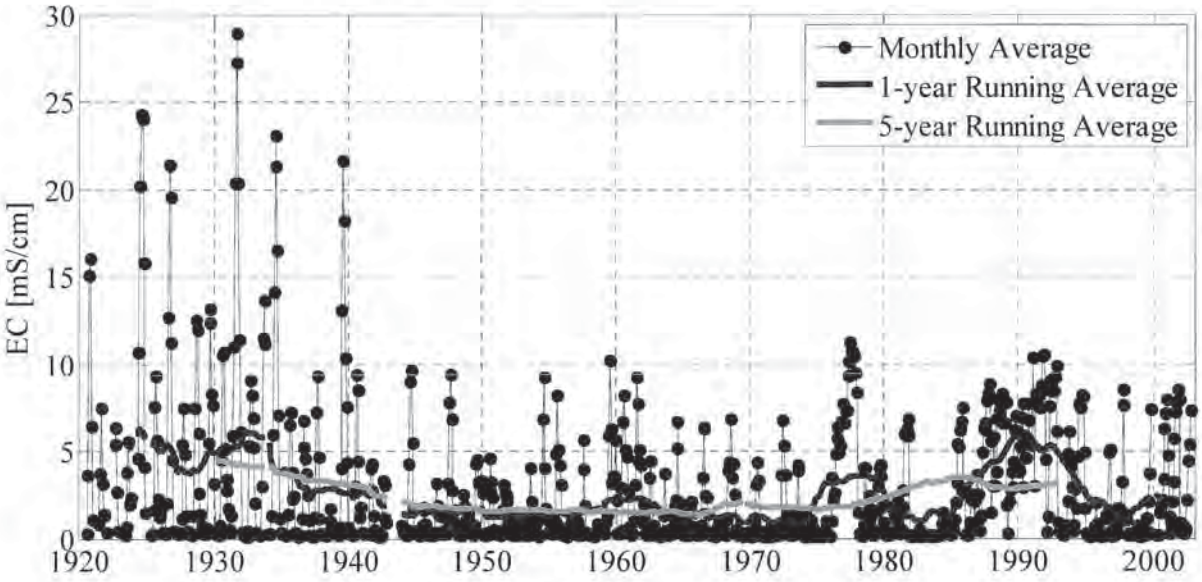


Figure 3-14 – Observed salinity at Collinsville

Monthly average salinity at Collinsville (black dots and black line), with the 12-month running average (red line) and 5-year running average (blue line).

Figure 3-14 shows the monthly average salinity at Collinsville for the period of 1920-2002, and Figure 3-15 shows the long-term trends in monthly salinity at Collinsville. Although the maximum values of salinity in the 1920's and 1930's far exceed subsequent salinity measurements at Collinsville, during the winters and springs of the 1920's and 1930's, the water at Collinsville freshened considerably. During the dry periods of 1920's and 1930's, monthly average salinity was below 350 µS/cm EC (approximately 50 mg/L chloride) for at least one month in every year. The one exception is 1924 which is inconclusive because no data were available from November through March. Monthly average EC data are missing for a portion of the winters and springs prior to 1926, and data for 1943 are missing entirely.

[20] Data provided by Chris Enright (DWR), personal communication, 2007.

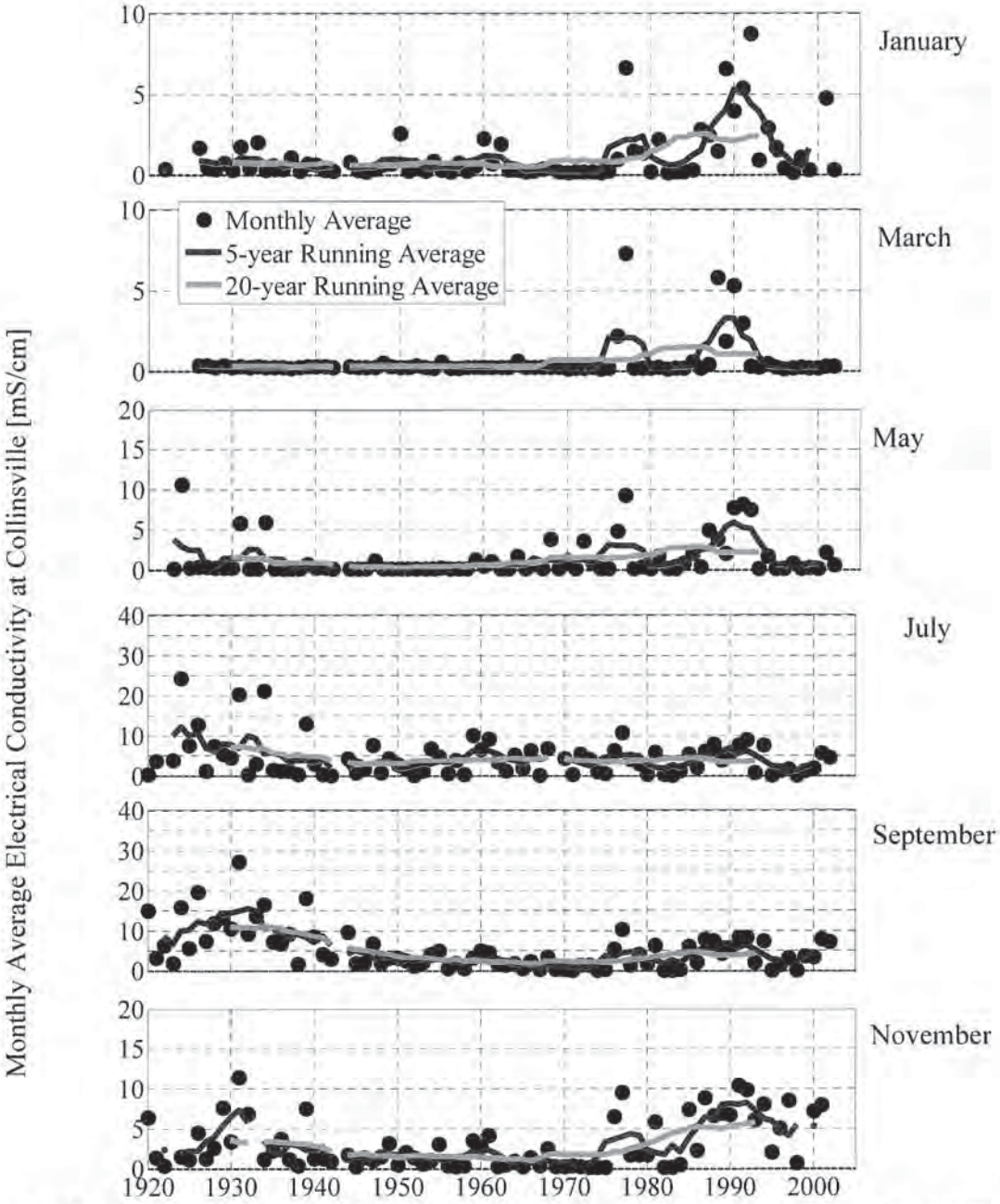


Figure 3-15 – Year-to-year trends in monthly-average salinity at Collinsville, 1920-2002

Monthly average salinity at Collinsville (black dots), with the 12-month running average (red line) and 5-year running average (blue line) for individual months.

Relatively fresh winters and springs during the 1920's are consistent with observations by C&H during that time period. However, monthly EC at Collinsville during the recent droughts (1976-1977 and 1987-1993) was always greater than 350 µS/cm EC, except for one month in both 1989 and 1992. These monthly observations of EC at Collinsville indicate that during the recent dry periods (1976-1977 and 1987-1993), EC at Collinsville was higher than that during similar dry periods in the 1920's and 1930's.

Enright and Culberson (2009) analyzed the trend in salinity variability at Collinsville from 1920-2006. They found increasing salinity variability in eleven of twelve months and

attributed it to water operations. In seven months (January-May, September-October) the increasing trend was significant ($p<0.05$).

Even in the six-year drought from 1928 to 1934, the Delta still freshened every winter (Figure 3-16). However, as shown in Figure 3-16, the Delta has not freshened during more recent droughts (1976-1977, 1987-1994, and 2007-2009). This indicates that the historical "flushing" of the Delta with fresh water is no longer occurring. This lack of flushing can also allow waste from urban and agricultural developments upstream of and within the Delta to accumulate. Contaminants and toxics have been identified as factors in the decline of the Delta ecosystem (Baxter *et al.* 2007). The data indicate the effect of managing to the X2 standard (implemented in 1995), as the salinity levels attained in the most recent drought are not as high as the 1976-77 and 1987-1992 droughts.

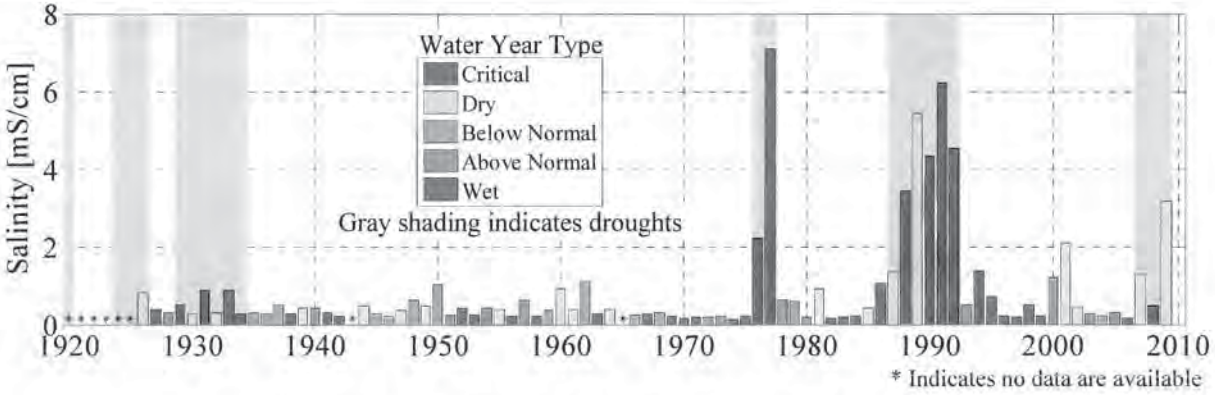


Figure 3-16 – Average Winter salinity at Collinsville

Annual average salinity during the winter (January through March) for water years 1927 to 2009. Bars are colored by water year type as defined by the Sacramento 40-30-30 index. Grey shading indicates multi-year droughts that include at least one critical water year.

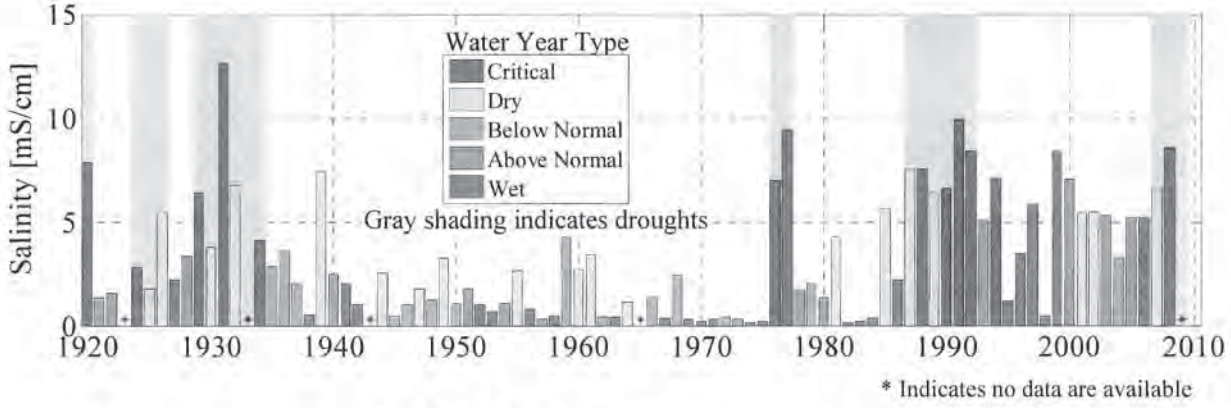


Figure 3-17 – Average Fall salinity at Collinsville

Annual average salinity during the fall months (October through December) for water years 1920 to 2009. Bars are colored by water year type as defined by the Sacramento 40-30-30 index. Grey shading indicates multi-year droughts that include at least one critical water year.

Figure 3-17 presents the variation in average fall salinity at Collinsville from 1920 to 2008 (October-December). Fall salinity is now high almost every year, while in the past, fall salinity was only high in dry and critical years. High salinity in the fall has been identified as a factor in the decline of the Delta ecosystem. Baxter *et al.* (2008) noted that "fall salinity has been relatively high during the POD years, with X2 positioned further [sic] upstream, despite moderate to high outflow conditions during the previous winter and spring of most years."

Conclusions

- In the 1920's and 1930's, the Delta freshened annually, even during droughts. In recent droughts, the Delta does not always freshen during the winter.
- Prior to 1976, fall salinity was high only in relatively dry years. Recently, fall salinity is high almost every year.

3.3.5. Salinity at Mallard Slough

A 1967 agreement between the Contra Costa Water District (CCWD) and the State of California requires the State to reimburse CCWD for the decrease in availability of usable river water, defined as water with less than 100 mg/L chlorides, at the Mallard Slough intake (CCWD, 1967). The 1967 agreement, and similar agreements between the State and other Delta water users, recognized the State Water Project (SWP) would increase salinity at Mallard Slough. The agreement defined a baseline of 142 days of usable water per year, based on the average number of days of usable water at the Mallard Slough intake from 1926-1967. Since 1967, the average number of days of usable water[21] (for the period 1967-2005) has declined to 122, indicating a 20-day (14%) reduction in the number of days of high quality water at Mallard Slough since the completion of the SWP.

[21] The data are from the USBR-CVO record of EC at Pittsburg, approximately 2 km upstream of Mallard Slough from 1967-2005. Since this station is located upstream of Mallard Slough, the number of days of usable water at Mallard Slough since the SWP was built may be overestimated.

ualitative Observations of istorical Freshwater Flow and Salinity Conditions

In this section, qualitative observations of salinity conditions in the western Delta and Suisun Bay from the lawsuit filed by the Town of Antioch in 1920 and from various literature reports are discussed to provide a perspective of the salinity conditions prevailing in the late 1800's and early 1900's. Qualitative observations from early explorers and settlers are discussed in Appendix E.

4.1. Town of Antioch Injunction on Upstream Diverters

In 1920, the Town of Antioch filed a lawsuit (hereinafter referred to as the "Antioch Case") against upstream irrigation districts, alleging that upstream water diversions were causing increased salinity intrusion at Antioch. An overview of the Antioch Case is provided in Appendix E. The court decision, legal briefings, and petitions provide qualitative salinity observations from a number of witnesses. Although testimony in the Antioch Case is generally anecdotal, not quantitative, it provides a perspective of the salinity conditions prevailing in the early 1900's. Because the proceedings were adversarial in nature, this report focuses on the testimony of the upstream interests, who were trying to demonstrate that salinity intrusion was common near Antioch prior to their diverting water (prior to 1920). Consequently, the testimony may be biased in support of this "more saline" argument.

The upstream interests in the Antioch Case provided information on the operation of pumping plants along the San Joaquin River at Antioch for domestic water supply and the quality of water obtained from the pumping plants, summarized in Table 4-1.

Table 4-1 – Testimony regarding pumping plant operations and water quality in the 1920 Antioch Case

Time period of observation	Relevant information from the testimony
1866-1878	Mr. Dodge ran a pumping/delivery operation at Antioch ▪ Dodge pumped water into a small earthen reservoir at Antioch and then hauled the water to residents in a wagon. ▪ Cary Howard testified that while he was living in Antioch (1867-1876), the water became brackish one or two years in the fall, when they had to drive into the country to get water. This likely occurred during the drought of 1870-71.
1878-1880	Mr. Dahnken bought and operated the Dodge operation ▪ Dahnken testified that the water became brackish at high tide every year in the late summer, and remained brackish at high tide until it rained "in the mountains."

Time period of observation	Relevant information from the testimony
1880-1903	Belshaw Company provided water ▪ Dahnken testified that Belshaw Company pumped only at low tide.
1903-1920	Municipal Plant ▪ William E. Meek (resident since 1910) testified the water is brackish at high tide every year, for some months in the year. ▪ James P. Taylor testified that for at least the last 5 years, insufficient storage required the plant to pump nearly 24 hours per day, regardless of tidal phase. ▪ Dr. J. W. DeWitt testified that during October of most years between 1897 and 1918, the water was too brackish to drink. Even when the city only pumped at low tide, the water was occasionally so brackish that it would be harmful to irrigate the lawns.

This testimony suggests that, in the late 1800's, water at Antioch was known to be brackish at high tide during certain time periods, but Antioch was apparently able to pump fresh water at low tide year-round. A possible exception was the fall season during a few dry years. Water at Antioch was apparently fresh at low tide until at least around 1915. At that time, due to increased demand and inadequate storage, the pumping plants started pumping continuously, regardless of tidal stage. The window of time each year when Antioch is able to pump fresh water from the river has been substantially reduced in the last 125 years.

As shown in Appendix A, DWR (1960) estimated that water with a chloride concentration of 350 mg/L or less would be available about 85% of the time if there were no water management effects. DWR (1960) estimated that chloride concentrations at Antioch would be less than 350 mg/L about 80% of the time in 1900 and about 60% of the time by 1940. DWR also projected further deterioration of water quality by 1960 and beyond but did not include the effects of reservoir releases for salinity control.

Observations of salinity at Antioch during recent years indicate that salinity is strongly dependent on ocean tides, and the diurnal range in salinity can be as much as the seasonal and annual ranges in salinity. This is discussed in more detail in Appendices D and E. For instance, salinity at high tide can be more than five times the salinity at low tide (Figures D-1, D-2, and D-3), and the salinity during the course of a single day may vary up to 6,000 µS/cm EC (Figure D-1). Average daily salinity at low tide during the period of 1983-2002 exceeded 1,000 µS/cm[22] EC for about four and a half months of the year (Figure D-3). During the driest 5 years between 1983 and 2002, salinity at low tide was always greater than 1,000 µS/cm EC (i.e., no fresh water was available at any time of day) for about eight months of the year. Fresh water is currently available at Antioch far less frequently than prior to the 1920's.

[22] The current water quality criterion for municipal and industrial use is 250 mg/L, equivalent to about 1,000 µS/cm EC.

Available data and observations indicate that, prior to about 1918, fresh water was available at least at low tide during almost the entire year, in all but a few dry years. Around 1918, an abrupt change to higher salinity occurred. Although a prolonged and severe drought also began about this time, salinity conditions at Antioch did not return to pre-drought levels when the drought ended, indicating that water management activities (increased upstream diversions and later storage of water in upstream reservoirs) were the primary causes of this increased salinity.

4.2. Reports on Historical Freshwater Extent

Several literature reports discuss the spatial extent and duration of salinity conditions in the western Delta and Suisun Bay during the late 1800's and early 1900's. Salinity conditions at several key Delta locations are summarized below.

Location: **Western Delta**
Source(s): DPW (1931)
Quotation: "*The dry years of 1917 to 1919, combined with increased upstream irrigation diversions, especially for rice culture in the Sacramento Valley, had already given rise to invasions of salinity into the upper bay and lower delta channels of greater extent and magnitude than had ever been known before.*" (DPW, 1931, pg. 22)
Quotation: "*It is particularly important to note that the period 1917-1929 has been one of unusual dryness and subnormal stream flow and that this condition has been a most important contributing factor to the abnormal extent of saline invasion which has occurred during this same time.*" (DPW, 1931, pg. 66)
Summary: Salinity intrusion into the Delta during the period 1917-1929 was much larger than experienced prior to that time.

Location: **Pittsburg, CA**
Source(s): Tolman and Poland (1935) and DPW (1931)
Quotation: "*From 1880 to 1920, Pittsburg (formerly Black Diamond) obtained all or most of its domestic and municipal water supply from New York Slough offshore.*" (DPW, 1931, pg. 60)
Quotation: "*There was an inexhaustible supply of river water available in the New York Slough* [near Pittsburg at the confluence of the Sacramento and San Joaquin Rivers], *but in the summer of 1924 this river water showed a startling rise in salinity to 1,400 ppm of chlorine, the first time in many years that it had grown very brackish during the dry summer months.*" (Tolman and Poland, 1935, pg. 27)
Summary: Prior to the 1920's, the water near the City of Pittsburg was sufficiently fresh for the City to obtain all or most of its fresh water directly from the river.

Location: **Antioch, CA**
Source(s): DPW (1931)

Quotation: "*From early days, Antioch has obtained all or most of its domestic and municipal water supply from the San Joaquin River immediately offshore from the city. This supply also has always been affected to some extent by saline invasion with the water becoming brackish during certain periods in the late summer and early fall months. However, conditions were fairly satisfactory in this respect until 1917, when the increased degree and duration of saline invasion began to result in the water becoming too brackish for domestic use during considerable periods in the summer and fall.*" (DPW, 1931, pg. 60)

Summary: Until 1917, the City of Antioch obtained all or most of its freshwater supplies directly from the San Joaquin River. Salinity intrusion has prevented domestic use of water at the Antioch intake in summer and fall after 1917.

Location: **Benicia, CA (Suisun Bay)**

Source(s): Dillon (1980) and Cowell (1963)

Quotation: "*In 1889, an artificial lake was constructed. This reservoir, filled with fresh water from Suisun Bay during the spring runoff of the Sierra snow melt water ...*" (Dillon, 1980, pg. 131)

Quotation: "*...in 1889, construction began on an artificial lake for the* [Benicia] *arsenal which would serve throughout its remaining history as a reservoir, being filled with fresh water pumped from Suisun Bay during spring runoffs of the Sacramento and San Joaquin Rivers which emptied into the bay a short distance north of the installation.*" (Cowell, 1963, pg. 31)

Summary: In the late 19th Century, fresh water was available in the Suisun Bay and Carquinez Straits for use by the City of Benicia.

The reported presence of relatively fresh water in the western Delta and the Suisun Bay during the late 1800's and early 1900's is consistent with the relatively fresh conditions observed in the paleoclimate records for this time period (Section 2.3) and the relatively wet conditions observed in the Sacramento River runoff and precipitation records (Section 3.1).

Additional observations between 1775 and 1841 are included in Appendix E. These qualitative observations indicated the presence of "*sweet*" water near the confluence of the Sacramento and San Joaquin Rivers in the vicinity of Collinsville in August 1775 (a period of average or above-average Sacramento River flow), and September 1776 (a period of below-average Sacramento River flow). The presence of "*very clear, fresh, sweet, and good*" water was reported in April 1776 (a dry year). Historical observations from 1796 and August 1841 (dry periods) indicated salinity "*far upstream*" at high tide and the presence of brackish (undrinkable) water in Threemile Slough. Current salinity controls and regulations put brackish water (averaged over 14 days) near Jersey Point and Emmaton, each about 2.5 miles below Threemile Slough, on a regular basis annually.

Conclusions

1. Measurements of ancient plant pollen, carbon isotope and tree ring data show that the Delta was predominately a freshwater marsh for the past 2,500 years, and that the Delta has become far more saline in the past 100 years because of human activity. Salinity intrusion during the last 100 years is comparable to the highest levels over the past 2,500 years.
2. Human activities during the last 150 years, including channelization of the Delta, elimination of tidal marsh, construction of deep water ship channels, and diversions of water, have resulted in increased salinity levels in the Delta. Today, salinity typically intrudes 3 to 15 miles farther into the Delta than it did in the early 20th Century.
3. Before the substantial increase in freshwater diversions in the 1940's, the Delta and Suisun Bay would freshen every winter, even during the extreme drought of the 1930's. However, that pattern has changed. During the most recent droughts (1976-1977, 1987-1994, and 2007-2009), the Delta did not always freshen in winter. Without seasonal freshening, contaminants and toxics can accumulate in the system and young aquatic species do not experience the same fresh conditions in the spring that occurred naturally.
4. While half of the past 25 years have been relatively wet, the fall salinity levels in 21 of those 25 years have resembled dry-year conditions. In terms of salinity, the Delta is now in a state of drought almost every fall because of human activity, including water diversions.
5. Seasonal and inter-annual variation in salinity has also been changed; however, this change is the result of reduced freshwater flows into the Delta. At any given location in the western Delta and Suisun Bay, the percentage of the year when fresh water is present has been greatly reduced or even eliminated.
6. The historical record and published studies show the Delta is far saltier now, even after the construction of reservoirs that have been used in part to meet State Water Resources Control Board water quality requirements in the Delta. Operation of reservoirs and water diversions for salinity management somewhat ameliorates the increased salinity intrusion, but the levels still exceed pre-1900 salinities.

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Historical Fresh Water and Salinity Conditions in the Western Sacramento-San Joaquin Delta and Suisun Bay

A summary of historical reviews, reports, analyses and measurements

Appendices

Water Resources Department

Contra Costa Water District

Concord, California

February 2010

Technical Memorandum WR10-001

Historical Fresh Water and Salinity Conditions in the Western Sacramento-San Joaquin Delta and Suisun Bay

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Appendix A. Factors Influencing Salinity Intrusion

Salinity intrusion in the Delta is the result of the interaction between tidally-driven saline water from the Pacific Ocean and fresh water from rivers flowing into the Delta. Regional climate change (e.g., sea level rise and change in precipitation regime), physical changes to the Central Valley landscape (e.g., creation of artificial channels and land use changes), and water management practices (e.g., reservoir storage, water diversions for agricultural and municipal and industrial use) affect this interaction between the ocean tides and the freshwater flow, in turn affecting salinity intrusion in the Delta (The Bay Institute (TBI), 1998, Department of Public Works (DPW), 1931, Nichols *et al.*, 1986, Conomos, 1979, and Knowles, 2000).

These factors are grouped into three categories (Table A-1) and discussed individually and qualitatively to provide context for observed salinity variability, which is necessarily due to the cumulative impact of all factors.

Table A-1 – Factors Affecting Salinity Intrusion into the Delta

Natural and artificial factors affect the salinity of the Delta. The factors are grouped into three categories: regional climate change, physical changes to the landscape, and water management practices.

Category	Factors affecting salinity intrusion and specific effect on Delta salinity
Regional Climate Change	• Precipitation regime o Long-term reduction of spring (April-July) snowmelt runoff may increase salinity in the spring, summer, and fall. o A shift to more intense winter runoff may not decrease salinity in the winter because outflows are typically already high during winter storms. • Ocean conditions o Added periodic variability to precipitation (via mechanisms such as the El Niño/Southern Oscillation (ENSO) or Pacific Decadal Oscillation (PDO)) • Sea level rise o Expected to increase salinity intrusion (DWR, 2006). Actual salinity response to rising sea level will depend upon actions taken to protect against flooding or overtopping (e.g., new tidal marsh vs. sea walls or dykes).
Physical Changes to the Landscape	• Deepening, widening, and straightening of Delta channels o Generally increase salinity, but response will depend upon location within the Delta (DWR, 2006)

Category	Factors affecting salinity intrusion and specific effect on Delta salinity
	• Separation of natural floodplains from valley rivers o Confining peak flows to river channels would reduce salinity during flood events. o Preventing floodplains from draining back into the main channel would increase salinity after floods (late spring and summer). • Reclamation of Delta islands o Varies (the effect on salinity depends on marsh vegetation, depth, and location), but marshes generally dampen tides, reducing salinity intrusion • Creation of canals and channel "cuts" o Generally creates more efficient routes for tidal flows to enter the Delta, thereby increasing salinity intrusion relative to native conditions • Deposition and erosion of sediments in Suisun Bay (Cappiella *et al.*, 1999) o Deposition of mining debris (occurred from 1860's to approximately 1887) reduced salinity in Suisun Bay and the western and central Delta (Enright, 2004, Enright and Culberson, 2009) o Erosion (occurring since 1887) increases salinity in Suisun Bay and the western and central Delta (Enright, 2004, Enright and Culberson, 2009)
Water Management Practices (reservoir operations, water diversions, and exports from the Delta)	• Decreasing Net Delta Outflow (NDO) by increasing upstream and in-Delta diversions as well as exports o Increases salinity • Increasing upstream storage capacity o Generally increases salinity when reservoirs are filling. Reservoir releases may decrease salinity if they increase outflow. Historically, this occurred when flood control or other releases were required in wetter years. However, as this study shows, this has generally been small and intermittent; salinity measurements indicate it occurred occasionally prior to 1985, and very seldom since. Increased early winter diversion of runoff to storage will maintain or increase high salinities in the winter.

A.1. Climatic Variability

Changes in precipitation regimes and sea levels, brought about by a changing climate, can affect the spatial and temporal salinity conditions in the Delta. Long-term variations in river runoff, precipitation and sea level are discussed below.

A egional Precipitation and unoff

Precipitation in the Bay-Delta watershed sets the amount of water available within the system which could ultimately reach the Bay and affect salinity conditions. However, since precipitation falls as both rain and snow, runoff to river channels is spread over more months than the precipitation events themselves; any runoff from rain generally reaches the river channels within days of the precipitation event, but runoff resulting from snow is delayed until the spring snowmelt. For this reason, estimates of unimpaired flow (runoff), rather than precipitation, are generally used to characterize hydrological variability. Unimpaired runoff represents the natural water production of a river basin, unaltered by water diversions, reservoir storage and operation, and export of water to or import of water from other basins.

Knowles (2000) determined that variability in freshwater flows accounts for the majority of the Bay's salinity variability. The spatial distribution, seasonal timing, annual magnitude, decadal variability, and long-term trends of unimpaired flow all affect the hydrology and salinity transport in the Delta. Total annual unimpaired flow in the Sacramento and San Joaquin basins from 1872 through 2009 is presented in Section 3.1, with the seasonal distribution provided for 1921 through 2003.

The total annual unimpaired flow of the upper Sacramento Basin for water years 1906 through 2006 exhibits substantial year-to-year variability with a strong decadal oscillation in the 5-year running average (see Figure 3-1). On average, over the last 100 years, the total annual unimpaired Sacramento River flow is increasing by about 0.06% or 11 thousand-acre feet (TAF) each year. However, increased total annual unimpaired flow does not necessarily reduce salinity intrusion. Knowles (2000) illustrated that the seasonal timing of runoff can significantly alter salinity intrusion without any change to the total annual runoff.

Typically, most precipitation in California occurs during winter in the form of snow in the Sierra Nevada. The subsequent melting of this snow, beginning in the spring, feeds the rivers that flow into the Delta. The four months from April through July approximately span the spring season and represent the period of runoff due to snow melt. The long-term trend in spring (April-July) runoff decreased by approximately 1.3 MAF from 1906 to 2006 (Figure A-1). This effect is believed to be caused by climate change; as temperatures warm, more precipitation falls as rain instead of snow, and what snowpack that does accumulate tends to melt earlier in the year. This leads to higher runoff during winter months, but lower runoff in spring or summer, resulting in the potential for greater salinity intrusion. These observed changes in the magnitude and timing of spring runoff of the Sacramento River watershed are consistent with similar changes in spring runoff observed across river watersheds of the

western United States (e.g., Dettinger, 2005; Mote *et al.*, 2005; Stewart *et al.*, 2005). Note that, from 1920 to 2006, the long-term trend in spring runoff actually increased slightly (approximately 0.5 MAF).

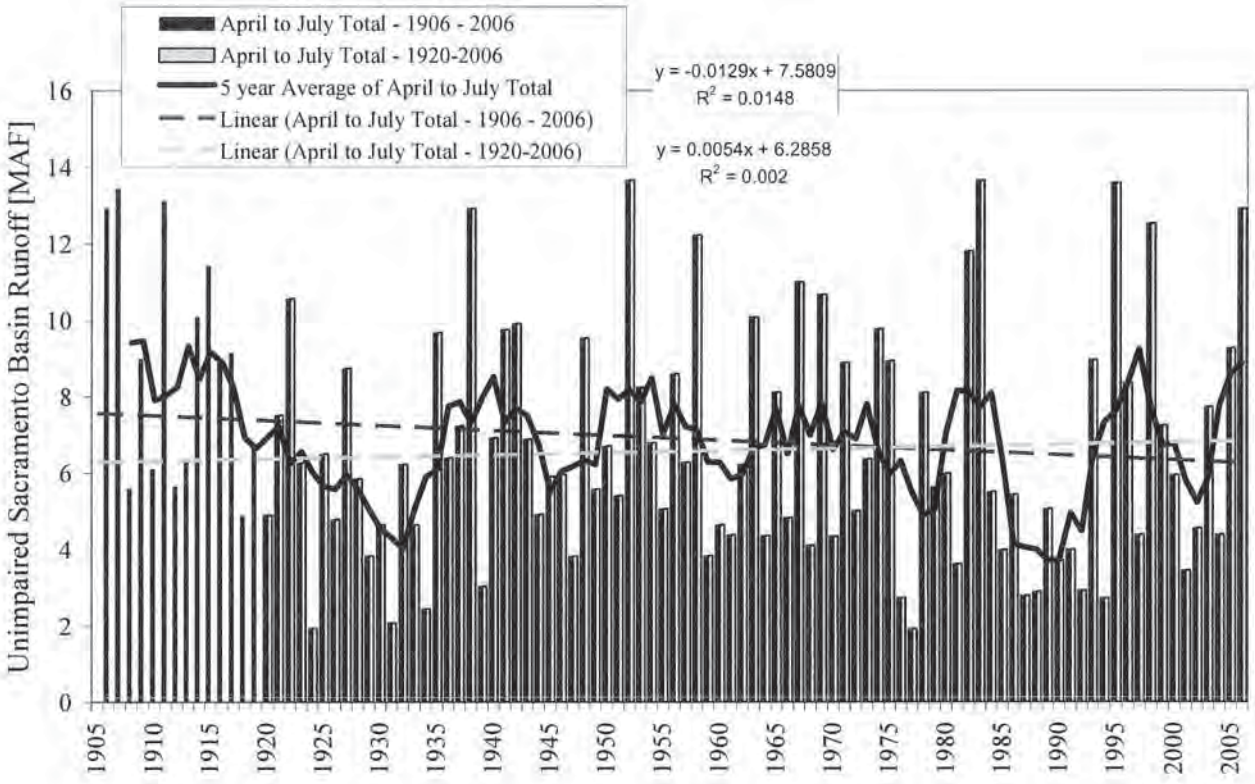


Figure A-1 – Unimpaired runoff from the Sacramento River basins from April to July
Data source: http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST.

Precipitation and runoff are influenced by regional events such as the Little Ice Age (about 1300 to 1850 CE) and the Medieval Warm Period (about 800 to about 1300 CE). During the Little Ice Age, the winter snowline in the Sierra was generally at a lower elevation, and spring and summer nighttime temperatures were significantly lower. This temperature pattern would allow the snowmelt to last further into the summer, providing a more uniform seasonal distribution of runoff such that significantly less salinity intrusion than occurs today would be expected. This expectation is borne out by paleosalinity studies (see Section 2.3).

At shorter time scales, oceanic conditions such as the Pacific Decadal Oscillation (PDO) and El Niño/Southern Oscillation (ENSO) also impact precipitation and runoff patterns. Runoff in the upper watershed is the primary factor that determines freshwater outflow from the Delta. Anthropogenic flow management (upstream diversions, reservoir operations, in-Delta diversions, and south-of-Delta exports) alters the amount and timing of flow from the upper watershed (see Section 2.3). Changes to the physical landscape further alter the amount and timing of flow (see Section 2.2).

A Sea evel ise

Sea level fluctuations resulting from the repeated glacial advance and retreat during the Pleistocene epoch (extending from 2 million years ago to 15,000 years ago) resulted in deposition of alternating layers of marine and alluvial sediments in the Delta (TBI, 1998). A warming trend starting about 15,000 years ago ended the last glacial advance and triggered rapid sea-level rise. At the end of this period (known as the "Holocene Transgression") approximately 6,000 years ago, sea level had risen sufficiently to inundate the Delta at high tide (Atwater *et al.*, 1979).

Sea level is estimated to have risen at an average rate of about 5 cm/century during the past 6,000 years and at an average rate of 1-2 cm/century during the past 3,000 years (Cayan *et al.*, 2008). Observations of sea level at the Golden Gate in San Francisco reveal that the mean sea level has risen at an average rate of 2.2 cm/decade (or 0.22 mm/yr) over the past 100 years (Cayan *et al.*, 2008). Future increases in sea level are expected to increase salinity intrusion into the Delta (DWR, 2006); actual salinity response to rising sea level will depend upon actions taken to protect against flooding or levee overtopping (e.g. new tidal marsh would generally reduce salinity intrusion, while construction of sea walls or dykes may further increase salinity).

A.2. Physical Changes to the Delta and Central Valley

Creation of artificial channels, reclamation of marshlands, land use changes and other physical changes to the landscape of the Delta and Central Valley have significantly altered water movement through the Delta and the intrusion of salinity into the Delta. Major physical changes to the Delta and Central Valley landscape have occurred over the last 150 years. As many of these physical changes were made prior to flow and salinity monitoring (which began in the 1920's), only a qualitative discussion is presented below.

A Deepening, Widening, and Straightening Channels early s-present

The lower Sacramento River was widened to 3,500 feet and straightened (creating Decker Island) around 1910 (Lund *et al.*, 2007). Progressive deepening of shipping channels began in the early 1900's. Original channel depths were less than 10 feet; channels were gradually dredged to depths exceeding 30 feet, and maintenance dredging continues today.

These changes to the river channels have increased salinity intrusion. Deepening the river channels increases the propagation speed of tidal waves, leading to increased salinity intrusion. Similarly, straightening the river channels provides a shorter path for the passage of the tidal waves and increases salinity intrusion. Widening of the river channels increases the tidal prism (the volume of water in the channels), resulting in further salinity intrusion. Larger cross-sections reduce velocities, lowering friction losses and maintaining more tidal energy, which is the driving force for dispersing salinity into the Delta.

A ecla ation of arshland -

In the Central Valley

The original natural floodplains captured large winter flows, gradually releasing the water back into the river channels throughout the spring and summer, resulting in a more uniform flow into the Delta (reduced peak flow and increased low flow) compared to current conditions. The increased surface area of water stored in these natural floodplains increased total evaporation and groundwater recharge, reducing total annual inflow into the Delta.

Even with less Delta inflow, the difference in the seasonal flow pattern may have limited salinity intrusion. The drainage of floodplains back into rivers during the spring and groundwater seepage back to the rivers in the summer and fall provided a delayed increase in river flows during the low flow period. Raising and strengthening natural levees in the Central Valley effectively disconnected the rivers from their floodplains, removing this natural water storage, increasing the peak flood flows and reducing the low flows. The net effect of these changes in the Central Valley was to reduce salinity during floods, when salinity is typically already low, and increase salinity during the following summers and falls, which is likely to have led to increased maximum annual salinity intrusion.

In the Delta

Reclamation of Delta marshland began around 1850. By 1920, almost all land within the legal Delta[1] had been diked and drained for agriculture (DPW, 1931). Before the levees were armored and the marshes were drained, the channels would have been shallower and longer (more sinuous), which would have slowed propagation of the tides into the Delta, reduced tidal energy and reduced salinity intrusion.

The natural marsh surface would have increased the tidal prism. However, the shallow marsh depth and native vegetation would have slowed the tidal wave progression. The combined effect on salinity intrusion depends on the location and depth of the marsh, the native vegetation distribution, and the dendritic channels that were removed from the tidally active system.

Figure A-2 shows the western, central, and southern portions of the Delta in 1869. For comparison, Figure A-3 shows the same area in 1992, with man-made channels highlighted grey.

A ining debris

Hydraulic mining in the Sierra Nevada began in the 1860's and produced large quantities of debris which traveled down the Sacramento River, through the Delta and into the Bay. Mining debris may have contributed to the extensive flooding reported in 1878 and 1881. Cappiella *et al.* (1999) estimate that, from 1867 to 1887, approximately 115 million cubic meters (Mm3) of sediment were deposited in Suisun Bay. This deposition was due to the inflow of hydraulic mining debris.

[1] The legal Delta is defined in California Water Code Section 12220.



Figure A-2 - Map of the Delta in 1869

Channels of the western, central, and southern Delta in 1869, prior to extensive reclamation efforts (Gibbes, 1869)



Figure A-3 – Map of the Delta in 1992

Channels of the western, central, and southern Delta from the Delta Atlas (DWR, 1992) Constructed waterways (highlighted in grey) generally create more efficient routes for tidal flows to enter the Delta, thereby increasing salinity intrusion relative to the native tidal marshes.

Cessation of hydraulic mining around 1884 resulted in erosion of Suisun Bay, which continues to erode even today. From 1887 to 1990, approximately 262 Mm3 of sediment were eroded from Suisun Bay. The net change in volume of sediment during 1867-1887 was 68 Mm3 (net deposition) and during 1887-1990 was -175 Mm3 (net erosion). As a result of these changes, the tidal flat of Suisun Bay increased from about 41 km^2 in 1867 to 52 km^2 in 1887, but decreased to 12 km^2 by 1990 (due to erosion subsequent to the cessation of hydraulic mining). Cappiella *et al.* (1999) attributed the change in the Suisun Bay area from being a largely depositional environment to an erosional environment not only to the hydraulic mining practices of the late 1800's but also to increased upstream water management practices. The Suisun Marsh Branch of the DWR estimated that erosion of Suisun Bay (modeled as a uniform change in depth of 0.75 meters) has increased salinity in Suisun Bay and the western Delta by as much as 20% (Enright, 2004; Enright and Culberson, 2009).

A.3. Water Management Practices

Extensive local, state, and federal projects have been built to move water around the state, altering the natural flow patterns throughout the Delta and in upstream watersheds. For clarity in the discussion that follows, definitions and discussions of actual flow and salinity, unimpaired flow and salinity, and natural flow and salinity, are given below.

Historical (actual) flow and salinity
Historical (or actual) flow and salinity refer to the flow and electrical conductivity, total dissolved solids concentration, or chloride concentration that occurred in the estuary. Historical conditions have been observed, measured, or estimated at various times and locations; they are now measured at monitoring stations throughout the estuary. Historical data are also used to estimate flow and water quality conditions at other locations with the following tools: the DAYFLOW program from IEP, the DSM2 model from the California Department of Water Resources, the X2[2] equation (Kimmerer and Monismith, 1992) and Contra Costa Water District's salinity outflow model (also referred to as the G-model) (Denton, 1993; Denton and Sullivan, 1993). The use of these tools to estimate flow and water quality is necessarily dependent upon the Delta configuration to which they were calibrated. Use of these tools in hypothetical configurations (such as pre-levee conditions, flooding of islands, etc) is subject to un-quantified error.

Unimpaired flow and salinity
Unimpaired flows are hypothetical flows that would have occurred in the absence of upstream diversions and storage, but with the existing Delta and tributary configuration. Unimpaired flows are estimated by the California Department of Water Resources (DWR) for the 24 basins of the Central Valley; the Delta is one of the 24 basins. Additionally, DWR estimates unimpaired in-Delta use and unimpaired net Delta outflow (NDO). Unimpaired NDO estimates can be used to estimate unimpaired water quality using a salinity-outflow relationship such as the X2 or G-model tools discussed above.

[2] X2 is defined as the distance from the Golden Gate to the 2 part-per-thousand isohaline (equivalent to a salinity of 2 grams of salt per kilogram of water), measured along the axis of the San Francisco Estuary. X2 is often used as an indicator of freshwater availability and fish habitat conditions in the Delta (Jassby *et al.*, 1995; Monismith, 1998).

Since unimpaired flows assume the existing Delta configuration, the use of these tools should not violate their basic assumptions. However, the results should be taken in context. Water quality based on unimpaired flows compared to water quality based on historical (actual) flows shows how water management activities affect water quality. Water quality based on unimpaired flows cannot be considered natural.

Natural flow and salinity

Natural flow and salinity reflect pre-European settlement conditions, with a virgin landscape in both the Central Valley and the Delta, native vegetation, and no diversions or constructed storage. As discussed above, the natural landscape included natural storage on the floodplains and extensive Delta marsh. Estimation of natural flow requires assumptions regarding the pre-European landscape and vegetation throughout the Central Valley. Estimation of natural salinity requires development of new models to account for pre-European Delta geometry, incorporating the estimates of natural flow. These assumptions induce an unknown level of error. For this reason, no attempt is made in this report to calculate natural flow or the resulting salinity. Instead, paleosalinity studies are examined to provide evidence of salinity in the pre-European era.

Water management practices have continually evolved since the mid-1850's. As discussed in Section 1.1, anthropogenic modification include diversion of water upstream and within the Delta, construction of reservoirs, and system operations to meet regulatory requirements.

The irrigated acreage in the Central Valley has been steadily increasing since 1880 (Figure 1-3), increasing the upstream diversions of water. There were two periods of rapid growth in irrigated acreage: from 1880 to 1920 and from 1940 to 1980. In-Delta diversions (Figure 1-3) began in 1869 with reclamation of Sherman Island; from 1869 to 1930, in-Delta diversions are assumed to have grown in proportion to the area of reclaimed marshland (from Atwater *et al.*, 1979).

Upstream diversions first became an issue with respect to Delta salinity around 1916 with the rapid growth of the rice cultivation industry (Antioch Case, Town of Antioch v. Williams Irrigation District, 1922, 188 Cal. 451; see Appendix E.2). These early "pre-project" diversions for irrigation had particularly large impacts because of the seasonality of water availability and water use. Diversions for agriculture typically start in the spring and continue through the early fall (when river flow is already low). These early irrigation practices, combined with the decrease in spring and summer flow due to the separation of rivers from their natural floodplains, resulted in a significant reduction of the spring and summer river flow, leading to increased salinity intrusion.

Figure A-4 shows the Department of Water Resources' estimates of the effects of upstream diversions and south-of-Delta exports on the salinity in the San Joaquin River at Antioch (DWR, 1960). DWR's 1960 report indicated that water with less than 350 mg/L chlorides would be present at Antioch approximately 88% of the time on average "naturally," and that availability decreased to approximately 62% by 1940 due to upstream diversions. This illustrates that upstream depletions had a significant effect on salinity at Antioch during 1900-1940, prior to the construction of large upstream reservoirs. (For reference, Shasta Dam was completed in 1945.)

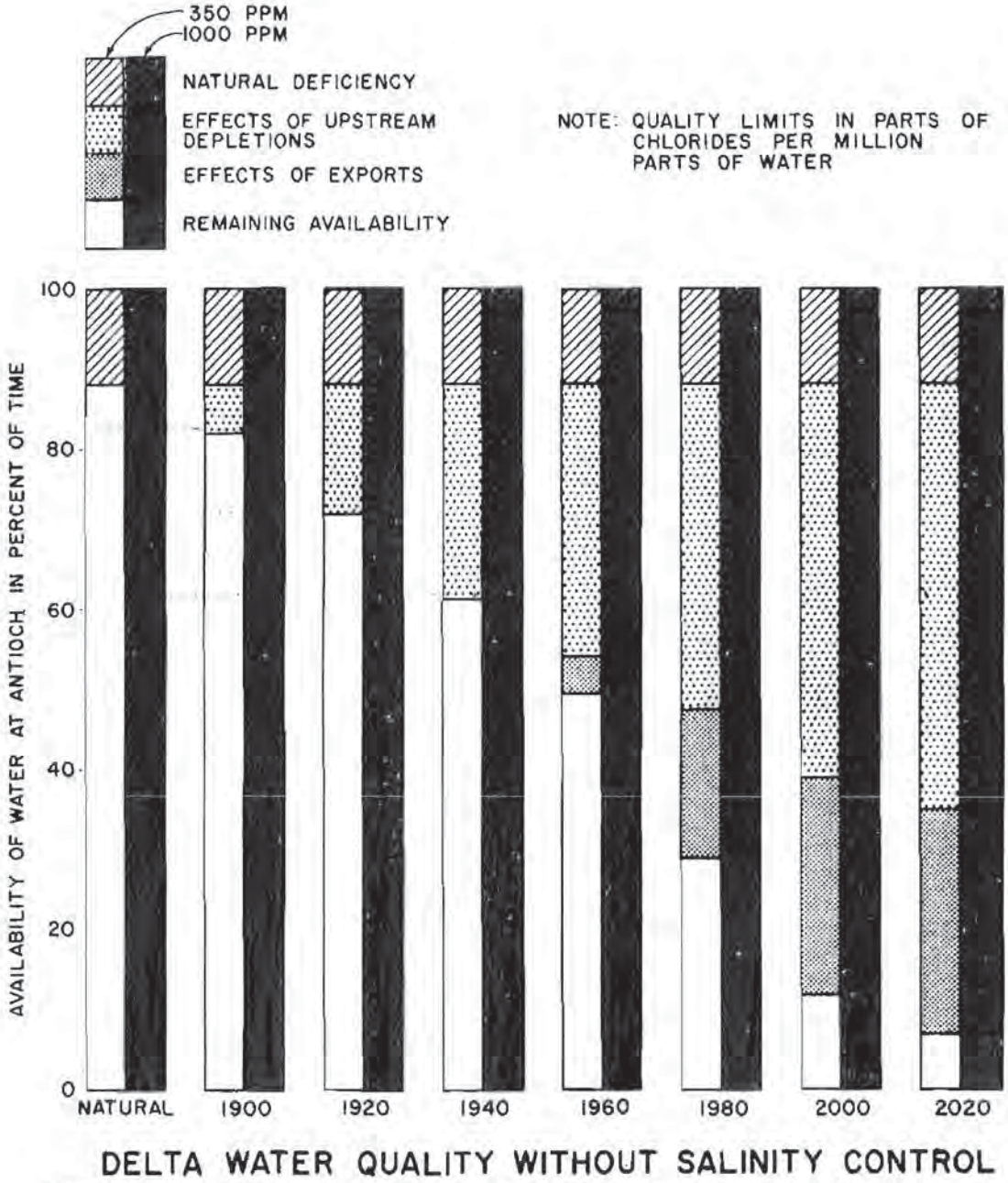


Figure A-4 - Salinity on the San Joaquin River at Antioch (DWR, 1960)

The Department of Water Resources examined the effects of upstream depletions and south-of-Delta exports on salinity in the San Joaquin River at Antioch, estimating the percent of time water that a certain quality of water (with less than 350 mg/L chlorides; or less than 1,000 mg/L chlorides) would be available in the river without reservoir releases to provide salinity control. The estimates for 1960, 1980, 2000, and 2020 assume the reservoirs do not make releases for salinity control and therefore underestimate the actual quality of water during these years.

Figure A-4 also shows estimates of the availability of water in 1960, 1980, 2000, and 2020, without reservoir releases to provide salinity control, demonstrating that upstream depletions and in-Delta exports would have continued to degrade water quality at Antioch.

Exports from the south Delta started in 1951 with the completion of the federal Central Valley Project pumping facility near Tracy, California. Exports from the State Water Project Banks Pumping Plant, just to the west of the federal facility, began in 1967. As shown in Figure 1-3, south-of-Delta exports increased rapidly from 1951 through the mid-1970s, and since then the combined exports have averaged more than 4 million acre-feet per year.

Construction of upstream reservoirs also altered natural patterns of flow into the Delta. Figure A-5 and Figure A-6 show the extent and rapid rise of constructed reservoirs in the upstream watersheds of the Delta (DWR, 1993). The location, year of completion and approximate storage capacities (in acre-feet, AF) are shown in Figure A-5. Figure A-6 shows the temporal development of reservoir capacity. Reservoir construction began in 1850. The major reservoirs of the Central Valley Project (CVP) and State Water Project (SWP) are the Shasta (4.5 MAF capacity) and Oroville (3.5 MAF) reservoirs, respectively. These reservoirs capture the flow in the wet season (reducing the flow into the Delta in the wet season) and release water for irrigation and diversions.

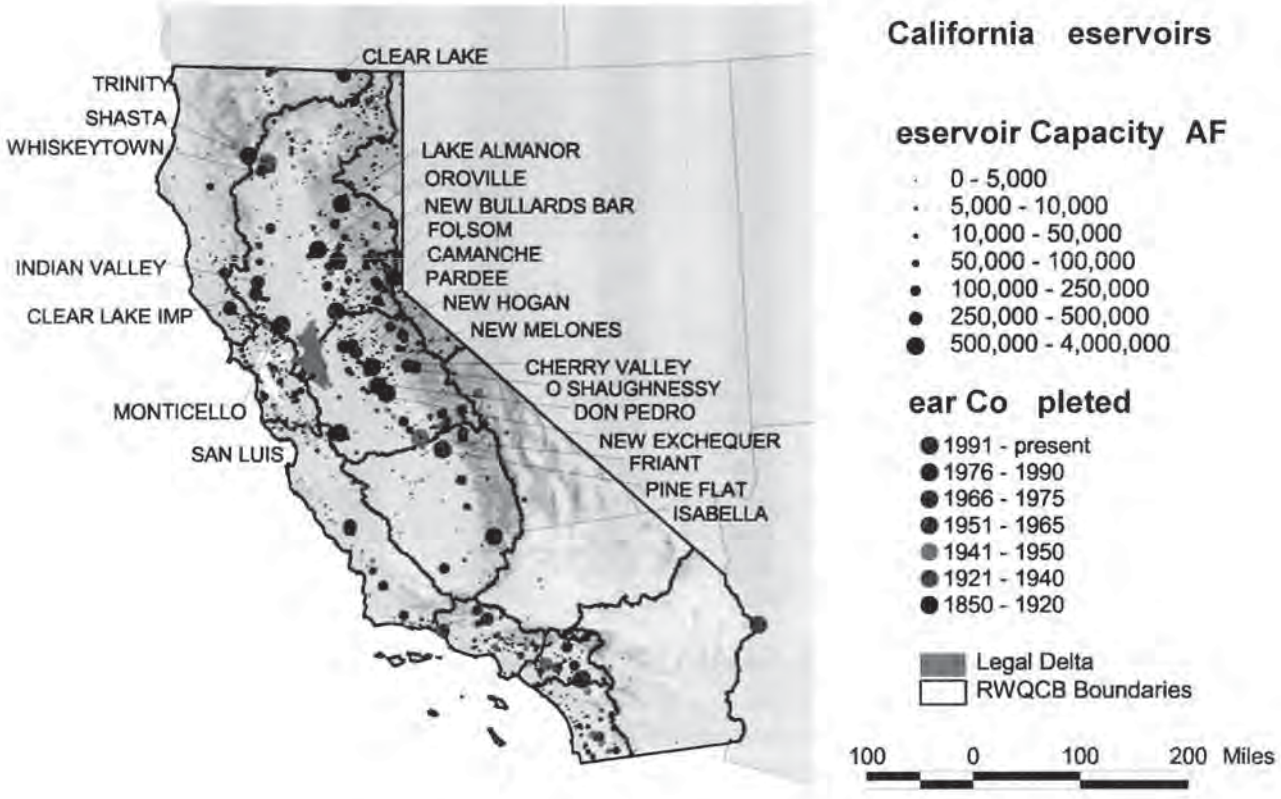


Figure A-5 – Storage reservoirs in California

Location of storage reservoirs within California. Reservoir capacity is indicated by the size of the circle, while the year construction was completed is indicated by color.

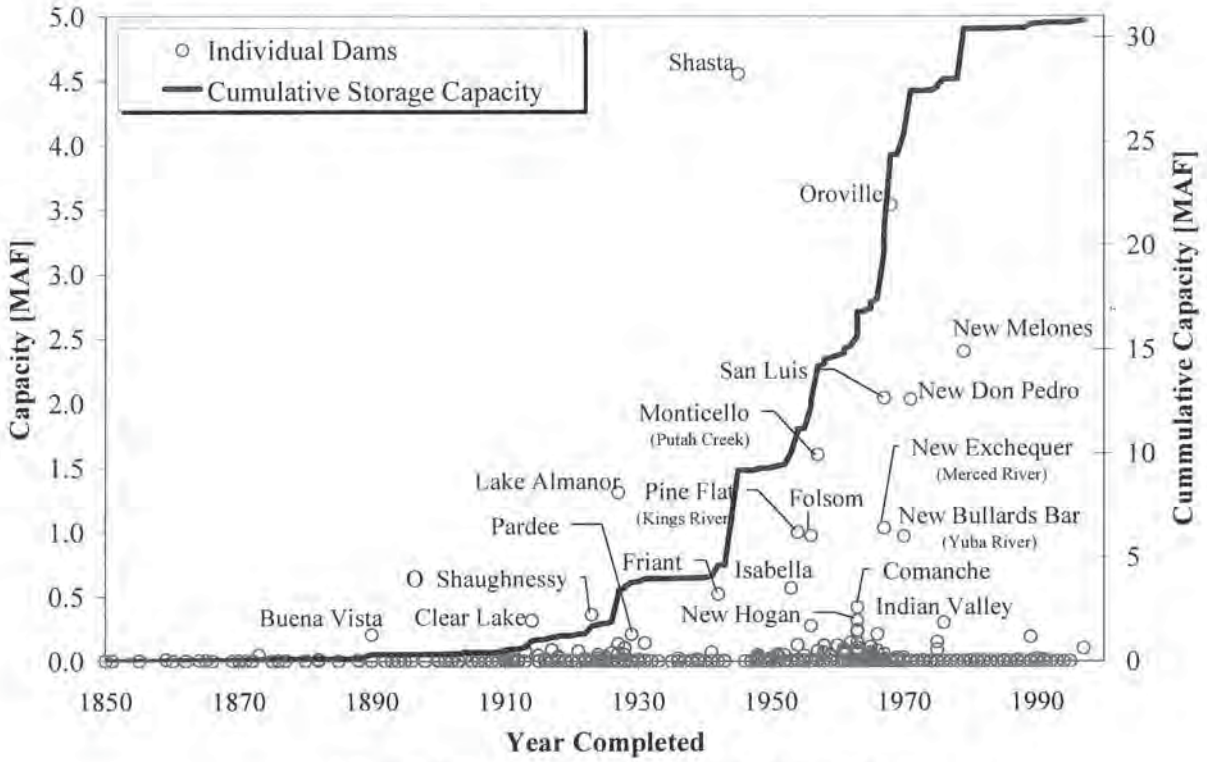


Figure A-6 – Surface Reservoir Capacity

Timeline of reservoir development in California. Individual reservoir capacity is indicated by the blue circles (left axis), while the cumulative capacity is indicated with the red line (right axis).

Water management practices have been altered by regulations that require maintenance of specified flow and salinity conditions at locations in the Bay-Delta region during certain periods of the year. The 1978 Water Quality Control Plan and State Water Resources Control Board (SWRCB) Decision 1485 established water quality standards to manage salinity to protect Delta agriculture and municipal and industrial (M&I) uses. The listing of delta smelt as a threatened species under the Endangered Species Act in 1993, followed by the Bay-Delta Accord in 1994 and the adoption of a new water quality control plan by the State Water Resources Control Board in 1995 changed the amount and timing of reservoir releases and south-of-Delta exports. California's Rice Straw Burning Act was enacted in 1992 to reduce air pollution by phasing out the burning of rice field stubble; by 1999, Sacramento Basin rice farmers were diverting additional water to flood harvested fields to decompose the stubble.

Changes in water diversions and reservoir operations have altered the magnitude and timing of river flows to the Delta, and anthropogenic modifications to the Delta landscape have altered the interaction of fresh water from the rivers with salt water from the ocean, thus changing patterns of salinity intrusion into the Delta.

Appendix B. Paleoclimatic Records of Hydrology and Salinity

This section presents paleoclimate records of hydrology (precipitation and unimpaired runoff) and salinity in the Bay-Delta region, in addition to those presented in Section 2 of the main report.

B.1. Methods of Paleoclimatic Reconstruction

The field of paleoclimatology aims to deduce climatological information from natural "archives" in order to reconstruct past global climate. These archives are created by such Earth processes as the formation of ice sheets, sediments, rocks, and forests. Examples of information sampled from such archives include atmospheric temperatures from ice cores and precipitation cycles from tree rings. When samples are dated, through radiometric or other methods, the data preserved therein become proxy indices, establishing a timeline of major events in the local environment of the sample. Multiple samples collected over larger spatial scales can be cross-dated to create regional climate and landscape process chronologies.

The material sampled for paleoclimatic reconstructions has limitations that decrease the resolution and confidence of data going back in time. Although paleoclimatic reconstructions have a coarser temporal resolution than modern measurements, the variations in climate and landscape responses to change are reliably described "in the first person" because the evidence of localized climate change is preserved as a time series *in situ*, absent of human influence.

The San Francisco Bay-Delta has been the focus of several paleoclimatic reconstructions. Surveys have sampled from Browns Island (Goman and Wells, 2000; May, 1999; Malamud-Roam and Ingram, 2004), Roe Island (May, 1999; Malamud-Roam and Ingram, 2004) Rush Ranch (Starratt, 2001; Byrne *et al.*, 2001; Starratt, 2004), and China Camp and Benicia State Parks (Malamud-Roam and Ingram, 2004).

Sediment cores are the predominate archive used to reconstruct Bay-Delta climate. Changes in wetland plant and algae communities are the dominant response in the Bay-Delta to climate change and associated fluctuations in temperature and precipitation. Proxies of plant and algae response to environmental conditions are preserved in the sediment cores and determined by quantification and taxonomic identification of diatom frustules (Byrne *et al.*, 2001; Starratt, 2001; Starratt, 2004), plant seeds and roots (Goman and Wells, 2000) and plant pollen (May, 1999; Byrne *et al.*, 2001; Malamud-Roam and Ingram, 2004) and measurement of peat carbon isotope ratios (Byrne *et al.*, 2001; Malamud-Roam and Ingram, 2004).

Plant communities in the Delta are characterized by salt tolerance. Salt-tolerant plant communities are dominated by pickleweed (*Salicornia* spp.) while freshwater plant

assemblages are dominated by tule (*Scirpus* spp.) and cattail (*Typha* spp.) (Atwater *et al.*, 1979). Plants contribute pollen, seeds, and vegetative tissue in the form of peat to the sediment archive. Plant material deposited to surface sediments are significantly correlated to the surrounding standing vegetation, and thus plant material preserved in sediment cores are considered autochthonous to the type of wetland existent at the time of sediment deposition, allowing reconstruction of the salinity conditions in the Delta over time.

Diatom taxa are classified according to their salinity preference expressed as the Diatom Salinity Index (DSI) (Eq 1) (Starratt, 2004). Starratt (2001) classified salinity preference as freshwater (F; 0-2‰), freshwater and brackish water (FB; 0-30‰), brackish (B; 2-30‰), brackish and marine (BM; 2-35‰), and marine (M; 30-35‰). Samples dominated by marine taxa have a DSI range of 0.00 to 0.30.

$$DSI = \frac{F + FB + 0.5B}{F + FB + B + BM + M} \quad (1)$$

Carbon-isotope ratios ($^{13}C/^{12}C$) (Eq 2) are measured by spectrometry and the δ notation calculated as

$$\delta^{13}C = \left[\left(\frac{{}^{13}C/{}^{12}C_{sample}}{{}^{13}C/{}^{12}C_{std}} \right) - 1 \right] \times 1000 \quad (2)$$

The $\delta^{13}C$ value of peat samples is a proxy for the composition of the plant assemblages contributing vegetation to the formation of the peat. Plants utilizing the C_4 mechanism have higher $\delta^{13}C$ values (~-14‰) than those utilizing the C_3 or CAM (~-27‰) (Table B-1). Using the $\delta^{13}C$ proxy can detect the presence of upland bunchgrasses such as *Spartina* and *Distichlis*.

Pollen can be classified to the taxonomic family level. *Chenopodiaceae (*now *Salicornioideae*) is representative of salt-tolerant *Salicornia*. *Cyperaceae* is representative of freshwater species including *Scirpus*. The ratio of *Chenopodiaceae* to the sum of *Chenopodiaceae* and *Cyperaceae* (Eq. 3) is a proxy of the percent relative abundance of salt-tolerant species (May, 1999).

$$\%ST = \frac{Chenopodiaceae}{Chenopodiaceae + Cyperaceae} \quad (3)$$

To establish chronologies for sediment archives, dates must be established for when material was deposited through the length of the sediment cores. Radiocarbon dating by Accelerator Mass Spectrometry (AMS) determines age by counting the ^{14}C content of plant seeds or carbonate shells calibrated against a northern hemisphere atmospheric carbon calibration curve (Malamud-Roam *et al.*, 2006). Radiocarbon dating is valid to about 40,000 years

before present (BP) [3], making it an ideal method for establishing dates through the period of interest for the Bay and Delta. When archived proxies are correlated with the sediment core chronology, a timeline is established reconstructing past climate and landscape response.

Table B-1 – Carbon Isotope Ratios ($\delta^{13}C$) of Plant Species in the San Francisco Estuary
(adapted from Byrne et al. 2001)

Species	Common Name	Photosynthetic Pathway	δ13C (‰)
Distichlis spicata	Saltgrass	C4	-13.5
Spartina foliosa	California cordgrass	C4	-12.7
Cuscuta salina	Salt-marsh dodder	C3	-29.8
Frankenia grandifolia	Alkali heath	C3	-30.2
Grindelia stricta	Gumplant	C3	-26.4
Jaumea carnosa	Marsh jaumea	C3	-27.2
Juncus balticus	Baltic rush	C3	-28.4
Lepidium latifolium	Perennial pepperweed	C3	-26.6
Scirpus californicus	California bulrush	C3	-27.5
Scirpus maritimus	Alkali bulrush	C3	-25.5
Typha latifolia	Cattail	C3	-27.8
Salicornia virginica	Pickleweed	CAM	-27.2

A large number of paleoclimatic reconstructions exist for California and the western U.S., but a complete discussion is beyond the scope of this report. These reconstructions are reviewed by Malamud-Roam *et al.* (2006; 2007) and provide important context to events in the Bay and Delta by recording major non-localized events and larger regional climate shifts. Important examples include: Central Valley oaks, Sierra Nevada giant sequoias, and White Mountain Bristlecone pines used to establish precipitation and temperature from the location of the tree line and tree rings; Mono Lake sediments and submerged tree stump rings for precipitation; and Sacramento and San Joaquin River floodplain deposits for flood events. These studies establish a record of environmental conditions in the Bay and Delta from their formation to the present.

B.2. Major Regional Climatic Events

Formation of the Sacramento-San Joaquin Delta

The Holocene epoch began approximately 8000 BCE at the end of Pleistocene glaciations (Malamud-Roam *et al.*, 2007). In the early Holocene, a general warming and drying period in California accompanied high orbitally driven insolation until insolation reached current values at approximately 6000 BCE. In the Sierra Nevada, western slopes were in the early stages of ecological succession following the retreat of glaciers. The modern river floodplain systems were forming in the Central Valley. Parts of the Delta and Bay were river valleys

[3] Before Present (BP) is a time scale, with the year 1950 as the origin, used in many scientific disciplines. Thus, 100 BP refers to the calendar year 1850.

prior to approximately 8000 to 6000 BCE, when rapidly rising sea level entered the Golden Gate and formed the early Bay estuary (Atwater *et al.*, 1979). A fringe of tidal marshes retreated from a spreading Bay until approximately 4000 BCE when the rate of submergence slowed to 1 to 2 cm per year, allowing the formation of extensive Delta marshes over the next 2000 years (Atwater *et al.*, 1979). Sedimentation from upstream sources kept up with subsidence from increasing sea-level rise.

2000 – 1 BCE

After 2000 BCE, information from archives indicates climate in the Bay and Delta was cooler with greater freshwater inflows. The Sierra Nevada became more moist and cooler during a period ca. 4000-3500 BP (Malamud-Roam *et al.*, 2006).

1 BCE - Present

The cooler and wetter period ended approximately 1 BCE, replaced by more arid conditions (Malamud-Roam, 2007). Major climatic events, known from other parts of the world, are captured in the regional paleoclimatic reconstructions and help to calibrate or correlate these reconstructions to global events. Unusually dry conditions prevailed during the Medieval Warm Period (approximately 800-1300 CE). Wetter and cooler conditions existed during the Little Ice Age (approximately 1400-1700 CE). These climate variations are reflected in variations in the plant communities.

Droughts

Two extreme droughts occurred in the region from about 900 to 1150 CE and from 1200 to 1350 CE. Low freshwater inflows to the Delta occurred during periods 1230-1150, 1400-1300, 2700-2600, and 3700-3450 B.P.

Flood Events

Periods of increase moisture occurred from 800-730 BP and 650-300 BP. Massive flooding inundated the Central Valley in the winter of 1861 (Malamud-Roam *et al.*, 2006). High periods of inflow occurred during 1180-1100, 2400-2200, 3400-3100, and 5100-3800 BP.

Sampling for paleoclimatic reconstructions captures the modern era, enabling a comparison of current conditions with conditions over the past several thousand years. The erratic nature of precipitation in California observed over the past century have been normal and small compared to natural variations over the past millennia.

Reconstructed River Flow and Precipitation Records

Meko *et al.* (2001a) used tree-ring chronologies in statistical regression models to reconstruct time series of annual unimpaired Sacramento River flow for approximately the past 1,100 years (see Section 2.1). Similarly, Graumlich (1987) used tree ring data from the Pacific Northwest to reconstruct precipitation records for the period of 1675-1975 (Figure B-1). Compared to the average observed precipitation from 1899 to 1975, the reconstructed record has above-average precipitation during the latter half of the nineteenth century (1850-1900) (Figure B-1). These relatively wet conditions during the late 1800's and the severe dry

conditions from the 1920's trough the 1930's in the reconstructed precipitation record are consistent with the annual unimpaired Sacramento River flow reconstruction from Meko *et al.* (2001) presented in Section 2.1.

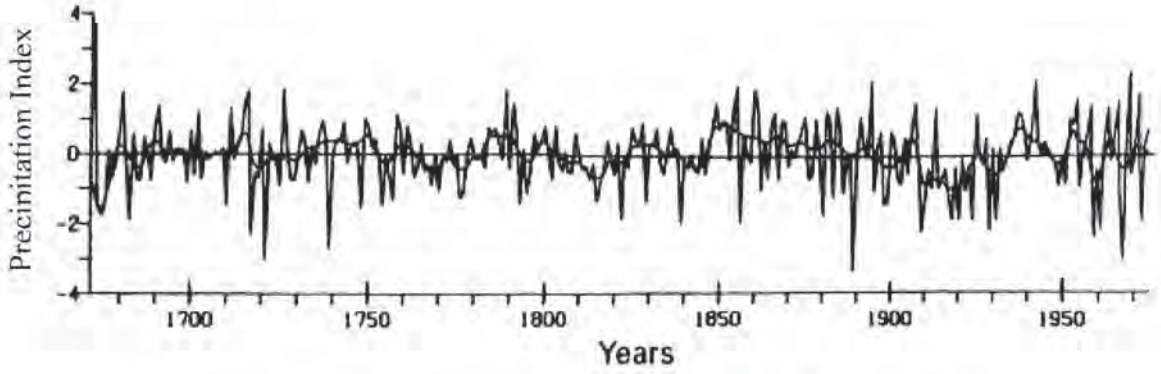


Figure B-1 – Reconstructed annual precipitation, 1675-1975
Data from Graumlich (1987). Precipitation index is presented in units of standard deviation from the 1899-1975 observed mean value.

Estimates of annual precipitation (Graumlich, 1987) and unimpaired runoff (Meko *et al.*, 2001a) from tree ring analysis are used in this study to provide hydrological context, indicating the relative hydrology (e.g. wet or dry) of a specific year and surrounding decade. The reconstructed hydrological data are not used to estimate salinity intrusion for two reasons. First, the seasonal distribution of hydrology is critical in determining salinity variability; two years with the same total annual flow could have significantly different salinity intrusion due to the timing of the flow (Knowles, 2000). Second, since 1850, anthropogenic modifications to the landscape and river flows alter the hydrodynamic response to freshwater flow, somewhat decoupling the unimpaired hydrology from the downstream response (i.e. salinity intrusion).

Malamud-Roam *et al.* (2005) and Goman *et al.* (2008) review paleoclimate as it relates to San Francisco Bay. Generally, they found that paleoclimatic studies showed that a wetter (and fresher) period existed from about 4000 BP to about 2000 BP. In the past 2,000 years, the climate has been cooling and becoming drier, with several extreme periods, including decades-long periods of very wet conditions and century-long periods of drought. As discussed in the next section, the century-long periods of drought are found in paleosalinity records in Suisun Bay and Rush Ranch in Suisun Marsh, but are much less evident in Browns Island, indicating a predominately freshwater marsh throughout the Delta. Citing Meko *et al.* (2001), they note that only one period had a six-year drought more severe than the 1928-1934 period: a seven-year drought ending in 984 CE. They also not the most extreme dry year was in 1580 CE, and state that it was almost certainly drier than 1977. On the whole, however, the last 600 years have been a generally wet period. This is reflected in the salinity records discussed in the next section.

B.3. Reconstructed Salinity in the Bay-Delta

Starratt (2001) reconstructed historical salinity variability at Rush Ranch, in the northwestern Suisun Marsh, over the last 3,000 years by examining diatoms from sediment cores. The taxa were classified according to their salinity preference: freshwater (< 2‰), freshwater and brackish water (0‰ to 30‰), brackish (2‰ to 30‰), brackish and marine (2‰ to > 30‰), and marine (> 30‰). Based on the composition of the diatom assemblages, Starrat identified centennial-scale salinity cycles (Table B-2).

Table B-2 – Salinity Intervals over the last 3,000 years at Rush Ranch
Salinity intervals determined from the diatom populations in a sediment core in northwestern Suisun Marsh.

Approximate Years	*Type of Interval* [a]
1850 CE – present	[not classified]
1250 CE – 1850 CE	fresh
250 CE – 1250 CE	brackish
500 BCE – 250 CE	fresh
1000 BCE – 500 BCE	brackish

[a] Classification according to Starratt (2001)

These results correspond well to other paleoclimatic reconstructions. The most recent broad-scale freshwater interval roughly corresponds to the Little Ice Age, and the most recent brackish interval corresponds to the Medieval Warm Period.

Starratt notes that the post-1850 interval indicates an increase in the percentage of diatoms that prefer brackish and marine salinities compared to the last freshwater interval, indicating an increase in salinity during the last 150 years, in comparison to the previous 600 years. During the post-1850 period, diatoms that prefer "marine" environments constitute as much as 50% of the total diatom population, a percentage that is at or above that of any other period. During the most recent years, "freshwater" assemblages constitute about 20% of the total population, a percentage that is only about 10% higher than the most recent *brackish* interval from 250 to 1250 CE.

Malamud-Roam *et al.* (2006) compared reconstructed salinity records for the past three thousand years from four locations (three tidal marsh locations and one location in the Bay) in the Bay-Delta region (Figure B-2(a)). Figure B-2(b) shows several periods with higher than average salinity (e.g., 1600-1300 and 1000-800 BP and 1900 CE to present) and several periods with lower than average salinity (e.g., 1300 to 1200 BP and 150 to 100 BP). These paleosalinity records are consistent with each other and with the paleoclimatic records of river flow and salinity presented in Section 2.

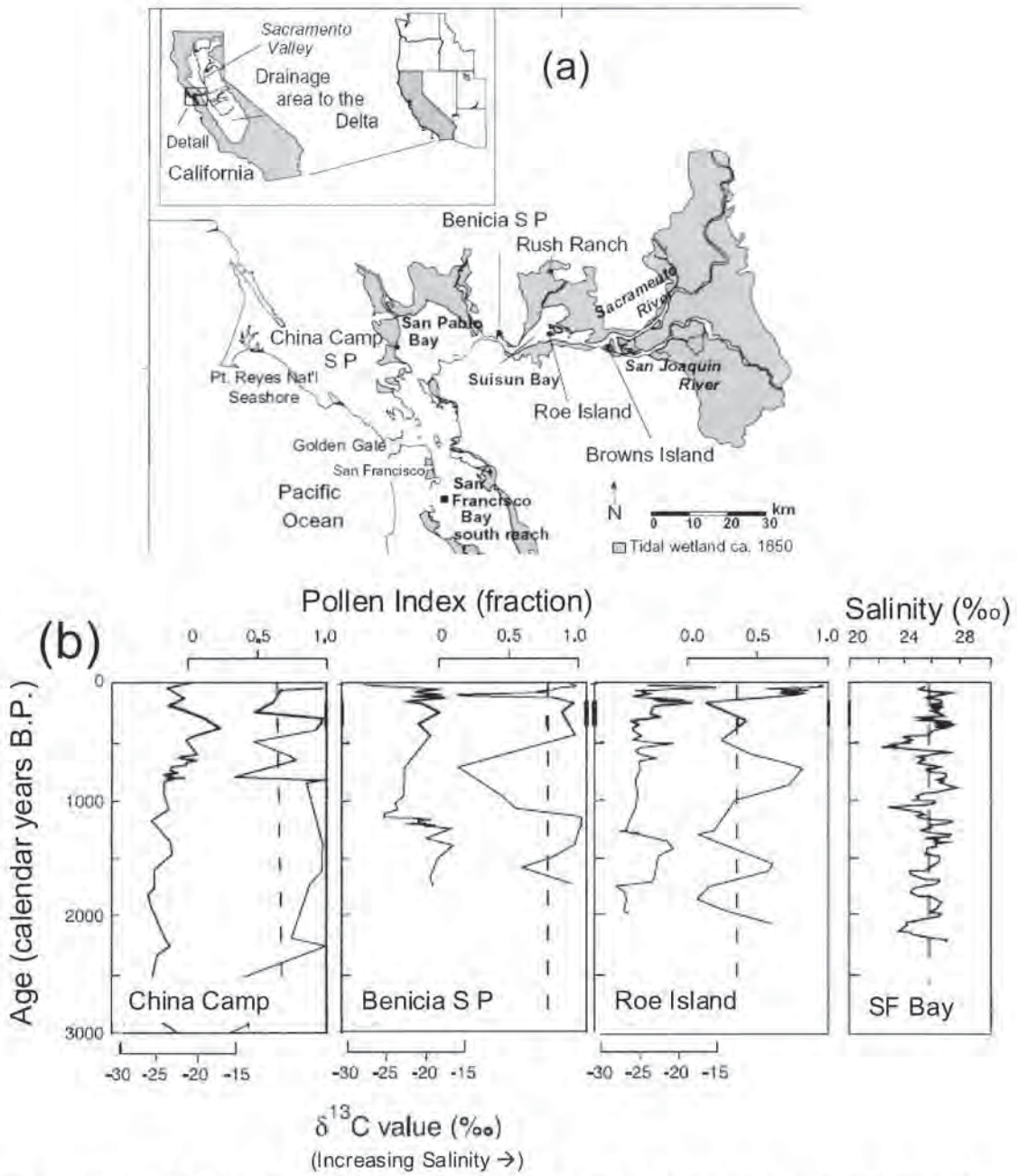


Figure B-2 – Paleosalinity records at selected sites in the San Francisco Estuary

(a) location of the three tidal marsh sites (China Camp, Benicia State Park and Roe Island) and one site in the Estuary (Oyster Point in San Francisco Bay) where sediment cores were obtained. (b) time series for the pollen index (ranging from 0 to 1, higher values corresponding to higher salinity) and the δ13C values at the tidal marsh sites; salinity at Oyster Point, San Francisco Bay (inferred from δ13O values) is also shown. The broken line shows the estimated mean pollen index prior to European disturbance. (modified from Malamud-Roam and Ingram (2004) and Malamud-Roam et al. (2006))

Appendix C. Quantitative Hydrological Observations

Long-term records of river runoff are useful in understanding hydroclimatic variations. Section 3.1 discusses the long-term variations of the unimpaired Sacramento River runoff and unimpaired San Joaquin River runoff. The estimates of these variables from early 1900's to the present are available on the internet . Estimates prior to the early 1900's (late 1800's to early 1900's) were obtained from a 1923 California Department of Public Works report (DPW, 1923). Table C-1 through Table C-4 present estimates of Sacramento River runoff and San Joaquin River runoff for the period of 1872-2008, obtained from DPW (1923) and http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST.

The unimpaired Sacramento River runoff is the sum of the flows from the Sacramento River at Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, and the American River inflow to Folsom Lake. The unimpaired San Joaquin River runoff is the sum of the flows from the Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River inflow to Millerton Lake.

Table C-1 – Annual unimpaired Sacramento River runoff for 1872-1905
Data source: DPW (1923

Water Year	Sacramento River @ Bend Bridge	Feather River @ Lake Oroville	Yuba River @ Smartville	American River @ Folsom Lake	Sacramento River Runoff
	Acre-feet (AF)				Million acre-feet (MAF)
1872	10,200,000	7,254,000	4,352,000	4,215,600	**26.0**
1873	4,780,000	3,347,000	1,638,400	1,862,200	**11.6**
1874	7,300,000	5,571,000	3,340,800	3,079,800	**19.3**
1875	4,390,000	2,747,000	1,561,600	1,391,600	**10.1**
1876	14,500,000	6,867,000	3,594,000	4,450,900	**29.4**
1877	9,870,000	2,437,000	1,292,800	1,289,200	**14.9**
1878	17,800,000	4,836,000	2,528,000	2,721,700	**27.9**
1879	8,380,000	5,513,000	2,796,800	3,304,900	**20.0**
1880	12,300,000	7,061,000	3,641,600	4,502,100	**27.5**
1881	15,400,000	5,610,000	3,104,000	3,540,300	**27.7**
1882	8,000,000	4,797,000	2,150,400	3,264,000	**18.2**
1883	6,670,000	3,714,000	1,804,800	2,169,200	**14.4**
1884	11,400,000	6,190,000	3,104,000	4,103,000	**24.8**
1885	6,460,000	3,482,000	2,304,000	1,780,400	**14.0**
1886	14,400,000	6,384,000	3,174,400	3,918,900	**27.9**
1887	6,670,000	2,611,000	1,561,600	1,862,200	**12.7**
1888	5,430,000	2,669,000	998,400	1,575,700	**10.7**
1889	10,600,000	5,126,000	1,612,800	1,903,200	**19.2**
1890	22,700,000	12,090,000	6,176,000	7,725,200	**48.7**

Water Year	Sacramento River @ Bend Bridge	Feather River @ Lake Oroville	Yuba River @ Smartville	American River @ Folsom Lake	Sacramento River Runoff
1891	6,460,000	3,482,000	1,747,200	1,944,100	**13.6**
1892	7,250,000	5,416,000	1,945,600	2,568,200	**17.2**
1893	12,400,000	7,177,000	3,488,000	4,399,800	**27.5**
1894	8,640,000	4,410,000	2,432,000	3,304,900	**18.8**
1895	12,300,000	7,177,000	4,160,000	4,737,400	**28.4**
1896	11,343,200	7,738,000	3,641,600	3,857,500	**26.6**
1897	10,391,400	5,610,000	3,040,000	3,632,400	**22.7**
1898	5,135,800	2,805,000	1,184,000	1,186,900	**10.3**
1899	5,977,400	3,288,000	1,984,000	2,362,600	**13.6**
1900	8,712,500	6,500,000	2,956,800	3,683,500	**21.9**
1901	9,020,900	6,229,000	2,854,400	3,714,200	**21.8**
1902	11,380,600	4,468,000	2,432,000	3,079,800	**21.4**
1903	9,941,800	4,483,500	2,368,000	3,038,900	**19.8**
1904	16,095,800	9,377,000	4,101,800	5,249,000	**34.8**
1905	10,775,200	4,529,200	2,403,500	2,050,000	**19.8**

Table C-2 – Annual unimpaired Sacramento River runoff for 1906-2009

Data Source: http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST

Water Year	Sacramento River Runoff (MAF)	Water Year	Sacramento River Runoff (MAF)	Water Year	Sacramento River Runoff (MAF)	Water Year	Sacramento River Runoff (MAF)
1906	26.7	1936	17.4	1966	13.0	1996	22.3
1907	33.7	1937	13.3	1967	24.1	1997	25.4
1908	14.8	1938	31.8	1968	13.6	1998	31.4
1909	30.7	1939	8.2	1969	27.0	1999	21.2
1910	20.1	1940	22.4	1970	24.1	2000	18.9
1911	26.4	1941	27.1	1971	22.6	2001	9.8
1912	11.4	1942	25.2	1972	13.4	2002	14.6
1913	12.9	1943	21.1	1973	20.1	2003	19.3
1914	27.8	1944	10.4	1974	32.5	2004	16.0
1915	23.9	1945	15.1	1975	19.2	2005	18.6
1916	24.1	1946	17.6	1976	8.2	2006	32.1
1917	17.3	1947	10.4	1977	5.1	2007	10.3
1918	11.0	1948	15.8	1978	23.9	2008	10.3
1919	15.7	1949	12.0	1979	12.4	2009	12.9
1920	9.2	1950	14.4	1980	22.3		
1921	23.8	1951	23.0	1981	11.1		
1922	18.0	1952	28.6	1982	33.4		
1923	13.2	1953	20.1	1983	37.7		
1924	5.7	1954	17.4	1984	22.4		
1925	16.0	1955	11.0	1985	11.0		
1926	11.8	1956	29.9	1986	25.8		
1927	23.8	1957	14.9	1987	9.3		
1928	16.8	1958	29.7	1988	9.2		
1929	8.4	1959	12.1	1989	14.8		
1930	13.5	1960	13.1	1990	9.3		
1931	6.1	1961	12.0	1991	8.4		
1932	13.1	1962	15.1	1992	8.9		
1933	8.9	1963	23.0	1993	22.2		
1934	8.6	1964	10.9	1994	7.8		
1935	16.6	1965	25.6	1995	34.6		

Table C-3 – Annual unimpaired San Joaquin River runoff for 1872-1900

Data source: DPW (1923)

Water Year	Stanislaus River @ New Melones Lake	Tuolumne River @ New Don Pedro Reservoir	Merced River @ Lake McClure	San Joaquin River @ Millerton Lake	San Joaquin River Runoff
	units of acre-feet (AF)				units of million acre-feet (MAF)
1872	1,860,000	2,624,000	1,511,000	2,627,000	**8.6**
1873	959,000	1,543,000	769,000	1,122,000	**4.4**
1874	970,000	1,576,000	791,000	1,862,000	**5.2**
1875	482,000	982,000	439,000	887,000	**2.8**
1876	2,930,000	4,059,000	2,384,000	2,862,000	**12.2**
1877	408,900	561,000	220,000	809,000	**2.0**
1878	1,570,000	2,286,000	1,274,000	2,218,000	**7.3**
1879	823,000	1,353,000	659,000	470,000	**3.3**
1880	1,390,000	2,071,000	1,132,000	3,349,000	**7.9**
1881	970,000	1,576,000	791,000	2,740,000	**6.1**
1882	944,000	1,526,000	764,000	1,000,000	**4.2**
1883	1,020,000	1,600,000	813,000	1,392,000	**4.8**
1884	2,250,000	3,152,000	1,840,000	5,732,000	**13.0**
1885	582,000	1,097,000	505,000	1,218,000	**3.4**
1886	2,070,000	2,929,000	1,692,000	5,211,000	**11.9**
1887	619,000	1,139,000	538,000	1,479,000	**3.8**
1888	540,000	1,048,000	478,000	957,000	**3.0**
1889	718,000	1,262,000	599,000	1,574,000	**4.2**
1890	3,580,000	5,099,000	2,955,000	4,349,000	**16.0**
1891	959,000	1,543,000	769,000	1,227,000	**4.5**
1892	1,050,000	1,650,000	846,000	1,931,000	**5.5**
1893	2,150,000	3,036,000	1,758,000	1,914,000	**8.9**
1894	1,860,000	2,624,000	1,511,000	1,331,000	**7.3**
1895	2,700,000	3,795,000	2,236,000	2,786,700	**11.5**
1896	1,380,000	1,588,100	1,110,000	1,985,700	**6.1**
1897	1,920,000	2,437100	1,566,000	2,219,700	**8.1**
1898	498,000	960,500	450,000	922,300	**2.8**
1899	1,030,000	1,334,700	824,000	1,269,500	**4.5**
1900	1,350,000	1,628,100	1,099,000	1,343,000	**5.4**

Table C-4 – Annual unimpaired San Joaquin River runoff for 1901-2009

Data Source: http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST

Water Year	San Joaquin River Runoff (MAF)	Water Year	San Joaquin River Runoff (MAF)	Water Year	San Joaquin River Runoff (MAF)	Water Year	San Joaquin River Runoff (MAF)
1901	9.4	1931	1.7	1961	2.1	1991	3.2
1902	5.1	1932	6.6	1962	5.6	1992	2.6
1903	5.7	1933	3.3	1963	6.2	1993	8.4
1904	7.6	1934	2.3	1964	3.1	1994	2.5
1905	5.3	1935	6.4	1965	8.1	1995	12.3
1906	12.4	1936	6.5	1966	4.0	1996	7.2
1907	11.8	1937	6.5	1967	10.0	1997	9.5
1908	3.3	1938	11.2	1968	2.9	1998	10.4
1909	9.0	1939	2.9	1969	12.3	1999	5.9
1910	6.6	1940	6.6	1970	5.6	2000	5.9
1911	11.5	1941	7.9	1971	4.9	2001	3.2
1912	3.2	1942	7.4	1972	3.6	2002	4.1
1913	3.0	1943	7.3	1973	6.5	2003	4.9
1914	8.7	1944	3.9	1974	7.1	2004	3.8
1915	6.4	1945	6.6	1975	6.2	2005	9.2
1916	8.4	1946	5.7	1976	2.0	2006	10.4
1917	6.7	1947	3.4	1977	1.1	2007	2.5
1918	4.6	1948	4.2	1978	9.7	2008	3.5
1919	4.1	1949	3.8	1979	6.0	2009	5.0
1920	4.1	1950	4.7	1980	9.5		
1921	5.9	1951	7.3	1981	3.2		
1922	7.7	1952	9.3	1982	11.4		
1923	5.5	1953	4.4	1983	15.0		
1924	1.5	1954	4.3	1984	7.1		
1925	5.5	1955	3.5	1985	3.6		
1926	3.5	1956	9.7	1986	9.5		
1927	6.5	1957	4.3	1987	2.1		
1928	4.4	1958	8.4	1988	2.5		
1929	2.8	1959	3.0	1989	3.6		
1930	3.3	1960	3.0	1990	2.5		

Appendix D. Instrumental Observations of Salinity

In Section 3, historical variations in the net quantity of water flowing from the Delta to the Suisun Bay (called net Delta outflow or NDO) and salinity in the western Delta were discussed using available observations and a suite of commonly used modeling tools. This section presents additional information on the historical variations of NDO and salinity in the western Delta and Suisun Bay discussed in Section 3.

D.1. Introduction

D Salinity nits

Salinity is specified in this report either as electrical conductivity (EC, in units of microSiemens per centimeter, or µS/cm) or as a concentration of chloride in water (in units of milligrams of chloride per liter of water, or mg/L). Conversion between EC and chloride concentration is accomplished using site-specific empirical relationships developed by Kamyar Guivetchi (DWR, 1986). Table D-1 presents a sample of typical EC concentrations and their approximate equivalent chloride concentrations.

Table D-1 – Typical electrical conductivity (EC) and equivalent chloride concentration

Electrical Conductivity (µS/cm)	Chloride (mg/L)
350	50
525	100
1,050	250
1,900	500
2,640	700
3,600	1,000

Qualitative terms such as "fresh" and "brackish" are often used to describe relative salinity. The quantitative thresholds of average chloride concentration that distinguish fresh water from brackish water and the averaging time period vary among studies. For instance, chloride concentrations of 1,000 mg/L, 700 mg/L, and 50 mg/L have been used by different studies (Table D-2).

D e poral and Spatial ariability of Salinity

The main variability in salinity along the length of the Bay-Delta system is due to the gradient from saline Pacific Ocean water (EC of approximately 50,000 µS/cm) to fresh water of the Central Valley rivers (EC of approximately 100 µS/cm). However, the salinity in the Bay-Delta varies both in space and time. It is important to clarify which time scales and measurement locations are being used when comparing and discussing salinity trends.

Table D-2 – Metrics used to distinguish between "fresh" and "brackish" water

Description	Sample timing or averaging	Salinity Value	
		Chloride (mg/L)	EC (µS/cm)
Isohalines in Delta Atlas (DWR, 1995)	Annual maximum of the daily maximum	1,000 mg/L	3,700 µS/cm
X2 position (Jassby *et al.*, 1995)	Daily average (or a 14-day average)	700 mg/L	2,640 µS/cm
Barge travel by C&H[4]	Monthly average of the daily maximum	50 mg/L	350 µS/cm

Salinity in the western Delta is strongly influenced by tides. The hourly or daily variability of salinity can be much larger than the seasonal or annual variability. For instance, during the fall of 1999 (following a relatively wet year[5]), hourly EC in the San Joaquin River at Antioch varied by about 6,000 µS/cm (from about 3,000 µS/cm to 9,000 µS/cm) while the daily-averaged EC for all of 1999 ranged from about 100 µS/cm to 6,000 µS/cm (Figure D-1).

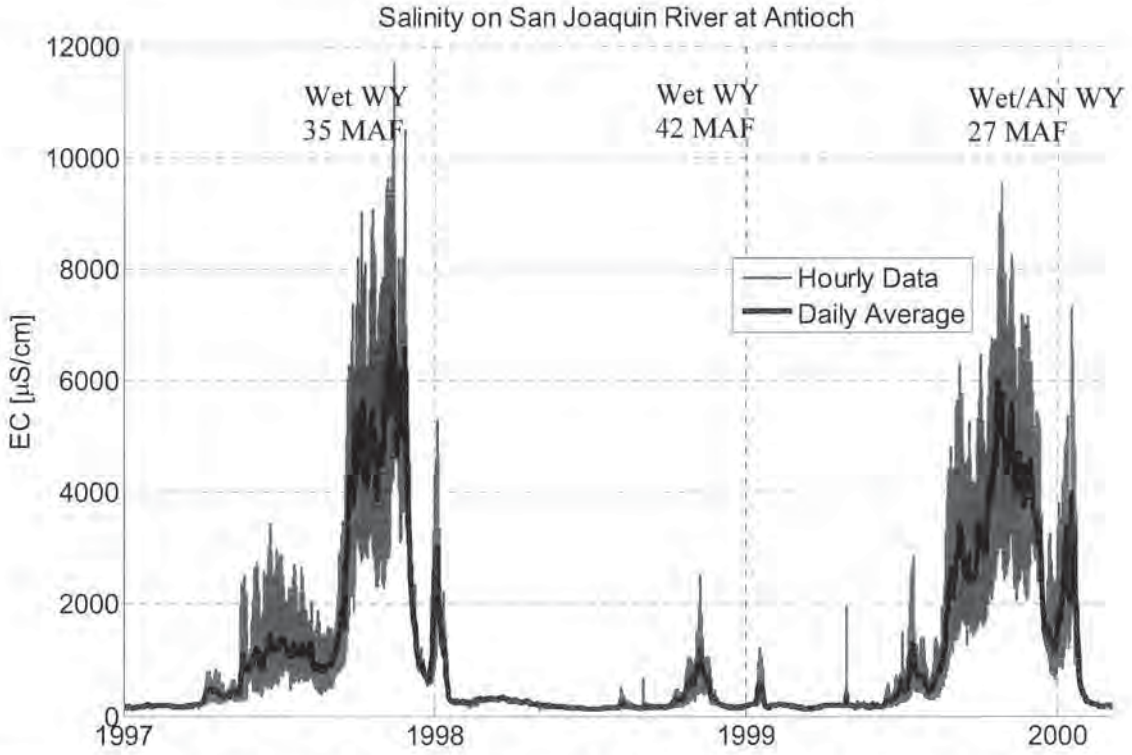


Figure D-1 – Hourly and daily salinity variability in the San Joaquin River at Antioch
Total annual unimpaired Sacramento River flow and water year type is indicated for each water year. Data Source: IEP Data Vaults (http://www.iep.ca.gov/dss/)

[4] The California & Hawaiian Sugar Refining Corporation in Crockett (C&H) obtained its freshwater supply from barges traveling up the Sacramento and San Joaquin Rivers, generally twice a day beginning in 1908 (DPW, 1931).
[5] Water year 1999 was classified as wet using the Sacramento Valley 40-30-30 index and above-normal using the San Joaquin Valley 60-20-20 index; indices are defined in D-1641.

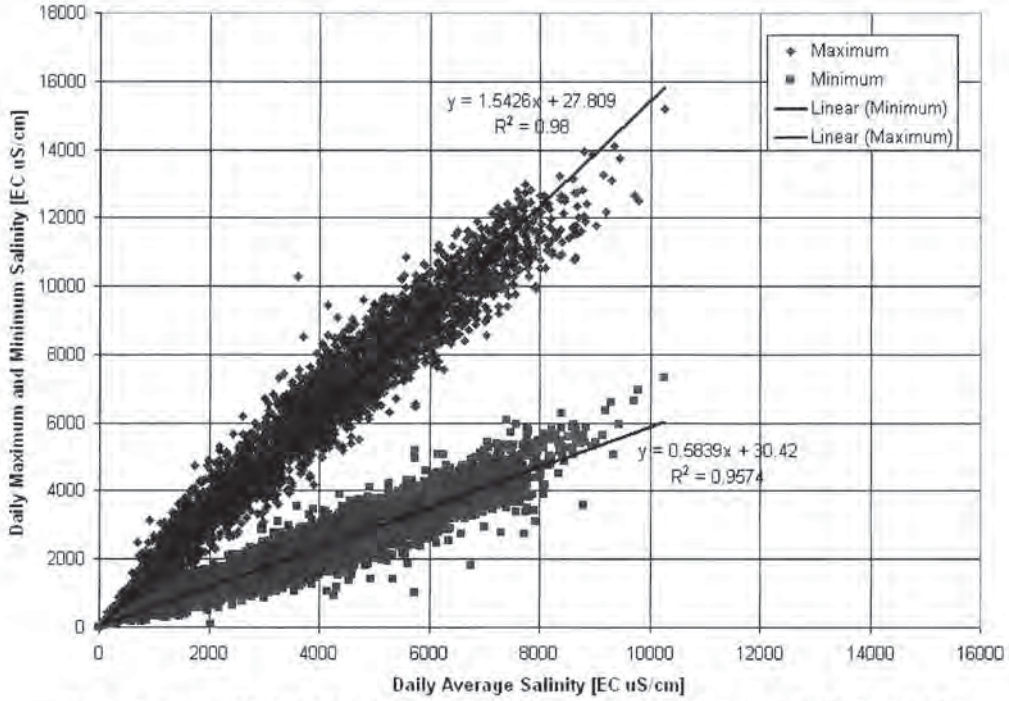


Figure D-2 – Tidal Variability in Salinity at Antioch (1967 to 1992)

Data Source: IEP Data Vaults (http://www.iep.ca.gov/dss/)

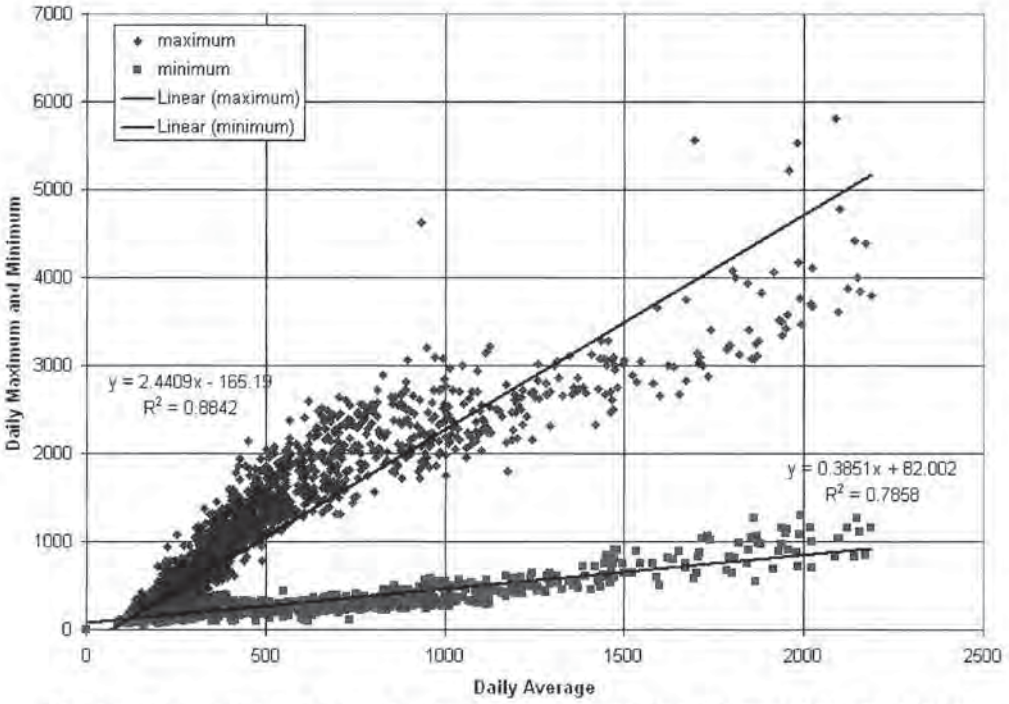


Figure D-3 – Tidal Variability in Salinity at Rio Vista (1967 to 1992)

Data Source: IEP Data Vaults (http://www.iep.ca.gov/dss/)

The high tide maximum, low tide minimum, and daily-averaged salinity at a given location are very different. As shown in Figure D-2, the daily maximum salinity in the San Joaquin River at Antioch can be double the daily-averaged salinity. Because of the large tidal variability in salinity, any comparisons of salinity observations should be at the same phase of the tide, or at least take into account tidal variability.

Similarly, as shown in Figure D-3, the daily maximum salinity in the Sacramento River at Rio Vista can be 170-400% of the daily average salinity. The daily minimum at Rio Vista may be 10-65% of the daily average.

D.2. Variations in the Spatial Salinity Distribution

Observations examined in this section and Section 3.3 include records from the early 1900's from the California & Hawaiian Sugar Refining Corporation in Crockett (C&H) and the long-term monitoring data from the Interagency Ecological Program (IEP). Estimates of salinity at specific locations of interest were obtained from DWR's DSM2 model and Contra Costa Water District's salinity-outflow model (also known as the G-model) (Denton, 1993). Estimates of salinity intrusion were obtained using the K-M equation (Kimmerer and Monismith, 1992).

D Distance to Freshwater fro Crockett

The California & Hawaiian Sugar Refining Corporation in Crockett (C&H) obtained its freshwater supply from barges traveling up the Sacramento and San Joaquin Rivers, generally twice a day beginning in 1905 through 1929 or later (DPW, 1931). The salinity information recorded by C&H is the most detailed salinity record available prior to the intensive salinity monitoring by the State of California, which started in 1920. This section presents a comparison of the salinity observations of C&H with recent monitoring data and modeling results to determine how the managed salinity regime of the late 20th Century compares to the salinity regime of the early 1900's.

Data Sources and Methods

C&H data: C&H operations required water with less than 50 mg/L chloride concentration. According to DPW (1931), the C&H barges typically traveled up the river on flood tide and returned downstream on ebb tide. Since the maximum daily salinity for a given location in the river channel typically occurs about one to two hours after high slack tide, the distance traveled by the C&H barges represents approximately the daily maximum distance to 50 mg/L water from Crockett. The monthly minimum, average, and maximum distance traveled by C&H barges are shown in Figure D-4 and Figure D-5. For the following analysis, monthly averages of the C&H daily maximum distances were extracted from Figure D-5 for the period of 1908-1918 (after 1917, extensive salinity intrusion was reported and agricultural diversions reportedly started affecting flows into the Delta).

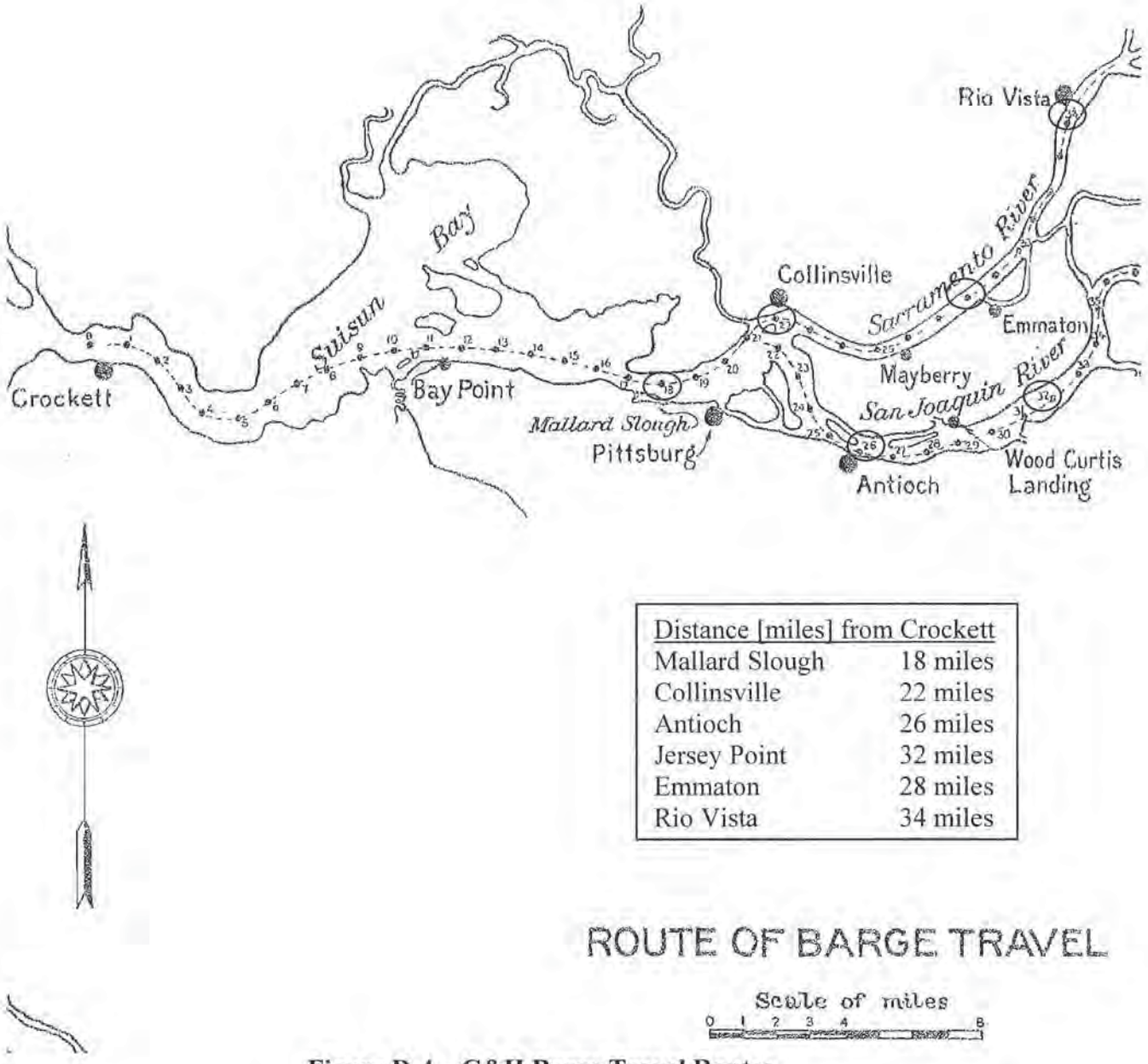


Figure D-4 – C&H Barge Travel Routes

Map adapted from DPW (1931). Red circles indicate locations of landmarks, with distance from Crockett listed in the inset box.

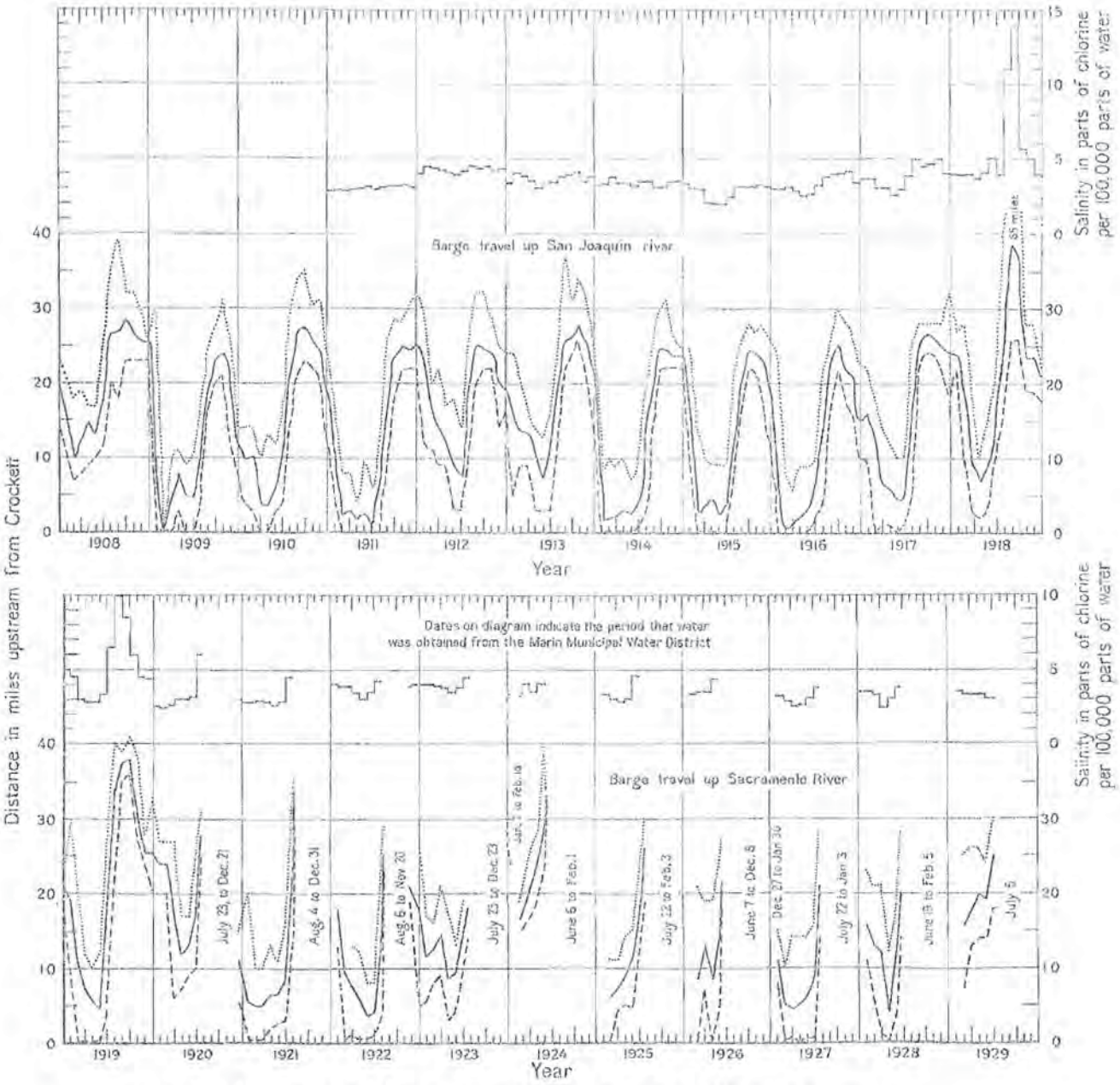


Figure D-5 – C&H Barge Travel and Quality of Water obtained

C&H barge travel up the San Joaquin River (1908 through 1918, top panel) and Sacramento River (1919 through 1929, bottom panel). The lower three lines on each panel (reference to the left axes) indicate the monthly minimum (dashed line), monthly maximum (dotted line), and monthly average (solid line) distance traveled by C&H barges to obtain their fresh water supply. The uppermost solid line on each panel (reference to the right axes) indicates the average monthly salinity of the water obtained by the barges. Figure adapted from DPW (1931)

From 1908 through 1917, C&H was able to obtain water with less than 50 mg/L chlorides within 30 miles of Crockett on average (below Jersey Point on the San Joaquin River). In 1918, the salinity of the water obtained by C&H barges had increased due to a combination of a lack of precipitation and upstream diversions (especially for newly introduced rice cultivation) (DPW, 1931). During August and September 1918, salinity exceeded 60 mg/L chloride, and the C&H barges traveled farther upstream than any time previously recorded.

In 1919, a wetter year than 1918, salinity was high for an even longer period of time, most likely due to increased upstream diversions for irrigation. Salinity exceeded 60 mg/L chloride during July, August, and September. Beginning in 1920, C&H abandoned the Sacramento and San Joaquin Rivers during the summer and fall seasons, replacing the water supply with a contract from Marin County. However, even during the driest years of the 1920's, C&H obtained water with less than 50 mg/L chloride below the confluence of the Sacramento and San Joaquin Rivers during a portion of every year.

Salinity observations from the Interagency Ecological Program (IEP): Long-term monitoring of electrical conductivity (EC) at multiple stations within the Bay and Delta began around 1964. Publicly-available daily-averaged data were obtained for this analysis from the Interagency Ecological Program (IEP) data vaults (Table D-3).

Table D-3 – Overview of long-term salinity observation records from IEP
(see http://www.iep.ca.gov/dss/)

Location	*Station*	*Source*	*Data*
Selby	RSAC045	USGS-BAY	Historical
Martinez	RSAC054	CDEC	Real-time
Benicia Bridge	RSAC056	USBR-CVO	Historical
Port Chicago	RSAC064	USBR-CVO	Historical
Mallard	RSAC075	CDEC	Real-time
Pittsburg	RSAC077	USBR-CVO	Historical
Collinsville	RSAC081	USBR-CVO	Historical
Emmaton	RSAC092	USBR-CVO	Historical
Rio Vista	RSAC101	USBR-CVO	Historical
		DWR-ESO-D1485C	Historical
Georgiana Slough	RSAC123	DWR-CD-SURFWATER	Historical
Greens Landing	RSAC139	USBR-CVO	Historical
Antioch	RSAN008	USBR-CVO	Historical
Jersey Pont	RSAN018	USBR-CVO	Historical
Bradford Point	RSAN024	USBR-CVO	Historical
San Andreas Landing	RSAN032	USBR-CVO	Historical

Delta Simulation Model (DSM2) Historical Simulation: The DSM2 historical simulation (1989-2006) was used to provide estimates of water quality to complement the limited field data from IEP. Because DSM2 has a very detailed spatial computational network covering the Delta and Suisun Bay, DSM2 can output much more detailed spatial and temporal salinity information than just the water quality at the IEP monitoring stations. DSM2 results include the daily-averaged EC at each model node along the lower Sacramento and San Joaquin Rivers. The location of the 350 μS/cm EC isohaline (corresponding to 50 mg/L chloride) was identified from the DSM2 results and compared with the equivalent C&H and IEP data.

Analysis time frame: The first decade of C&H barge travel (1908-1917) was a relatively wet period compared to the entire period of record (1906-2006) (Figure D-6). To compare conditions under similar hydrological conditions, specific recent decades (Figure D-6(a)) and select recent years (Figure D-6(b)) were selected that have comparable or slightly wetter hydrology than the C&H years. The periods 1966-1975 and 1995-2004 have similar annual unimpaired Sacramento River flow to the C&H data period (1908-1917) (see Figure D-6(a)). In addition, two wet years (1911 and 1916) and two dry years (1913 and 1918) selected from the C&H time period were compared with two wet years (1969 and 1998) and two dry years (1968 and 2002) from the IEP record.

Limitations of the analysis: The C&H data approximately represent the maximum daily salinity at a given location, whereas recent conditions (IEP or DSM2 data) are represented by the daily-averaged salinity. The estimates of the distance that must be traveled to reach fresh water under current conditions are, therefore, underestimated.

In addition, the C&H barges traveled up the San Joaquin River from 1908 through 1917, yet the equivalent travel distance for C&H barges under current conditions are estimated for the Sacramento River, and not the San Joaquin River. Under present-day conditions, the upstream distance to fresh water on the San Joaquin River is greater than for the Sacramento River, so this approach will also serve to underestimate the actual distance that C&H barges would have to travel under present-day conditions.

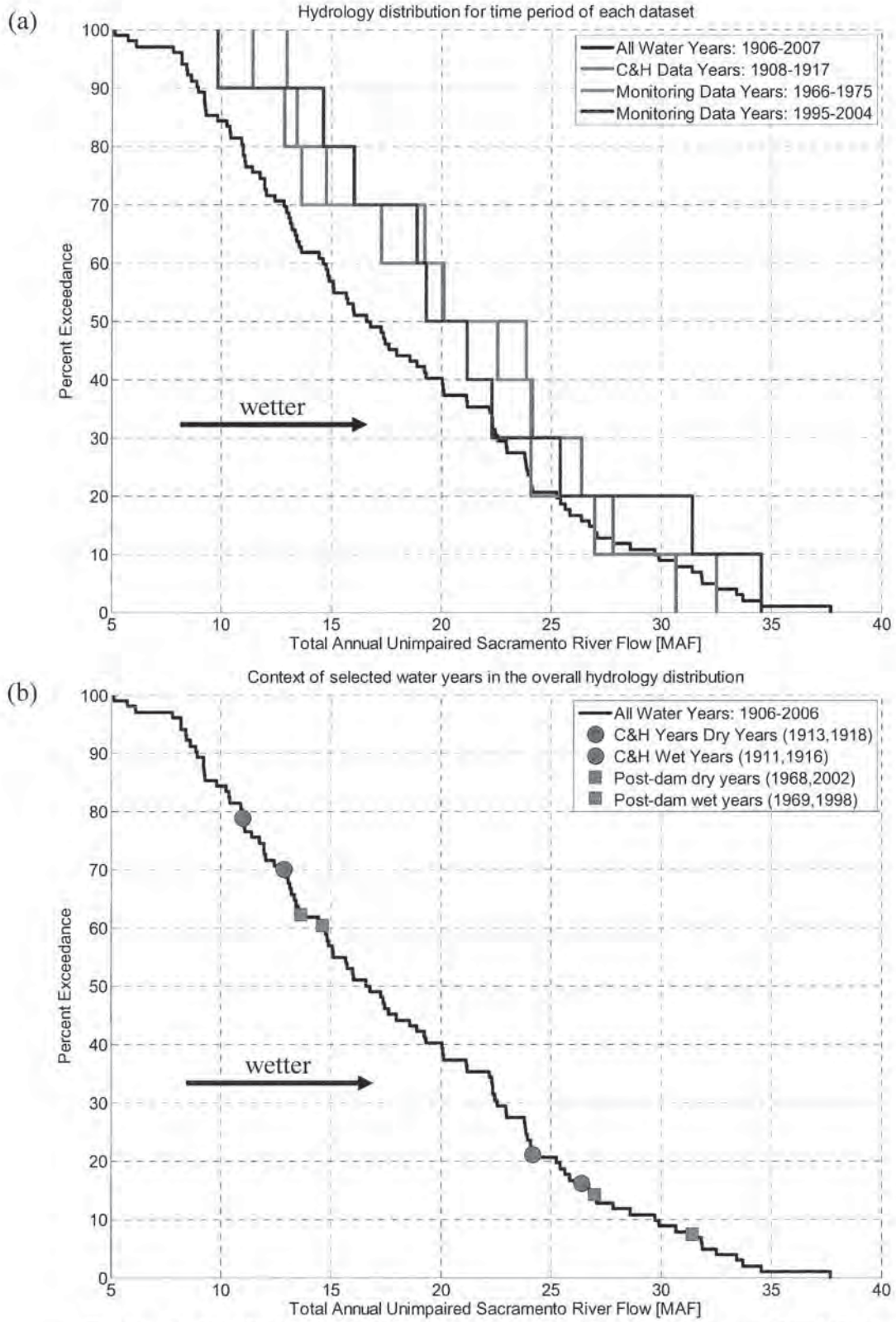


Figure D-6 – Hydrologic Context for Analysis of Distance to Fresh Water

(a) Hydrology distribution for water years 1906 to 2007, and select decades.

(b) Hydrology distribution for water years 1906 to 2007, with select water years shown for context.

Results and Discussion

Selected Wet Years

As shown in Figure D-7, the salinity patterns during the two selected C&H-era wet years, 1911 and 1916, are similar to each other. During these wet years, the location of 50 mg/L chloride water is west of Martinez for about 4-5 months (late February to early August in 1911 and from early February to late June in 1916). In contrast, during recent wet years 1969 and 1998, water with 50 mg/L chlorides or less was west of Martinez for only about 6 weeks in February and March. This comparison shows that in 1969 and 1998 the western Delta was saltier in the fall and spring than it was in 1911 and 1916, and salinity intrusion occurred much earlier in 1969 and 1998.

If barges were still traveling up the Sacramento River today to find fresh water, they would have to travel farther during the fall, spring, and summer than the C&H barges traveled during similar wet years. In 1916, fresh water retreated upstream about one month earlier than in 1911, possibly influenced by the increasing upstream diversions during 1911-1916 (see Figure 1-3). In recent years with even greater unimpaired runoff, fresh water retreats two to three months earlier than in 1916. Additionally, fresh water reaches Martinez for a much shorter period of time, about less than one month in recent years compared to four and five months during 1916 and 1911, respectively.

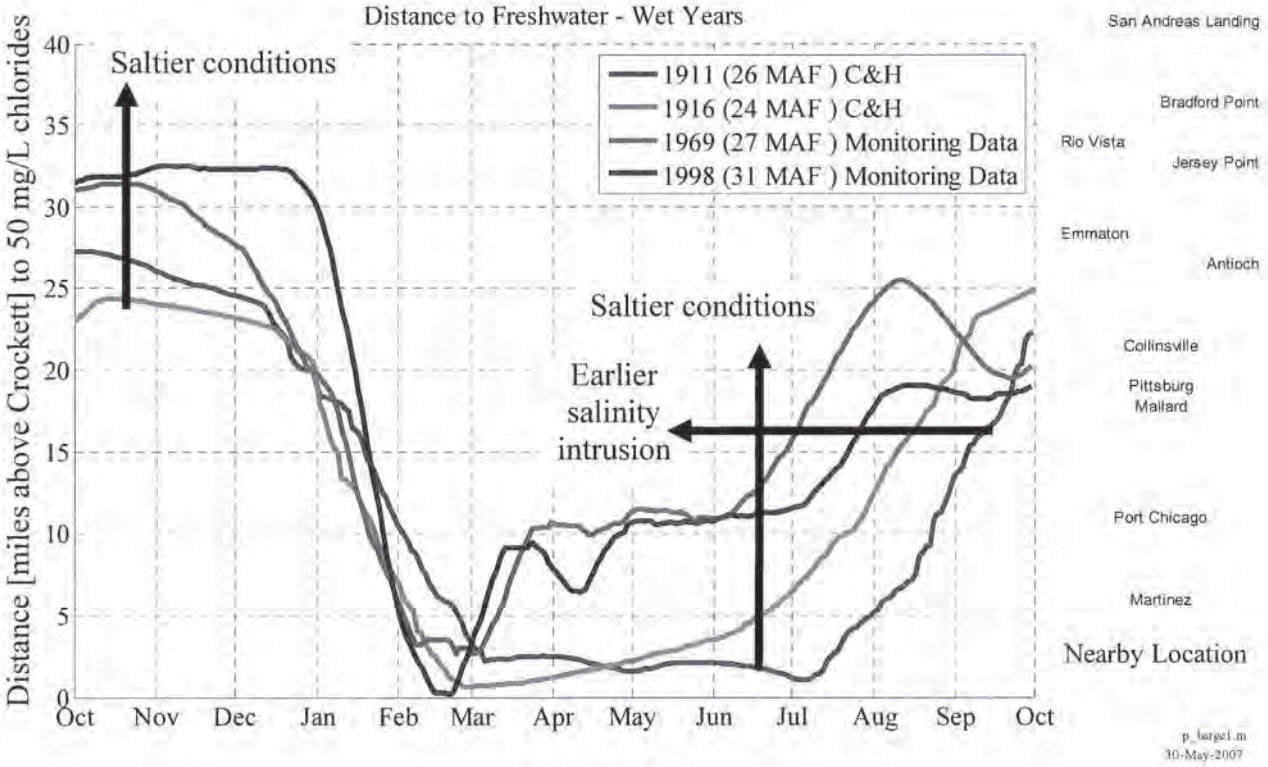
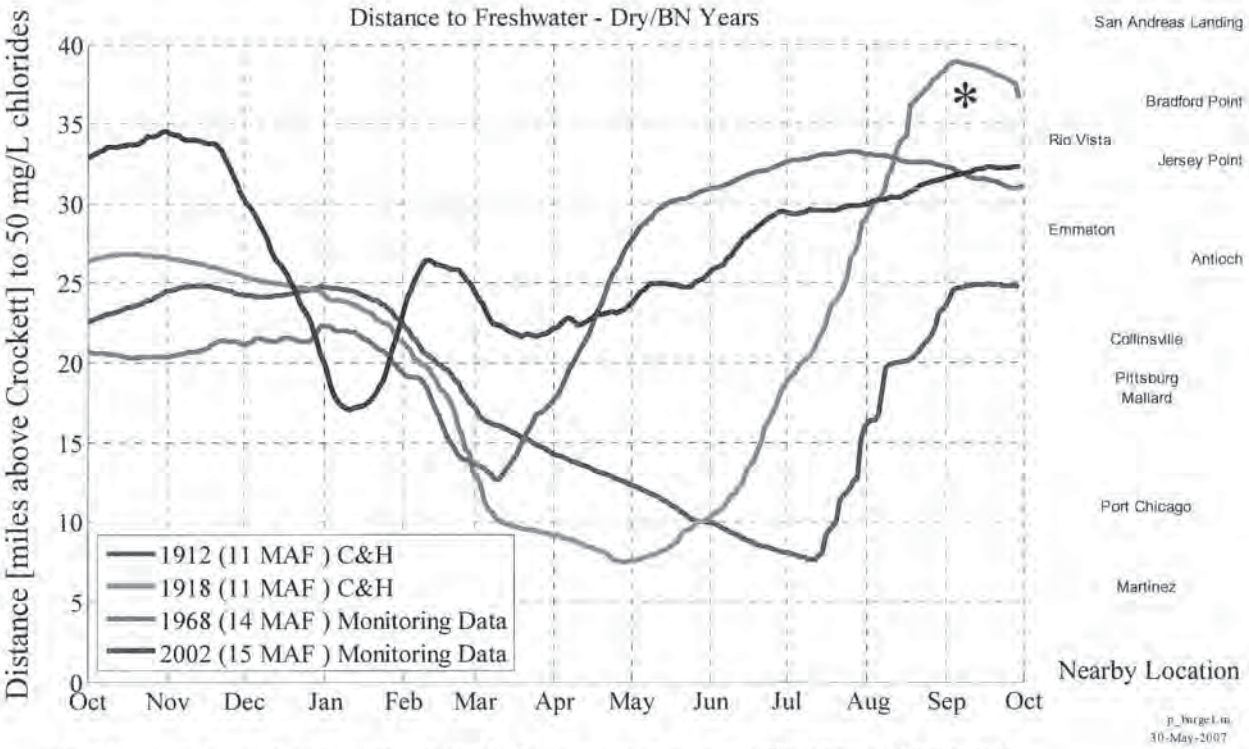


Figure D-7 – Distance to Fresh Water in Select Wet Years

Selected Dry Years

Figure D-8 shows that the most visible difference between the distance to fresh water in dry years of the early 1900's and more recent dry years is the substantial increase in distance to fresh water, particularly from April through June. This indicates the spring was much fresher during the dry years of the early 1900's, before large upstream reservoirs were built to capture the spring runoff. In dry and below-normal water years under today's conditions, barges would have to travel farther during spring, summer and fall than they traveled in the early 20th Century.

The C&H barge travel distance in the dry years of 1913 and 1918 are quite different, especially the additional 10 miles of distance to fresh water traveled in August and September of 1918. C&H recorded relatively high salinity (greater than 110 mg/L chlorides) above Bradford Point on the San Joaquin in 1918, which is greater than observed salinity on the Sacramento River near Rio Vista in similar water years. This may be partially explained by the development of the rice cultivation industry around 1912 (DPW, 1931) and increased upstream diversions when seasonal river flows were already low.



* During August and September 1918, average water quality obtained by C&H exceeded 110 mg/L chlorides

Figure D-8 – Distance to Fresh water in Select Dry or Below Normal Years

Figure D-9 shows the exceedance probabilities for distance traveled up the Sacramento River for different salinity levels. During 1908-1917, on a monthly-averaged basis, C&H barges had to travel above the confluence of the Sacramento and San Joaquin Rivers (approximately 22 miles above Crockett) about 26% of this time period to reach water with salinity less than

350 µS/cm EC (about 50 mg/L chlorides). In contrast, from 1995-2006, DSM2 simulations suggest that barges would have to travel above the confluence approximately 56% of the time to reach water with salinity of 350 µS/cm EC.

The location of the 50 mg/L chloride isohaline during 1908-1917 approximately corresponds to the location of X2 (2,640 µS/cm EC, or 700 mg/L chlorides) during 1995-2006 (Figure D-9). This is equivalent to more than a 7-fold increase in salinity from the early 1900's to the present day.

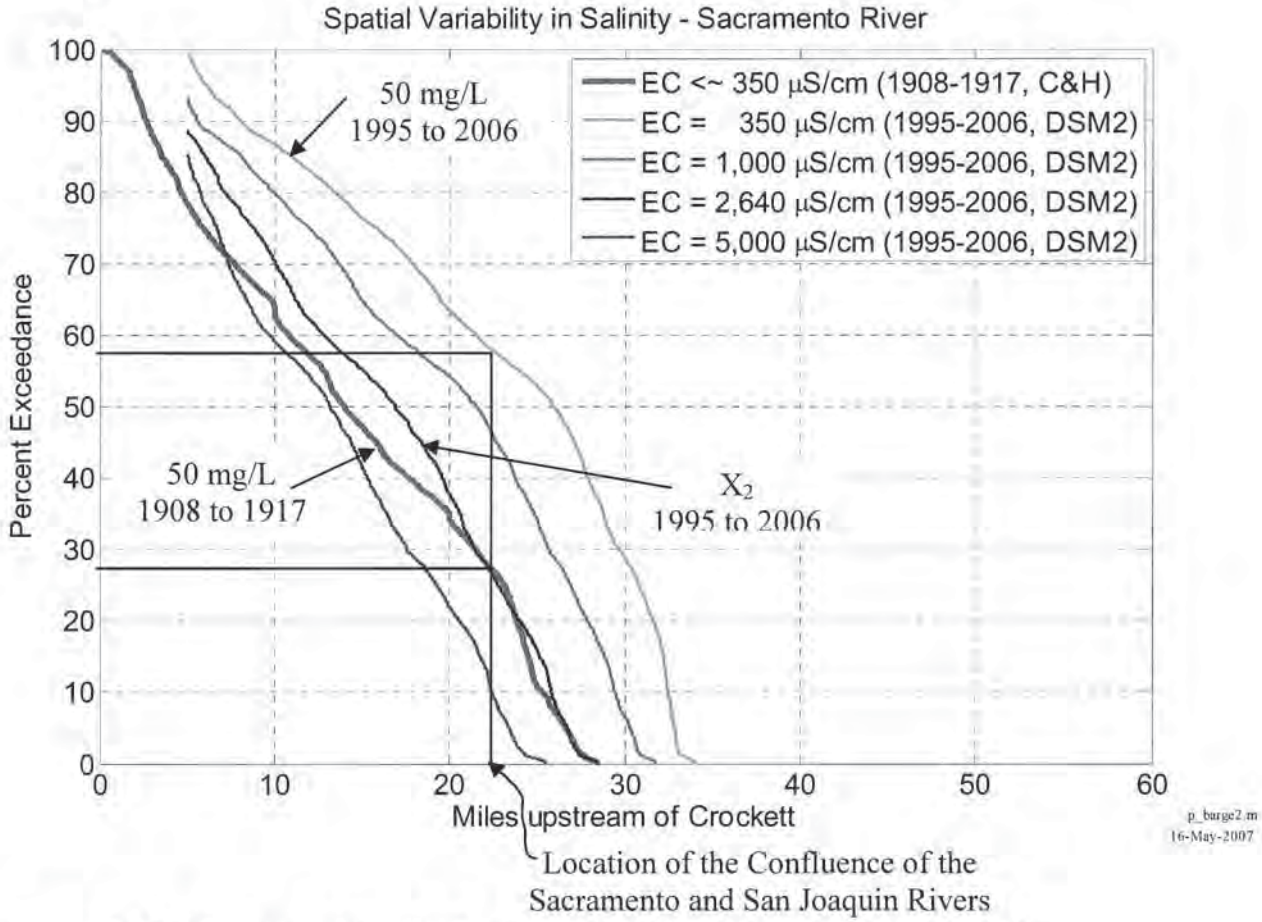


Figure D-9 – Distance along the Sacramento River to Specific Salinity Values

D a i u Annual Salinity ntrusion Before and After arge-scale eservoir Construction

Figure D-10 shows maximum salinity intrusion during 1921-1943 (pre-CVP period), prior to the completion of the Shasta Dam of the Central Valley Project in 1945. Salinity intrusion is presented in terms of contours of 1,000 mg/L chlorides. Figure D-11 shows the maximum salinity intrusion during the post-CVP period of 1944-1990. These figures indicate the pre-CVP period experienced greater salinity intrusion than the post-CVP period, with seawater intruding farther into the Delta during 6 of the 24 pre-CVP years (1920, 1924, 1926, 1931, 1934, and 1939) than in any of the 47 years in the post-CVP period (1944-1990).

The extreme salinity intrusion during the pre-CVP period was due, in part, to relatively low runoff during these years. Meko *et al.* (2001a) determined that the period from 1917 through 1936 was the driest 20-year period in the past 400 years; this long-term drought encompassed 16 of the 24 years in the pre-CVP period. In addition, estimates of unimpaired runoff from the Sacramento River (obtained from http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST) indicate that the Sacramento River had 6 critical water years during the 24-year period of 1920-1943, whereas, the Sacramento River had only 4 critical water years during the 47-year period of 1944-1990.

Figure D-12 shows that the peak salinity intrusion during the pre-CVP period occurred between mid-August and mid-September, while peak salinity intrusion during the first portion of the the post-CVP period (1944-1960) occurred between late-July and late-August. Salinity intrusion during the pre-CVP period was not only affected by relatively low runoff, but also by extensive upstream diversions (DPW, 1931).

The salinity investigations of the pre-CVP era found that the extreme salinity intrusion was larger than any previous intrusions known to local residents and concluded the intrusion was due, in part, to the extensive upstream diversions. As observed in DPW (1931):

> "Under conditions of natural stream flow before upstream irrigation and storage developments occurred, the extent of saline invasion and the degree of salinity reached was much smaller than during the last ten to fifteen years." (DPW, 1931, page 15)
>
> "Beginning in 1917, there has been an almost unbroken succession of subnormal years of precipitation and stream flow which, in combination with increased irrigation and storage diversions from the upper Sacramento and San Joaquin River systems, has resulted in a degree and extent of saline invasion greater than has occurred ever before as far as known." (DPW, 1931, page 15)
>
> "The abnormal degree and extent of saline invasion into the delta during recent years since 1917 have been due chiefly to: first, subnormal precipitation and run-off with a subnormal amount of stream flow naturally available to the delta, and second, increased upstream diversions

> for irrigation and storage on the Sacramento and San Joaquin River systems, reducing the inflow naturally available to the delta. It is probable that the degree of salinity in the lower channels of the delta and the extent of saline invasion above the confluence of the Sacramento and San Joaquin rivers have been about doubled by reason of the second factor." (DPW, 1931, page 42)

Conclusions from DPW (1931) and similar investigations have been corroborated by paleosalinty studies (see Section 2.3), which indicate that Browns Island in the western Delta was a freshwater marsh for approximately 2,500 years until salinity intruded in the early 20th Century.

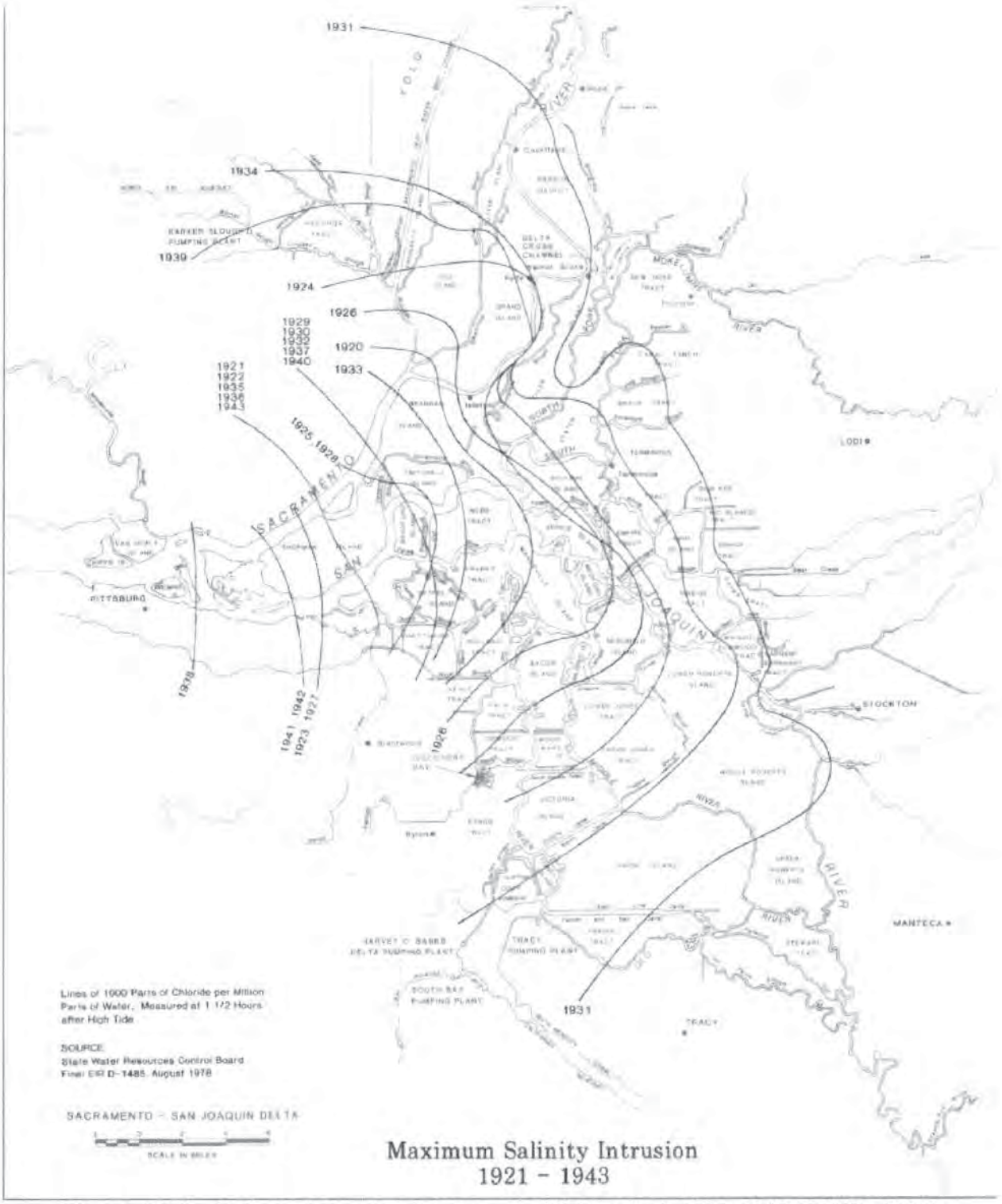


Figure D-10 – Salinity intrusion during pre-CVP period, 1921-1943 (DWR, 1995)

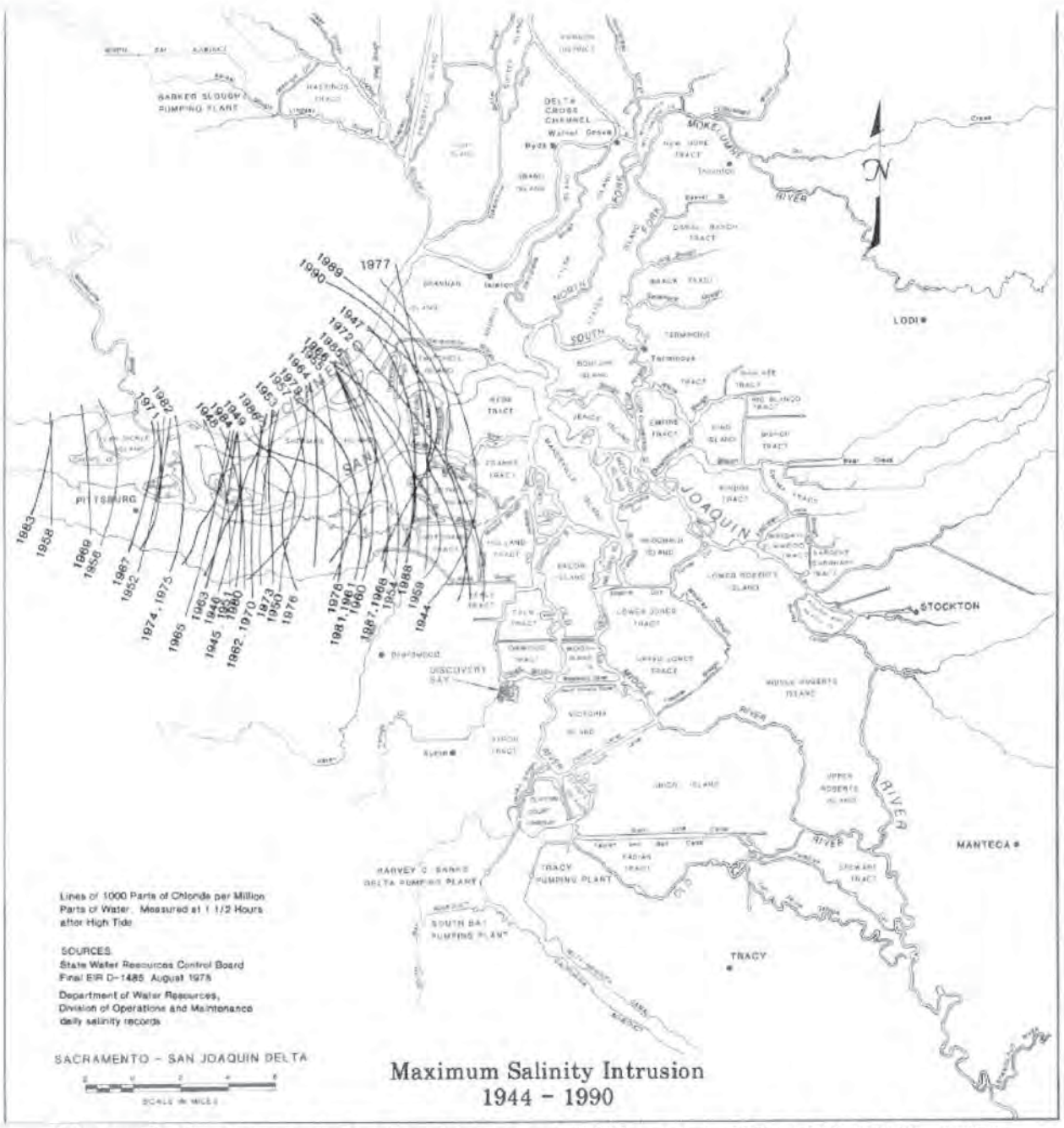


Figure D-11 – Salinity intrusion during post-CVP period, 1944-1990 (DWR, 1995)

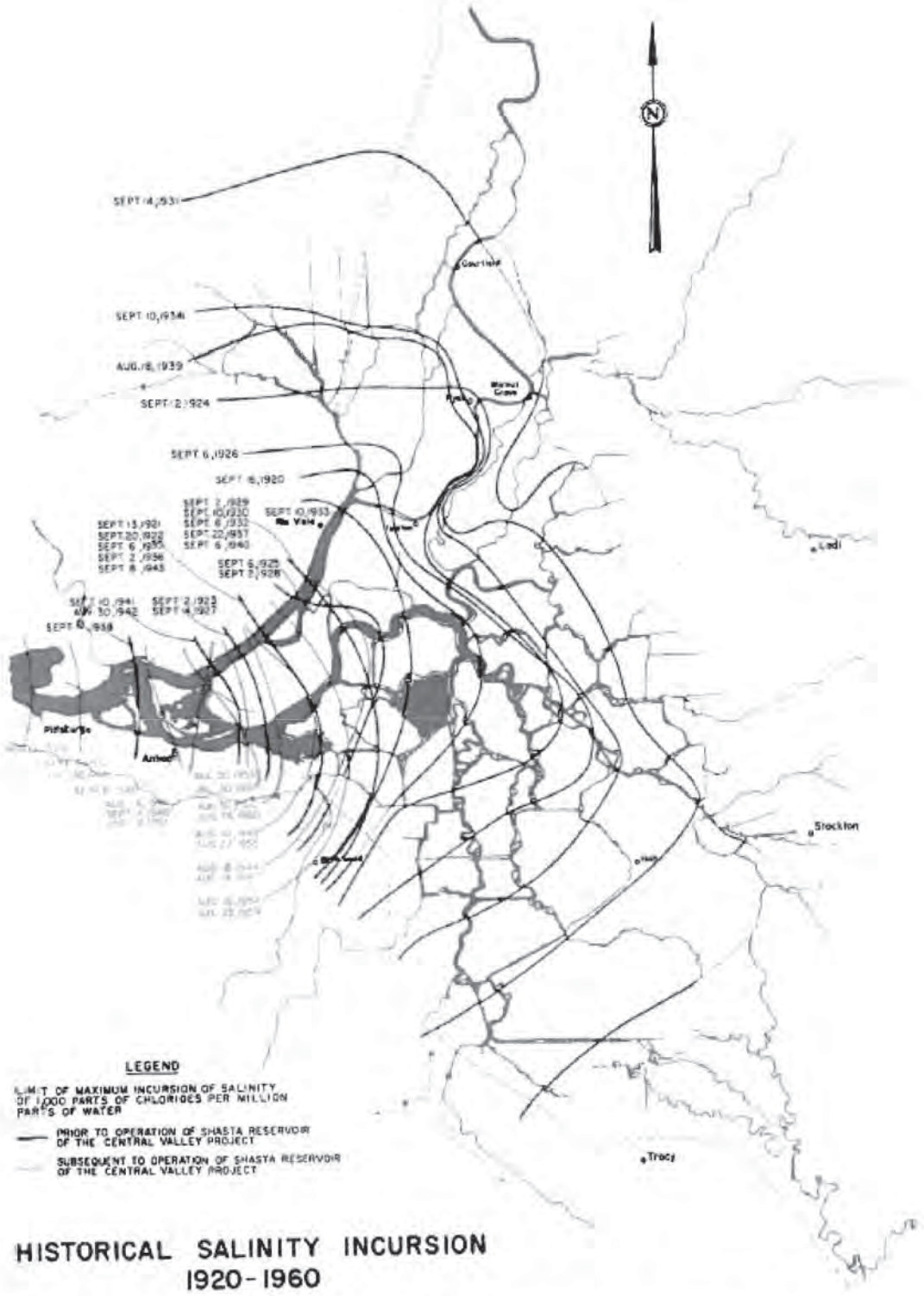


Figure D-12 – Salinity intrusion during 1920-1960 (DWR, 1960)

Figure D-13 illustrates the maximum annual salinity intrusion for comparable dry years[6]. Water year 1913 experienced the least extent of intrusion, most likely because upstream diversions were significantly less than in later years. Water years 1926 and 1932 were subject to extensive upstream agricultural diversions, while water years 1979 and 2002 had the benefit of the CVP and SWP to provide "salinity control". The CVP and SWP operations now regulate the amount of freshwater flowing through the Delta in order to prevent extreme salinity intrusions such as those observed during the 1920's and 1930's.

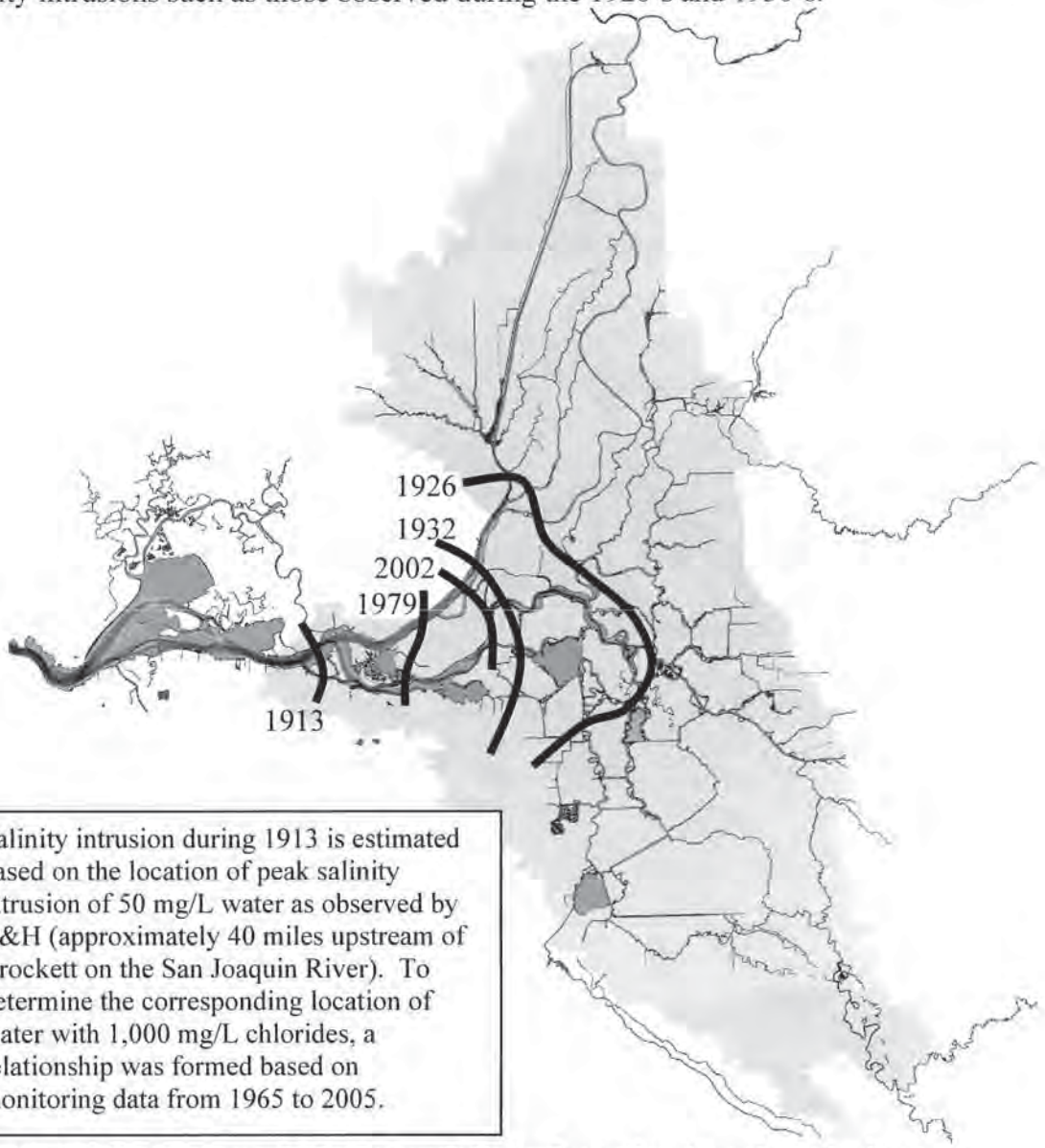


Figure D-13 – Annual Maximum Salinity Intrusion for relatively dry years

Salinity intrusion for relatively dry water years with similar total annual unimpaired runoff, using 1,000 mg/L chloride concentration to distinguish the extent of intrusion.

[6] Hydrological metrics from http://cdec.water.ca.gov/cgi-progs/iodir/wsihist for comparison: total unimpaired Sacramento River and San Joaquin River flow for water years 1913, 1926, 1932, 1979, and 2002 was 15.9 MAF, 15.3 MAF, 19.8 MAF, 18.4 MAF, and 18.7 MAF, respectively; Sacramento River water year type index for water years 1913, 1926, 1932, 1979, and 2002 was 6.24, 5.75, 5.48, 6.67, and 6.35, respectively; and San Joaquin River water year type index for water years 1913, 1979, and 2002 was 2.00, 2.30, 3.41, 3.67, and 2.34, respectively.

D.3. Temporal Variability of Salinity in the Western Delta

D Seasonal Salinity at Collinsville

Collinsville, near the confluence of the Sacramento and San Joaquin Rivers, was one of the first long-term sampling locations implemented by the State of California. The Suisun Marsh Branch[7] of the DWR estimated monthly average salinity at Collinsville for the period 1920-2002, using a combination of 4-day TDS (total dissolved solids) grab samples from 1920-1971 and EC measurements from 1966-2002. Data from the overlap period of 5 years between the TDS grab samples and EC measurements were used in a statistical regression model, and the monthly averaged 4-day TDS samples were converted to monthly average EC (Enright, 2004). The result of this regression analysis was a time series of monthly EC values at Collinsville for the period of 1920-2002.

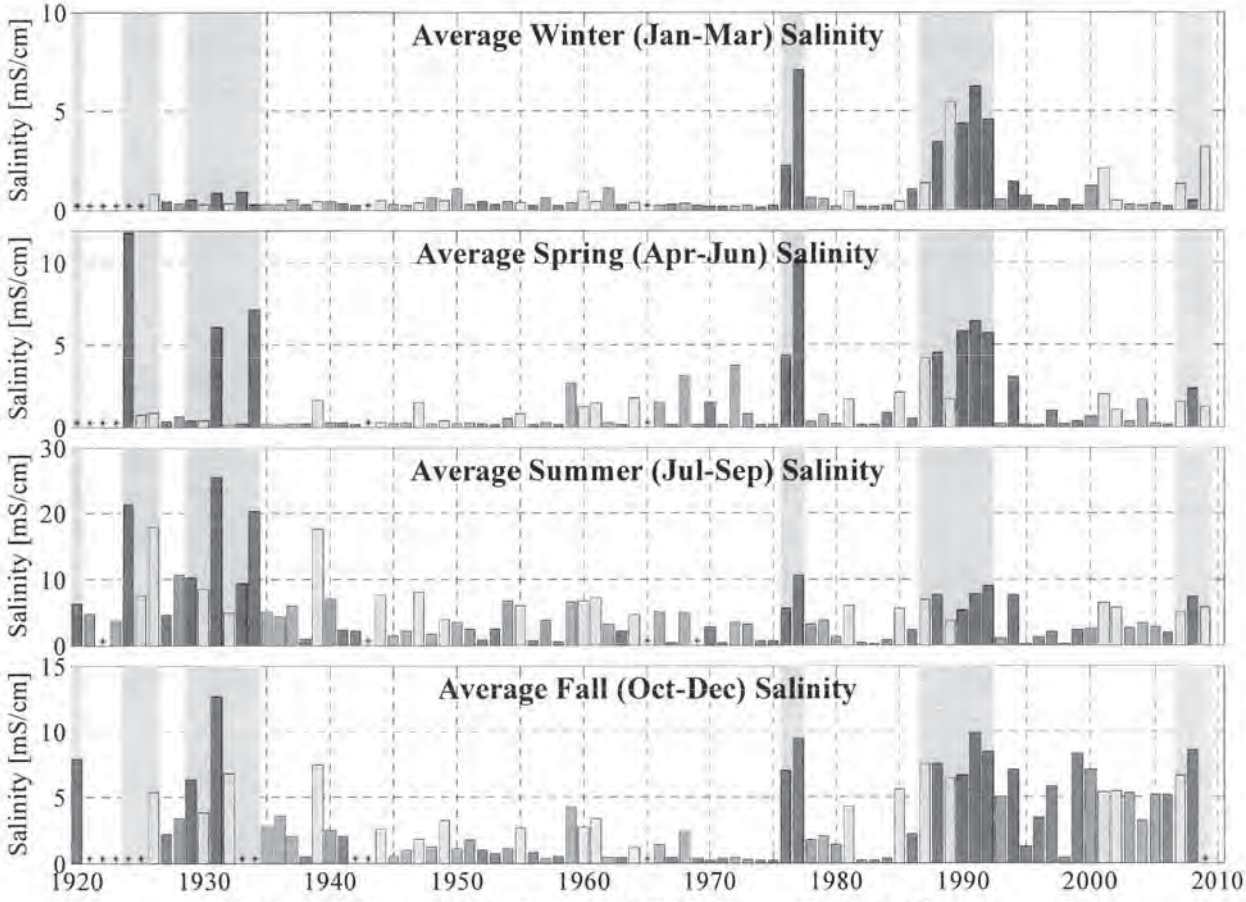


Figure D-14 – Average Seasonal Salinity at Collinsville

[7] Data provided by Chris Enright (DWR), personal communication, 2007.

D Effects of Water anage ent on Salinity at Collinsville

In order to compare the effects of water management on salinity at Collinsville, an empirical model of salinity transport (Denton (1993), Denton and Sullivan (1993)) was used in the following analyses. Contra Costa Water District's salinity-outflow model (also known as the G-model) estimates salinity in the western Delta as a function of NDO. Estimates of salinity at Collinsville were derived for both actual historical flow (1930-2008) and unimpaired flow (1922-2003) conditions.

Figure D-15 shows the estimated monthly-averaged salinity at Collinsville under unimpaired and actual historical flow conditions. The predicted seasonal and annual variations of EC at Collinsville are dependent on corresponding variations of NDO under both unimpaired and actual flow conditions. Water management practices have a significant effect on the seasonal variability of salinity at Collinsville, particularly during dry years (1930's, 1976-1977 and 1987-1993), when Collinsville experiences a much greater range of monthly-averaged salinity under actual historical conditions than would be the case under unimpaired conditions.

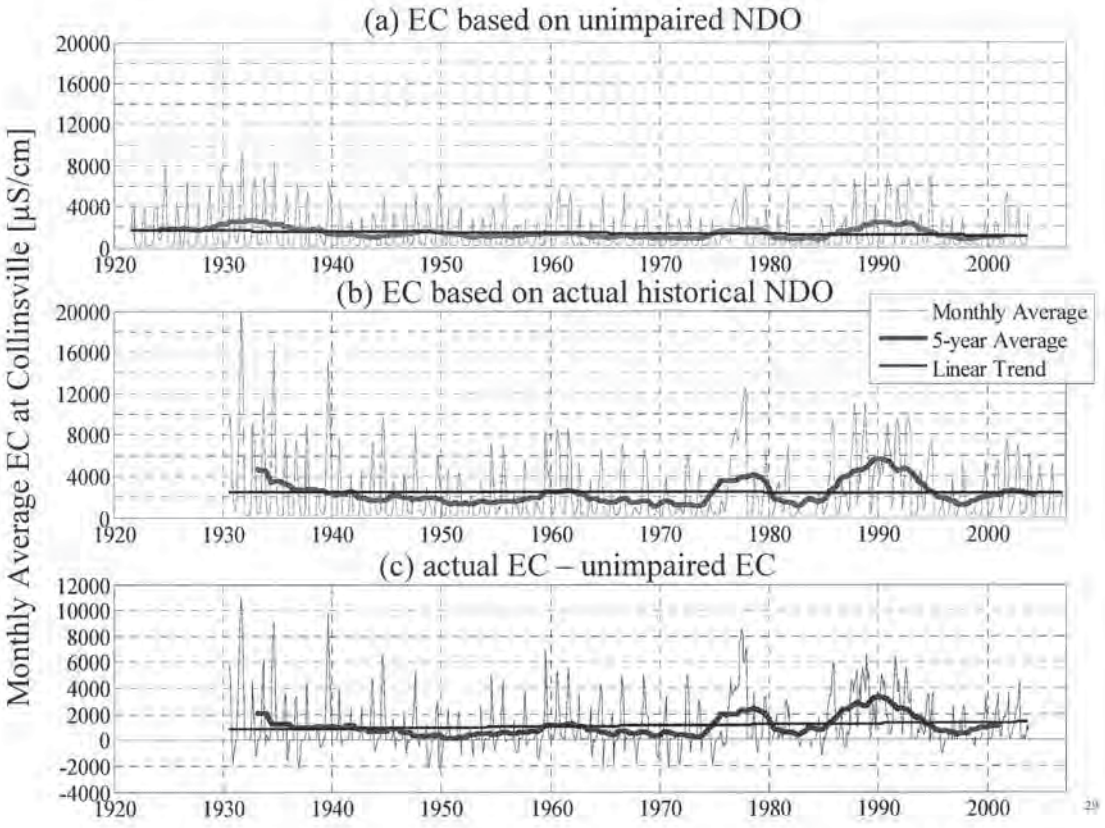


Figure D-15 – Estimates of Collinsville salinity using the G-model for unimpaired and actual historical flow conditions

Historical (actual) NDO during the 1930's was relatively low, sometimes averaging about -3,000 cfs for several months under actual conditions. The low values of NDO result in the high variability of estimated salinity in the 1930's under actual historical conditions.

The effects of water management on salinity at Collinsville are highlighted in Figure D-16, which shows the estimated salinity under actual historical conditions as a percent change from the unimpaired conditions. The data in Figure D-16 are the change in G-model estimates of salinity at Collinsville for the period of 1956-2003, computed as the difference between actual and unimpaired salinity as a percent change from the unimpaired salinity. Positive values indicate an increase in salinity under actual conditions and negative values indicate a decrease in salinity (freshening).

From April through August, estimated median salinity under actual historical conditions is substantially greater (more than a 100% increase) than median salinity under unimpaired conditions (Figure D-16). For the remainder of the year, there are no substantial differences between the estimates of median salinity under unimpaired and actual conditions. These distributions of estimated salinity indicate that water management practices result in significant increase in salinity throughout the year at Collinsville.

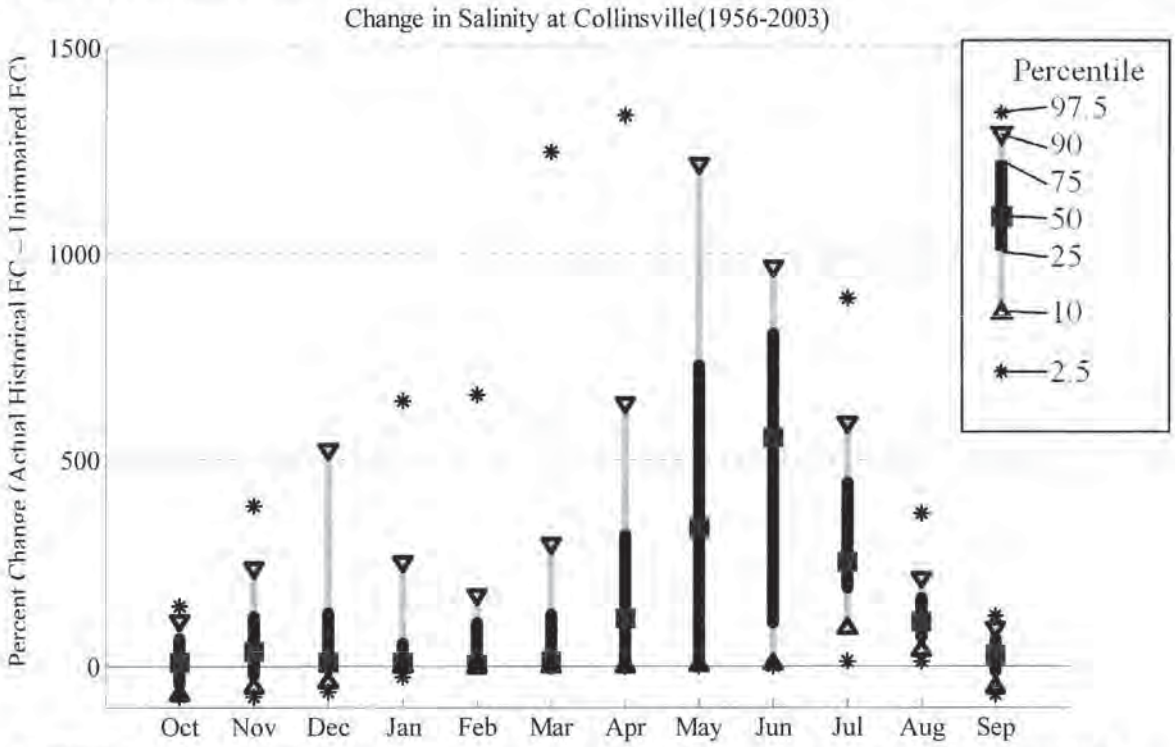


Figure D-16 – Estimated change in salinity at Collinsville under actual historical conditions, as a percent change from unimpaired conditions, 1956-2003

Figure D-17 shows the estimated salinities at Collinsville under actual historical and unimpaired conditions for just the more recent years (1994-2003). Positive values again indicate an increase in salinity under actual conditions and negative values indicate a decrease in salinity. The effects of water management on fall salinity are greater during this recent period 1994-2003 than during the longer period (1956-2003), but the effects during the recent period in the spring and early summer are smaller. This response reflects implementation of the X2 regulatory requirements agreed upon in the 1994 Bay-Delta Accord and regulated by the subsequent 1995 Water Quality Control Plan.

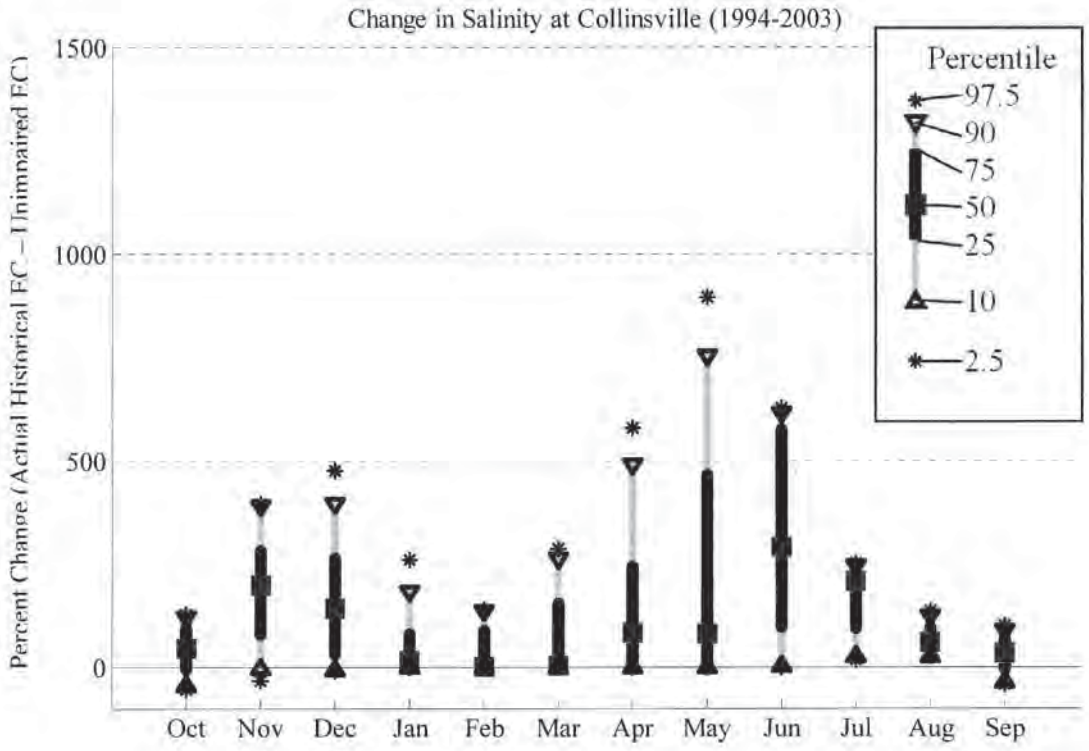


Figure D-17 – Estimated change in salinity at Collinsville under actual historical conditions, as a percent change from unimpaired conditions, 1994-2003

D Fall Salinity in the Western Delta

Figure D-18 shows the average fall salinity (October-December) at three stations in Suisun Bay and the western Delta (Chipps Island, Collinsville, and Jersey Point). The fall salinity data categorized according to the pre-Endangered Species Act (ESA) period of 1964-1992 and the post-ESA period (1993-2006)[8]. Figure D-18 illustrates that there has been a noticeable increase in fall salinity since the release of the ESA biological opinions for winter-run salmon and Delta smelt in 1993. These increases occur during normal water years, when total annual runoff ranges from 15 to 30 MAF. During very wet years, there are large Delta outflows and the ESA limits do not affect water operations. Similarly, during very dry years, the biological opinions do not have a large effect on water operations because upstream reservoir storage is low and exports from the south Delta are already small.

[8] In 1993, delta smelt and winter-run salmon were listed under the California ESA, triggering new water management regulations.

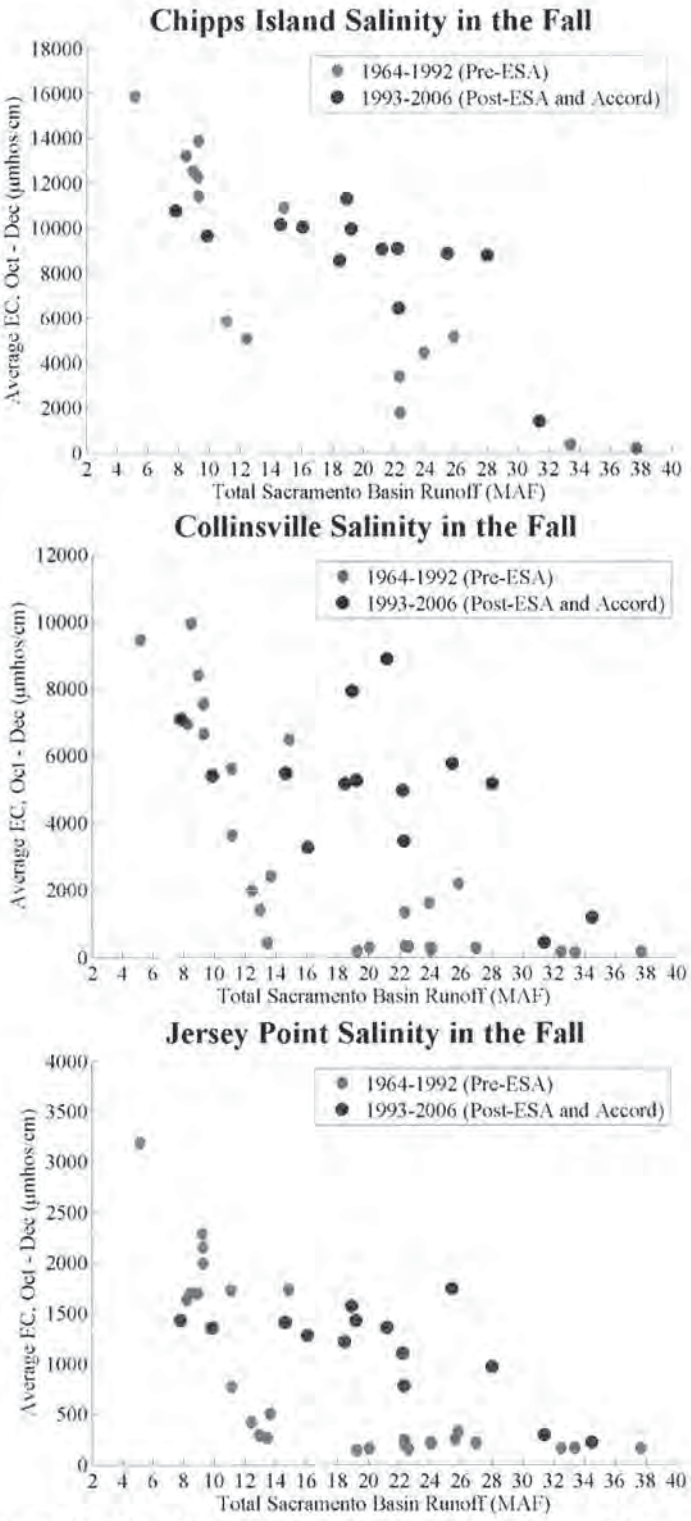


Figure D-18 – Post-ESA salinity in the Suisun Bay and western Delta

Figure D-19 shows the observed salinity at Chipps Island during the fall (October-December) for the period of 1976-1992 (pre-ESA) and 1993-2005 (post-ESA). Fall salinity at Chipps

Island during normal years is now comparable to fall salinity during dry and critical years prior to 1994.

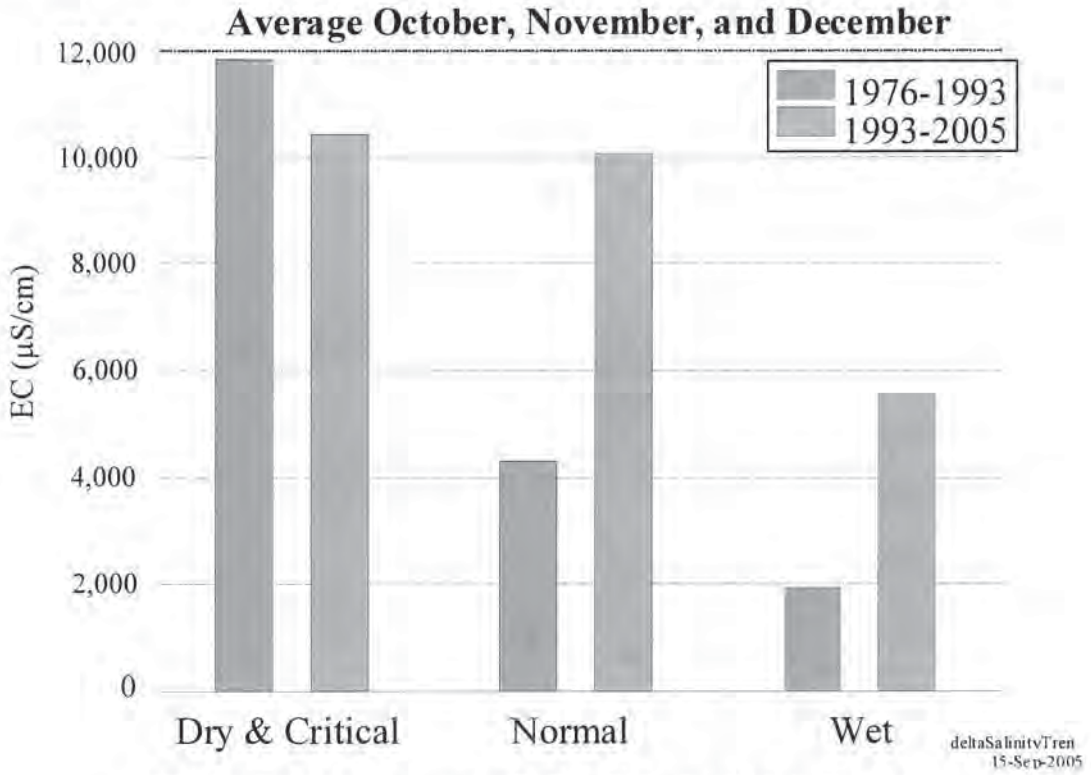


Figure D-19 – Increase in Fall Salinity at Chipps Island

D.4. General conceptual overview of salinity changes

Observed changes in seasonal salinity with time

The salinity regime in the western Delta has changed as the level of development has increased and water project operations have changed due to regulatory requirements. The comparison of three decades with similar hydrology in Figure D-20 presents a conceptual illustration of the changing salinity regime in Suisun Bay and the western Delta.

Monthly-averaged salinity in the spring and summer was substantially greater from 1966 through 1975 than during the early 1900's. However, fall and early winter salinity was lower than the early 1900's. This reduction in salinity in the fall and early winter was likely due in part to CVP and SWP reservoir releases for flood control purposes in the fall, which freshened the Delta. Flood control releases during this period were large because CVP and SWP diversions and exports were not fully developed and upstream reservoirs were often above flood control maximum storage levels in the fall, entering the wet season.

Salinity during 1995 through 2004, however, exceeded the salinities in the early 1900's during all months, for years with similar hydrologic conditions. The dramatic increase in fall

salinity relative to observed levels from 1966 to 1975 is accompanied by a slight decrease in spring and summer salinity. This is likely due to minimum flow and X2 requirements imposed by the State Water Resources Board in 1995. However, spring and summer salinities remain much greater relative to salinity in the early 1900's.

The range of seasonal variability during 1966-1975 was greatly reduced because the Delta did not get as fresh as it did in the early 1900's. During the last decade, seasonal variability has increased such that the range of salinity observed in the Delta over the course of a year is similar to that in the early 1900's. However, salinity intrusion has moved inland relative to the early 1900's, resulting in saltier conditions in the Suisun Bay and western Delta and a reduction in the period when fresher water is available.

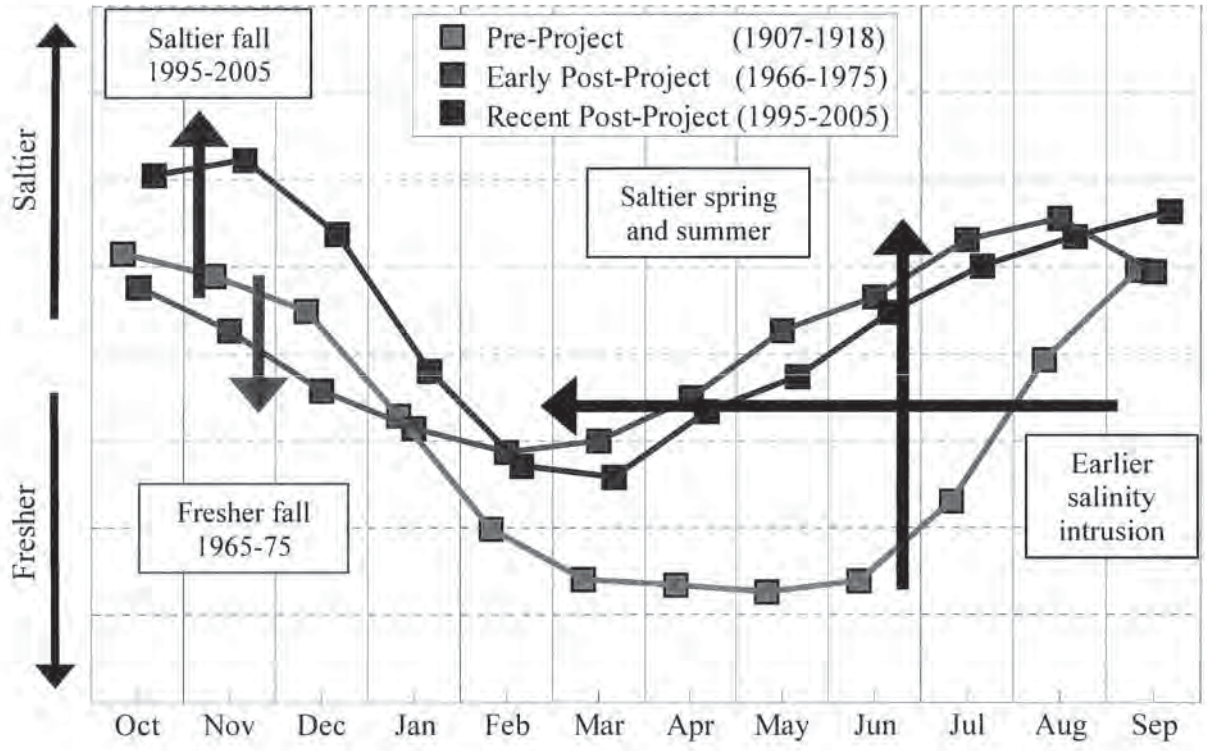


Figure D-20 – Conceptual plot of seasonal variability of salinity in Suisun Bay and the western Delta during different water management eras

The effect of water management for wet and dry years

Water management has the largest effect during dry years when the Delta stays relatively salty throughout the year with limited seasonal variability compared to unimpaired conditions. As shown conceptually in Figure D-21, during wet years the Delta freshens as much as it would under unimpaired conditions, but the Delta does not stay fresh for as long.

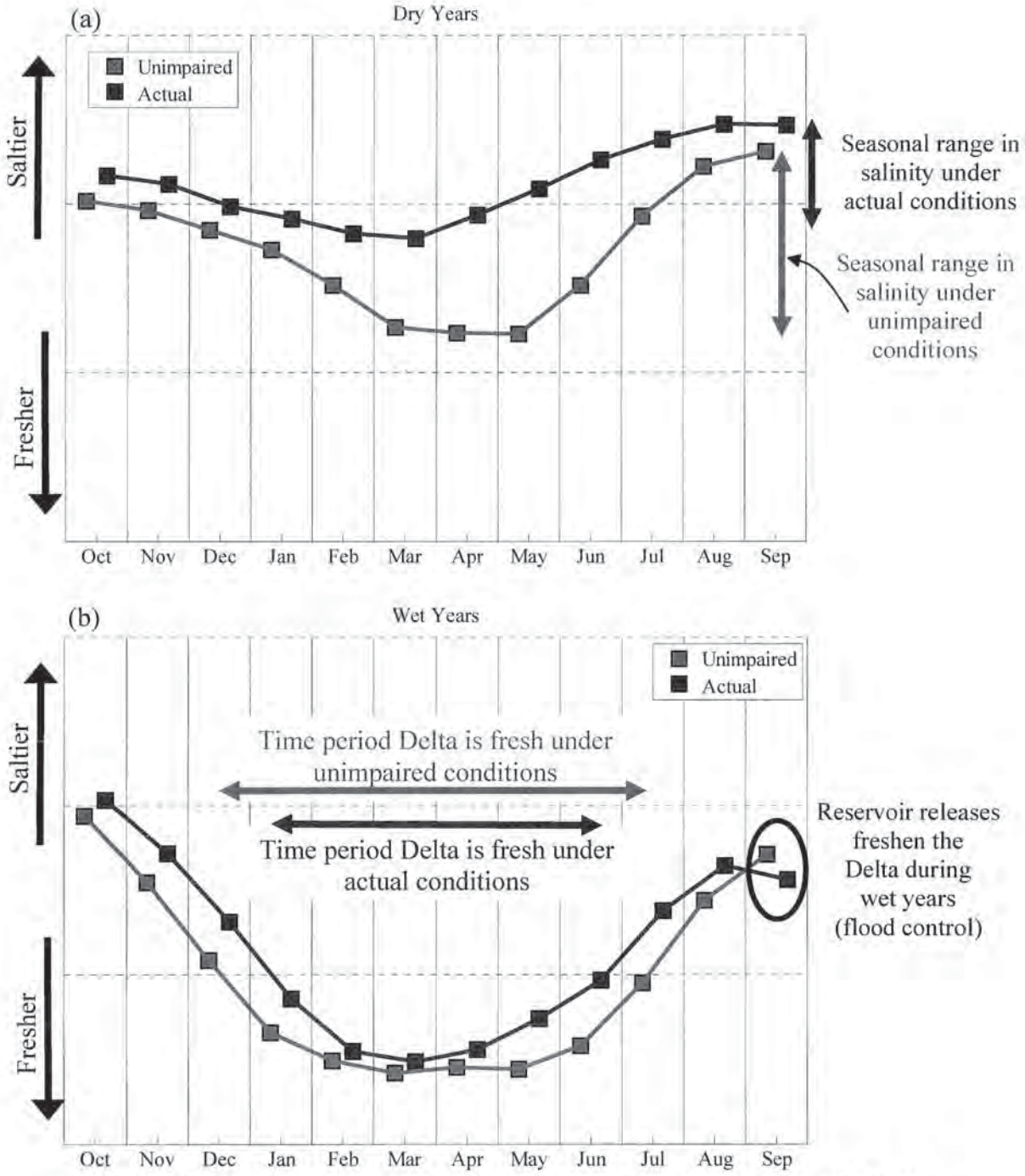


Figure D-21 – Conceptual plot of seasonal salinity variations in the Delta under actual historical conditions compared to unimpaired conditions in (a) dry years and (b) wet years

Appendix E. Qualitative Salinity Observations

The earliest written accounts of explorers were often concerned with adequate drinking water, and salinity was generally described in qualitative terms, such as "brackish," "fresh," or "sweet." For the purposes of comparing the present-day water quality with the historical conditions, these qualitative observations need to be quantified.

Testimony from Antioch Case (Town of Antioch v. Williams Irrigation District, 188 Cal. 451) indicated early settlers required water with less than 100 mg/L of chloride (approximately 525 µS/cm EC) for municipal use.[9] Similarly, DPW (1931) indicated that a "noticeable" level of salinity was 100 mg/L chloride. The current secondary water quality standard for municipal and industrial use is 250 mg/L chloride (1,000 µS/cm EC) (SWRCB 2006; US EPA 2003). This report assumes a value of 250 mg/L chloride (equivalent to 1000 µS/cm EC) to be the demarcation between "fresh" (or "sweet") water and "brackish" water.

E.1. Observations from Early Explorers

Table E-1 summarizes some reported observations of water quality made by early explorers and settlers. These observations were qualitative and were most likely only a glimpse of the ambient conditions and may not completely represent true historical water quality conditions. Moreover, these observations were from a time period when anthropogenic effects on this region were minimal and this region was close to natural conditions.

Table E-1 also lists the reconstructed Sacramento River annual flow (MAF) from Meko *et al.* (2001b) for the year of observation and for the previous year. For reference, the average Sacramento River flow from Meko *et al.* (2001b) for the period 1860-1977 is 18 MAF/yr.

Table E-1 – Qualitative salinity observations from early explorers

Date	Location	Description	Year / Reconstructed Flow [MAF]	Observer	Reference
1775 August	near the Sacramento-San Joaquin confluence	sweet, the same as in a lake	1774 / 25 1775 / 19	Canizares	Britton, 1987 in Fox, 1987b
1776 April	near Antioch (San Joaquin River)	very clear, fresh, sweet, and good	1775 / 19 1776 / 9	Font	Britton, 1987 in Fox, 1987b
1776 September	near the Sacramento-San Joaquin confluence	sweet	1775 / 19 1776 / 9	Canizares	Britton, 1987 in Fox, 1987b

[9] Supplement to Respondent's Answering Brief, p. 10.

Date	Location	Description	Year / Reconstructed Flow [MAF]	Observer	Reference
1796	unknown	salinity "far upstream" at high tide	1795 / 6 1796 / 10	Hermengildo Sal	Cook, 1960 in TBI, 1998
1811 October	near the Sacramento-San Joaquin confluence	sweet	1810 / 19 1811 / 23	Abella	Britton, 1987 in Fox, 1987b
1841 August	Three Mile Slough north of Emmaton	brackish (undrinkable)	1840 / 16 1841 / 6	Wilkes	Britton, 1987 in Fox 1987b

E Fresh Conditions

Table E-1 indicates that some early explorers observed "sweet" water near the confluence of the Sacramento and San Joaquin Rivers both in relatively wet years (August of 1775 and October of 1811, reconstructed runoff about 19 MAF/yr) and in relatively dry years (September of 1776, reconstructed runoff about 9 MAF/yr). Except as noted, it is unknown whether these observations were made at high tide or low tide.

In order to provide a context for these anecdotal observations, present-day observed monthly salinity (EC) conditions at Collinsville (located near the confluence of Sacramento and San Joaquin Rivers) are plotted against unimpaired annual Sacramento River flow in Figure E-1. The observed data are monthly-averaged salinity (μS/cm) during August-October for the period 1965-2005. The data for the post-ESA years (1994-2005) are shown as shaded circles. Note that the anecdotal observations in Table E-1 are likely "one-time" observations, while those shown in Figure E-1 are average monthly values.

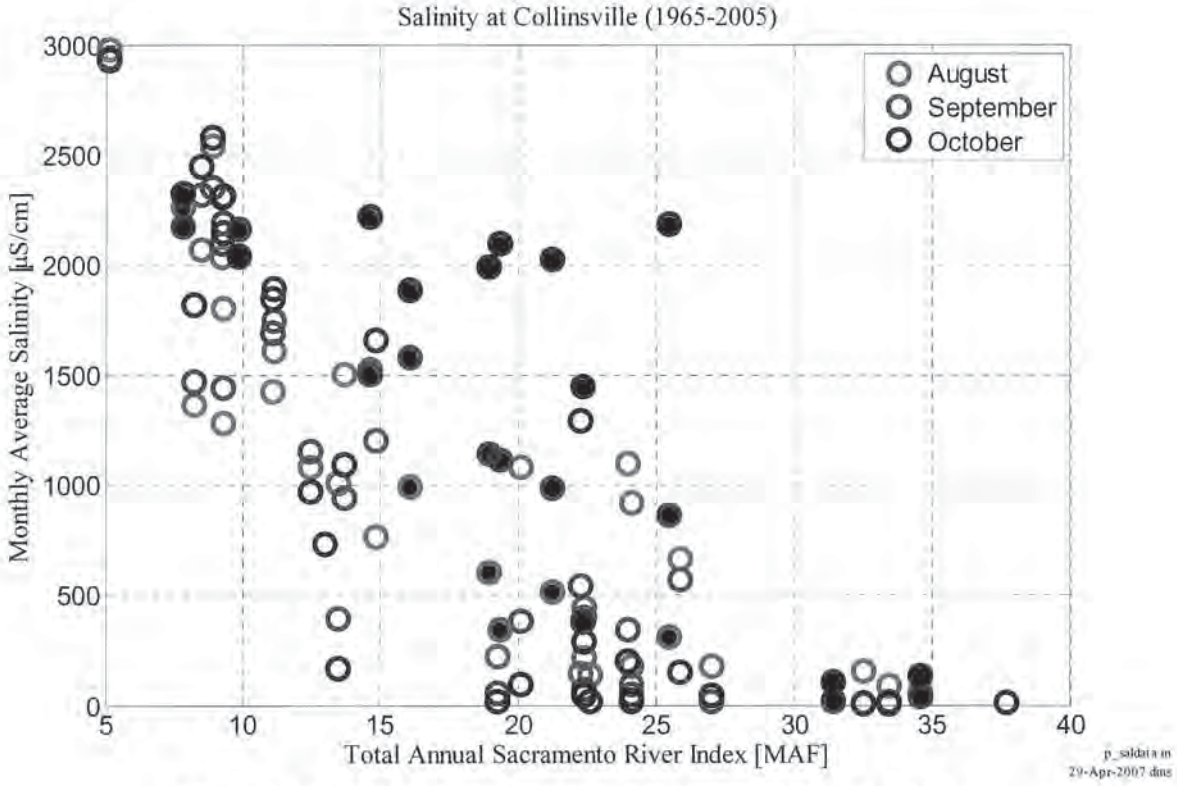


Figure E-1 – Observed salinity at Collinsville, 1965-2005

Under current management conditions, the monthly average salinity at Collinsville from August through October is only less than 1,000 µS/cm EC (the interpretation of the "sweet" threshold for drinking water) when the unimpaired runoff is greater than about 20 to 25 MAF/yr (Figure E-1). This suggests either the "sweet" threshold used in this report is too small, or salinity at Collinsville is higher today than it was in the late 18th and early 19th centuries.

If the definition of the "sweet" threshold is changed to 1,300 µS/cm EC and the post-ESA years (1994-2005) are excluded, then the monthly-averaged salinity at Collinsville during August-October is "fresh" (less than 1,300 µS/cm EC) when runoff is greater than 16 MAF/yr. This corresponds better to the anecdotal observations, discussed above, but suggests a recent increase in salinity at Collinsville during moderately wet years (with runoff between 14 and 26 MAF/yr). In 5 of the 12 post-ESA years (1997, 1999, 2000, 2003 and 2004), the water at Collinsville in October would not be considered "sweet" even under the relaxed criterion of 1,300 µS/cm EC, suggesting that October salinity under present conditions could be greater than it was in 1811.

E Brackish Conditions

The qualitative observations of high salinity intrusion in Table E-1 are less specific about location. However, some of these observations have been interpreted by others (Cook, 1960, in TBI, 1998; Fox, 1987b) to indicate intrusion as far upstream as Rio Vista. The drought periods of 1976-1977 and 1987-1992 are similar to these periods when these qualitative

observations were made. During 1976-1977, daily average salinity at Rio Vista exceeded 1,000 µS/cm for approximately six months of the year. During 1987-1992, salinity at Rio Vista at high tide often exceeded 2,000 µS/cm, particularly during the fall. This is consistent with the anecdotal observations made in 1796 and 1841, which report salt water extending into the western Delta.

Summary: Interpretation of the above observations in the context of the reconstructed Sacramento River flows shows that the Delta is generally saltier than the historical levels for equivalent runoff conditions and does not support the hypothesis that the present-day Delta is managed as a freshwater system in comparison with its historical salinity regime. Moreover, this analysis indicates that salinity in the western Delta has increased during September and October in the recent years (post-1994 period).

E.2. Observations from early settlers in the Western Delta

Observations from early settlers in the western Delta provide a more complete description of salinity in the late 1800's and early 1900's than the observations from early explorers discussed earlier. Assuming the early settlers inhabited a particular region for longer time periods than the early explorers, observations from the early settlers capture the temporal variability better than those from the early explorers.

E own of Antioch n unction on pstrea Diverters

In 1920, the Town of Antioch filed a lawsuit against upstream irrigation districts alleging that the upstream diversions were causing increased salinity intrusion at Antioch. The court decision, legal briefings, and petitions provide salinity observations from a variety of witnesses. Although anecdotal testimony summarized in these legal briefs is far from scientific evidence, it provides a perspective of the salinity conditions prevailing in the early 1900's. Because the proceedings were adversarial in nature, this report focuses on the testimony of the upstream interests, who were trying to demonstrate that salinity intrusion was common near Antioch prior to their diverting water (prior to 1920). Consequently, the testimony may be biased in support of this "more saline" argument. Nonetheless, these anecdotal testimonies indicate that the western Delta was less salty in the past than it is today. Analyses of some of the testimonies are presented below.

Case History

On July 2, 1920, the Town of Antioch filed suit in the Superior Court of the State of California (hereinafter referred to as the "Antioch Case") against upstream diverters on the Sacramento River and Yuba River. A hearing for a temporary injunction began on July 26, 1920, and lasted approximately three months. On January 7, 1921, Judge A. F. St. Sure granted a temporary injunction, restraining the defendants "from diverting so much water from the said Sacramento River and its tributaries, to non-riparian lands, that the amount of water flowing past the City of Sacramento, in the County of Sacramento, State of California, shall be less than 3500 cubic feet per second" (Town of Antioch v. Williams Irrigation District, Supplement to Appellants' Opening Brief, p. 13).

The defendants appealed to the Supreme Court of the State of California, which issued its opinion on March 23, 1922. The Supreme Court reversed the lower court and withdrew the injunction, declaring "[i]t is evident from all these considerations that to allow an appropriator of fresh water near the outlet of these two rivers to stop diversions above so as to maintain sufficient volume in the stream to hold the tide water below his place of diversion and secure him fresh water from the stream at that point, under the circumstances existing in this state, would be extremely unreasonable and unjust to the inhabitants of the valleys above and highly detrimental to the public interests besides."

The Supreme Court did not make any comment whatsoever on the evidence of salinity intrusion prior to the upstream diversions in question. The Court indicated that their decision was based on a "policy of our law, which undoubtedly favors in every possible manner the use of the waters of the streams for the purpose of irrigating the lands of the state to render them fertile and productive, and discourages and forbids every kind of unnecessary waste thereof." (Town of Antioch v. Williams Irrigation District (1922) 188 Cal. 451). The Court concluded that allowing 3,500 cubic feet per second (cfs) to "waste" into the Bay to provide less than 1 cfs of adequate quality water for the Town of Antioch would constitute unreasonable use of California's limited supply of water.

The court did not base their decision on historical salinity observations at Antioch, which indicate that Antioch was able to divert freshwater at low tide at all times from 1866 to 1918, except possibly for some fall months during some dry years (Section 3.1).

E Salinity at Antioch then and now

In the present day, the City of Antioch maintains a municipal water intake on the San Joaquin River at Antioch. As a general operating rule, the City of Antioch pumps water from the river when salinity at the intake is less than 1,000 µS/cm EC. Salinity varies substantially with the tide; generally the greatest salinity is observed near high tide and the lowest salinity is observed at low tide. Figure E-2 shows that salinity in the San Joaquin River at Antioch is highly variable and is dependent on tidal conditions and season. Figure E-2 indicates that for water year 2000 (an above-normal water year) the City of Antioch could pump water all day for about four and half months (early February through mid-June) and could pump for a portion of the day at low tide for another three and half months (mid-June through September). For the remaining four months (October-January), water at Antioch's intakes exceeded 1,000 µS/cm EC for the entire day, regardless of tidal phase.

Testimony from multiple witnesses in the Antioch Case indicates that fresh water was always available in the San Joaquin River at Antioch at low tide until just prior to 1920. Antioch's legal position was that fresh water was always available before upstream development. In cross-examination of Antioch's witnesses, the upstream irrigators demonstrated that brackish conditions did occasionally exist at high tide.

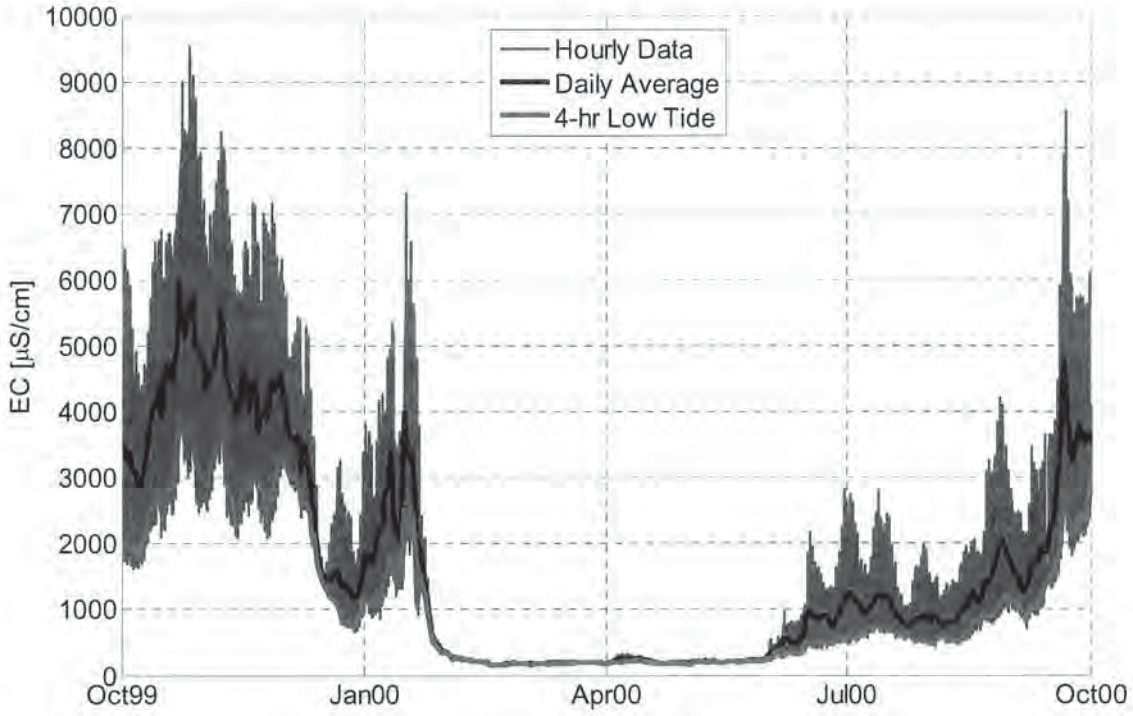


Figure E-2 – Salinity variations in the San Joaquin River at Antioch, water year 2000

Figure E-3 shows the distribution of low tide salinity (salinity during the freshest 4 hours of each day) for the period of May 1, 1983 through September 30, 2002.[10] These data indicate that, on average (in 50% of the water years), low tide salinity exceeds 1,000 µS/cm EC from late-August through December. The data in Figure E-3 provide context for the qualitative observations from the Antioch Case. During the driest 25% of the years (5 out of 20 years), low tide salinity exceeds 1,000 µS/cm EC from June through January, leaving the Antioch intake with no fresh water for eight months of the year.

Under average conditions corresponding to the period 1983-2002, Antioch would have to stop pumping from late August to late December in 10 of the 20 years; i.e., they would have an average of eight months of low-tide pumping per year, compared to the pre-1915 average of twelve months per year (based on the anecdotal information filed by the Appellants (upstream diverters) in the Antioch Case).

[10] Data Source: Interagency Ecological Program, HEC-DSS Time-Series Databases. Station RSAN007. Agency: DWR-ESO-D1485C. Measurement: 1-hour EC. Time Range: May 1, 1983 through September 30, 2002

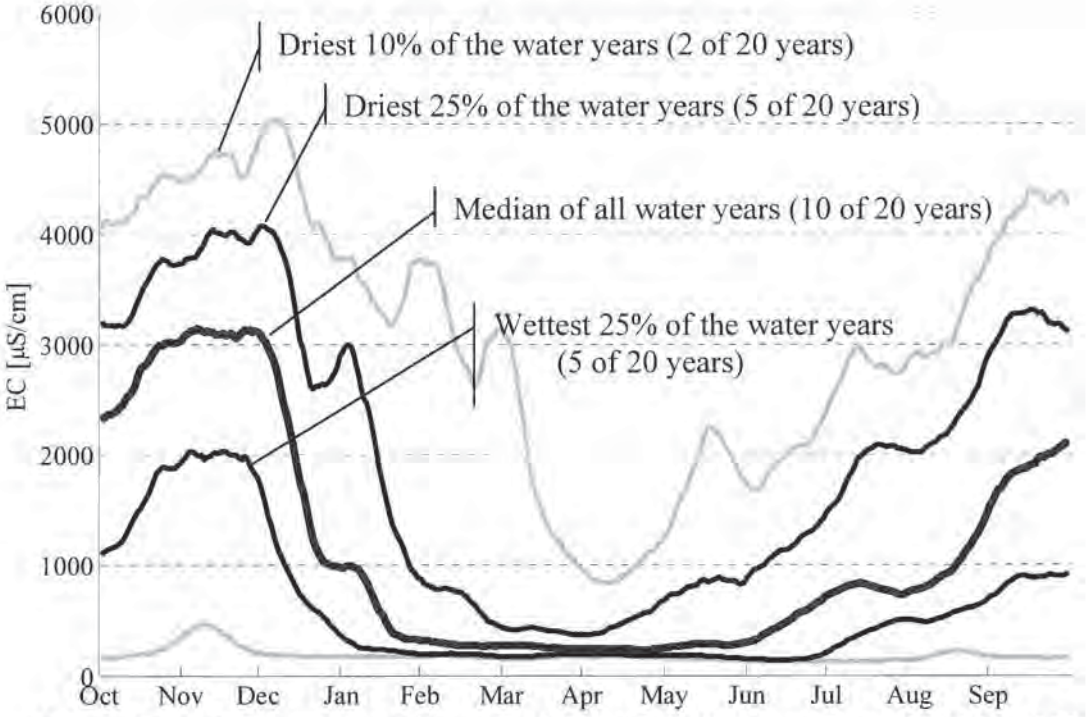


Figure E-3 – Seasonal Distribution of low-tide salinity at Antioch, 1983-2002

Conclusions

- The window, when Antioch is able to pump water with salinity less than 1,000 µS/cm EC, has substantially narrowed in the last 125 years.
- Antioch was apparently able to pump fresh water at low tide year-round in the late 1800's, with the possible exception of the fall season during one or two dry years.
- During 10 of the 20 years between 1983 and 2002, salinity was less than 1,000 µS/cm EC at low tide for only about eight months of the year.
- During the driest 5 years between 1983 and 2002, salinity was less than 1,000 µS/cm for only about four months per year; i.e., no fresh water was available at any time of the day for about eight months of the year.

E Salinity at entucky Point on witchell sland then and now

The appellants in the Antioch Case, representing the upstream diverters, identified one resident of Twitchell Island who reported the water at Kentucky Landing was brackish on "one or two occasions" between 1870 and 1875 during August and September. During this time, he had to travel up the San Joaquin River to Seven Mile Slough (the eastern boundary of Twitchell Island) and sailed as far as the mouth of the Mokelumne River (approximately 2

miles further up the San Joaquin River than the Seven Mile Slough junction) to obtain fresh drinking water.

For comparison, we look at salinity monitoring data in that region for 1981 and 2002 to see the location of potable water.[11] The source document (Town of Antioch v. Williams Irrigation District, 188 Cal. 451) for the 1870's drought uses up to 100 mg/L chloride concentration as the threshold for a potable water supply. Monitoring data from 1981 shows similar salinity intrusion as described by the Twitchell Island resident; salinity along the San Joaquin River at Bradford Island (about 1.5 miles upstream of Three Mile Slough) exceeded 1,000 µS/cm EC (about 250 mg/L Cl) during August and September. During the same time period, salinity was around 400 µS/cm EC (about 64 mg/L Cl) approximately 5 miles upstream on the San Joaquin River between Seven Mile Slough and the Mokelumne River. This comparison indicates that the extent of salinity intrusion in 1981 is similar to that which occurred in 1870 and 1871.

Similarly, in September 2002, the salinity in the San Joaquin River at San Andreas landing (less than 2 miles downstream of the Mokelumne River mouth) peaked at 977 µS/cm EC, which corresponds to approximately 225 mg/L chloride concentration. Therefore, if the observer was to travel upriver for potable water in 2002, they would have likely traveled up to the mouth of the Mokelumne River as they did in 1870. Salinity intrusion in critically dry years is even farther into the Delta than was found in 2002.

In conclusion, salinity intrusion up the San Joaquin River during the dry years of 1870 and 1871 as described by a Twitchell Island resident is consistent with salinity intrusion in 1981 and 2002 under similar hydrological conditions. There is no evidence that salinity intrusion during the drought of 1870-71 was more extensive than salinity intrusion during similar water years in the current salinity regime.

[11] 1981 and 2002 were both dry water years in the Sacramento River basin as defined in D-1641 with similar annual unimpaired Sacramento River flow to the years 1870 and 1871. Annual unimpaired Sacramento River flow in 1870, 1871, 1981, and 2002 was 11 MAF, 10 MAF, 11 MAF, and 14 MAF, respectively.

AGREEMENT

THIS AGREEMENT made this 21 day of April 1967, between the STATE OF CALIFORNIA, acting by and through its Department of Water Resources, hereinafter referred to as the "State", and CONTRA COSTA COUNTY WATER DISTRICT, a public body organized and existing pursuant to Division 12 of the Water Code of the State of California, hereinafter referred to as the "District",

WITNESSETH:

WHEREAS, since 1930 the District and its predecessor, California Water Service Company, have been diverting water from Mallard Slough on Suisun Bay in Contra Costa County pursuant to Water Right Permit to Appropriate Water number 3167 issued on Application number 5941 filed on November 19, 1928. Said diversions have been for direct beneficial use and to storage for later beneficial use within the service area of the Treated Water Division of the District when the water in Mallard Slough had a chloride ion content (mean tidal cycle surface zone) of 100 parts per million or less and was not otherwise polluted to make it unsuitable for treatment for municipal and domestic use (hereinafter referred to as usable river water), and

WHEREAS, the average number of days per water year (October 1 to September 30, hereinafter referred to as "year") that usable river water has been available to the District at said point of diversion is 142 and the median period of said availability is from January 15 to June 5, both days inclusive, and

WHEREAS, during each day usable river water has been and will in the

future be available to the District the quantity thereof has been and will be adequate to meet the water requirements of the District from that point of diversion during such day, and

WHEREAS, in the future the average number of days per year that usable river water will be available to the District will decrease and such decrease will be due in part to the operation of the State Water Resources Development System as defined in Section 12931 of the Water Code, and

WHEREAS, it is contemplated that the Contra Costa Canal, supplemented by the Kellogg Unit or other facilities to be constructed by the Bureau of Reclamation, will meet the District's future water requirements which are not met by usable river water. If such facilities are not constructed by the Bureau of Reclamation, water supply facilities will have to be constructed by another agency or agencies to meet the District's future requirements including a substitute water supply equal to the District's water deficiency entitlement as defined in this agreement;

NOW, THEREFORE, the parties agree as follows:

1. The term of this agreement shall begin on the first day of October, 1967, and shall continue in effect until terminated by either party by written notice to the other party given at least 12 months prior to the effective date of such termination. The effective date of termination shall be the last day of a year (September 30) and no termination shall be effective prior to September 30, 2007.

2. The State shall reimburse the District in the manner hereinafter provided for any decrease in availability to the District of usable river water

in Mallard Slough during the term of this agreement caused by operation of the State Water Resources Development System. Such decrease in availability of usable river water is hereinafter referred to as the District's "water deficiency entitlement".

3. The quantity of the District's water deficiency entitlement shall be determined for each year during the term of this agreement by the formula $E=\frac{(142-D)}{3}\ \frac{(R+P)}{142}$ where E is the District's water deficiency entitlement for such year in acre-feet, D is the number of days during such year that usable river water is available to the District at Mallard Slough, R is the total quantity of water in acre-feet diverted by the District from Mallard Slough from 8:00 A. M. on January 15 to 8:00 A. M. on June 6 and P is the total quantity of water in acre-feet purchased by the District and introduced into its facilities in the vicinity of Chenery Reservoir from 8:00 A. M. on January 15 to 8:00 A. M. on June 6. If in any year D exceeds 142, the District shall have no water deficiency entitlement for such year and the amount of such excess shall offset any water deficiency entitlement of the District for an equal number of days in the next succeeding year or years when D is less than 142.

4. For the purpose of computing the District's water deficiency entitlement, the District will at its expense measure the chloride ion content of water in Mallard Slough at such intervals as shall be reasonably necessary and shall make the results of such measurements available to the State. The State may at its expense verify the accuracy of the District's measurements and any error thus disclosed shall be corrected by the District.

5. Each year during the term of this agreement that the District has a water deficiency entitlement it shall purchase a quantity of substitute water equal thereto from the Contra Costa Canal as supplemented by the Kellogg Unit or other facilities constructed by the Bureau of Reclamation to meet the District's requirement, but if sufficient water is not available to the District from such source it shall purchase said quantity of substitute water from a project or projects constructed by another agency or agencies to meet the District's future water requirements. For the purposes of this agreement, substitute water shall be deemed to have been purchased during the period beginning at 8:00 A. M. on January 15 and ending at 8:00 A. M. on June 6 of such year and the price paid by the District for substitute water shall be deemed to be the average price per acre-foot paid by the District for all untreated water purchased by it for introduction into its facilities in the vicinity of Chenery Reservoir during said period without deduction for any discount, allowance or rebate that may hereafter be made or allowed by the U. S. Bureau of Reclamation in the event the District hereafter undertakes, to any extent to operate and maintain any facilities of the U. S. Bureau of Reclamation not operated and maintained by the District as of the date of this agreement.

6. Each year during the term of this agreement that the District purchases substitute water for its water deficiency entitlement, the State will pay the District an amount of money computed in accordance with the formula $M=E(Cw + Ce - \$4.90)$ where M is the amount in dollars to be paid by the State, E is the District's water deficiency entitlement for such year determined in

the manner provided in Section 3 hereof, Cw is the amount per acre-foot paid by the District for substitute water delivered to the District as provided in Section 5 hereof, and Ce is the average amount (if any) per acre-foot paid by the District for electric energy to transport substitute water from the point of delivery thereof to the District to the District's facilities in the vicinity of Chenery Reservoir. The State shall pay said amount to the District not later than October 31 of the following year. Such payments are hereby determined to be reasonable costs of the annual maintenance and operation of the State Water Resources Development System and shall be disbursed from the California Water Resources Development Bond Fund pursuant to subsection (b) (1) of Section 12937 of the Water Code.

7. The District, in consideration of the payments by the State herein provided, releases the State from liability for any decrease in the availability to the District of usable river water at Mallard Slough caused by operation of the State Water Resources Development System during the term of this agreement.

8. The obligations of the State herein shall not be affected by any modification or discontinuance of the District's Mallard Slough pumping plant or Chenery Reservoir.

9. Nothing herein shall be deemed to be a release or waiver of any right of the District to purchase supplemental water supplies from the State with the priorities established by Water Code Section 11460, 12201 to 12204 inclusive, and 12931.

IN WITNESS WHEREOF the parties hereto have executed this agreement by their respective officers thereunto duly authorized on the date first above written.

Approved as to legal form and sufficiency:

By P. A. Towner /s/
Chief Counsel

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES

By William R. Gianelli /s/
Director

ATTEST:

B. M. McCloskey /s/
Secretary

CONTRA COSTA COUNTY WATER DISTRICT

By Ralph D. Bollman /s/
President

BDCP1563.

Alternative Intake Project

Draft

Environmental Impact Report/ Environmental Impact Statement

VOLUME I

State Clearinghouse # 2005012101

May 2006



CONTRA COSTA WATER DISTRICT

Executive Summary

Introduction

This Draft Environmental Impact Report/Environmental Impact Statement (EIR/EIS) has been prepared to evaluate the potential environmental effects of the Alternative Intake Project, which is a drinking water quality improvement project proposed for implementation by the Contra Costa Water District (CCWD). The Draft EIR/EIS has been prepared on behalf of CCWD and the U.S. Department of the Interior, Bureau of Reclamation (Reclamation) in accordance with the requirements of the California Environmental Quality Act (CEQA) and the National Environmental Policy Act (NEPA). CCWD is the lead agency under CEQA and Reclamation is the lead agency under NEPA. The Draft EIR/EIS provides the public and responsible and trustee agencies with information about the project and the potential direct, indirect, and cumulative environmental effects of the project.

CCWD's mission is to "strategically provide a reliable supply of high-quality water at the lowest cost possible, in an environmentally responsible manner." CCWD obtains its water supply exclusively from the Sacramento-San Joaquin Delta and serves treated and untreated water to approximately 500,000 people in central and eastern Contra Costa County. CCWD's Board of Directors (Board) has adopted water quality objectives in order to keep constituents of major health concern at the lowest levels that are technically feasible and provide its customers with a consistent supply of aesthetically-pleasing, high-quality water.

Water quality in the Delta at CCWD's existing intakes currently does not meet CCWD's Board-adopted water quality objectives for extended periods each year, requiring CCWD to use the higher-quality water stored in Los Vaqueros Reservoir to blend with the directly diverted Delta water to meet CCWD's water quality objectives. Los Vaqueros Reservoir is an off-stream reservoir that CCWD uses to improve water quality by filling when Delta salinity is low and releasing water for blending when Delta salinity is high. However, even with the blending benefits of the Los Vaqueros Reservoir, CCWD expects to not meet its water quality objectives during extended periods of high salinity in the Delta and expects these periods to occur more frequently in the future as statewide demands on the Delta increase. In addition, Federal and State drinking water regulations are becoming more stringent. To ensure that regulatory requirements and its water quality objectives can be met now and in the future, CCWD must take action to improve the quality of both its source and delivered water.

As part of CCWD's comprehensive water quality strategy to protect and improve water quality for its customers, the Proposed Action would enable CCWD to relocate some of its existing diversions to Victoria Canal, a Delta location with higher-quality source water than is currently available at its Old River and Rock Slough intakes. The project area is

shown in Exhibit ES-1. Reclamation is assisting CCWD in this action in a manner and to the extent consistent with the long-term renewal contract for Central Valley Project (CVP) water service between Reclamation and CCWD (Contract No. I75r-3401A-LTR1), water right permits issued to Reclamation for operation of CVP, CVP operational requirements, and Section 103 [f][1][E] of Public Law 108-361.

Project Objectives

The basic project purpose is to protect and improve the quality of water delivered to CCWD's untreated- and treated-water customers. Key objectives of the project purpose are as follows:

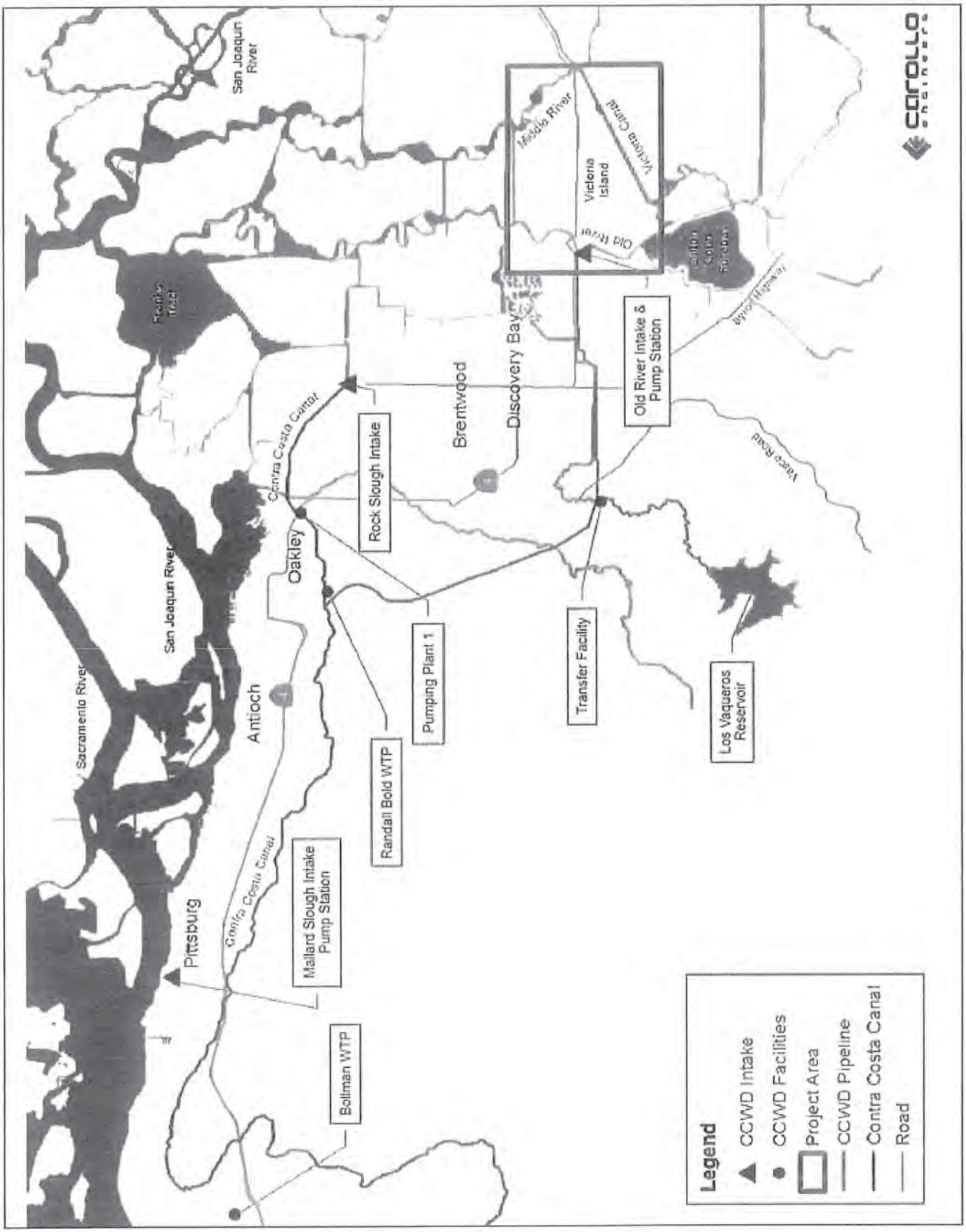
- **Improve Delivered Water Quality, Especially During Drought Periods.** Ensure delivery of high-quality water, particularly in late summer/fall months and during drought periods, when Delta source water quality is typically lowest.
- **Protect and Improve Health and/or Aesthetic Benefits to Consumers.** Enable CCWD to consistently meet or exceed current and future Federal and State drinking water regulations and CCWD objectives to provide high-quality water and protect public health by reducing salinity and disinfection byproducts precursors.
- **Improve Operational Flexibility.** Increase operational flexibility to help deliver high-quality water and maintain the benefits of the Los Vaqueros Project by enabling CCWD to extend the time periods during which Delta water of sufficient quality is available for: 1) filling Los Vaqueros Reservoir, and 2) direct use without the need for blending with higher quality Los Vaqueros Reservoir water to meet delivered water quality goals.
- **Protect Delivered Water Quality During Emergencies.** Help protect CCWD's delivered water quality during emergency situations by enabling CCWD to avoid diverting water from areas of the Delta affected by a levee failure, chemical or hazardous spill, or other potentially catastrophic events.

Purpose and Need

The project purpose is to protect and improve the quality of water delivered to CCWD's untreated- and treated-water customers.

The need for this project derives from the following conditions:

- Delta water quality at CCWD's current intakes does not meet CCWD's Board-adopted water quality objectives during late summer and fall, as well as during drought periods.
- Future and more stringent Federal and State drinking water standards will be increasingly difficult to meet.



Source: Carollo Engineers

Project Location Area for the Proposed Action

EXHIBIT ES-1

- Los Vaqueros Project benefits can be affected by periods of insufficient Delta water quality for reservoir filling or for direct diversion.
- Unforeseen events, such as levee failure, chemical and hazardous spills, and other events can seriously compromise water quality at CCWD's intakes.

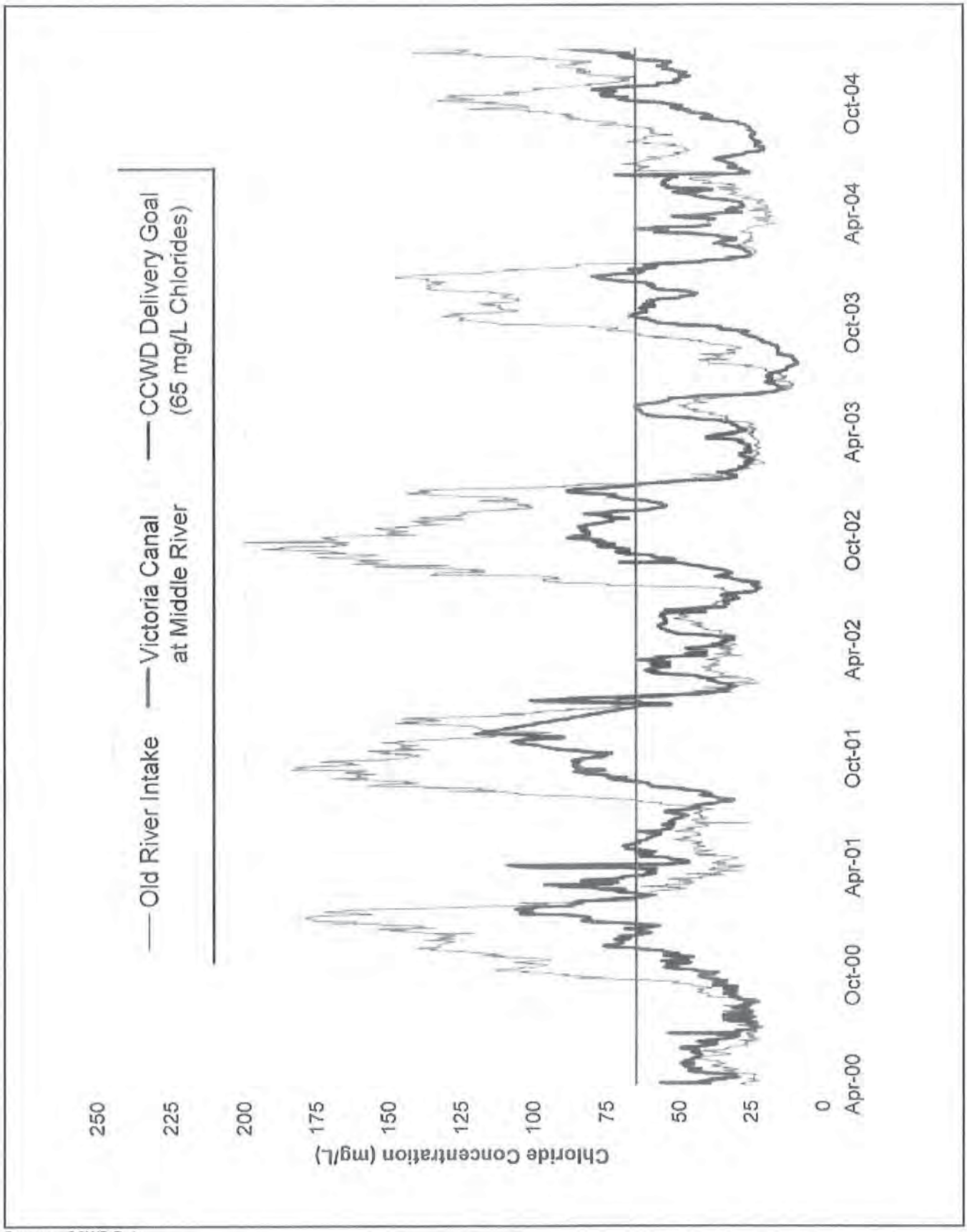
Summary Description of Proposed Action and Alternatives

This document evaluates the potential environmental effects of the Proposed Action and four alternatives: No-Action Alternative; Alternative 2, Indirect Pipeline Route; Alternative 3, Modified Operations Alternative; and Alternative 4, Desalination Alternative.

The **Proposed Action (Alternative 1)** would protect and improve delivered water quality for CCWD customers by enabling CCWD to relocate some of its existing diversions to Victoria Canal, a Delta location with better source water quality than is currently available at its Old River and Rock Slough intakes. Exhibit ES-2 illustrates the better water quality, measured as chlorides, available in Victoria Canal during key periods. While CCWD has water quality goals for several constituents, salinity measured in terms of chloride concentration is generally used as an indicator of overall Delta water quality at CCWD's intakes for both aesthetic and health concerns. The alternative intake would divert up to 250 cubic feet per second (cfs) from a new intake on Victoria Canal. Although it would change the location, timing, and quality of some of CCWD's existing diversions, the Proposed Action would not increase CCWD's total Delta diversion capacity (rate or average annual quantity) and would not change CCWD's demands or the quantity of water delivered to its service area each year; under current conditions, no more than 250 cfs would be diverted from the combined Old River intake and new alternative intake.

The Proposed Action includes a new, screened water intake and pump station located along the lower third of Victoria Canal on Victoria Island in the central Delta, and a buried pipeline that would extend 12,000–14,000 feet from the new intake directly across Victoria Island and beneath Old River and tie into CCWD's existing Old River conveyance system on Byron Tract (see Exhibit ES-3). The Proposed Action would involve adding a new point of diversion to certain existing water rights held by CCWD and by Reclamation. CCWD would not seek to increase its water rights, CVP contract amounts, or permitted Los Vaqueros Reservoir filling rates through this action.

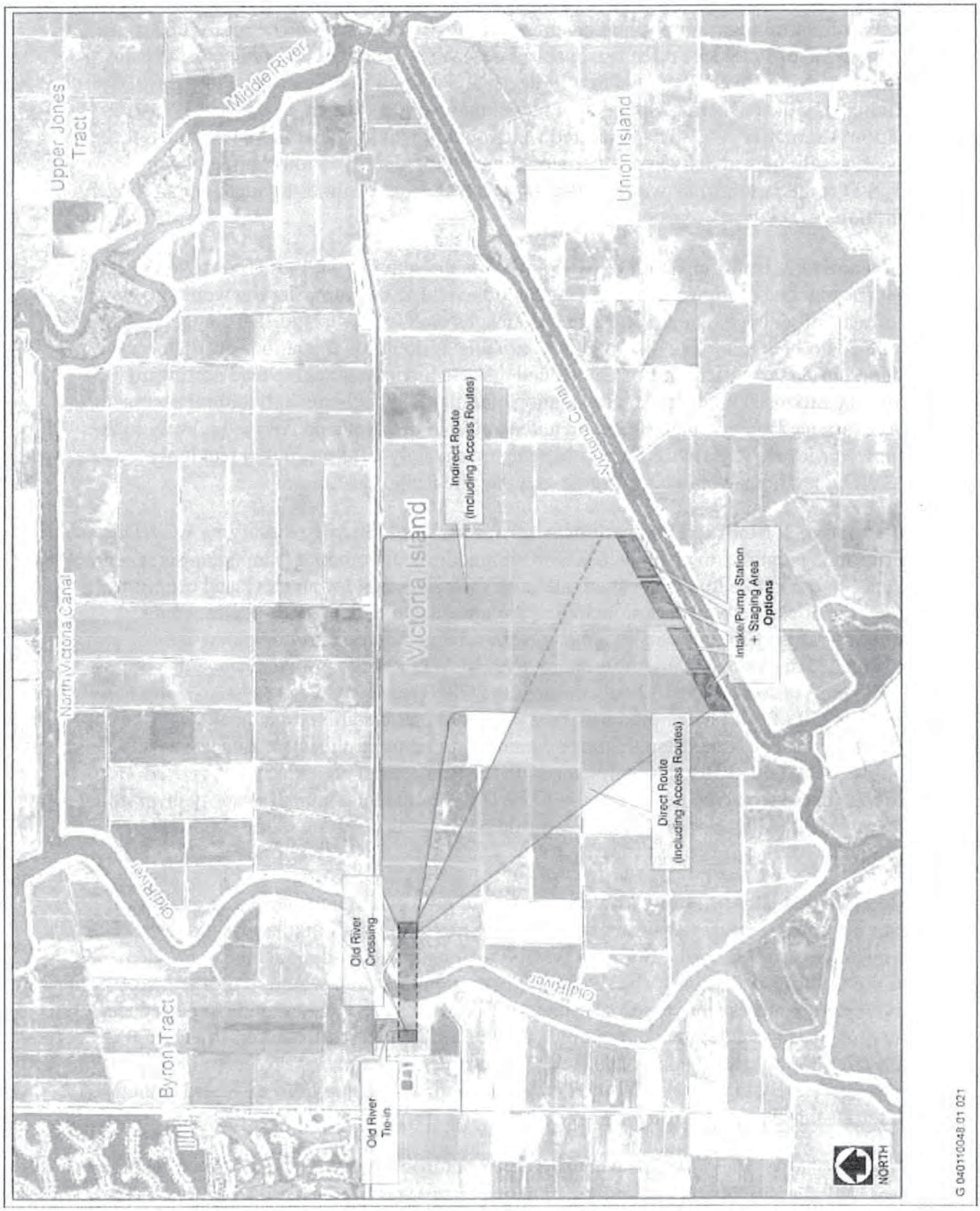
The **No-Action Alternative** would entail CCWD continuing to operate and maintain its existing facilities to provide the highest-quality water available with existing facilities consistent with environmental regulations and permit conditions. In the near term, there would be no substantive or predictable operational changes implemented under the No-Action Alternative. Under future levels of demand, the No-Action Alternative includes the expansion of the Old River pump station to a capacity of 320 cfs consistent with the



Source: CCWD Data

Comparison of Chloride Concentrations at Old River Intake Versus Victoria Canal

EXHIBIT ES-2



Source: CCWD Data

Conceptual Alignments for Alternative1 (Proposed Action) and Alternative 2

EXHIBIT ES-3

CCWD Future Water Supply Implementation EIR (CCWD 1998). The No-Action Alternative also includes three reasonably foreseeable future CCWD projects: the Rock Slough and Old River Water Quality Projects, and a small intertie project with East Bay Municipal Utility District. Operational modeling results indicate that under the No-Action Alternative, CCWD's delivered water quality would decrease in the future. Average salinities in delivered water would increase, and the periods during which CCWD could not meet its water quality objectives would be more frequent and of longer duration.

Alternative 2, Indirect Pipeline Alternative, is the same as the Proposed Action except that the pipeline route from the new intake to the Old River pump station would be indirect, following existing agricultural drainages on Victoria Island. This longer pipeline route could help minimize disruptions to existing agricultural operations on Victoria Island during construction. It is envisioned that the pipeline would extend northward from the proposed intake structure location, parallel to an existing agricultural access road, to State Route 4, then westward and parallel to the south side of the highway to the Old River levee. The alignment would be approximately 17,000–20,000 feet long. CCWD operations would be the same as under the Proposed Action.

Alternative 3, Modified Operations Alternative, would involve modifying CCWD permitted operations to enable CCWD to shift additional pumping from the unscreened Rock Slough intake to the screened intake at Victoria Canal for an increased benefit to Delta fisheries. Delta fisheries, including threatened and endangered species, could benefit because fish mortality is reduced with screened diversions compared to unscreened diversions. Under this alternative, CCWD would apply to change its permits to allow diversion of up to 320 cfs through the Old River conveyance system using the existing 250-cfs Old River intake and the proposed 250-cfs alternative intake in combination. The Rock Slough intake would continue to provide a portion of CCWD supply, but would be used less frequently in the near term than under the Proposed Action. There would be no increase in CCWD's average total annual quantity diverted. The physical features of Alternative 3 would be the same as those of the Proposed Action.

Alternative 4, Desalination Alternative, would protect and improve water quality for both untreated- and treated-water customers by providing high-quality desalinated water to customers served by the Bollman Water Treatment Plant and reducing overall demands on the Contra Costa Canal. The reduced demands on the canal would in turn reduce diversion quantities from the Rock Slough and/or Old River intakes, and would reduce the quantity of blending water required from the Los Vaqueros Reservoir to meet delivered water quality goals. This would allow the Los Vaqueros Project to be used more effectively to provide high-quality water to the remaining untreated- and treated-water customers.

This alternative would include a new brackish water desalination plant with a treatment capacity of approximately 70 million gallons per day and associated infrastructure for conveyance of brackish water to the plant and concentrate disposal from the plant for discharge into Suisun Bay. A new screened intake would be constructed at CCWD's

existing Mallard Slough pump station located near the City of Pittsburg and Suisun Bay. To accommodate the shift of additional CCWD pumping to Mallard Slough and the slight increase in diversions for losses in the desalination process, water rights modifications to the existing Mallard Slough water rights or adding Mallard Slough as a CVP diversion point would be required.

Major Conclusions of the Environmental Analysis

Summary of Impacts and Mitigation Measures

The Proposed Action and alternatives would affect some environmental resources. The majority of the impacts would be temporary, construction-related effects that would be less than significant or would be reduced to less-than-significant levels through mitigation. In addition to the water quality benefits to CCWD, the Proposed Action and several alternatives have the potential to provide environmental benefits to Delta fisheries by reducing net fish entrainment and impingement at CCWD intakes.

Table ES-1, included at the end of this Executive Summary, summarizes the environmental impacts of the Proposed Action and alternatives, the level of significance of each impact before mitigation, recommended mitigation measures, and the level of significance of each impact after mitigation.

The Proposed Action and Alternatives 2 and 3 are very similar in terms of their potential environmental impacts. The primary difference in effect between the Proposed Action and Alternative 2 is the amount of temporarily affected agricultural land along the indirect pipeline alignment during construction and pipeline installation (approximately 200–470 acres with implementation of the Proposed Action versus approximately 155–305 acres with implementation of Alternative 2). The impacts of Alternative 3 would be similar to those of the Proposed Action and Alternative 2, with the primary difference being a greater near-term benefit for fisheries resources; Alternative 3 would reduce estimated fish entrainment and impingement losses compared with existing conditions and with the Proposed Action. The impacts of Alternative 3 would be the same as those of the Proposed Action and Alternative 2 under future conditions.

One of the primary differences between Alternative 4 and the Proposed Action, Alternative 2, and Alternative 3 is project location. The Proposed Action and Alternatives 2 and 3 would be located in a rural area with few sensitive receptors and developed land uses that could experience project impacts, especially during construction. The primary land impacts associated with the Proposed Action and Alternatives 2 and 3 would be agricultural land conversion of 6-8 acres and temporary impacts to agricultural operations. In comparison, some components of Alternative 4, in particular the untreated water conveyance pipeline, would be located in urban areas, in close proximity to sensitive receptors and developed land uses. Temporary construction impacts such as air quality, noise, traffic, and visual impacts would be substantially greater under Alternative 4 than under the Proposed Action and Alternatives 2 and 3.

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HEALTH RISKS CAUSED BY FRESHWATER CYANOBACTERIA IN RECREATIONAL WATERS

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Toxic cyanobacteria are increasingly being perceived as a potential health hazard, particularly in waters used for recreation. A few countries are developing regulations to protect human health from these toxins, and the World Health Organization (WHO) has published both a guideline value for one cyanotoxin in drinking water and a procedural guideline for recreational waters. This article presents an overview of the currently known cyanotoxins and of documented cases of human illnesses attributed to them. It further discusses exposure pathways and approaches to risk management. In this context, the WHO guideline for recreational waters is presented, and monitoring approaches are outlined.

Livestock poisoning and adverse human health effects following the drinking of contaminated water have lead to increased research into cyanobacterial toxicity, and during the past two to three decades, the chemical structures of a number of cyanobacterial toxins ("cyanotoxins") have been identified and their mechanisms of toxicity established.

The first documented case of a lethal intoxication of livestock caused by drinking water from a lake heavily infested with cyanobacteria was published over a century ago (Francis, 1878), and cases recorded since include sheep, cattle, horses, pigs, dogs, fish, rodents, amphibians, waterfowl, bats,

[1]The views expressed in this article are those of the author and not necessarily those of the World Health Organization.

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zebras, and rhinoceros (Codd et al., 1989). Dogs have died after licking accumulations of cyanobacteria from their fur, or after ingesting beached mats of benthic cyanobacteria (Gunn et al., 1992). Reports of human deaths attributed to cyanobacterial toxins have been via exposure through renal dialysis (Jochimsen et al., 1998) and contaminated drinking water (Teixera et al., 1993). Health impairments are also indicated by numerous anecdotal reports of irritations of the skin and/or mucous membranes, and from documented cases of illnesses after exposure through drinking water as well as accidental swallowing or aspiration of scum material (Table 1).

Cyanobacterial toxins occur naturally, but pollution with nutrients from agriculture and domestic wastewater has lead to increased fertilization ("eutrophication") of many water bodies. This in turn results in proliferation of cyanobacteria and thus has considerable negative impact upon recreational water quality. In temperate climates cyanobacterial dominance is most pronounced during the summer months, when the demand for recreational water is highest. Thus, eutrophication together with a lack of "avoidance behavior" by recreational water users may lead to increased health risks from cyanotoxins.

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TABLE 1. Cyanobacterial Toxins and Their Acute Toxicity

Cyanotoxins	LD50 (ip, mouse) of pure toxin	Taxa known to produce the toxin(s)	Mechanism of toxicity
Protein-phosphatase-blockers (cyclic peptides with ADDA)			Block protein phosphatases by covalent binding and cause hemorrhaging of the liver; cumulative damage may occur
Microcystins in general (~60 known congeners)	45–>1000 µg/kg	*Microcystis, Planktothrix/ Oscillatoria, Nostoc, Anabaena, Anabaenopsis, Hapalosiphon*	
Microcystin-LR	60 (25–125) µg/kg		
Microcystin-YR	70 µg/kg		
Microcystin-RR	300–600 µg/kg		
Nodularin	30–50 µg/kg	*Nodularia spumigena*	
Neurotoxins			
Anatoxin-a (alkaloid)	250 µg/kg	*Anabaena, Oscillatoria, Aphanizomenon, Cylindrospermum*	Blocks postsynaptic depolarization
Anatoxin-a(s) (unique organophosphate)	40 µg/kg	Known only from 2 species of *Anabaena*	Blocks acetyl-cholinesterase
Saxitoxins (carbamate alkaloids)	10–30 µg/kg	*Aphanizomenon, Anabaena, Lyngbya, Cylindrospermopsis raciborskii*	Block sodium channels
Cytotoxin	2100 µg/kg/d	*Cylindrospermopsis raciborskii*	Blocks protein synthesis; substantial cumulative toxicity
Cylindrospermopsin (alkaloid)	200 µg/kg/5–6 d		

Note. ADDA: 2*S*,3*S*,8*S*,9*S*-3-amino-9-methoxy-2,6,8-trimethyl-10-phenyldeca-4,6-dienoic acid.

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Several countries are now developing guidelines for the quantity of toxic cyanobacteria in recreational waters. The World Health Organization (WHO) has published a provisional guideline value for microcystin-LR in drinking water (WHO, 1998) in the context of the revision of the WHO "Guidelines on Drinking-Water Quality," and has compiled a monograph, "Toxic Cyanobacteria in Water: a Guide to Health Significance, Monitoring and Management" (Chorus & Bartram, 1999). Thus, guidance for assessment and management of cyanobacterial hazards in recreational waters is becoming available.

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CYANOBACTERIA

Cyanobacteria are prokaryotic, single-celled, widespread organisms that grow (1) planktonically in water or (2) benthically on surfaces in water bodies, and (3) on moist terrestrial surfaces. Many species form filaments or colonies, sometimes up to 1 or 2 mm in diameter. Benthic species may form dense mats.

In contrast to true eukaryotic algae, many species of planktonic cyanobacteria possess specialized, intracellular gas vesicles. These enable the cells to regulate buoyancy by a balance of carbohydrate content and gas volume, enhancing growth opportunities. Cells adapted to turbulent mixing by enhanced buoyancy may accumulate at the surface overnight under calm weather conditions. Light winds drive them to leeward shores and bays, where they form scums. In extreme cases, such agglomerations may become very dense and even acquire a gelatinous consistency. More frequently, they are seen as streaks or slimy scums that appear like blue-green paint or jelly. Such situations may change rapidly, within hours, if wind mixing of the water surface increases. However, especially in shallow bays, scum material may take a rather long time to disperse, either as a result of wave wash or, ultimately, disintegration of the cells. Dying and lysing cells release their contents into the water, including toxins and blue-green pigments (phycocyanin). Bacterial decomposition leads to rapid putrefaction of the material. The in-shore deposits are unsavory, often repulsive, and—as is now appreciated—potentially toxic.

Mass aggregations of cyanobacteria have earned the collective term "water blooms," which is applied to both dense cell numbers dispersed in water and to scums on the surface. Some cyanobacteria produce, during normal growth, characteristic odors that may be described as "musty," "geranium," or "vegetable-like." The occurrence of odorous substances does not, however, correlate with toxicity. Such smells may only be taken as a warning signal for the potential presence of cyanobacteria.

While agglomerations of cyanobacteria are usually caused by planktonic species in eutrophic waters, benthic mats in oligotrophic waters also occasionally cause problems: These surface-covering mats can grow only in clear water, in which sunlight penetrates to the bottom. During sunny days, photosynthesis may lead to high rates of oxygen production,

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causing bubbles that loosen parts of the mats and drive them to the surface. Mats of benthic cyanobacteria washed to the shore and scavenged by dogs have been lethal (Edwards et al., 1992), and cattle deaths on Swiss alpine meadows may also have been caused by benthic cyanobacteria (Mez et al., 1996). Though relevant for pets and livestock, the human health impact of these cyanobacteria on beaches will be considerably lower than that of scums in the water.

TOXIGENICITY

Toxic cyanobacteria are found worldwide in inland and coastal water environments. Currently, at least 46 species have been shown to cause toxic effects in vertebrates (Sivonen & Jones, 1999). The most common toxic cyanobacteria are:

Microcystis spp.
Planktothrix (syn. *Oscillatoria*) *rubescens*
Planktothrix (syn. *Oscillatoria*) *agardhii*
Anabaena spp.
Aphanizomenon spp.
some *Oscillatoria* spp.
Cylindrospermopsis raciborskii
Synechococcus spp.
Gloeotrichia spp.
Lyngbia spp.
Nostoc spp.
Schizothrix spp.
Synechocystis spp.

and in brackish water environments *Nodularia spumigena.* Toxicity cannot be excluded for further species and genera, and as research broadens and covers further regions over the globe, more toxic species are likely to be found.

The most common bloom-forming genus, *Microcystis,* is almost always toxic (Carmichael, 1995), but nontoxic strains do occur. A similar pattern is seen in other potentially toxic species. While the conditions leading to cyanobacterial proliferation are well established, the physiological or biochemical functions of toxins for the cyanobacteria are unknown, and the factors favoring dominance of toxic strains over nontoxic ones are poorly understood. Evidence is accumulating for genetic differences between strains containing or not containing microcystins within taxonomic categories otherwise identified as one species (Dittmann et al., 1997). Studies with cyanobacterial cultures also show that toxicity is a fairly constant trait for a given strain (or "genotype"), and is only somewhat modified by environmental conditions.

Worldwide, about 75% of the cyanobacterial samples investigated proved to contain toxins. The toxicity of a single bloom may, however,

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fluctuate in both time and space. Demonstrations of toxicity of the cyanobacterial population in a given lake do not necessarily imply an environmental or human hazard as long as the cells remain thinly dispersed—mass developments and especially surface scums pose the health risks (see Chorus & Bartram, 1999).

CYANOTOXINS

Three groups of cyanotoxins are now recognized: (1) three neurotoxins with somewhat different modes of blocking neuronal signal transmission [anatoxin-a, anatoxin-a(s), and saxitoxins], (2) one general cytotoxin that inhibits protein synthesis (cylindrospermopsin), and (3) a group of toxins termed microcystins that inhibit protein phosphatases. Phosphatase inhibition may generally be cytotoxic, but microcystins are primarily hepatotoxic because they use a carrier like the bile acid carrier of liver cells to pass through cell membranes. These toxins were named after the organism from which they were first isolated, but most of them have been found in a wider array of genera. Further, some species contain more than one toxin or both microcystins and neurotoxins. Table 1 presents an overview of the most important cyanotoxins currently known and their mode of acute action (Turner et al., 1990; Sivonen & Jones, 1999; Kuiper-Goodman et al., 1999).

These toxins are chiefly found within the cyanobacterial cells. Liberation into the surrounding water is possible, particularly when cells die and lyse, and differences may occur between toxins and species regarding "leakage" from intact cells. However, toxin dissolved in water is rapidly diluted and subsequently degraded, whereas hazardous toxin concentrations usually result from accumulation of cell material as scums. Thus, measures for recreational safety should chiefly address cyanobacterial cells containing toxins.

Though the toxins listed in Table 1 are assumed to be the substances most significant for human health, it is unlikely that all of the important cyanotoxins have been discovered. Yoo et al. (1995) point out that various of new toxins are being discovered. Numerous pharmacological working groups are conducting research for pharmacologically active substances from cyanobacteria (e.g., Falch et al., 1995; Mundt & Teuscher, 1988). Fastner et al. (1995) found that primary rat hepatocytes reacted to microcystins in crude extracts of some strains of cyanobacteria in close correlation to their content of microcystins, but that this reaction was enhanced by some unknown factor. Oberemm et al. (1997) demonstrated substantial toxicity of cyanobacterial crude extracts to fish eggs, with the effects not being due to the presence of any of the known cyanotoxins.

HEALTH RISK ASSESSMENT

Some cases of human injury through cyanotoxins are documented. Most involved exposure through drinking water and demonstrate that humans became ill—in some cases seriously—through ingestion or aspira-

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tion of toxic cyanobacteria (Table 2). However, the bulk of human illnesses caused by cyanobacteria probably remain unrecognized (Yoo et al., 1995).

Human health hazards occur from three routes of exposure:

1. Direct contact of exposed parts of the body, including the ears, eyes, mouth, and throat.
2. Accidental ingestion of water containing cells by swallowing.
3. Uptake of water containing cells by aspiration (inhalation).

Exposure by Direct Contact

Allergic or irritative dermal reactions of varying severity have been associated with cyanobacteria but have not been documented extensively. Bathing suits and particularly diving suits tend to aggravate such effects by accumulating algal material and enhancing disruption of cells and liberation of cell content. Reports from the United States have recorded allergic reactions from recreational exposure, and the cyanobacterial pig-

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TABLE 2. Case Studies and Reports on Acute Injury of Humans After Exposure to Cyanobacteria

Cases attributed to cyanotoxins in drinking water	
1931	USA: A massive *Microcystis*-bloom in the Ohio and Potomac Rivers caused illness of 5000–8000 persons whose drinking water was obtained from these rivers. Drinking water treatment by precipitation, filtration and chlorination was not sufficient to remove the toxins (Tisdale, 1931).
1968	Numerous cases of gastrointestinal illness after exposure to cyanobacteria compiled by Schwimmer & Schwimmer (1968).
1975	Endotoxic shock of 23 dialysis-patients in Washington, DC, attributed to a cyanobacterial bloom in a drinking-water reservoir (Hindman et al., 1975)
1979	Australia: Combating a bloom of *Cylindrospermopsis raciborskii* in a drinking water reservoir on Palm Island with copper sulfate caused liberation of toxins into the water, thus resulting in serious illness (with hospitalization) of 141 persons supplied from this reservoir (Falconer, 1993, 1994).
1981	Australia: In the city of Armidale liver enzyme activities were elevated in the blood of the population supplied from surface water polluted by *Microcystis* spp. (Falconer et al., 1983).
1985	USA: Carmichael et al. (1985) compiled case studies on nausea, vomiting, diarrhea, fever, eye-, ear-and throat-infections after exposure to cyanobacteria.
1988	Brazil: Following the flooding of the Itaparica Dam in Bahia State, some 2000 cases of gastroenteritis were reported over a 42 day period, of which 88 resulted in death. Investigation of potential causes of this epidemic eliminated pathogens and identified a very high population of toxic cyanobacteria in the drinking water supply in the affected areas (Teixera et al., 1993).
1993	China: The incidence of liver cancer relates clearly to water sources and is significantly higher for populations using cyanobacteria-infested surface waters as compared to those drinking groundwater (Yu, 1995).
1993	Australia: Falconer (1993) estimated that due to toxic cyanobacterial blooms, more than 600,000 person-days are lost for drinking water abstraction annually.

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TABLE 2. Case Studies and Reports on Acute Injury of Humans After Exposure to Cyanobacteria (*Continued*)

Cases attributed to cyanotoxins in drinking water (*continued*)	
1994	Sweden near Malmö: Illegal use of untreated river water in a sugar factory led to an accidental cross-connection with the drinking water supply for an uncertain number of hours. The river water was densely populated by *Planktothrix agardhii,* and samples taken few days before and a few days after the incident showed these cyanobacteria to contain microcystins. A total of 121 of 304 inhabitants of the village (as well as some dogs and cats) became ill with vomiting, diarrhea, muscular cramps, nausea (Anadotter et al., in press).
Cases attributed to cyanotoxins in recreational water	
1959	Saskatchewan: Despite mortality of livestock and warnings against recreational use, people did swim in the lake infested with cyanobacteria. Thirteen persons became ill (headaches, nausea, muscular pains, painful diarrhea). In the excreta of one patient—a medical doctor who had accidentally ingested 300 ml of water—numerous cells of *Microcystis* spp. and some trichomes of *Anabaena circinalis* could be clearly identified (Dillenberg & Dehnel, 1959).
1989	England: 10 of 20 soldiers became ill after swimming and canoe-training in water with a heavy bloom of *Microcystis* spp.; two of them developed severe pneumonia attributed to the aspiration of a *Microcystis* toxin and needed hospitalization and intensive care (Turner et al., 1990). Swimming skills and the amount of water ingested appear to have been related to the degree of illness.
1995	Australia: Epidemiological evidence of adverse health effects after recreational water contact from a prospective study involving 852 participants showed elevated incidence of diarrhea, vomiting, flu symptoms, skin rashes, mouth ulcers, fevers, and eye or ear irritations within 2–7 d after exposure (Pilotto et al., 1997). Symptoms increased significantly with duration of water contact and density of cyanobacterial cells, but were not related to their content of known cyanotoxins as listed in Table 1.
Cases due to other exposure routes	
1996	Caruaru in Brazil: A total of 131 dialysis patients were exposed to microcystins with the water used for dialysis; 56 of them died. At least 44 of these victims showed the typical common symptoms associated with microcystin, now referred to as "Caruaru syndrome," and liver microcystin content corresponded to that of laboratory animals having received a lethal dose of microcystin (Jochimsen et al., 1998).

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ment phycocyanin has been shown to be responsible in one case (Cohen & Reif, 1953). Severe dermatitis resembling skin burns has been reported from marine bathing in the presence of cyanobacteria dislodged from rocks after storms in tropical seas (Hindman et al., 1975; Kuiper-Goodman et al., 1999). Skin irritations were a frequent symptom in the epidemiological study of Pilotto et al. (1997) on health effects after recreational exposure to cyanobacteria, which showed correlation to cyanobacterial cell density and duration of exposure, but not to microcystin concentrations. These symptoms are unlikely to be due to the identified cyanotoxins listed in Table 1, but rather to other (currently unidentified) substances. Recreational contact with toxic *Microcystis* may, however, cause blistering of the lips, likely to be through the effects of the toxin (Turner et al., 1990).

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Allergic reactions to algae and cyanobacteria are frequently reported on the level of "anecdotal evidence" from eutrophic bathing waters. Yoo et al. (1995) point out that "allergic reactions to cyanobacteria are relatively common" (p. 77). Among the small number of publications available, Heise (1949, 1951) described ocular and nasal irritations in swimmers exposed to *Oscillatoriaceae*. McElhenny et al. (1962) applied extracts from 4 different algal species (cyanobacteria and *Chlorophyceae*) as intracutaneous skin tests to 20 nonallergic children, none of whom responded, and to 120 children with respiratory allergies, 98 of whom showed clear positive reactions to at least one of the test strains. Mittal et al. (1979) tested 4000 patients in India with respiratory allergies, 25% of whom showed positive reactions either to *Chlorophyceae* or to cyanobacteria or to both.

Pronounced skin reactions in response to a bloom of *Uroglena* spp. were observed in a small number of bathers, especially under bathing suits where cells accumulated and partially disrupted during swimming (Chorus, 1993). Pressure and friction between fabric and skin lead to disruption of cells, liberation of content, and thus to intensified dermal exposure, not only to algal cell-wall material, but also to substances otherwise largely confined within the cells.

Exposure by Ingestion or Aspiration

Swallowing or inhalation was the exposure route in most of the documented cases of human illnesses that have been associated with cyanobacteria (Table 2). In contrast to direct contact, ingestion of cyanobacteria involves a risk of intoxication from the cyanotoxins listed in Table 1. This risk may be estimated from cell density, cellular toxin content, and known mechanisms of toxicity. Acute mechanisms of toxicity are well known for the neurotoxins and microcystins, and some information is available to estimate risks due to repeated or chronic exposure.

All three cyanobacterial neurotoxins may be lethal by causing suffocation, with anatoxin-a and -a(s) through cramps, while with saxitoxins through paralysis. Artificial support of respiration may enable survival. Anatoxin-a(s) is the only known naturally occurring organophosphate cholinesterase inhibitor and triggers strong salivation (s stands for salivation), cramps, tremor, diarrhea, vomiting, and an extremely rapid death within minutes. Saxitoxins and anatoxin-a(s) are among the most neurotoxic substances known. However, evidence is accumulating that in lakes and rivers they do not occur as frequently as microcystins. This applies especially to anatoxin-a(s): To date it has only been found in a small number of *Anabaena* blooms in North America. Further, concentrations even of these highly toxic substances in scums will scarcely reach levels acutely neurotoxic to a human ingesting a mouthful. In contrast, livestock will drink many liters, and pets—especially dogs—gather scum material in their fur and ingest it through grooming with their tongue. After ingestion of a sublethal dose of these neurotoxins, recovery appears to be complete,

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and no chronic effects have been observed to date. For these reasons, the neurotoxins are a hazard to be aware of when using waters infested with cyanobacteria for recreation, but on the basis of current knowledge it is reasonable to consider them less dangerous than microcystins or cylindrospermopsin, which may cause ongoing injury.

Microcystins are the most frequent and widespread cyanotoxins. They are cyclic heptapeptides containing the side chain of a specific amino acid—ADDA: 2*S*,3*S*,8*S*,9*S*-3-amino-9-methoxy-2,6,8-trimethyl-10-phenyldeca-4,6-dienoic acid—side chain which to date has only been found in microcystins and in nodularin (a cyclic pentapeptide toxin of cyanobacteria from brackish waters). About 60 structural analogues of microcystin are known so far (Rinehart et al., 1994; Sivonen & Jones, 1999). They vary with respect to methyl groups and two amino acids within the ring. This has consequences for the geometry of the molecule and results in pronounced differences in toxicity as well as in hydrophobic/hydrophilic properties. Microcystins block the protein phosphatases 1 and 2a, which are important "molecular switches" in all eukaryotic cells, with an irreversible covalent bond (MacKintosh et al., 1990). Nodularin, produced by the brackish species *Nodularia spumigena,* is very similar to microcystis in structure and effect.

The chief pathway for microcystins into cells is a transport mechanism similar to the bile acid carrier, which is found in liver cells, but to a lesser extent also in intestinal epithelia (Falconer, 1993). Thus, for vertebrates, a lethal oral dose of microcystin causes death by liver necrosis within hours up to a few days. Permeability of other cell membranes for microcystins is still controversial. Possibly, hydrophobicity influences penetration into cells without the bile acid carrier and thus, toxicity (Ward & Codd, 1999). Further, Fitzgeorge et al. (1994) demonstrated destruction of nasal epithelia even by the common hydrophilic analogue microcystin-LR. Whilst toxicity by oral uptake is generally at least an order of magnitude lower than by intraperitoneal (ip) injection, intranasal application in these experiments was equally toxic as ip injection, additionally, membrane damage by microcystin enhanced the toxicity of anatoxin-a. This uptake route may be relevant for water sports activities such as water skiing that lead to inhalation of spray and droplets.

Microcystins are found in most populations of *Microcystis* spp., which frequently form surface scums, and in some strains of *Anabaena* spp., which may also form scums. High microcystin content has further been observed in *Planktothrix* (syn. *Oscillatoria*) *agardhii* and *P. rubescens* (Fastner et al., 1999). However, *P. agardhii* never forms scums, and *P. rubescens* usually does not form them during the bathing season. This reduces hazard to bathers as compared to the hazard arising from scum-forming species.

Fitzgeorge et al. (1994) demonstrated that microcystin toxicity is cumulative, which may be explained by the irreversible covalent binding

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of microcystin to the protein phosphatases and subsequent substantial damage to cell structure (Falconer, 1993). Repair of the liver probably requires growth of new hepatocytes. Subacute liver injury is likely to go unnoticed up to levels close to severe acute toxicity. In consequence of the lack of apparent symptoms at moderate toxin exposure, this is likely to be continued by persons uninformed of the risk (e.g., for consecutive days of a vacation or hot spell), which will increase the risk of cumulative liver damage.

There are two aspects of chronic microcystin damage to the liver: One is progressive active hepatic injury (Falconer et al., 1988), and the other is the potential for promotion of tumor growth. Tumor-promoting activity of microcystins is well documented, although microcystins alone have not been demonstrated to be carcinogenic. Promotion of mouse skin tumors has been shown after initiation by exposure to a carcinogen followed by ingestion of a *Microcystis aeruginosa* extract (Falconer & Buckley, 1989). In rat liver studies, the appearance of preneoplastic hepatic foci and nodules was promoted by pure microcystin-LR in a protocol involving one ip dose of diethylnitrosamine and ip doses of microcystin-LR over several weeks (Nishiwaki-Matushima et al., 1992). Studies on the mechanism of cell toxicity show that microcystin interferes with cell structure and mitosis, and this may contribute to explaining the tumor-promoting activity (Falconer & Yeung, 1992; Kaya, 1996).

Cylindrospermopsin is a recently identified alkaloid isolated from *Cylindrospermopsis raciborskii* (Ohtani et al., 1992). It is a general cytotoxin that blocks protein synthesis, and the first clinical symptoms of poisoning are kidney and liver failure. Oral dosing with whole cells of the organism causes widespread organ damage, including injury to the lungs, adrenals, stomach, and intestine, and more than one toxin may be involved (Falconer et al., 1999b; Seawright et al., 1999). It is especially dangerous because clinical symptoms may only become manifest several days after exposure. Thus, cause and effect will often be difficult to correlate. Patients intoxicated with cylindrospermopsin via drinking water in an incident in Australia escaped death only through skilled and intensive hospital care (Byth, 1980; Hawkins et al., 1985). *Cylindrospermopsis raciborskii* is considered to be a tropical and subtropical species, but recently it has been reported to form blooms as far north as Vienna (Roschitz, 1996). Substantial cell populations are reported from northeastern Germany (Wiedner, personal communication), and generally it appears to be invading temperate regions (Padisák, 1997).

TOXICITY OF CYANOBACTERIA IN LAKES AND RIVERS

Data from surveys in a number of countries show that toxicity is to be expected in about three-fourths of all samples containing cyanobacteria (Sivonen & Jones, 1999). Generally, the heptatotoxic microcystins appear

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to be more common than the neurotoxins, although the latter have caused animal poisonings in North America, Europe, and Australia. Blooms containing cylindrospermopsin have been reported from Australia, Hungary, Japan, and Israel, with animal poisoning seen in Australia.

Cyanotoxin content of cells can reach levels of several milligrams per gram dry weight. This has been established for microcystins, nodularin, cylindrospermopsin, anatoxin-a, and saxitoxins, with the maximum being found for nodularin, 18 mg/g dry weight (dw) (Sivonen & Jones, 1999). Generally, cyanobacteria containing microcystins at levels more than 1 mg/g of cells should be considered highly toxic. If the biomass of cyanobacteria per liter, or chlorophyll-a content, or cell number per milliliter is known for a given body of water, maximum toxin concentrations to be expected can be estimated.

Very few studies have addressed the variability of toxin content in the course of development of cyanobacterial populations (Benndorf & Henning, 1989; Jungmann et al., 1996; Kotak et al., 1995). For management of recreational waters, a few years of regular investigation of the toxin content of prevalent cyanobacterial blooms may provide information on the variability of toxin content in both time and space. If toxin content proves to show little variation during several weeks or even months of blooming of certain species, a regional basis for future predictions may be established.

Toxin concentrations per liter of water depend upon cell density, and scum formation is critical in determining cell density. In one study, microcystin concentrations ranged from 0.01 to 0.35 mg/L while the cyanobacteria were evenly dispersed (Fastner et al., 1999), but sampling of shoreline scums of the same water bodies has shown microcystin concentrations of more than 1 mg/L in 7 of 34 samples, and the maximum concentration reached 24 mg/L (Chorus, 2000).

Some commonly occurring species, such as *Planktothrix agardhii,* never form scums. The maximal microcystin concentration per liter of water currently reported is 0.35 mg/L (Fastner et al., 1999), but concentrations up to 0.5 mg/L can be estimated for shallow water bodies where population densities of this species may be extremely high.

RISK MANAGEMENT: SURVEILLANCE, IMMEDIATE MEASURES, AND RISK MINIMIZATION

Risk management must take the current uncertainties of risk assessment into account. Currently, the information available on adverse health effects from various groups of eukaryotic algae and dinoflagellates in freshwater suggests that risk management should focus on health risks due to toxic cyanobacteria, while collection of case studies and information on health effects of algae in general should be intensified.

Cyanobacteria are increasingly being included in bathing water monitoring programs, and in some cases so are their toxins. It is unclear whether

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all important cyanotoxins have been identified, and the health outcomes observed after recreational exposure—particularly irritation of the skin and mucous membranes—may be due to substances other than the toxins listed in Table 1. For this reason, monitoring of cyanobacterial cell density may be more relevant than monitoring selected cyanobacterial toxins. Further, approaches including the capacity of a water body to sustain major cyanobacterial populations have a greater predictive power.

Several countries have derived guidelines regarding cyanobacteria and/or their toxins in drinking and/or recreational waters. Short-term measures encompass warning of the public, closing of bathing sites, and canceling water sports activities such as competitions. Medium- to long-term measures are identification of the sources of nutrient (usually phosphate) enrichment and significant reduction of nutrient input in order to effectively reduce proliferation not only of cyanobacteria, but of algae as well. Metabolites of algae have scarcely been studied for their effects on human health; however, allergic reactions have been reported to Chlorophyta (McElhenny et al., 1962; Mittal et al., 1979), and dermal irritation after exposure to a species of Raphidophyta, *Gonyosstomum semen,* led to closure of numerous bathing sites in Sweden (Cronberg et al., 1988).

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Guidelines and Their Derivation

The international discussion on guidelines for cyanotoxins is focusing on microcystins because the neurotoxins are not considered to be as hazardous (due to their lack of chronic toxicity) nor as widespread. *Cylindrospermopsis,* whose toxin is very hazardous, does not form surface scums, and thus is more of a health risk in drinking water than in bathing waters.

A first move to establish a guideline for microcystins was made by Falconer (1994) on the basis of a 6-wk exposure study with pigs and other toxicological data. Falconer (1994) suggested 1 μg/L for microcystins in drinking water, a concentration that may be reached by 5000 cells of *Microcystis* per milliliter of water.

The Australian New South Wales Blue-Green Algae Task force recommended a level of 15,000 cells/ml as "acceptable contact exposure to cyanobacteria." Ressom et al. (1994) questioned the feasibility of determining "safe" levels of cyanobacteria in bathing waters, but suggested 20,000 cells/ml as a threshold. This is a density that will show as a slight discoloration of the water and thus may be recognizable to the informed public. The epidemiological results of Pilotto et al. (1997) shown in Table 2 show that the frequency of adverse health effects may begin to increase at cell densities as low as 5000 to 20,000 cells/ml.

The Bathing Water Directive of the European Union (European Community, 1977) does not regulate density of algae or cyanobacteria, but it requires a minimum of 1 m transparency (Secchi disc reading) and recommends at least 2 m. Of all the parameters in the directive, this is one of the least enforced. For example, in Germany and the Netherlands,

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almost half of the freshwater bathing sites reported less than 1 m of transparency, in most cases due to algal turbidity. The original intention of this parameter was understood to have been a physical one: Persons drowning are easier to see and rescue in clear water. However, this parameter is at present the only one in the directive that reflects phytoplankton density and thus can be used indirectly to regulate algae and cyanobacteria. This transparency criterion is measured in the context of routine bathing site monitoring according to the EC Directive at intervals of 14 d, and was used in Germany as a basis for a hierarchical approach to monitoring mass developments and scums at bathing sites (Bundesgesundheitsamt, 1997). The approach is based on the observation that if the transparency criterion of 2 m is continuously met, prolonged mass developments of cyanobacteria and intensive surface scums rarely occur in the water body. Bathing sites with higher turbidity must be monitored occasionally for their nutrient content to check whether this provides a carrying capacity for mass developments of cyanobacteria; if so, frequent monitoring for mass developments at the bathing site is advised.

On the basis of exhaustive review of available evidence and consensus among an international expert group, the following approach is recommended by WHO (Falconer et al., 1999a, pp. 166–171).

> Health impairments from cyanobacteria in recreational waters must be differentiated between the chiefly irritative symptoms caused by unknown cyanobacterial substances . . . and the potentially more severe hazard of exposure to high concentrations of known cyanotoxins, particularly microcystins. A single guideline therefore, is not appropriate. Rather, a series of guidelines associated with incremental severity and probability of adverse effects has been defined at three levels as described below (Table 3).
>
> 1. *Relatively mild and/or low probabilities of adverse health effects:*
>
> For protection from health outcomes not due to microcystin toxicity, but due to the irritative or allergenic effects of other cyanobacterial compounds, a guideline level of 20,000 cyanobacterial cells per ml (corresponding to 10 µg/L of chlorophyll-a under conditions of cyanobacterial dominance) can be derived from the prospective epidemiological study by Pilotto et al. (1997). Whereas the health outcomes reported in this study were related to cyanobacterial density and duration of exposure, they affected less than 30 percent of the individuals exposed. At this cyanobacterial density, 2–4 µg/L of microcystin may be expected if microcystin-producing cyanobacteria are dominant, with 10 µg/L being possible with highly toxic blooms (regional differences in microcystin content of the cells may be substantial). This level is close to the WHO provisional drinking-water guideline value of 1 µg/L for microcystin-LR (WHO, 1998), which is intended to be safe for life-long consumption. Thus, health outcomes due to microcystin are unlikely, and providing information for

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TABLE 3. Guidelines for Safe Practice in Managing Bathing Waters Which May Produce or Contain Cyanobacterial Cells and/or Toxins

Guidance level or situation	How guidance level derived	Health risks	Recommended action
Cyanobacterial scum formation in bathing areas	Inference from oral animal lethal poisonings Actual human illness case histories	Potential for acute poisoning Potential for long-term illness with some cyanobacterial species Short-term adverse health outcomes, e.g., skin irritations, gastrointestinal illness	Immediate action to prevent contact with scums; possible prohibition of swimming and other water-contact activities Public health follow-up investigation Inform relevant authorities
100,000 cells cyanobacteria/ml or 50 µg chlorophyll-a/L with dominance of cyanobacteria	From provisional drinking-water guideline for microcystin-LR, and data concerning other cyanotoxins	Potential for long-term illness with some cyanobacterial species Short-term adverse health outcomes, e.g., skin irritations, gastrointestinal illness	Watch for scums Restrict bathing and further investigate hazard Post on-site risk advisory signs Inform relevant health authorities
20,000 cells cyanobacteria/ml, or 10 µg chlorophyll-a/L with dominance of cyanobacteria	From human bathing epidemiological study	Short-term adverse health outcomes, e.g., skin irritations, gastrointestinal illness, probably at low frequency	Post on-site risk advisory signs Inform relevant authorities

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visitors to bathing sites with this low-level risk is considered to be sufficient. Additionally, it is recommended that the authorities are informed in order to initiate further surveillance of the site.

2. Moderate probability of adverse health effects:

At higher concentrations of cyanobacterial cells, the probability of irritative symptoms is elevated. Additionally, cyanotoxins (usually cell-bound) may reach concentrations with potential health impact. To assess risk under these circumstances the data used for the drinking water provisional guideline value may be applied. Swimmers involuntarily swallow some water while bathing, and the harm from ingestion of bathing water will be comparable to that from a drinking water supply with the same toxin content. A swimmer can expect to ingest 100–200 ml of water in one session, sailboard riders and water skiers would probably ingest more.

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A density of 100,000 cyanobacterial cells per ml (which is equivalent to approximately 50 µg/L of chlorophyll-a if cyanobacteria dominate) is a guideline for a moderate health alert in recreational waters. At this density, 20 µg/L of microcystins are likely, if the bloom consists of *Microcystis* and has an average toxin content per cell of 0.2 pg, or 0.4 µg microcystin per µg chlorophyll-a (up to 50 µg/L of microcystin are possible, but toxin levels may approximately double if *Planktothrix agardhii* is dominant. This toxin concentration is equivalent to twenty times the WHO provisional Guideline Value for microcystin-LR in drinking water, but would result in consumption of an amount close to the TDI (Tolerable Daily Intake; 0.04 µg/kg/d; WHO, 1998) for an adult of 60 kg consuming 100 ml of water while swimming (rather than 2 L of drinking-water). However, a child of 15 kg consuming 250 ml of water during extensive playing could be exposed to ten times the TDI. The health risk will be increased if the person exposed is particularly susceptible (e.g., because of chronic hepatitis B). Therefore, cyanobacterial levels likely to cause microcystin concentrations of 20 µg/L should trigger further action.

Non-scum-forming species of cyanobacteria such as *Planktothrix agardhii* have been observed to reach cell densities corresponding to 200 µg/L of chlorophyll-a or even more in shallow water bodies. Transparency in such situations will be less than 0.5 meters when measured with a Secchi disk. *Planktothrix agardhii* has been shown to contain a very high cell content of microcystin (1–2 µg per µg chlorophyll-a) and therefore toxin concentrations of 200 to 400 µg/L can occur without scum formation.

An additional reason for increased alert at 100,000 cells/ml is the potential of some frequently occurring cyanobacterial species (particularly *Microcystis* spp. and *Anabaena* spp.) to form scums. . . . These scums may increase local cell density and thus toxin concentration by a factor of 1000 or more in a few hours, thus rapidly changing the risk from moderate to high (see next subsection) for bathers and others involved in body-contact water sports.

Cyanobacterial scum formation presents a unique problem for routine monitoring at the usual time intervals of one or two weeks, because such monitoring intervals are unlikely to detect hazardous maxima. Because of the potential for rapid scum formation at a cyanobacterial density of 100,000 cells/ml or 50 µg/L chlorophyll-a (from scum-forming cyanobacterial taxa), intensification of surveillance and protective measures are appropriate at these levels. Daily inspection for scum formation (if scum-forming taxa are present) and measures to prevent exposures in areas prone to scum formation are the two main options.

Intervention is recommended to trigger effective public information campaigns to educate people on avoidance of scum contact. Furthermore, in some cases (e.g., with frequent scum formation), restriction of bathing may be judged to be appropriate. An intensified monitoring program should be implemented, particularly looking for scum accumulations. Health authorities should be notified immediately.

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3. High risk of adverse health effects:

Abundant evidence exists for potentially severe health hazards associated with scums caused by toxic cyanobacteria. . . . No human fatalities have been unequivocally associated with oral ingestion of scum, even though numerous animals have been killed by consuming water containing cyanobacterial scum material. . . . This discrepancy can be explained by the fact that animals would drink higher volumes of scum-containing water, compared with the small amounts of scum accidentally ingested by humans during bathing (resulting in a lower dose).

Cyanobacterial scums can represent thousand-fold to million-fold concentrations of cyanobacterial cell populations. It has been calculated that a child playing in *Microcystis* scums for a protracted period and ingesting a significant volume could receive a lethal exposure, although there are no reports that this has actually occurred. Based on evidence that the oral LD50 of microcystin-LR in mice is 5000–11,600 μg/kg body weight (Sivenon & Jones, 1999, p. 116), for a child of 10 kg the ingestion of 2 mg of microcystin or less could be expected to cause serious acute liver injury. . . . concentrations of up to 24 mg/L of microcystins have been published from scum material. . . . Substantially higher enrichment of scums—up to gelatinous consistency—is occasionally observed, and accidental ingestion of smaller volumes could cause serious harm. Anecdotal evidence indicates that children, and even adults, may be attracted to play in scums. The presence of scums caused by cyanobacteria is a readily detected indicator of a high risk of adverse health effects for those bathers who come into contact with the scums. Immediate action to control scum contact is recommended for such situations.

The approach outlined in this section, however, does not cover all conceivable situations. Swimmers may be in contact with benthic cyanobacteria after a storm breaks off clumps of filaments, or cyanobacterial mats naturally detach from the sediment and are accumulated on the shore (Edwards et al., 1992). Some marine beaches have been reported to have widespread problems due to a benthic marine cyanobacterium, *Lyngbya majuscula,* growing on rocks in tropical seas and causing severe blistering when trapped under the bathing suits of people following a storm (Grauer, 1961). This response may be due to acute toxicity; *Lyngbya* can produce irritant toxins. Measures of cyanobacterial cell density as outlined in Table 3 will not detect these hazards. Instead, this type of hazard calls for critical and well-informed observation of bathing sites, coupled with a flexible response.

It is difficult to define "safe" concentrations of cyanobacteria in recreational water in relation to allergenic effects or skin reactions, because individual sensitivities vary greatly. Aggravation of dermal reactions due to accumulation of cyanobacterial material and enhanced disruption of cells under bathing suits and wet suits may be a problem, even at densities below the guidelines described above. Further information related to monitoring and management of recreational waters is available in Bartram and Rees (1999).

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MONITORING AND SURVEILLANCE

Table 4 shows an approach to monitoring that aims at narrowing regular surveillance efforts down to those sites that are likely to present a risk. This is a summary of the strategy developed by WHO and presented in more detail by Chorus and Cavalieri (2000). Table 5 supplements this approach by giving a scheme for immediate temporary assessment and action.

Effective approaches to risk management and surveillance must take into account that both mass developments of cyanobacteria and their potentially very heterogeneous distribution in a water body are governed by complex ecological mechanisms. Primarily, nutrient concentrations (usually phosphate) determine the maximal biomass possible, and at moderate to low concentrations, they strongly influence whether cyanobacteria or other algae dominate. However, scum formation depends upon hydromorphological parameters such as the depth from which cyanobacteria can rise to the surface and the length of wind fetch over which surface aggregations can be swept together to form shoreline scums. For

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TABLE 4. Monitoring Phosphorus in Water and Surveillance for Toxic Cyanobacteria

1. *Monitor total phosphorus* at least twice a year, in subtropical and temperate climates at total overturn (e.g., in spring) and in summer during the main bathing season. If total phosphorus concentrations (not only soluble phosphorus or "*ortho*-phosphate") are below 0.01–0.02 mg/L P, mass developments of cyanobacteria are unlikely and high turbidities may have other causes. Use a method of sample digestion such as that of ISO/FDIS 6878 (ISO, 1988). At higher concentrations of total phosphorus, phytoplankton should be checked for mass developments of cyanobacteria (see steps 2 and 3).

2. *Monitor mass developments of phytoplankton (algae and cyanobacteria)* at fortnightly intervals. Perform visual inspection following scheme given in Table 5. For quantitative assessment, use chlorophyll-a concentration (ISO 10260; ISO, 1992) as a simple measure for algal (including cyanobacterial) density. If concentrations of chlorophyll-a remain below 0.01 mg/L hazardous densities of cyanobacteria are unlikely.

   At higher concentrations, microscopic investigations for dominance of cyanobacteria are required (see step 3).

   Inspect as much as possible of the catchment area for signs of sewage outlets, excessive fertilization close to the shoreline, erosion, or other potential sources of phosphate input.

3. *Monitor dominance of potentially toxic cyanobacteria:* If microscopic investigations show dominance of cyanobacteria and chlorophyll-a concentrations above 0.01 mg/L, immediate measures, such as posting warning signs or checking bathing beaches regularly for scum formation, must be taken, and long-term measures for restoration of bathing water quality should be planned.

   Monitoring of toxin concentrations is optional, but not necessary, unless health effects are reported.

It is recommended to include measurements of transparency (Secchi disk readings) in steps 2 and 3, because transparency data greatly enhance understanding of the system. Values of <2 m frequently indicate cyanobacterial or algal mass developments. Methods for steps 1–3 are given in Chorus and Bartram (1999).

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TABLE 5. Structured, Quantitative Investigation Approach to Monitoring and Surveillance for Toxic Cyanobacteria

1. Begin with visual inspection of the bathing site. Assess the most likely areas to be affected first, i.e., downwind shorelines.
2. Note any changes in wind direction or strength in the preceding 24 h as conditions can vary within hours.
3. Determine if: (a) the bottom of the lake can be seen at 30 cm depth along the shore line, or—if a Secchi disc is available—whether the Secchi transparency is >2 m; (b) cyanobacteria are visible at the water edge or as green or blue-green streaks on the water surface; and/or (c) a green or blue-green scum is on the water surface in any area.
4. If cyanobacteria are suspected, decide whether or not to (a) buoy off affected areas and prohibit access to them by water users; (b) prohibit access to the water edge affected by scum or reduced visibility, except for launching boats; and/or (c) prohibit access by all recreational users where cyanobacterial blooms cover a large part of the water surface.
5. If cyanobacteria are suspected, immediately take a grab sample (100 ml) for microscopic analysis.
6. If cyanobacteria are present, initiate the structured monitoring program given in Table 4.

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these reasons, the values given in Table 4 may serve as guidance and orientation, to be further developed as information on a given water body builds up.

For visual inspection of the bathing site, follow the scheme given in Table 5. Temporarily, for immediate assessment and action, this scheme may be applied without assessing the quantitative data suggested in Table 4. However, investigation should not remain limited to these visual parameters, unless they can be assessed daily. If the quantitative approach given in Table 4 is omitted, authorities have no measure of scum forming potential, and must therefore constantly expect this hazard.

This approach aims at maximizing efficacy by reducing effort of investigation to situations likely to present a hazard. It is further self-strengthening, because it addresses the carrying capacity of the system for the hazardous organisms and thus builds up an increasing understanding of the respective ecosystems. Carmichael (1995) emphasizes that factors that govern the spatial and temporal distribution of cyanobacteria are fairly predictable in many water bodies, and can be acquired by regular observation. Limnological information will thus facilitate anticipation of bloom situations and well-targeted monitoring.

METHODS OF MONITORING THE OCCURRENCE OF CYANOBACTERIA AND OF CYANOTOXIN ANALYSIS

Cyanobacteria

Sampling must take into account that horizontal and vertical distribution of cells may be extremely heterogeneous and variable within short periods of time. To assess health risks, dense blooms and surface scums should be

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sought and sampled. Cyanobacterial density itself may be assessed by counting cells or filaments in an inverted microscope (Lawton et al., 1999b; Padisák & Adrian, 1999; Cronberg, 1982; Utermöhl, 1958). However, if phytoplankton biomass is quantified by chlorophyll analysis, microscopical analysis may be limited to a brief investigation of dominant species, rather than conducting labor-intensive cell counts. General experience shows that at chlorophyll-a concentrations of more than 40 µg/L and dominance of cyanobacteria, surface scums may form rapidly. Severe scums contain more than 100–150 µg/L of chlorophyll-a measured in the open water. Cell density can commonly increase in scums by a factor of 1000 or more as compared to the open water; the larger the surface area of the water body, the higher is the potential concentration of cyanobacterial scums through wind action.

In countries following the directive of the European Union for bathing waters (European Community, 1977), sampling is usually undertaken fortnightly. This will usually be sufficient when no cyanobacterial populations are detected. However, as soon as cyanobacterial population growth begins (in temperate climates often in midsummer), sampling frequency should be increased to weekly.

Cyanobacterial Toxins

Sampling for toxins must take into account that cyanotoxins (especially microcystins) are largely contained within the cells and are released into the surrounding water only upon lysis. This may not apply to anatoxin-a (Bumke-Vogt et al., 1996). Most analytical methods address intracellular content. Therefore, rapid filtration of samples before onset of lysis is necessary to prevent underestimation of toxin content. On-site enrichment with plankton nets has proven to be very effective for "harvesting" larger amounts for toxin analysis. In situations in which seston (particle) concentrations largely consist of cyanobacteria, the dry weight of concentrated bloom samples may easily be related to the water volume sampled by also determining the seston concentration in the lake water.

For the cyanotoxins whose structure has been described, analytical methods suitable for routine analysis have been established, some of them quite recently (Codd et al., 1994). Reviews of methods, their sensitivity and fields of application are given by Harada (1994) and Lawton et al. (1999a). Health authorities will largely focus on microcystins; however, analysis for neurotoxins may be indicated in specific situations (e.g., with animal mortality). Microcystins may be effectively and quite accurately analyzed within 1–2 d using the high-performance liquid chromatography (HPLC) method of Lawton et al. (1994). A rapid preliminary assessment of high sensitivity is possible by a commercially available immunoassay; reliability is greatly augmented by parallel use of an enzyme inhibition assay (An & Carmichael, 1994; Ueno et al., 1996). Beyond these methods, which address known substances, the mouse bioassay will show an inte-

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grated response to known as well as unknown toxins in cyanobacteria. It is rapid and easy to perform for laboratories routinely doing mouse assays, but ethically controversial in many countries, and usually more expensive than analytical methods. A cell-based test has been developed using primary rat hepatocytes to test for hepatotoxicity (Heinze, 1996).

SHORT-TERM MEASURES

Perception of risks due to toxic cyanobacteria has lead to different reactions: In the United Kingdom, water sports events have been canceled because of cyanobacterial blooms (National Rivers Authority, 1990), but experience is also being gathered with alternatives, such as close observation of scum formation and protecting bathers by "fencing" scums in with buoyant barriers or launching boats and swimmers only from piers rather than from shorelines (Codd, personal communication). In Australia, responsibility for reacting to warnings is largely left to the public: Bathing sites are rarely closed, but care is taken to post warnings in a clearly understandable way (with pictograms to overcome language barriers in this multicultural society). In Australia, this policy can be based on an especially high degree of public awareness towards cyanotoxins, because of relatively frequent occurrence of cyanobacterial blooms, and a long history of poisoning of domestic animals. In Germany, a two-step reaction is being practiced with an alert level at high cyanobacterial densities, which triggers publication and posting of warning notices, and an intervention level at scum formation, which triggers temporary closure of the site (Bundesgesundheitsamt, 1997).

The most important short-term measure is adequate information provided to the public on the cyanobacterial risk. Communication of warnings to the public may occur through local news media and by posting warning notices.

Differentiation between the degrees of water contact in different types of water sports should be included in the warning.

LONG-TERM MEASURES AND RISK AVOIDANCE: HOW CAN WE MAINTAIN OR ACHIEVE LOW POPULATION DENSITIES OF HARMFUL ALGAE?

The aim of measures to minimize risks due to toxic algae is not to close bathing sites, but rather the restoration of bathing water quality with transparencies of >2 m (Secchi disc reading) and absence of cyanobacterial blooms by measures that address the primary causes of the problem (Figure 1). In most water bodies this can be achieved by keeping total phosphorus concentrations below 0.01 mg/L P. Cyanobacterial densities rarely reach hazardous levels even in water bodies containing 0.02–0.03 mg/L total P.

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Identification of the chief sources of phosphorus (Figure 1) is the basis for development of restoration strategies as compiled by Chorus and Mur (1999). If the major source is sewage outfall, its treatment may be highly effective. Nutrient input from agricultural runoff may in many cases easily be reduced (without cost and even at economic gain) by reducing the application of fertilizers to the actual demand of the crop, or by simple measures such as protection from erosion by planting shrubs along a strip of about 20 m along the shoreline, rather than plowing and fertilizing to the very edge of the water. Health authorities can initiate substantial improvement in such situations through catchment management programs, launched through intersectoral cooperation.

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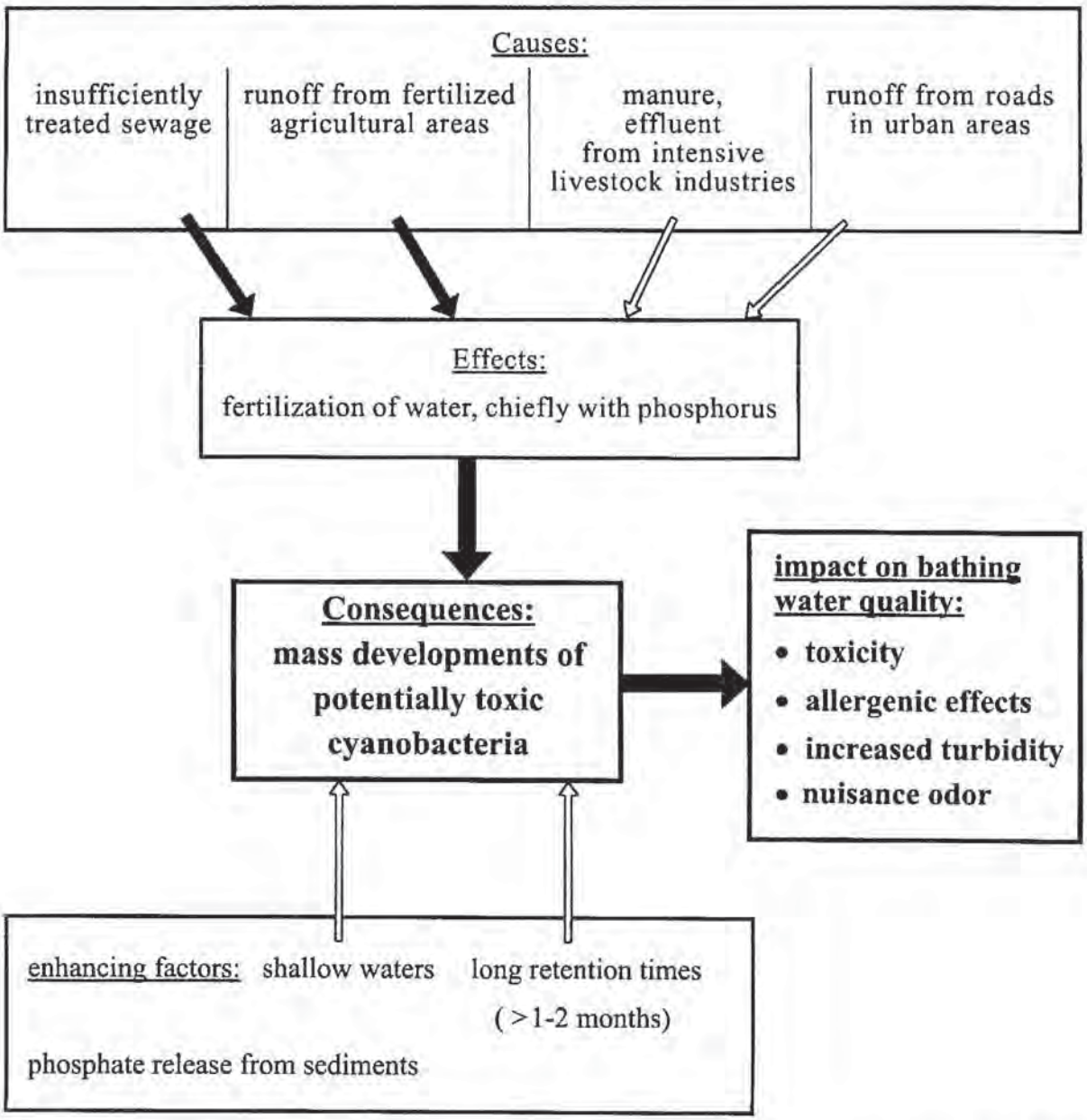


FIGURE 1. Causes of fertilization of water bodies to be addressed by measures targeting the abatement of cyanobacterial proliferation.

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Deutsches Elektronen-Synchrotron
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URL: http://www.desy.de/news/subsidence/index_eng.html

TUNNEL CONSTRUCTION FOR THE EUROPEAN XFEL.

News about the subsidence above the tunnel of 2 July 2011
Joint website of DESY and European XFEL

On Saturday, 2 July 2011, a subsidence was discovered in the lawn of a private estate in Hamburg Lurup. It is located directly above the tunnel for the European XFEL accelerator, which is currently being built between the construction sites Osdorfer Born and DESY-Bahrenfeld using a large tunnel boring machine. The tunnel lies at a depth of around 25 metres beneath the concerned estate, its construction is expected to be completed at the end of July. The hole had a volume of about one cubic metre and apparently appeared four weeks after the tunnel boring machine was working beneath this spot. After careful examination, the experts agree that the subsidence poses no threats and that it was due to a localized, very loose soil formation that was influenced by the tunnelling.

Final evaluation and restoration of the garden (as of 29 August 2011)

Right after the initial assessment of the situation, the tunnel construction experts unanimously agreed that this subsidence does not pose any further risks to local residents. This has been confirmed after a thorough examination. The surface turns out to be stable. The experts involved speak of an atypical incident, for which there had been no prior indications based on the knowledge of the geological formation and on the analysis of existing tunneling protocols. Together with the tunneling experts of the participating construction consortium and the builder, a number of external experts worked intensively on elucidating the cause of the subsidence. They unanimously found that there are no voids in this place above the tunnel, and that the soil—which is made of sand—is very loosely packed in a narrow area beneath the hole. These particular soil conditions have a limited extension and start at a depth of about 12 metres below ground level. The tunnel excavation apparently triggered local ground movements, which led to the subsidence around four weeks after the tunnel boring machine had been working under that spot.

According to the engineers involved in the study, the results show a generally stable ground. Nevertheless, all parties have agreed to consolidate the region of loose sandy soil. This is done with so-called flushing lances, which have a diameter of about 6 cm and work from the bottom upwards. By slowly pulling the lance, the sand is washed down by water pressure, causing it to consolidate in the

depths. The ground potentially lacking at the surface it then refilled. The result will be checked after a certain time in a depth sounding investigation.

First reaction (as of 13 July 2011)

Within an hour after notification, DESY's leading tunnel construction engineer was on site to analyse the situation and provide for the necessary first measures. The area was cordoned off and surveyed, and the hole filled. Until further notice, it is being inspected twice a day and measured. Since the occurrence of the subsidence, the tunnel construction engineers of the consortium ARGE Tunnel XFEL, DESY engineers and other experts have been working intensively on the elucidation of its nature and the search for its causes. Among others, they use special tools to carry out depth sounding of the soil (see "Depth sounding measures" and Photos). In addition, an independent geotechnical expert was consulted.

Once the investigations are completed and evaluated, a concept for the restoration of the garden will be developed, which may also include a special consolidation of the subsoil.

The ground above the tunnel is being routinely surveyed by the ARGE Tunnel XFEL consortium for possible subsidence. The time interval between the measurements depends on the location of the tunnel boring machine. The survey is done in a tight grid which also includes buildings, with the fixed measurement points located – with a few exceptions – in public areas (streets, sidewalks, etc.). Until further notice, the hole is now being surveyed twice a day. In addition and as a precaution, the landed properties located above the tunnel are being inspected in a wide area in front of and behind the hole, with special emphasis on the green areas.

Depth sounding measures

Since Monday, 4 July 2011, the nature of the subsidence and its surroundings have been analysed using various depth sounding methods, such as light and heavy dynamic probing and cone penetration testing. In addition, a magnetometer is used to detect metallic materials.

Light dynamic probing (DPL) involves driving a solid cone with a cross section of 5 cm^2 into the soil in several steps from the same drop hight. The number of strokes required to drive the cone to a determined depth is recorded. This number of strokes allows conclusions to be drawn on the density of the soil.

In heavy dynamic probing (DPH), a probe with a larger cross section (15 cm^2) is used. As with DPL, the number of strokes required gives indications on the soil conditions (compactness). Compared to DPL, the DPH method enables deeper soil layers to be examined.

In cone penetration testing (CPT), an instrumented probe with a conical tip is pushed into the soil at a constant rate (usually 2 cm/s) using a rod system. The CPT instrument reports tip and sleeve friction along the probe. The tip friction allows conclusions to be drawn on the density of the soil, and the ratio of sleeve and tip friction gives indications as to soil properties.

A magnetometer is used to measure magnetic flux densities. One of its classical applications is measuring the earth's magnetic field and its variations (geomagnetics). Local deviations of the magnetic field on the earth's surface indicate the presence of ferromagnetic materials in the underground.

Smallest fluctuations of the Earth's gravitational field can be measured using a

icrogravi eter. In a complex process, geophysicists can then extract information on the density distribution in the subsurface of the probed area.

Does the construction process present a risk for the residents and their houses?

The experts say that this tunnel construction method poses no danger for the residents. This is the reason why we have agreed to this construction method in the first place. On the other hand, no construction process and no building project is ever one hundred percent safe. Both the engineers involved in this tunnel construction and the external and independent experts we consulted are convinced that this subsidence and the one that occurred in November 2010 in a horse pasture are atypical. They still agree that another such subsidence is extremely unlikely.

To what extent have the neighbours been informed about the tunnel construction and possible risks?

Since the tunnel route was fixed in the plan approval process, that is **since** , not only the owners and residents whose land is affected by the tunnel route, but also a broader community of neighbours along the tunnel route have been regularly informed about the project and the construction process. In this context, the great safety of the tunnel boring process was always pointed out, but also that no construction methods can be one hundred percent safe.

Key measures of neighbourhood work are the establishment of a **neighbourhood office**, which can be contacted by phone even outside office hours, **public infor ation events**, **newsletters and personal visits** during which questions can be asked and answered directly.

In addition, an **infor ation point on tunnel construction** was established at the shopping centre Bornheide from 21 February to 7 April 2011 and at the care centre Lupine from 9 May to 24 June 2011, where affected neighbours could inform themselves personally about the tunnel work.

In addition, notices are placed in appropriate places and press releases issued to local media. In addition, the neighborhood office distributed an **infor ation package** to all affected households. This package included a DVD with the movie "The construction of the new X-ray laser tunnel under your residential area", flyers on the tunnel construction and the European XFEL project, as well as the business card of the neighborhood office.

European XFEL

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3 July 2011

Press release in er an »
Joint local press release from DESY and the European XFEL GmbH: "Small subsidence above the tunnel route in residential area"

6 July 2011

nfor ation letter in er an »
Information letter to owners and residents whose property is located above the tunnel route



Film

unnel construction fil
(in German)

Further infor ation in er an

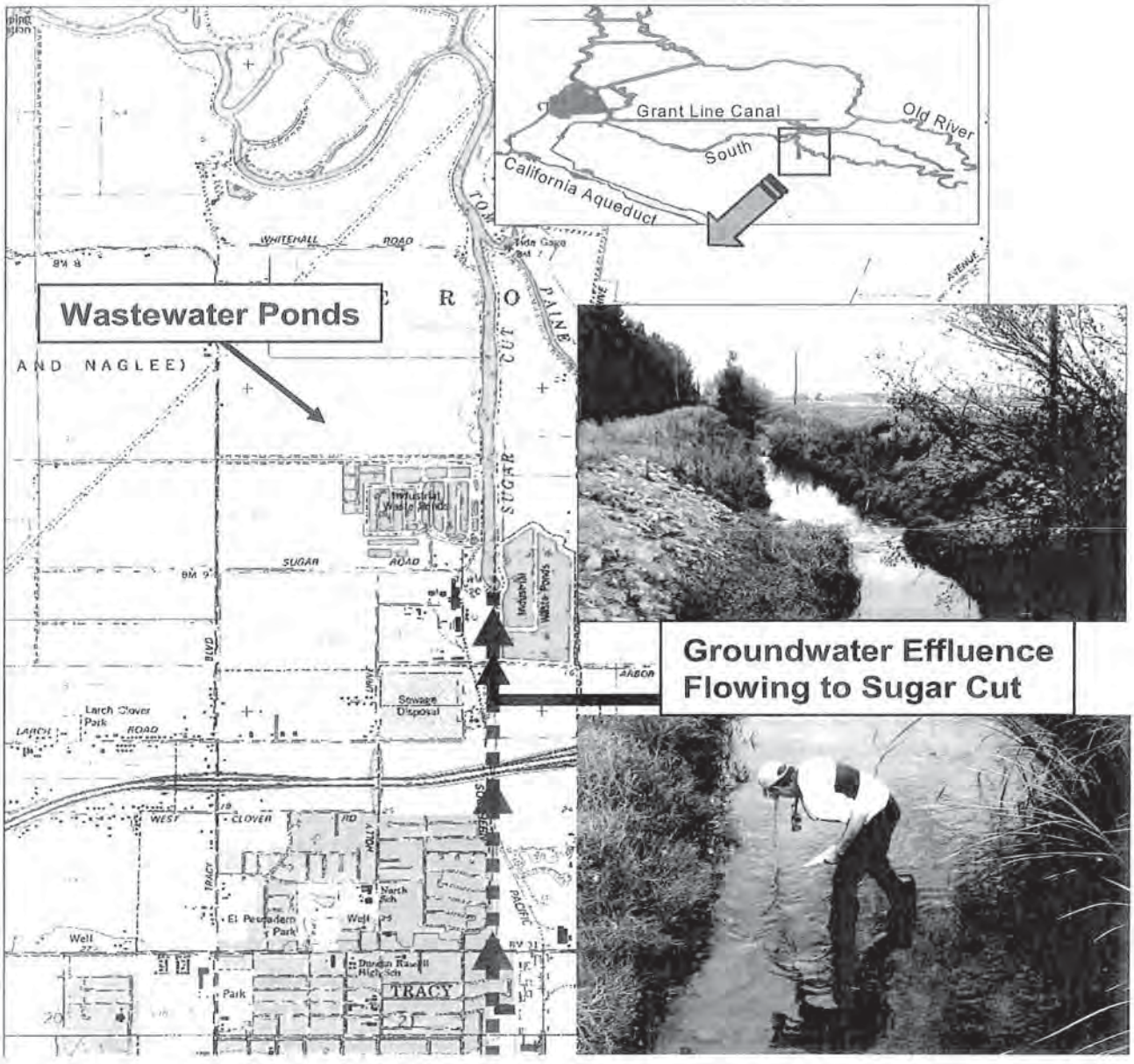
- **Construction progress**
  (incl. film about construction progress)
- **Construction calendar**
- **unnel construction**
  (incl. information film)
- **Progress of tunnel construction**
  Locations of the tunnel boring machines and information film

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Sources of Salinity in the South Sacramento-San Joaquin Delta

Memo Report
May 2007



State of California
The Resources Agency
Department of Water Resources
Division of Operations and Maintenance
Environmental Assessment Branch

State of California Department of Water Resources The Resources Agency

OFFICE MEMO

TO: Dean F. Messer, Chief, Environmental Assessment Branch	DATE: 5/30/07 SUBJECT: Memo Report: **Sources of Salinity in the South Sacramento-San Joaquin Delta**
FROM: Barry L. Montoya, Staff Environmental Scientist	

Summary

Approximately 74 discharge sites are situated along waterways immediately upstream from the State and federal export sites in the south Sacramento-San Joaquin Delta (south Delta). Most are agricultural followed by treated sewage, urban runoff, and groundwater effluence. The discharges are relatively saline and appear to be raising the salinity of water flowing from Vernalis on the San Joaquin River to the export sites via south Old River and Grant Line Canal. This report characterizes the discharges and their influence on salinity between Vernalis and the export sites.

Discharges

Twenty-two agricultural, stormwater, or point-source discharges are located on the 17-mile stretch of San Joaquin River between Vernalis and the head of Old River (James et al. 1989, DWR 1995, National Pollutant Discharge Elimination System [NPDES] permits). From the head of Old River, the distance to Jones (formerly Tracy) Pumping Plant is roughly 21 miles via Old River and 18 miles via Grant Line Canal. Distances to Clifton Court Forebay via both routes are a few miles shorter. Approximately 52 discharge sites are situated along these waterways and their tributaries Tom Paine Slough, Paradise Cut, and Sugar Cut (DWR 1995, Stantec 2003, NPDES permits). Most are agricultural drains with two point-source effluents, four urban runoff outfalls, and groundwater effluence conveyed to Old River in urban/agricultural drainage channels.

Point-Sources: Point-source discharges along the lower San Joaquin River (Vernalis to head of Old River) include municipal wastewater from the cities of Manteca/Lathrop and pit drainage from an historic sand excavation company. Municipal/industrial wastewater from the City of Tracy and Deuel Vocational Institute is discharged to Old River and Paradise Cut, respectively. Discharge volumes from all point-sources average between 0.6 and 5.7 million gallons per day (mgd) with conductivity averages ranging between 1,099 and 1,753 μS/cm (NPDES permits).

Agricultural Drainage: The vast majority of discharge sites along the identified waterways are agricultural. Although agricultural drainage volumes are not routinely reported, two studies measuring or estimating agricultural drainage

shows pumping from Delta islands was consistently highest during winter, with a smaller increase during summer (DWR 1956 and 1997). Pumping is increased during winter, in part, to remove precipitation, seepage, and water applied to leach salts. Historic discharge estimates ranged from 0.03 to 0.7 acre-feet per acre during the peak discharge month of January (1955).

Conductivity in south Delta agricultural drains ranges from 350 to 4,500 μS/cm with an overall average of 1,496 μS/cm (Belden et al. 1989, DWR 1990, 1994, and 1999). Agricultural drains in the south Delta are particularly saline compared to others around the Delta (DWR 1967). The extra-saline nature of these drains can be explained by the origin and makeup of the underlying soils. The resident soils in the southernmost portion of the Delta are composed of eroded, heavily mineralized, marine sedimentary rock from the Diablo Range (Davis 1961, DWR 1970).

Groundwater Effluence: Three to four urban/agricultural drainage channels are believed to be conveying saline groundwater to Old River year-round. Groundwater effluence in 3 of these channels exhibited flows between 1 and 2 cubic-feet per second (cfs) and conductivities between 2,100 and 2,600 μS/cm (measurements made for this study).

Upstream/Downstream Salinity

Upstream/downstream salinity was compared between the automated water quality stations at Vernalis on the San Joaquin River and Old River at Tracy Boulevard Bridge. Conductivity was consistently highest at the Old River station with the exception of a few relatively short duration periods. Differences in conductivity between the stations were highest between April and November. During this 8-month period, conductivity at the Old River station was 100 to 185 μS/cm higher than at Vernalis (median values). A similar upstream/downstream comparison between the Vernalis and Grant Line Canal stations also showed increases, but to a lesser degree.

A number of factors can explain why conductivity consistently increased between the Vernalis and Old River stations. The sheer number saline discharges (as well as diversions) situated between these two stations provides strong rational for causative effects. The Old River station appears to be especially influenced by saline inputs from Tom Paine Slough, Paradise Cut, and groundwater effluence. This was evidenced by a statistically higher conductivity in Old River than Grant Line Canal during most months of the year. Further, the intake of the Old River water quality station appears to be located in the plume of a nearby saline agricultural discharge(s).

Editorial review: Gretchen Goettl, Supervisor of Technical Publications, and Marilee Talley, Research Writer. Thanks to Dan Peterson and Rob Duvall for their extensive reviews.

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I. Introduction

Background

Water is exported from the south Delta at Banks Pumping Plant and Jones Pumping Plant (Figure 1-1). Water can flow westward to both export sites from the lower San Joaquin River via south Old River (hereafter Old River) and Grant Line Canal. Approximately 74 discharge sites are situated along these and other contributory waterways – most are agricultural drains with a smaller number of point-source, urban runoff, and groundwater inputs. A majority of the discharges are relatively saline and appear to be raising the salinity of water approaching the export sites from the west.

Agricultural drainage within the Delta was recognized as a source of saline water in the inaugural State Water Project (SWP) operations report (DWR 1963). Other more specific water quality observations have suggested that discharges along Old River and Grant Line Canal are increasing the salinity of water flowing to the export sites from the San Joaquin River. Conductivity was consistently higher at Banks Pumping Plant than in the San Joaquin River under certain high flow conditions when State exports were entirely composed of that river (DWR 2004B). The suggested explanation was salinity augmentation by the numerous interjacent agricultural discharges. A similar claim was made in a review of data collected during the 1950s and 1960s concluding that an area of high salinity between Vernalis on the San Joaquin River and the Delta-Mendota Canal was caused principally by agricultural drainage (DWR 1967).

Problem Description

Salinity in south Delta exports is a parameter-of-concern to SWP drinking water contractors. Effects of salt in drinking water above the Maximum Contaminant Level can include hardness, deposits, colored water, staining, or salty taste (USEPA 1992). Although not a major direct concern to human health, salinity can cause other problems for SWP contractors. Elevated salinity in drinking water can:

1. be an indicator of bromide, a disinfection by-product precursor;
2. limit the use of recycled water for groundwater recharge or crop irrigation; and,
3. reduce opportunities for blending with higher-salinity sources.

A list of management actions were developed to promote salinity controls, reductions, and forecasts (Bookman-Edmonston Engineering, Inc. 1999).

Objectives

1. Identify discharges to Old River, Grant Line Canal, and a 17-mile stretch of the San Joaquin River (Vernalis to the head of Old River);
2. Characterize discharge volume and salinity trends; and,
3. Quantify upstream/downstream salinity increases between Vernalis on the San Joaquin River and Old River.

An Overview of the Draft Conservation Strategy for the Bay Delta Conservation Plan

January 12, 2009

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I. INTRODUCTION

This document is intended to provide an overview and synopsis of the draft Conservation Strategy, including its key components, for the Bay Delta Conservation Plan (BDCP). The Steering Committee agrees the approach and direction contained in the Overview provides a guide for moving forward, identifying issues for further analyses, without foreclosing additional refinements of the characterizations presented herein. The Overview reflects the substantial progress to date by the BDCP Steering Committee in developing the Conservation Strategy for the plan, and builds upon concepts set out in the BDCP Planning Agreement dated April 2006, and the subsequent Points of Agreement issued by the Steering Committee in November 2007. It is intended to enable the Steering Committee to confirm a number of the key components of the draft Conservation Strategy as they now stand and thereby help guide the remaining work that is necessary to complete a proposed conservation plan by June 2009, pursuant to the Endangered Species Act (ESA), the Natural Community Conservation Planning Act (NCCPA), and the California Endangered Species Act (CESA).[1] The draft BDCP will then undergo further detailed environmental review and

[1] The Potential Regulated Entities (PREs) have not yet determined whether it would be feasible or practicable to implement the BDCP to meet the substantive requirements of the NCCPA for all covered species. However, to enable the BDCP to serve as an NCCP, should that be feasible and practicable, the signatories of the BDCP Planning Agreement have established a mutually agreeable planning process for the BDCP that meets the procedural requirements of the NCCPA, CESA and FESA.

16. Maintain and conserve a viable population of Sacramento splittail in the Delta.
17. Increase the proportion of green sturgeon that successfully migrate upstream through the Delta to upstream spawning habitats.
18. Increase juvenile green sturgeon habitat availability.
19. Maintain or increase life history diversity of green sturgeon.
20. Increase the proportion of white sturgeon that successfully migrate upstream through the Delta to upstream spawning habitats.
21. Increase juvenile white sturgeon habitat availability.
22. Maintain or increase life history diversity of white sturgeon.

In addition, it is anticipated that the core elements that provide for restoration of inundated floodplain and tidal marsh habitats would also contribute towards achieving biological goals and objectives for the terrestrial covered species, which will be developed in January 2009.

Each of the listed goals contains specific objectives that can be found in section 3.2 of the draft BDCP Chapter 3. In addition to the ecosystem and natural community goals and objectives, several draft species-specific goals and objectives for Delta smelt, longfin smelt, Chinook salmon, Central Valley steelhead, Sacramento splittail, green sturgeon, and white sturgeon, also found in section 3.2. These core elements are designed to help meet many of these aquatic covered species biological goals and objectives and will also be important for meeting objectives for terrestrial species that are currently being developed.

C. Lessons Learned re Interaction of Core Elements

The core elements are likely to interact substantially with one another to strongly influence the future hydrodynamic patterns of the Delta. The BDCP Steering Committee and consultants participated in a series of modeling analyses to evaluate these interactions and identify synergies and trade-offs both between core elements and other factors including upstream reservoir levels, Delta inflows, and south Delta water quality. The analyses mostly relied on the CaLite and DSM2 models to characterize hydrologic, hydrodynamic, water quality, and water supply responses to various rules for operating the export of water from the Delta, assuming a constant demand for water. The key lessons of theses analyses are summarized below:

- Large scale tidal marsh restoration, particularly in Cache Slough and Suisun Marsh, substantially changes hydrodynamics, and can also change salinities and the location of the low-salinity region of the estuary (known as "X2").
- Increases in the Hood Bypass flow requirement results in increased diversions from the south Delta to meet water demand.
- New diversions from the north Delta affect tidal influence (bi-directional flow) in the Sacramento River and Steamboat and Sutter Sloughs, while large-scale tidal

marsh restoration in the Cache Slough region can offset this effect by reducing tidal action influence up these channels.

- Even with rules specifying preferential north Delta diversions and a relatively low Hood Bypass flow requirement, there are still sizeable, although substantially reduced, south Delta diversions. These residual diversions combined with strategic operation of the cross channel gates in late summer and early fall appear to be sufficient to achieve most water quality standards in the south and central Delta.
- Delta Cross Channel gate operations have a large effect on central and south Delta water quality. Large reductions in south Delta diversions results in higher salinity levels in the south and central Delta due to less dilution from fresher Sacramento River water, but this outcome can be largely offset by strategic operations of the cross channel gates and some continued base level of south Delta diversions.
- Operation of the system to export water solely from the fully isolated facility with 15,000 cfs capacity would not meet water supply demands or existing levels of water delivery and would perform relatively poorly compared to dual conveyance scenarios.
- High Hood bypass criteria under a fully isolated facility cause large reductions in exports and excessive declines in upstream storage. This is due to the fact that minimum export levels can only be achieved after meeting the minimum Hood bypass target
- Modeled changes in Delta infrastructure and operating rules generally result in changes in Delta inflow and upstream reservoir releases. In some cases, the model predicts extreme changes in upstream reservoir management due to the models logic for allocating water between upstream and downstream objectives. In reality, new allocation logic or additional operational constraints would accompany new infrastructure and rule changes resulting in a better balance between upstream and downstream objectives (see next steps). Efforts are ongoing to improve model performance.
- Even with relatively restrictive rules for diversions, exports were limited by South of Delta storage. One model run indicated that expanding use of existing South of Delta storage, by approximately 1 million acre-feet, combined with a 15,000 cfs canal and dual diversion points, could significantly increase flexibility in meeting water supply and environmental objectives. The same is generally true related to North of Delta storage.

X. Next Steps for Completing the BDCP

The schedule for the Steering Committee anticipates the publication by the federal and state lead agencies of a draft joint environmental impact statement/report on the proposed BDCP by the end of 2009, with extensive public reviews to follow. To meet this schedule, the scoping process for the NEPA/CEQA work has already commenced, and other work is underway to map out the necessary analyses that will be undertaken to ensure a full and complete environmental review of the proposed plan. The schedule also contemplates the completion of a working draft of BDCP by the end of June, 2009.

In January and February 2009 the Steering Committee will need to address a number of important and difficult issues that are intrinsic to such a large and complex conservation planning processes. The following is a brief enumeration of some of those challenging issues and the various tasks awaiting further work in the next two months.

A. Pending Issues

Over the course of the BDCP planning process, Steering Committee members have raised a number of issues that extend beyond the current scope of the BDCP, yet are related to the actions being considered in the Conservation Strategy. In the upcoming months, the Steering Committee will consider these issues in detail and determine whether and how to address them within the BDCP. These issues include, but are not limited to:

- **Sacramento River Inflows**: Sacramento River inflow targets, particularly in the spring, may be desirable to provide suitable conditions for covered species. Such inflow targets would affect upstream reservoir operations, which may fall outside the scope of the BDCP, and could adversely impact covered species upstream. Regardless of whether BDCP specifies inflow targets, changes in Delta infrastructure and operations are likely to affect inflow patterns and upstream reservoir operation. It may be necessary to identify inflow targets that benefit covered species in the Delta without harming covered species upstream. The potential direct and indirect effects of the BDCP on upstream resources will be analyzed as part of the planning and permitting processes.
- **San Joaquin River Inflows**: Increased San Joaquin River flows could improve water quality and conditions for covered species in the south Delta, but reoperation of upstream reservoirs to provide increased flows may lie beyond the scope of the BDCP. Increases in San Joaquin River inflows could increase flexibility for increasing south Delta exports without harming covered species. It may be possible to build contingencies into the BDCP that allow for increased diversions of water from the south Delta if San Joaquin inflows are increased during the BDCP implementation period.
- **New Water Storage Facilities**: New storage facilities are currently outside the scope of BDCP. New storage, however, could help advance water supply and conservation goals. Some combination of improved operations of existing

storage, new surface storage, and expanded groundwater storage is likely to occur in the future and may result in changes to the way the Delta is operated.

- **Conservation Measures Outside the Planning Area:** With the exception of the Suisun Marsh and the upper Yolo Bypass, BDCP working groups have not considered conservation measures that would involve areas upstream or downstream of the Delta. Such measures, however, may be desirable to achieve BDCP biological goals and objectives or to more efficiently achieve BDCP water supply goals. Before June 2009, the Steering Committee will identify whether upstream conservation measures are necessary or desirable to achieve the these planning and biological goals and will develop a process for identifying and evaluating those measures as part of the overall BDCP.
- **Measures to Address Changed Circumstances, including Levee Failure and Climate Change:** The effects of climate change, levee failure, and other potential changed circumstances will be addressed by the BDCP, and measures will be identified to minimize risk to covered species and water supply under these future anticipated conditions. The BDCP working groups will specifically evaluate strategies for implementing the BDCP conservation measures in a manner that reduces the risk to covered species and water supply associated with levee failure, additional invasive species (e.g., quagga mussel), sea level rise, and climate change.

B. Central Governance and Assurances Questions

The Governance Working Group is developing a proposed implementation structure for the BDCP. The Working Group expects to provide the Steering Committee with its recommendations for consideration on January 30, 2009.

C. On-going Tasks in January-February 2009

- In early 2009, the Steering Committee will develop and approve a work plan to expeditiously complete remaining tasks, included the tasks listed below to be conducted in January and February 2009.
- Continue identification, development, and refinement of measures to address other stressors, based on the list in draft Chapter 3, section 3.4.
- Completing further analytical work on the Conservation Strategy using the DRERIP Conceptual Models and other applicable models and methods to assess and refine the conservation measures;
- Further refining the operating parameters for the SWP and CVP for both the near-term and long-term BDCP implementation periods taking into consideration effects on Delta water quality;
- Continuing to refine the draft biological goals and objectives for the BDCP and to develop biological goals and objectives and conservation measures for covered terrestrial species;

- Further describing the governance and implementation structures for the plan;
- Completing the draft adaptive management and monitoring plans, including an enumeration of changed circumstances and responsive measures and the approach to addressing unforeseen circumstances;
- Further refining conservation measures and their monitoring metrics in response to comments and new information;
- Continuing to solicit input and comment from the public, including local governments and other in-Delta interests, and other stakeholders; and
- Expanding opportunities for coordination and integration of the BDCP with existing and developing conservation plans and programs in the Delta and local communities.
- Continuing identification, development, and refinement of measures to address other stressors.
- Work with other permitting agencies that are not currently active in BDCP such as the US Army Corps of Engineers to encourage their involvement in the planning, environmental review, and permitting aspects of the BDCP Conservation Strategy to make sure their needs are addressed early in the BDCP process to allow for rapid implementation.

MUNICIPAL WATER QUALITY INVESTIGATIONS PROGRAM

JONES TRACT FLOOD WATER QUALITY INVESTIGATIONS

Division of Environmental Services
California Department of Water Resources

July 2009

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Executive Summary

Purpose

The report documents all the water quality data collected by the Department of Water Resources (DWR) at Upper Jones Tract and Lower Jones Tract and the Middle River after the levee breached at Upper Jones Tract. Sampling was conducted while Middle River was filling the Upper Jones Tract and Lower Jones Tract and continued through the levee repair and the dewatering. Analyses were done with the monitoring data required by the Regional Water Quality Control Board (Regional Water Board) and the independent data collected by DWR staff. Because the delta provides drinking water to many Californians, a comprehensive monitoring program was implemented to collect and analyze the water quality constituents. The methods used by the field staff as well as the Bryte Laboratory have been summarized in the report, and the analyses done by laboratories under contract to DWR also are described. The results and the discussion of the data analysis are in Chapter 3.

Within the overall DWR goal of recovering Jones Tract from the levee breech and flood, the Municipal Water Quality Investigations Branch of the Division of Environmental Services of DWR undertook the water quality monitoring with 3 project purposes:

1 Evaluate the water quality of pump discharge as required by the Regional Water Quality Control Board to meet water quality objectives;
2 Evaluate water quality at the pump-out site to determine possible water quality effects to delta waters used for municipal purposes; and
3 Gather and analyze data that might help assess potential water quality effects of future island water storage projects.

Background

On the morning of June 3, 2004, a levee on the southwest side of Upper Jones Tract breached. Within about 48 hours both Upper and Lower Jones tracts were flooded, forming a new 12,000-acre lake in the central-south delta. The exact cause and time of the breach are not known. The 300-foot breach allowed the Middle River water to stream into the Upper Jones Tract. Water flowed under the east-west-running railroad embankment via an underpass, filling Lower Jones Tract to the north. Just before noon on June 4, 2004, staff from the DWR Office of Water Quality, Municipal Water Quality Investigations Program (MWQI) arrived at the Upper Jones Tract.

The breach was 10 stream miles northeast of the State Water Project's Clifton Court Forebay gates and 11 stream miles northeast of the federal Central Valley Project's Delta-Mendota Canal intake. Water from the Middle River filled Jones Tract, and once filled, a tidal reverse flow of water from Jones Tract carried dissolved and suspended material into the Middle River.

The volume of water pulled into the Upper and Lower Jones tracts in just three days was about 150,000 to 200,000 acre-feet on an area of 12,000 acres and filled to an average depth between 12 and 16 feet. This represents about 35% of the entire volume of the Delta, not including Suisun Bay, and almost 10 times the volume of water in the south delta. The Jones Tract flood pulled primarily on the San Joaquin River, from the south and east. This temporarily reduced the water level at nearby water stage monitoring stations. As the river water was pulled in, increased seawater intrusions became a concern. To reduce the seawater intrusions, pumping was reduced at the export facilities, the Delta Cross Channel was opened, and more water was released from the upstream reservoirs on the Sacramento River. Within a few days after the breach, rocks were brought in to fill the levee starting from the south side. Once the levee was filled in July, dewatering (or pump-out) activity began.

Scope of the Report

The report documents all the water quality data collected by DWR related to the Jones Tract flood, along with preliminary analysis and discussion. The Municipal Water Quality Investigations Branch of the Division of Environmental Services of DWR undertook the water quality monitoring with 3 project purposes:

- Evaluate the water quality of pump discharge as required by the Regional Water Quality Control Board to meet water quality objectives;
- Evaluate water quality at the pumps to determine water quality effects of pump-out on drinking water source water; and
- Gather and analyze data that might help assess potential water quality effects of future island water storage projects.

From the day after the levee breach, samples were collected from the breach site, Lower Jones Tract, and the Middle River, by MWQI staff. After the breach was filled in July, samples were collected from temporary sampling stations at Upper Jones Tract and Lower Jones Tract. In addition, to comply with the Regional Water Quality Control Board requirements, grab samples were collected at three Middle River Sampling sites after the dewatering started in July 2004. Automated water quality sondes were placed in the floodwater at several locations to collect continuous water quality data. A weather station to measure wind speed, air temperature, and other meteorological variables, was installed by the California Irrigation Management Information System (CIMIS) and was maintained until December 2004. Analysis included comparison between observed organic carbon concentrations at Jones Tract and those observed or predicted in other studies.

The monthly monitoring reports delivered to the Regional Board kept the Board apprised of changes in water quality. With the exception of a positive fish toxicity test which, when repeated, came up negative, Regional Board staff did not express concerns with the levels or concentrations of the monitored water quality parameters. That said, this study quantified a wide range of water quality parameter effects that provided information on the effects on source water quality for drinking water, and on the likely water quality effects of reservoir-island systems.

Summary of Findings

The Jones Tract flood was a serious and disruptive event in the Delta. In the short term, it necessitated a large flood-fighting mobilization to prevent further levee bank erosion, and the loss of crops, farm equipment, and buildings. The levee breach had to be repaired, and large pumps installed on the west side of Jones Tract, to drain the island. Pumping continued for approximately five months, during which discharge water affected water quality at State Water Project and Central Valley Water Project pumps to the south.

Physical conditions and weather were strong drivers of water quality conditions. On windy days floodwater was stirred up and turbidity increased. Turbidity and total suspended solids (TSS) were strongly correlated with wind ($r^2 = 0.91$); total suspended solids and total settleable solids increased when wind speed increased. Precipitation on and near Jones Tract was very low between June and October during the time when most of the floodwater was pumped out. Thus, precipitation did not play a significant role in the hydrology of the flood recovery.

Before the levee was repaired, the southwest side of Upper Jones Tract was open to the Middle River. At this time the water temperature at Upper Jones Tract was lower than Lower Jones Tract, to the north.

Presumably, water in Upper Jones Tract was exchanging with relatively cooler Middle River water. After the levee was repaired and water was contained within Upper and Lower Jones Tracts, the temperatures in both tracts were very similar.

Water temperature affects the water's ability to hold dissolved oxygen (DO). All else being equal, cold water holds more DO than does warm water. Comparisons between the temperature variations from June through November at both Upper and Lower Jones indicated that the DO variations were affected by other processes in addition to water temperature. Often the concentration of DO was higher in the surface water than at the bottom due to oxygen demands in the organic sediments, oxygen diffusion from the air, and, during daylight hours, oxygen production by algal photosynthesis. DO concentrations were frequently below 6 mg/L required for the proposed In-Delta water storage project discharges. High dissolved iron and manganese concentrations were observed in Jones Tract waters, a condition that occurs when flooded soils become anoxic. After the floodwaters had been removed and the soil itself could be examined, mottle formations were observed, which further suggests that low DO conditions existed in the flooded island.

On hourly to daily time scales, the data suggests that there is a strong relationship between DO, pH and algal phytoplankton photosynthetic activity. Diurnal (daily) variation in DO appears to be similar to the changes in pH. This is most likely due to photosynthesis during daylight hours. Photosynthesis removes carbon dioxide (CO_2, or carbonic acid, H_2CO_3) and produces oxygen, driving both pH and DO up. At night, respiration consumes oxygen and produces CO_2, reducing both DO and pH.

The Jones Tract flood provided an opportunity to perform a natural experiment on the dissolved organic carbon (DOC) production that might be produced from flooding of a delta peat-soil island. An areal DOC yield rate of about 0.5 $gC/m^2/d$ (0.47 $gC/m^2/d$) described reasonably well the increase in DOC concentrations observed on Jones Tract. There appeared to be a decrease in this areal yield rate in October and November as water temperatures declined. The Jones Tract summer data are also consistent with the growing season (March through October) rate of 0.47 g/m2/d developed from mesocosm studies and used in earlier modeling of the proposed In-Delta Storage Project.

These calculated rates may be lower after a few years of continuous flooding and might be expected to decline from 0.5 $gC/m^2/d$. Nevertheless, in complex, dynamic, and productive aquatic ecosystems like flooded islands in the delta, many factors such as re-exposure, oxidation of soils, wind mixing, biological productivity, and re-suspension of sediments and soil, will tend to keep the DOC yield rates higher than the minimum rate.

Once pumped off of Jones Tract, a portion of the high-DOC waters were drawn southward to the export facilities. DOC concentrations at the Banks Pumping Plant are affected by interannual variability and hydrology. However, field/grab sample data agree with Delta Simulation Model (DSM2) computer model numerical results suggesting that Jones Tract caused a sustained increase in DOC at Banks on the order of 0.5 to 1 mg/L due to the Jones Tract pump-out relative to the historical mean.

Naturally-occurring algal populations are known to produce complex organic molecules that result in objectionable tastes and/or odors in drinking water. One of these, methylisoborneol (MIB), rose to relatively high concentrations and created taste and odor problems at Banks in July during dewatering. At the same time field staff reported that the Jones Tract water had "a bad smell." These problems have not received much attention in recent discussions of potential impacts from In-Delta Storage Projects. Taste and odor compounds from In-Delta Storage Project islands could cause operational problems at the urban intakes.

The concentrations of organic nitrogen and organic phosphorus compounds increased in the Jones Tract floodwater relative to those in the surrounding river channels. Dewatering that moved the floodwater to Clifton Court Forebay may have increased the algal population at the forebay and resulted in higher than normal MIB at Banks.

Trihalomethanes are carcinogens that are formed by DOC reacting with chlorine during chlorination of drinking water, or in a laboratory test. The results showed that the trihalomethane concentrations steadily went up in chlorinated laboratory water samples as the dewatering activities continued at Jones Tract, in parallel with increased DOC concentration. Many samples contained higher than 1,500 µg/L of chloroform after September. These levels were compared to levels that were found in Upper Jones Tract agricultural drain grab-samples between 1988 and 1991; the agricultural drainage samples seldom had trihalomethane concentrations higher than 1,500 µg/L.

Bromodichloromethane is another disinfection by-product (DBP) of concern in delta waters. Bromodichloromethane concentrations were high in water samples that contained higher concentrations of bromide. The bromodichloromethane concentrations increased with the increase in bromide in the floodwater. Usually in delta water, bromide concentration is closely related to the chloride concentration and the bromide to chloride ratio is similar to the seawater ratio of 0.0034. The ratio observed at Lower Jones was 0.006. The ratio at Jones Tract was higher than the ratio observed in the Delta, and there was a possibility of another source of bromine in the floodwater other than the seawater.

Ultraviolet (UV) absorption data were collected through September. The chloroform and bromodichloro-methane concentrations correlated with UV light absorption at 254 nm (UVA-254). At the same time DOC concentrations were highly correlated at lower values of chloroform concentrations. At chloroform levels higher than 2000 µg/L, DOC did not correlate well with chloroform concentration.

Electrical conductivity (EC) is a surrogate measurement of salinity and dissolved solids concentration. EC was measured by field instruments, standard laboratory methods, and automated *in-situ* sondes placed in the water. All these methods gave similar readings. The EC at Jones Tract did not rise above 512 µS/cm, a level often found in Delta channels. The change in EC, total dissolved solids (TDS), sodium, calcium, magnesium, chloride, and hardness were very similar. In all cases the amounts were higher at Lower Jones relative to Upper Jones just after the levee break, suggesting that these were coming into solution from the flooded soil. After the levee breach was closed, the concentrations were very similar in both Lower Jones and Upper Jones. The correlation of EC to TDS was lower than what is usually expected in delta water. Unusually high concentration of carbon compounds in the floodwater may have affected the TDS readings. Potassium levels were higher in the floodwater than in the Middle River. Boron was always present in floodwater samples collected after the levee was repaired and its concentration varied from 0.1 to 0.2 mg/L. But levels of boron could not be detected in most samples collected from the Middle River.

Iron and manganese concentrations above the maximum contaminant level (MCL) were recorded in Jones Tract floodwaters. (The maximum contaminant level is the highest permissible level of contaminant in drinking water for it to be deemed suitable for human consumption). This was caused by the anaerobic conditions on the bottom during the pump-out. In organic soils, anaerobic conditions and temperatures higher than 5 °C, as observed at Jones Tract, transform insoluble ferric and manganic compounds to soluble ferrous and manganous compounds, respectively. These soluble chemicals then mix upwards into the water column. Average concentrations of iron and manganese at Lower Jones were about seven times those found in the Middle River. The average concentration of iron and manganese at Upper Jones was about three to four times the concentration at Middle River. When the water receded during the pump-out,

red and orange mottling was seen on the exposed soil. This is characteristic of re-oxidation of iron and manganese compounds that were left behind on the soil.

The concentrations of many common pesticides were below the limits of detection. Pesticides that were detectable were metolachlor, diazinon, molinate, atrazine, diuron, simazine, and trifluralin. None of their concentrations were above the MCLs for drinking water.

Because farm equipment containing petroleum products were submerged, tests were carried out for organic carbon compounds. Diesel range organics were detected in the floodwater while benzene, toluene, ethyl benzene, xylene, gasoline range organics, oil and grease, volatile organic compounds, semi volatile organic compounds were below reporting limits.

In the beginning of June, the concentrations of total coliforms, fecal coliforms, and *E. coli* were high in the floodwater compared to the Middle River. By the end of June the total bacterial count in the floodwater dropped to very low values and the fecal coliforms and *E.coli* became so low that sometimes these were undetectable. The total bacterial count at these sites varied from 8 to >1600 MPN/100ml between June and end of August. At the same time the fecal coliforms varied from 2 to 30 MPN/100 ml and *E. coli* count was 20 MPN/100 ml and sometimes undetectable. The bacterial monitoring stopped after August.

Large variability in average chlorophyll concentration was seen at Lower and Upper Jones tracts and at Upper Jones Tract. The chlorophyll concentrations in the samples collected at the bottom were lower than the samples collected at upper levels of the water column. Acute toxicity tests conducted in the floodwater showed that the water was not toxic.

The monthly monitoring reports delivered to the Regional Board kept the Board apprised of changes in water quality. With the exception of a positive fish toxicity test which, when repeated, came up negative, Regional Board staff did not express concerns with the water quality findings.

While the changes in water quality directly outside of Jones Tract due to the pump-out did not rise to the level of concern that would have threatened the environment or the continued pump-out operations, the study did find many potential effects of interest or concern regarding delta water as a drinking water source. These included increases in dissolved organic carbon concentration, algae concentration and type, potential for the formation of disinfection byproducts, nutrient loading, production of unpleasant taste and odor compounds, and anoxia in the bottom waters leading to elevated dissolved manganese and iron concentrations. Of these, DOC loading from the island peat soils is probably among the top concerns for drinking water use, due to the production of DBPs during treatment.

It is very likely that the intentional flooding of a delta island similar to Jones Tract for the purposes of water storage would exhibit most or all of the effects discussed above. How these and other effects evolve over time would likely vary according to how the island water storage project were operated, but the fundamental controlling mechanisms would be approximately the same.

The CALFED Record of Decision states that the goal of the Water Quality Program is to provide "safe, reliable, and affordable drinking water in a cost-effective way," with a target to "achieve either: (a) average concentrations at Clifton Court Forebay and other southern and central Delta drinking water intakes of 50 µg/L bromide and 3.0 mg/L total organic carbon, or (b) an equivalent level of public health protection using a cost effective combination of alternative source waters, source control, and treatment technologies." At present, TOC, of which approximately 80 to 90 percent is DOC, at the Banks Pumping Plant (immediately downstream from Clifton Court Forebay) exceeds 3.0 mg/L approximately 80% of the time on an annual basis. TOC tends to be highest in winter due to inputs from the tributary rivers and in-

delta island drainage, and lowest in the summer and fall, from approximately July to the onset of winter rains in October and November.

The potential water quality effects of an island water storage project would depend substantially on the seasonal timing of water movement into and out of the storage island. One likely scenario is that the island would be filled in the winter when river stages are high and water is relatively plentiful, and drained during the summer when water is relatively scarce. A likely water quality implication of this scenario is that the island would be filled with water containing seasonally elevated TOC/DOC concentrations. The stored water would receive additional DOC through the spring and summer. The resultant high-TOC/DOC water would be released into the delta during the months in which TOC/DOC is generally lowest and closest to reaching the CALFED water quality goal. From a drinking water standpoint, the net effect would be to move delta waters even further from the CALFED water quality TOC goal.

BDCP1563.

Chapter 4 Conclusions

4.1 The Jones Tract Flood: Water Quality Monitoring Project purposes

Within the overall DWR goal of recovering Jones Tract from the levee breech and flood, the Municipal Water Quality Investigations Branch of the Division of Environmental Services of DWR undertook the water quality monitoring with 3 project purposes:

1 Evaluate the water quality of pump discharge as required by the Regional Water Quality Control Board to meet water quality objectives;
2 Evaluate water quality at the pump-out site to determine possible water quality effects to delta waters used for municipal purposes; and
3 Gather and analyze data that might help assess potential water quality of future island storage projects.

4.2 Monitoring to meet Regional Board requirements

The monthly monitoring reports delivered to the Regional Board kept the Board apprised of changes in water quality. With the exception of a positive fish toxicity test which, when repeated, came up negative, Regional Board staff did not express concerns with the levels or concentrations of the monitored water quality parameters.

DWR worked closely with the Regional Board to meet water quality objectives. The Trapper Slough levee, on the southeast side of Jones tract, was initially raised with material purchased from the Port of Stockton. DWR worked with the Central Valley Regional Water Quality Control Board and the Port of Stockton to determine the effect of these materials on water quality in the Delta. Tests were conducted in response to concerns that this material was acidic and contained elevated levels of several metals. There was a concern that under acidic conditions these materials could dissolve and leach into Delta waterways. Lime was applied and incorporated to raise the pH level (counteract the acidity) of the fill material. The levee road was reshaped so that runoff from precipitation would flow toward the inward side of the levee, and fill material was pulled back from contact with the slough.

4.3 Evaluation of pump-out on Delta municipal source water quality

While the changes in water quality directly outside of Jones Tract due to the pump-out did not rise to the level of concern that would have threatened the environment or the continued pump-out operations, the study did find many potential effects of interest regarding Delta water as a source of drinking water. These included changes in dissolved organic carbon, algae concentration and type, potential for the formation of disinfection byproducts, nutrient loading, production of unpleasant taste and odor compounds, and anoxia in the bottom waters leading to elevated dissolved manganese and iron concentrations.

The most dramatic water quality change, and the one probably of greatest concern to drinking water quality, was the high concentration (or loading) of dissolved organic carbon (DOC) from the peat soils. When chlorinated, such

as in a drinking water treatment plant, DOC can react with chlorine to form disinfection byproducts (DBPs), several of which are regulated by the US EPA as potential carcinogens. With increasing DOC concentration, water treatment plant operators are required to use successively more expensive treatment processes in an effort to reduce the DOC and DBP concentrations in the finished water. By a combination of comparing 2004 values to historical averages, and numerical modeling, it is possible to conclude that it is quite likely that the Jones Tract flood contributed to elevated concentrations of DOC of 0.5 to 1 mg/L at the Delta water export facilities during pump-out operations. This has water quality implications for any similar flooded island.

The flooded island provided a sudden new habitat for algae growth, and measurements of overall chlorophyll concentration, as well as photographs, provided an indication that algae grew quite well in Jones Tract flood waters. This has direct and indirect implications for drinking water for future events or projects. Among the effects, the growth and decay of algae can produce unpleasant taste and odor compounds (e.g., 2-methylisoborneol (MIB) and geosmin) that make otherwise safe water unpalatable to drink. Routine water quality sampling by the DWR O&M Water Quality branch observed a significant increase in MIB concentration at Clifton Court and, downstream, in the South Bay Aqueduct, coinciding with the Jones Tract pump-out. While MIB and geosmin had been observed in previous years, concentrations during the Jones Tract pump-out were among the highest observed. The cyanobacterial algal species, *Planktothrix perornata* was identified as the main producer of MIB, and it has subsequently been found in the State Water Project and reservoirs downstream. Among the indirect effects, decaying algae are another source of DOC and thus DBPs. Certain species of algae also tend to clog water filtration apparatus.

Jones flood waters appear to have been a source of nutrient loading, specifically of phosphate. While concentrations of nutrients are not in themselves a direct concern in drinking water (high nitrate are an exception), nutrients carried from the Delta can cause algal blooms in downstream reservoirs under the right conditions. These subsequent blooms can, in turn, produce taste and odor problems and increased DOC concentrations. The presence or absence of a needed nutrient can strongly influence the kind of algae that succeeds. For example, ready availability of phosphorus and a relative lack of nitrogen can provide a competitive advantage to blue-green algae (cyanobacteria), because cyanobacteria are capable of fixing the necessary nitrogen themselves.

The high organic matter content of Jones Tract peat soils, along with nutrients and water, provided ideal growing conditions for a microbial community at the sediment-water interface. The aerobic portion of this community used oxygen for sustenance and growth. This oxygen demand tended to produce anoxic conditions at depths some distance from the bottom. Anoxia in the bottom waters would have implications for drinking water as anoxia was observed to lead to elevated dissolved manganese and iron concentrations. Anoxia has ecological implications for what kinds of organisms could live, and where, in a flooded island such as Jones Tract.

4.4 Potential water quality effects of a future island water storage project

It is very likely that flooding a Delta island similar to Jones Tract would exhibit most or all of the effects discussed in section 4.2 above. How these and other effects evolve over time would likely vary according to how the island water storage project were operated, but the fundamental controlling mechanisms would be approximately the same.

The CALFED Record of Decision states that the goal of the Water Quality Program is to provide "safe, reliable, and affordable drinking water in a cost-effective way," with a target to "achieve either: (a) average concentrations at Clifton Court Forebay and other southern and central Delta drinking water intakes of 50 μg/L bromide and 3.0 mg/L total organic carbon, or (b) an equivalent level of public health protection using a cost effective combination of alternative source waters, source control, and treatment technologies."

At present, TOC at the Banks Pumping Plant (immediately downstream from Clifton Court Forebay) exceeds 3.0 mg/L approximately 80% of the time on an annual basis (MWQI real-time carbon data at Banks Sept 2001 to May 2009). The median is 3.78 mg/L; the TOC concentration is greater than 3.78 mg/L half the time. TOC tends to be highest in winter due to inputs from the tributary rivers and in-Delta island drainage, and lowest in the summer and fall, from approximately July to the onset of winter rains in October and November.

The close agreement between TOC and DOC loading rates found by the SMARTS tank mesocosm study (see 3.2.1), by independent researchers elsewhere (e.g., Aguilar and Thibodeaux, 2005), and observed in the large-scale "natural experiment" of Jones Tract suggest that organic carbon loading model developed in section 3.2 is valid. TOC/DOC concentrations in an island storage project would depart rapidly from the desired low organic carbon concentration.

The Jones Tract flood provided an unexpected opportunity for a natural experiment. However, since Jones Tract itself was returned to the state of a drained, reclaimed island, the Jones Tract data by themselves do not tell us as much as we might like about the likely carbon loading on multi-year time scales. Here, the results of the SMARTS study and the theoretical work of Aguilar and Thibodeaux may provide insight. They suggest that the microbially-mediated production of DOC will tend to continue indefinitely after an initial rapid DOC release mechanism fades. This presumes that the island soils remain essentially submerged. If the island is managed such that soils are repeatedly exposed to air (the island completely drained), the return of the initial rapid DOC release upon re-flooding should not be unexpected.

The potential water quality effects of an island water storage project would depend substantially on the seasonal timing of water movement into and out of the storage island. One likely scenario is that the island would be filled in the winter when river stages are high and water is relatively plentiful, and drained during the summer when water is relatively scarce. A likely water quality implication of this scenario is that the island would be filled with water containing seasonally elevated TOC/DOC concentrations. The stored water would receive additional DOC through the spring and summer, with

increasing temperatures likely to increase the rate of DOC loading. Finally, the resultant high-TOC/DOC water would be released into the Delta during the months in which TOC/DOC is generally lowest and closest to reaching the CALFED water quality goal. From a drinking water standpoint, the net effect would be to move Delta waters even further from the CALFED water quality TOC goal.

Memorandum

Date: October 1, 2010

To: Ms. Kathy Harder
Central Valley Regional Water Quality Control Board
11020 Sun Center Drive, Ste 200
Rancho Cordova, California 95670-6114

From: Gerald E. Johns
Department of Water Resources

Subject: Comments on the Sacramento Regional County Sanitation District's tentative National Pollutant Discharge Elimination System Permit Renewal for the Sacramento Regional Wastewater Treatment Plant.

The Department of Water Resources (DWR) strongly supports the tentative permit prepared by the Central Valley Regional Water Quality Control Board (Central Valley Water Board) staff for the Sacramento Regional County Sanitation District's (SRCSD) discharge on the Sacramento River and the Delta. We encourage the Central Valley Water Board to adopt this permit.

DWR appreciates the opportunity to provide comments on the Central Valley Water Board's tentative National Pollutant Discharge Elimination System (NPDES) permit renewal process for the SRCSD Wastewater Treatment Plant. This letter augments our comments submitted February 4, 2010, regarding potential drinking water supply and public health impacts and the May 18, 2010 comments regarding aquatic life and wildlife preservation associated with SRCSD's previously proposed expansion and relicensing. As indicated in the Central Valley Water Board's tentative permit, the Delta is a source of drinking water for more than 25 million Californians and is one of the most ecologically important aquatic habitats in the State. DWR is the state's primary water resources management agency and has an inherent interest in ensuring that Sacramento River and Delta water supplies are of sufficient quality to protect the aquatic life and suitable for the production of a safe and reliable drinking water supply.

Primary drinking water constituents of concern associated with the SRCSD discharge include, but are not limited to, organic carbon, nutrients, pathogens, taste and odor producing compounds, and nitrosamines and their pre-cursors. Control of nutrients, oxygen demand, and toxic contaminants is also a major consideration for the protection of ecosystem function. The tentative permit represents a positive step toward assessing and reducing the potential adverse effects of SRCSD's discharge on the Sacramento River and the Delta. As drafted, the tentative order would provide significant direct and indirect benefits to water quality in the Sacramento River and Delta. DWR supports and appreciates the Central Valley Water Board staff efforts in incorporating best available science into the development of the tentative order. Accordingly, we strongly support adoption of Water Quality Based Effluent Limits and implementation of Best Practical Treatment Controls in the form of

nitrification/de-nitrification and Title 22 (or equivalent) tertiary filtration. We also support inclusion of expanded monitoring requirements, special studies, and reopener provisions to allow for modification of the SRCSD permit if new information becomes available.

Below are specific comments and recommendations pertaining to the protection of the municipal and aquatic life beneficial uses of the Sacramento River and Delta.

Specific Comments

Organic Carbon

Discharge of organic carbon to the Delta is a concern because of the potential for formation of disinfection byproducts (DBPs), such as haloacetic acids (HAAs) and trihalomethanes (THMs), when source waters are disinfected with chlorine or ozone. HAAs have the potential to increase the risk of cancer, and THMs may cause liver, kidney, or central nervous system problems and also increase the risk of cancer (USEPA, 2010). Organic carbon, along with the pathogens Cryptosporidium and Giardia, were recently identified by the Central Valley Water Board as the focus for consideration in the development of a regional drinking water policy (CVRWQCB Resolution No. R5-2010-0079). Organic carbon concentrations in the Sacramento River downstream of the SRCSD discharge are relatively low with a median total organic carbon concentration of 2.1 mg/L at Hood for the period covering Water Years 2004-2009 (DWR, 2010). Dissolved organic carbon concentrations, however, have shown an increasing trend in the Sacramento River at Hood during the 10-year period running from 1999-2008 (DWR, 2010b). Additionally, the SRCSD's total organic carbon effluent concentration was more than eight times higher than ambient Sacramento River levels with a median effluent concentration of 17 mg/L (CVRWQCB, 2009).

Reopener Provision G

Given the potential for SRCSD's discharge to increase ambient organic carbon concentrations in the Sacramento River we support inclusion of Reopener Provision G (see tentative order, p. 24) and monitoring requirements for organic carbon in the permit. DWR operates four water quality monitoring stations in the Delta where we measure organic carbon on a near real-time basis. Based on our experience, monthly sampling is not always sufficient to capture natural variability. We therefore recommend that the monitoring frequency be increased from monthly to daily to better capture the variability of the discharge, especially during the winter storm season when the plant receives a considerable volume of urban runoff. To accommodate a broader range of

potential outcomes from the Regional Board's future drinking water policy[1] we suggest rewording Reopener Provision G. As written, Reopener Provision G would only take effect if the Regional Board adopts water quality objectives for certain drinking water constituents, but a drinking water policy could lead to other actions that would necessitate reopening the permit.

NDMA

Nitrosodimethylamine (NDMA) is a member of a chemical family known as nitrosamines which are several orders of magnitude more toxic than currently regulated DBPs (i.e., THMs, HAAs). NDMA and five other nitrosamines are on the current EPA Contaminant Candidate List and are currently being monitored by selected public water systems under EPA's Unregulated Contaminant Monitoring Regulation 2, a process which identifies whether a contaminant has the potential to harm human health and if regulation would reduce public health risks. NDMA is commonly found in treated wastewater as a chlorine byproduct.

Ammonium and Nutrients

Elevated levels of ammonium and dissolved organic nitrogen in receiving waters can lead to the formation of Nitrosamines during the treatment of drinking water. Over the last year and a half, water quality monitoring downstream of SRCSD's discharge has detected elevated levels of precursors associated with NDMA. Therefore, we support inclusion of the monitoring requirements and effluent limits for NDMA that are contained in the tentative order. Additionally, we believe that the proposed requirements for nitrification/ denitrification will reduce the potential for nitrosamine formation during the disinfection at the wastewater treatment plant and during the drinking water treatment process.

Nutrients, and ammonium, in particular, have elevated importance in the drinking water, ecosystem, and regulatory environment. From a drinking water perspective, increased nutrient loading can lead to eutrophication of source waters, which in turn can lead to increased levels of organic carbon, objectionable taste and odor producing compounds (i.e., Geosmin and 2-Methylisoborneol [MIB]), and toxic microcystins. Data and information provided by the Central Valley Water Board suggests that the current SRCSD discharge is already causing concentrations of phosphorus and nitrogen in the Sacramento River to exceed levels recommended by the USEPA to prevent eutrophication, which are 0.055 mg/L for total phosphorus and 0.66 mg/L for total nitrogen (CVRWQCB, 2009). Recent data collected by DWR also suggests that the SRCSD discharge results in significant increases in nutrient concentrations in the Sacramento River. For example, median total

[1] Central Valley Regional Water Quality Control Board Resolution No. R5-2010-0079 expresses a commitment to developing a comprehensive drinking water policy for the Delta and tributaries and directs their staff to develop a policy for consideration by the Board by July of 2013.

phosphorus and total nitrogen concentrations downstream of the SRCSD discharge at Hood were 0.10 and 0.77 mg/L respectively for water years 2007-2009 (DWR, 2010). Ammonium accounted for approximately half of the total nitrogen in the Sacramento River at Hood and was more than ten times the levels recorded at three sites upstream of the SRCSD discharge. When nutrient enriched waters enter the State Water Project (SWP), the eutrophication effect can be amplified as hydraulic residence time increases. We therefore support requirements for nitrification/denitrification as proposed in the tentative order and DWR continues to support ongoing and future ammonia studies and the use of *Hyalella azteca* and rainbow trout as test species.

Fish Passage issues

DWR supports the United States Fish and Wildlife Service (USFWS) request to characterize fish response to the discharge field and predator concentrations. We also recommend that additional fish tracking studies be required to validate the SRCSD's anti-degradation analysis paper's assumption that fish passage is not restricted and fish will maneuver around rather than travel through the discharge and mixing zone plume. Additionally, we recommend high frequency discrete or continuous monitoring of water quality parameters in the outfall area to validate plume dispersion. Both federal and State guidelines state that mixing zones shall not restrict the passage of aquatic life. The SRCSD proposed NPDES requirement would allow for a thermal mixing zone which would be 50 percent of the cross-sectional area of the river, and evaluated as a daily average. Under this requirement, plume scenarios may occur where passage of aquatic life is in fact restricted. Accordingly, we support the more stringent requirements contained in the tentative order which limit the thermal mixing zone to 25 percent of the cross sectional area of the river.

Unknown Contaminates

Unknown contaminates in the SRCSD discharge is an issue of ongoing concern. The SRCSD's compliance summary shows no acute toxicity in 2005, 2006, and 2007, then the occurrence increases to six acute events in 2008 and nine in 2009. Studies conducted with delta smelt at the University of California at Davis Aquatic Toxicology Laboratory (UCD ATL) demonstrated that ammonium associated with SRCSD effluent was 30-40% more toxic to larval smelt than ammonium by itself and research elsewhere has demonstrated that mixtures of ammonium and other chemical pollutants, such as copper, cyanide, phenol, zinc, and chlorine (with the formation of inorganic chloramines), may result in additive toxicity or even cause synergistic effects (Camargo and Alonso 2006). Additionally, the unknown contaminants in addition to unionized ammonia may have contributed to the low survival of the copepod species *Eurytemora affinis* in tests conducted by Dr. Teh of UC Davis in April 2008, with water samples collected from the DWR water quality monitoring station at Hood on the Sacramento River (Teh 2008). Given the potential implications for the pelagic organism decline, we recommend these issues be further evaluated.

The tentative order includes several important requirements that could improve aquatic life and other beneficial uses. These include full nitrification for removal of ammonia, denitrification, and the equivalent to Title 22 filtration. Concerning dilution alternatives, the tentative order includes an acute toxicity effluent limitation determined by acute bioassays using 100% effluent and requires the discharger to investigate the causes of and to identify corrective actions to reduce or eliminate effluent toxicity. Due to the "unknown" contaminants in the effluent and the research mentioned previously, we support this action. In addition, we continue to recommend studies be conducted to characterize the temperature effects on migrating fish, especially in the relation to being exposed to elevated ammonium and other contaminants.

While contaminants of emerging concern (CECs), including pharmaceuticals and personal care products (PPCP's) are not currently regulated, additional studies could provide information about expression of PPCP exposure in whole effluent to species of concern. To this end, the Central Valley Water Board should consider incorporating permit conditions requiring monitoring and special studies related to the effects CEC's on aquatic life.

Pathogens

Evaluation and control of pathogens, in particular Cryptosporidium and Giardia, is an issue of increasing focus and concern for SWP drinking water contractors. The tentative order prescribes Title 22 (or equivalent) tertiary filtration for the control of pathogens. We recognize that this level of treatment is primarily required for the protection of the agricultural and recreational beneficial uses; we note however, that tertiary filtration has the added benefit of reducing risks associated with pathogens in drinking water supplies. Advanced filtration should also reduce total organic carbon loading. We also note that tertiary treatment appears to be reasonably common for wastewater treatment plants that discharge to the Delta (see Appendix F of the tentative order, p. F-75). For these reasons DWR supports the imposition of Title 22 (or equivalent) tertiary filtration requirements in SRCSD's NPDES permit as well as the proposed monthly monitoring requirements for Cryptosporidium and Giardia. We recommend, however, that the monitoring requirements be revised to require analysis of infectivity for Giardia and genotyping for Cryptosporidium and Giardia. This would provide information on the sources of Cryptosporidium and Giardia and the effectiveness of treatment, which ultimately could lead to better and/or more cost effective control.

Protection of high quality waters

Major drinking water intake facilities are located both downstream and immediately upstream of the SRCSD discharge point. Upstream drinking water intakes could potentially be affected by SRCSD's discharge when low river flows coincide with high tides and the direction of flow in the Sacramento is reversed. The proposed permit conditions should protect drinking water quality at existing drinking water intakes, but it is also incumbent upon the Central

Valley Water Board to consider the State Water Resources Control Board's (State Water Board) "Sources of Drinking Water Policy" (Resolution 88-63), as incorporated into the Central Valley Water Board's Basin Plan. The Sources of Drinking Water Policy effectively designates the entire Sacramento River as having municipal and domestic supply beneficial uses. Additionally, the State Water Board's Statement of Policy with Respect to Maintaining High Quality Waters in California (anti-degradation policy/Resolution 68-16) requires that existing high quality waters be maintained to the maximum extent possible. Collectively these policies require the Central Valley Water Board to protect and maintain the domestic and municipal beneficial of water in the immediate vicinity of SRCSD's discharge point as well as at downstream locations. The tentative permit, with the revisions recommended herein, will likely satisfy these stringent requirements and go a long way towards the overall protection of the municipal and aquatic life beneficial uses of the Sacramento River and Delta.

Higher treatment instead of reliance on dilution

Determining possible future dilution flows is speculative and cannot be relied upon to protect beneficial uses. When historical records are used as an indicator of future flows the longest available data set should be used. The use of U.S. Geological Survey gauge flow data from 1942-1989 may reduce the probability of a flow less than or equal to 10,000 cfs by removing multiple back to back low flow years in the early nineties. Using only the years 1970-2009 to develop critical low flow values may not be fully representative due to the use of the criteria of lowest daily, and seven day average, flow with a return frequency of 10 years. The use of matching time periods in addition to full historical records when calculating daily flow probabilities and critical flows may be more appropriate.

Current and near future changes in flow volumes and patterns need to be addressed in setting permit limits. With the recent construction of the Freeport diversion, existing Vernalis Adaptive Management Program export restrictions, restrictions included in the recent Biological Opinions, and likely flow changes due to the effects of climate change, historic calculations of assimilation capacity may no longer be valid. Change analysis of Sacramento River flows under these new regimes needs to be analyzed by the SRCSD and changes of assimilative capacity presented to the Central Valley Water Board and stakeholders for assessment of current permit capacity. Future scenarios as detailed in the draft Bay-Delta Conservation Plan, as well as the Woodland/Davis Joint Powers Authority proposal for a Sacramento intake, point to a future where dilution capacity of the Sacramento River below Freeport may be severely limited, or temporally different. This only strengthens the argument of enhanced treatment requirements minimizing release of contaminants and nutrients at any flow rate. The burden of protecting the water quality falls on SRCSD, not on water supplies provided for beneficial uses.

Conclusion

In summary, existing and ongoing research already suggest that the current loading from waste water treatment facilities to the Delta may already be adversely affecting municipal water supplies and aquatic life directly and through food web interactions. There is a significant body of scientific evidence to support a reduction in nutrient and effluent loading to the Delta. We therefore support adoption of the proposed permit requirements contained in the Central Valley Water Board's tentative order.

DWR appreciates the Central Valley Water Board staff efforts in preparing the tentative NPDES permit and the many challenges associated with assessing these important issues. Please feel free to contact Dean Messer, Chief of Environmental Services, DWR, at (916) 376-9700 if you have any questions regarding these comments.

Sincerely,

Gerald E. Johns, Deputy Director
Department of Water Resources

Attachments: See attached References

Cc: See attached list

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References:

Camargo, J.A., Alonso, A. (2006) Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment. Environment International 32, 831-849.

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CCWD Water Quality Analysis

Department of Water Resources

Erik Reyes
Subir Saha
En-Ching Hsu
Parviz Nader
02/15/2013

BDCP1563.

Objective

- Compare water quality at CCWD intakes for NAA Alternative versus Alt 4 (ELT and LLT)
- Discuss the use of LV Module
- Discuss the accuracy of ANNs used for CCWD intakes

BDCP1563.

Background

- In Summer 2009, CCWD requested that LV Module be inserted in CalSim II for all BDCP studies.
- The goal was to improve the representation of CCWD operations in CalSim II.
- LV Module performed the blending, and predicted the monthly salinity (Chloride), and LV storage.
- LV Module relied on ANNs (Artificial Neural Network) to predict salinity at the three CCWD intakes.

BDCP1563.

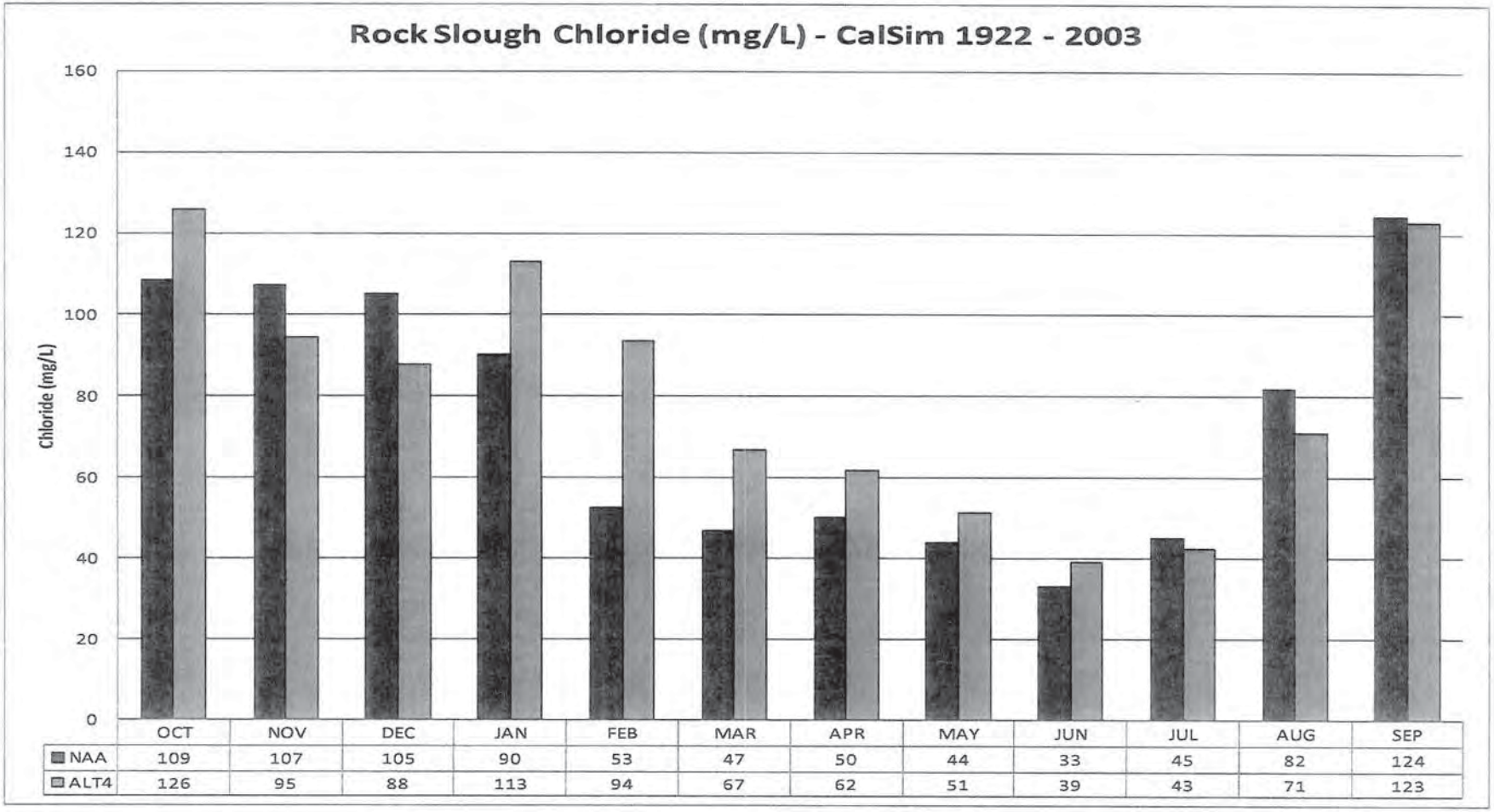
Development of ANNs

- ANNs provide Flow-salinity relationship used in CalSim II
- DWR generated all the ANNs needed for all BDCP scenarios
- Traditionally ANNs are generated for 11 stations within the Delta.
- Full Circle Analysis is only performed at 4 stations (Jersey Point, Emmaton, Old River Rock Slough, and Collinsville)

BDCP1563.

ELT

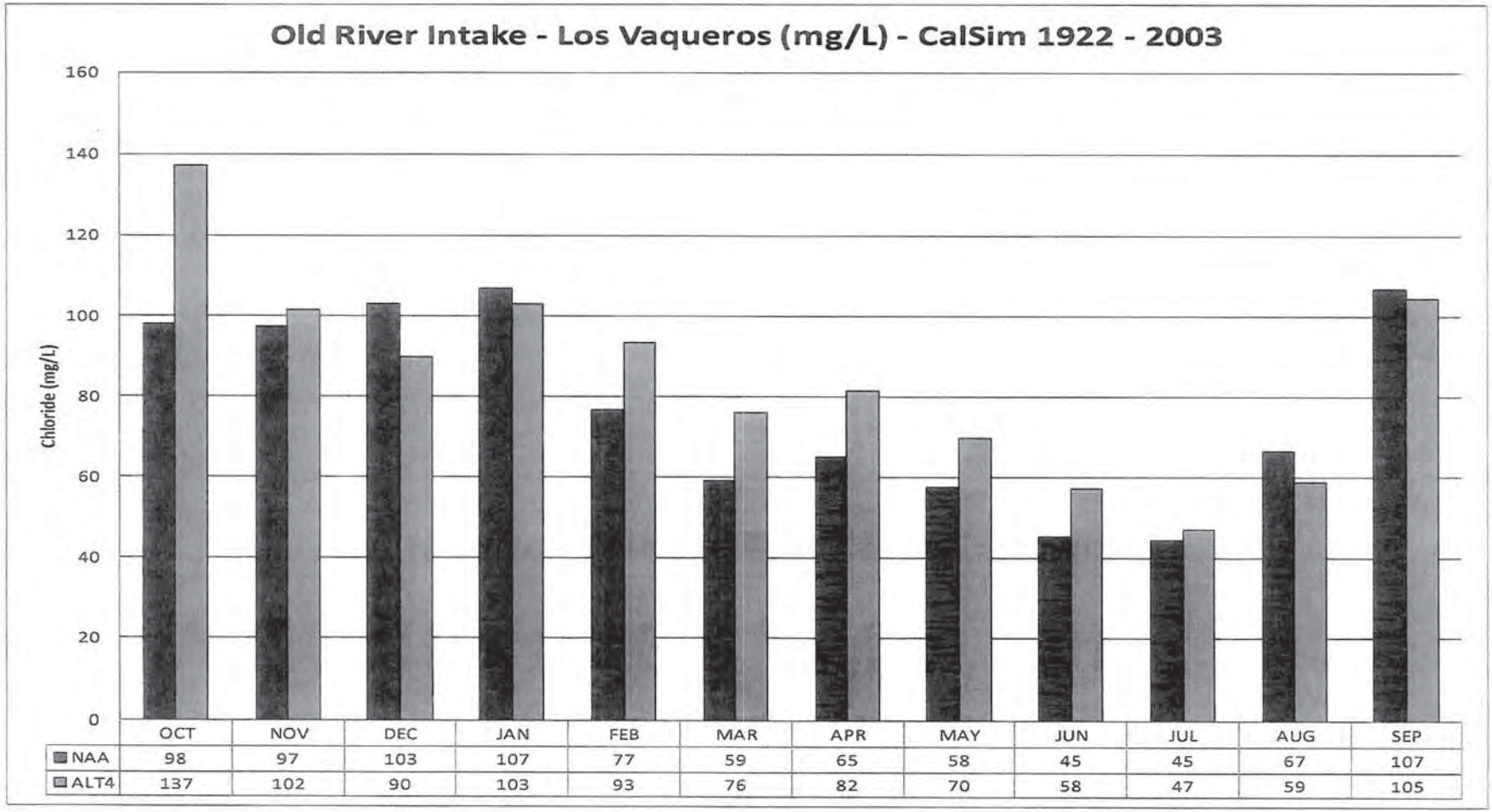
LV Module uses ANN for salinity



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	109	107	105	90	53	47	50	44	33	45	82	124
ALT4	126	95	88	113	94	67	62	51	39	43	71	123

BDCP1563.

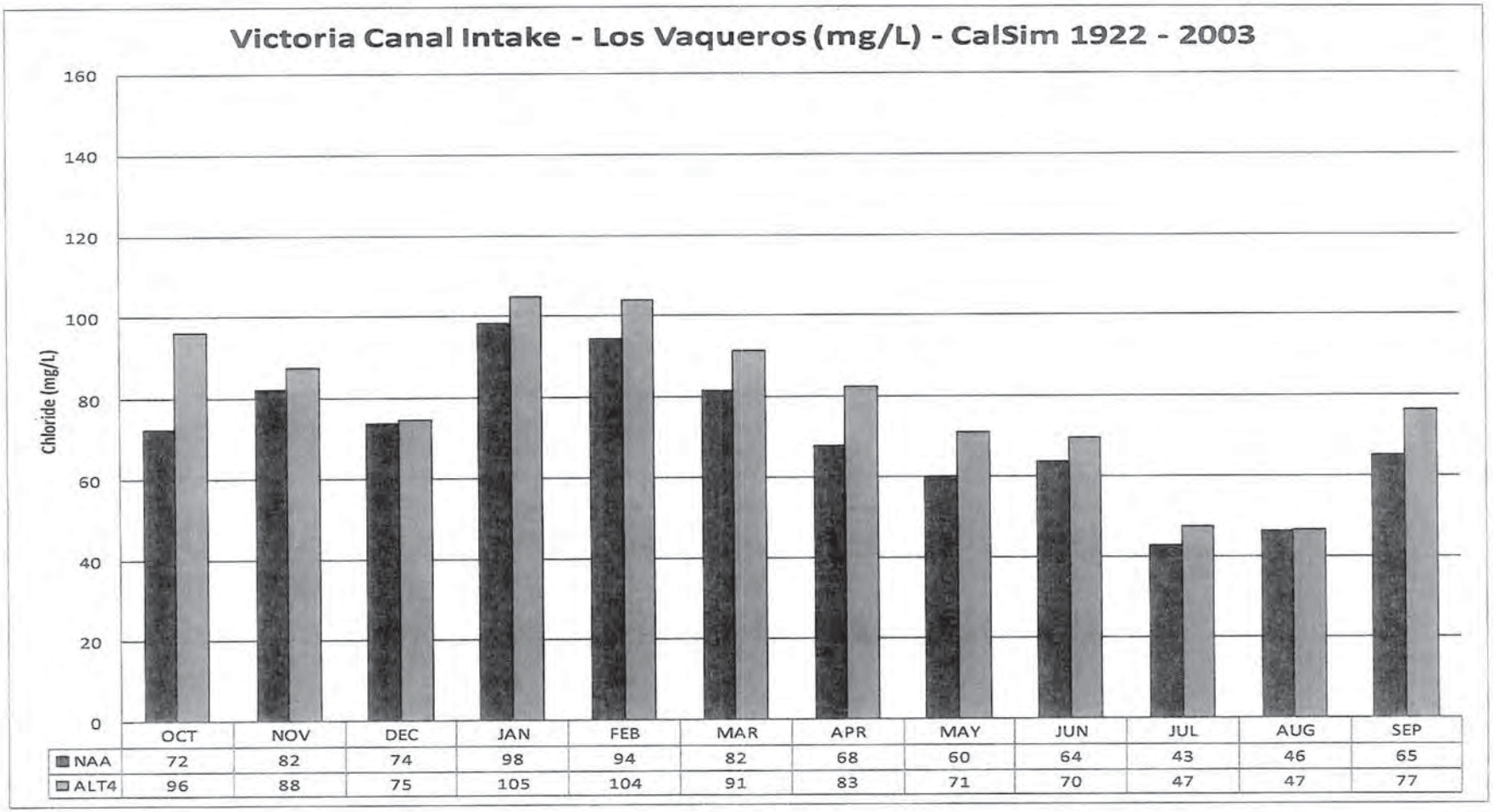
ELT



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	98	97	103	107	77	59	65	58	45	45	67	107
ALT4	137	102	90	103	93	76	82	70	58	47	59	105

BDCP1563.

ELT

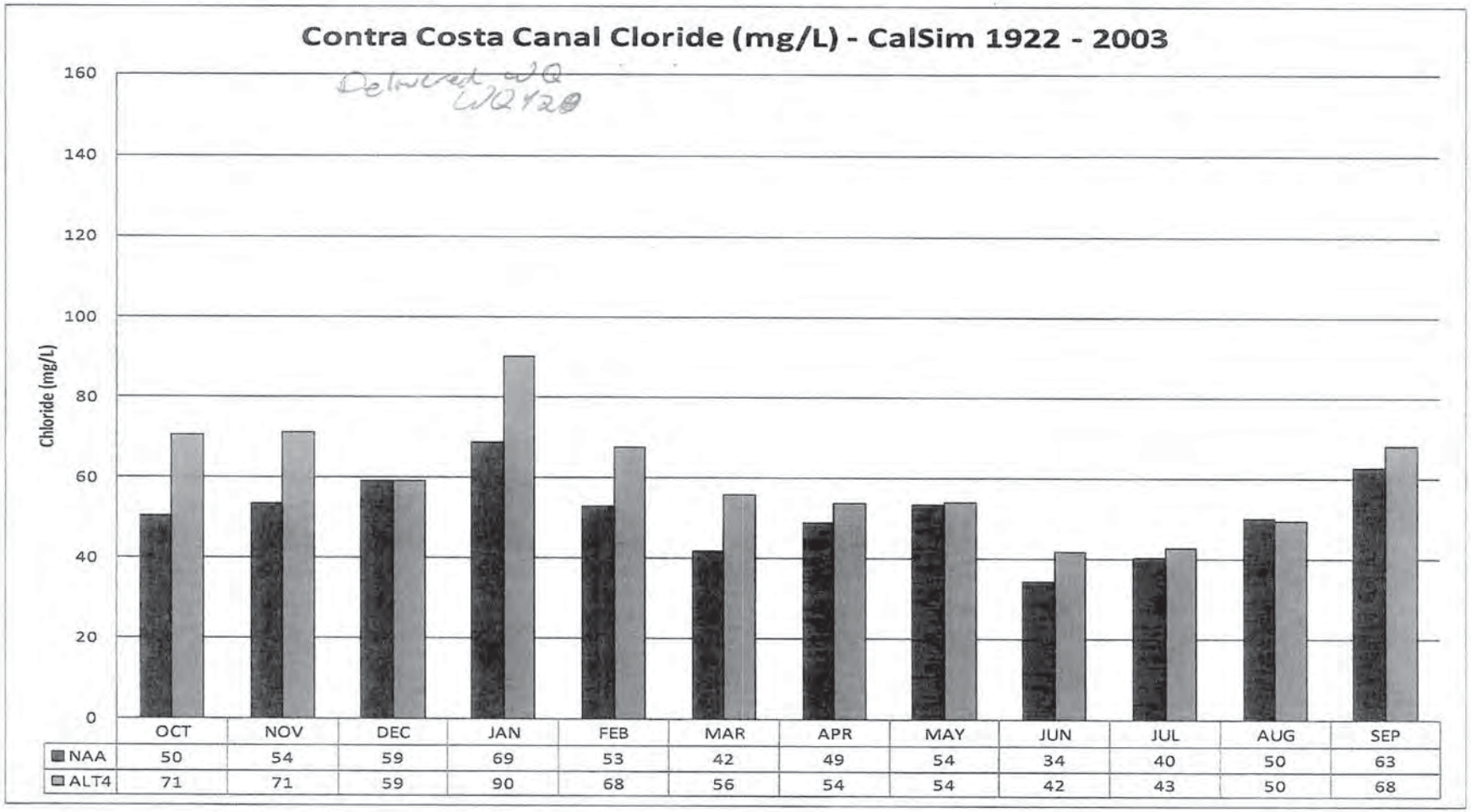


	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	72	82	74	98	94	82	68	60	64	43	46	65
ALT4	96	88	75	105	104	91	83	71	70	47	47	77

BDCP1563.

After All the Blending(Still using ANN)

(Noticeable Impact)

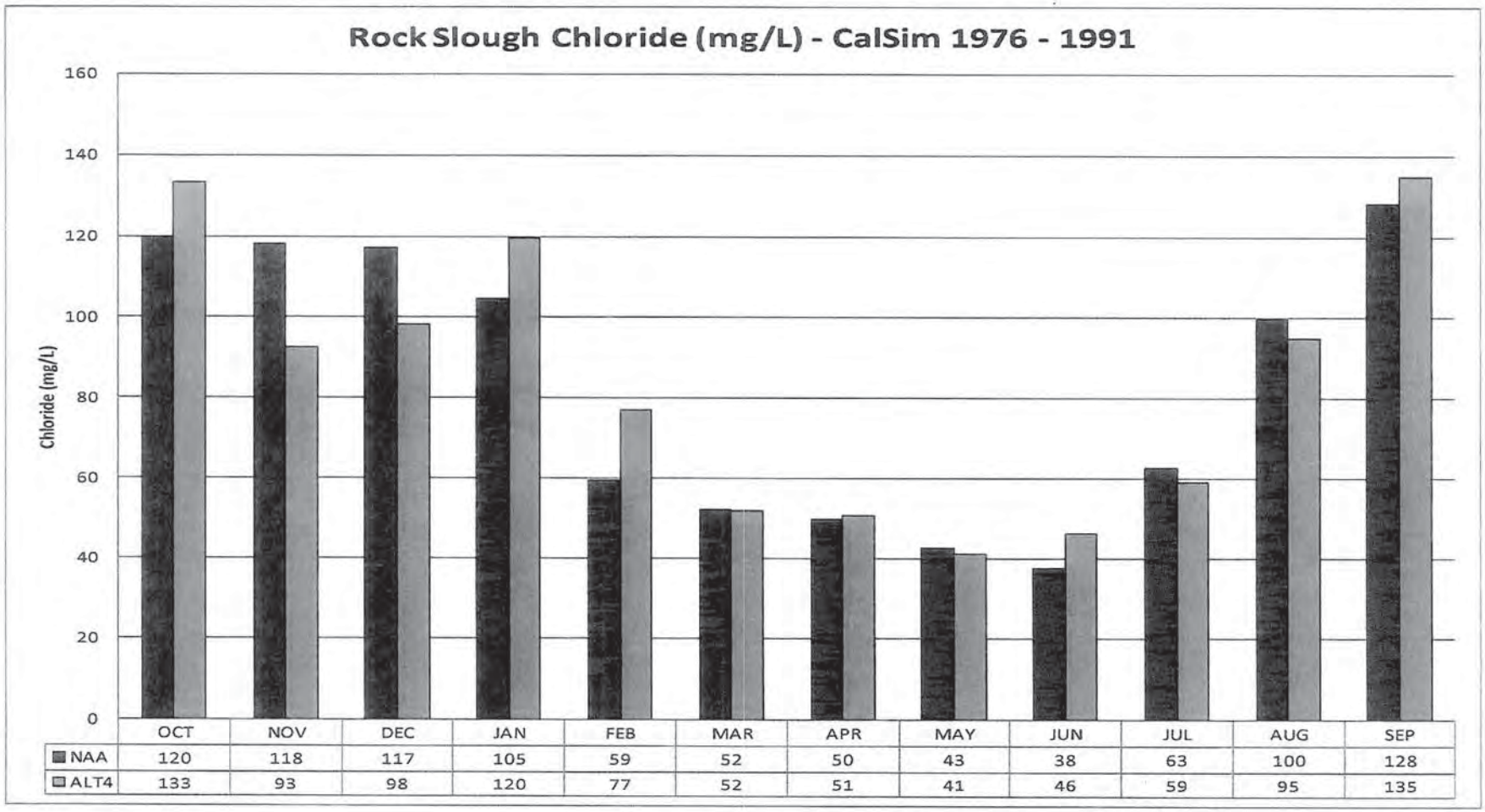


	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	50	54	59	69	53	42	49	54	34	40	50	63
ALT4	71	71	59	90	68	56	54	54	42	43	50	68

BDCP1563.

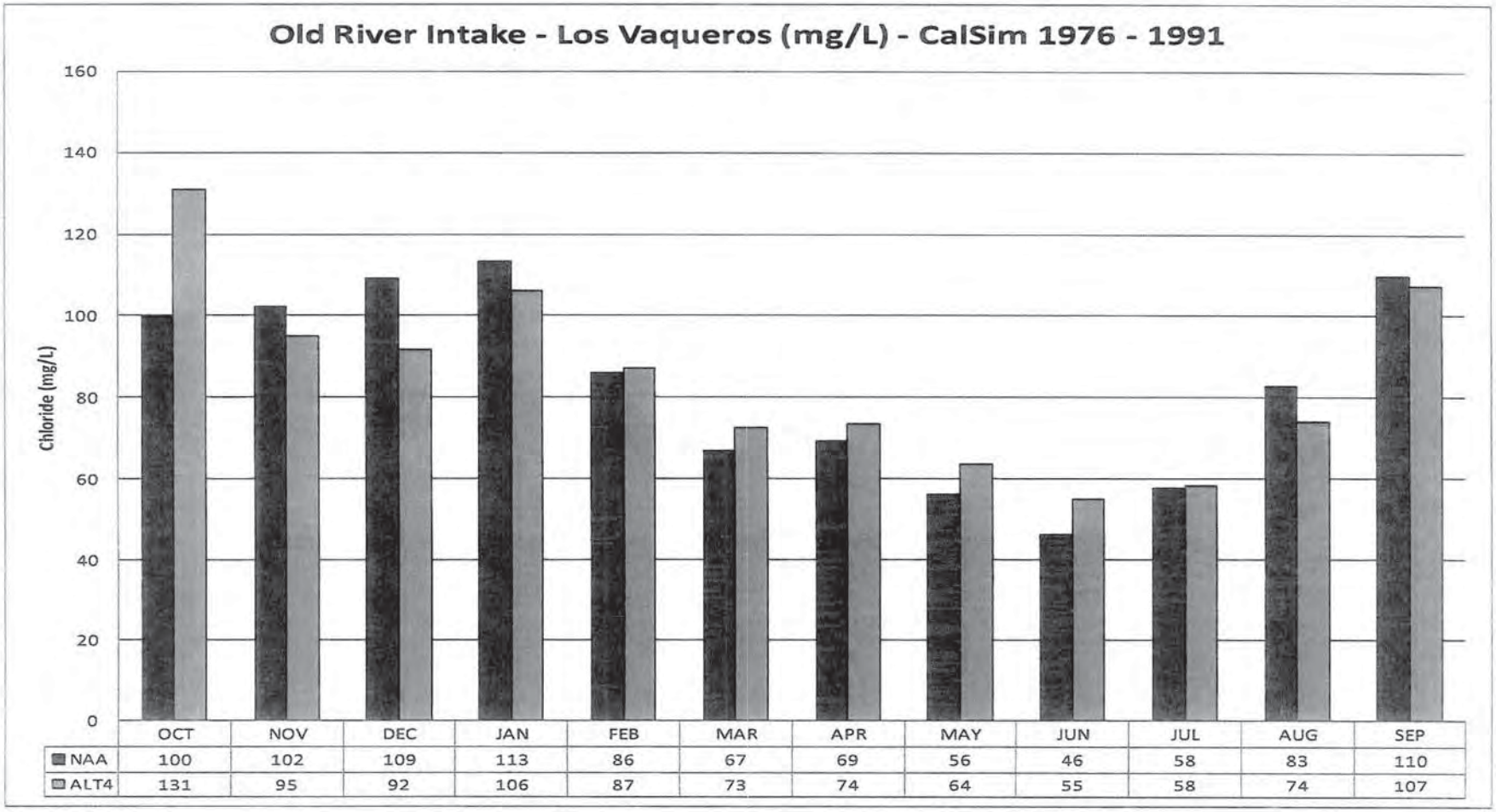
What about the 16 years? (1976-1991)

BDCP1563.



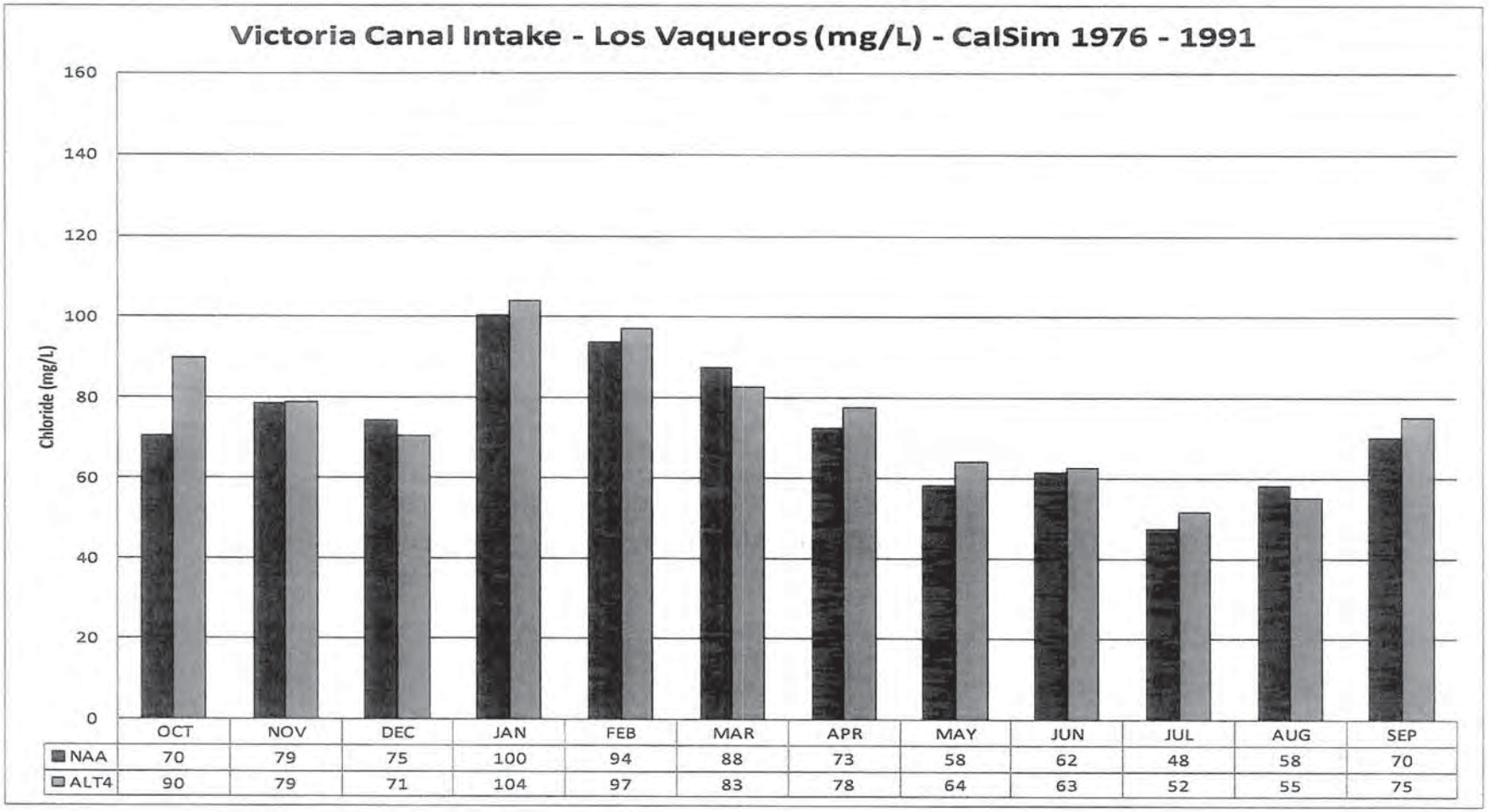
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	120	118	117	105	59	52	50	43	38	63	100	128
ALT4	133	93	98	120	77	52	51	41	46	59	95	135

BDCP1563.



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	100	102	109	113	86	67	69	56	46	58	83	110
ALT4	131	95	92	106	87	73	74	64	55	58	74	107

BDCP1563.

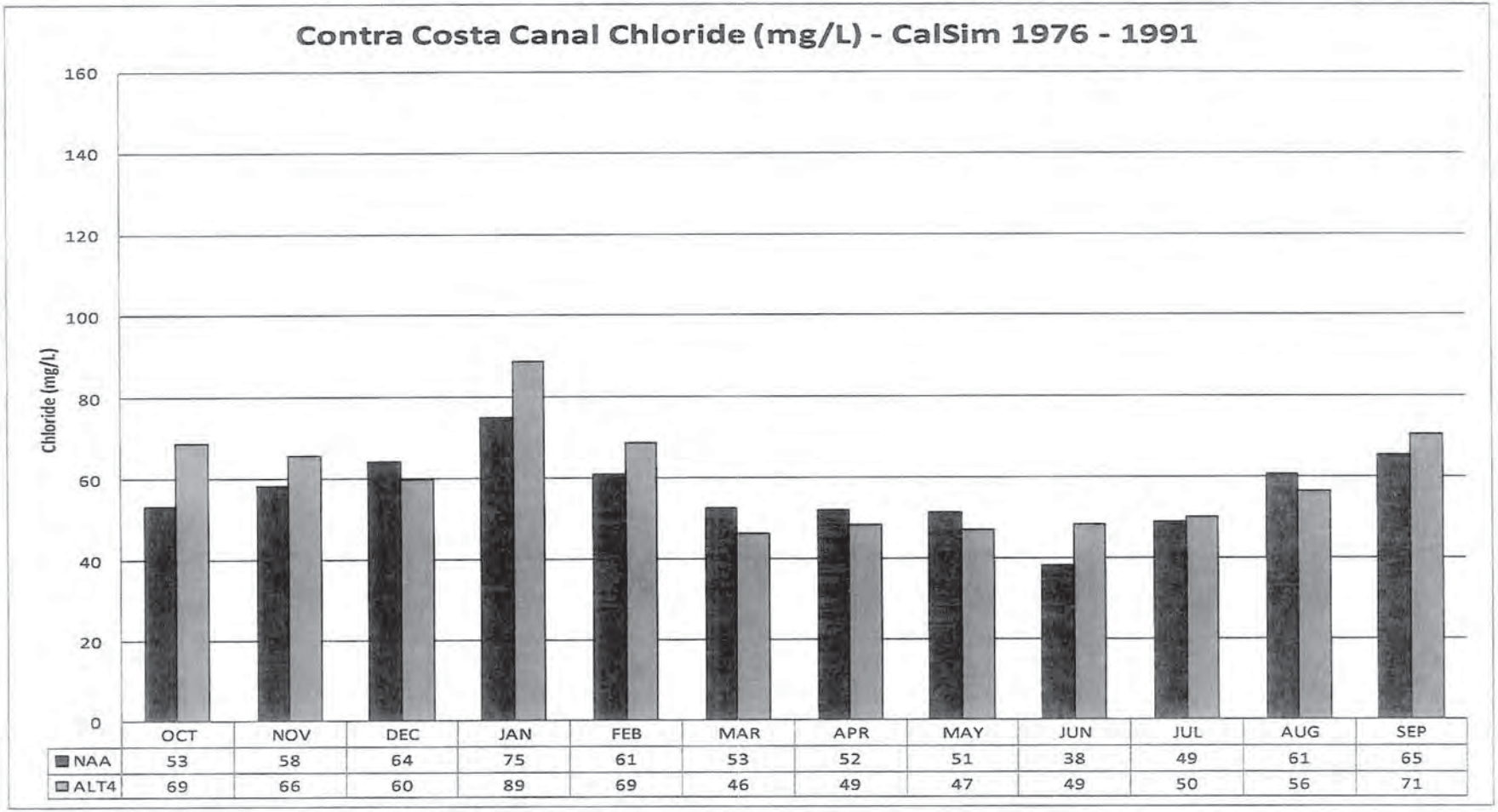


	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	70	79	75	100	94	88	73	58	62	48	58	70
ALT4	90	79	71	104	97	83	78	64	63	52	55	75

BDCP1563.

After All the Blending(Still using ANN)

(Lower impacts compared to 82 year period)



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	53	58	64	75	61	53	52	51	38	49	61	65
ALT4	69	66	60	89	69	46	49	47	49	50	56	71

BDCP1563.

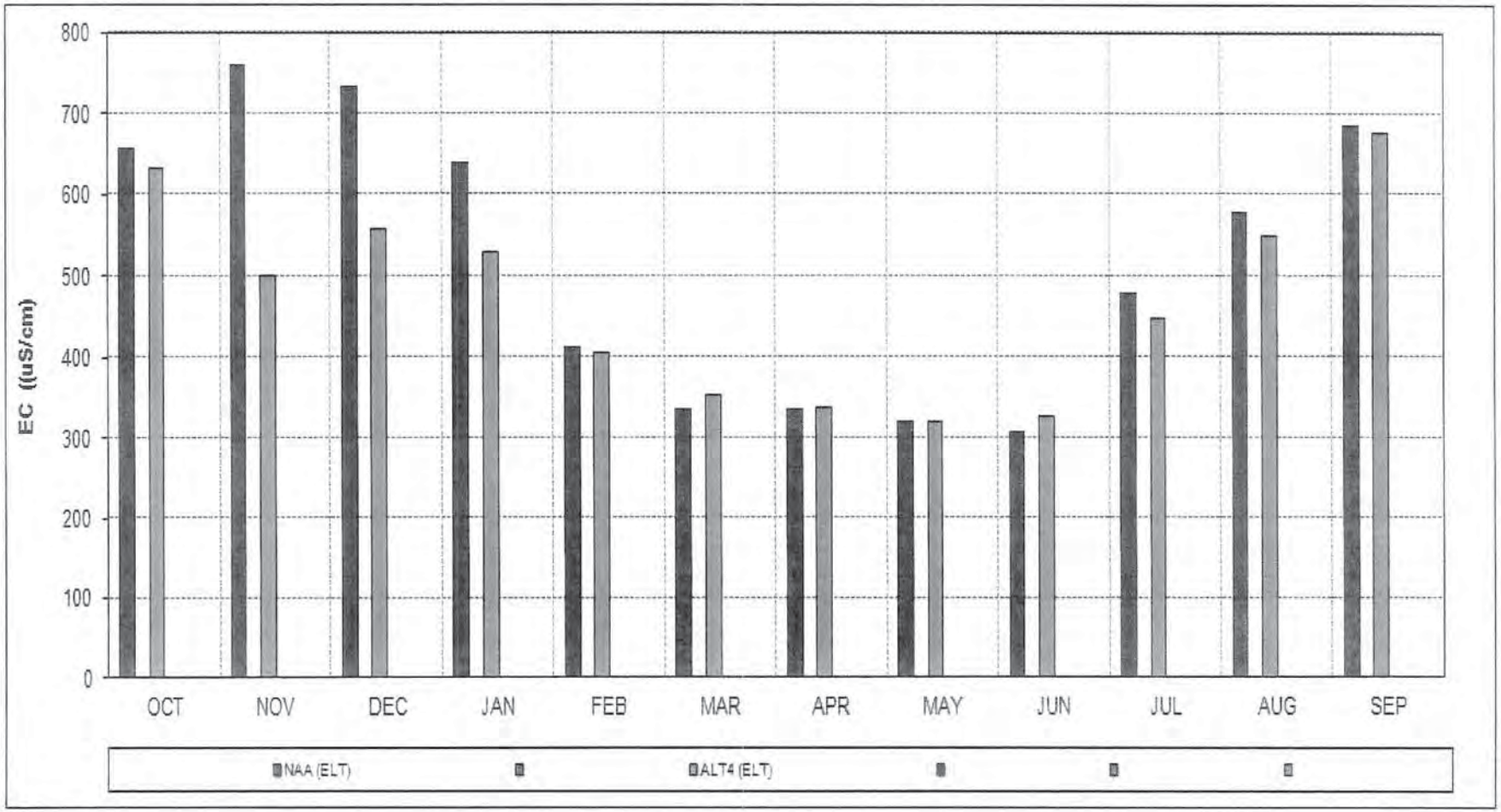
DSM2 is more accurate than ANNs

(But can't do the blending)

BDCP1563.

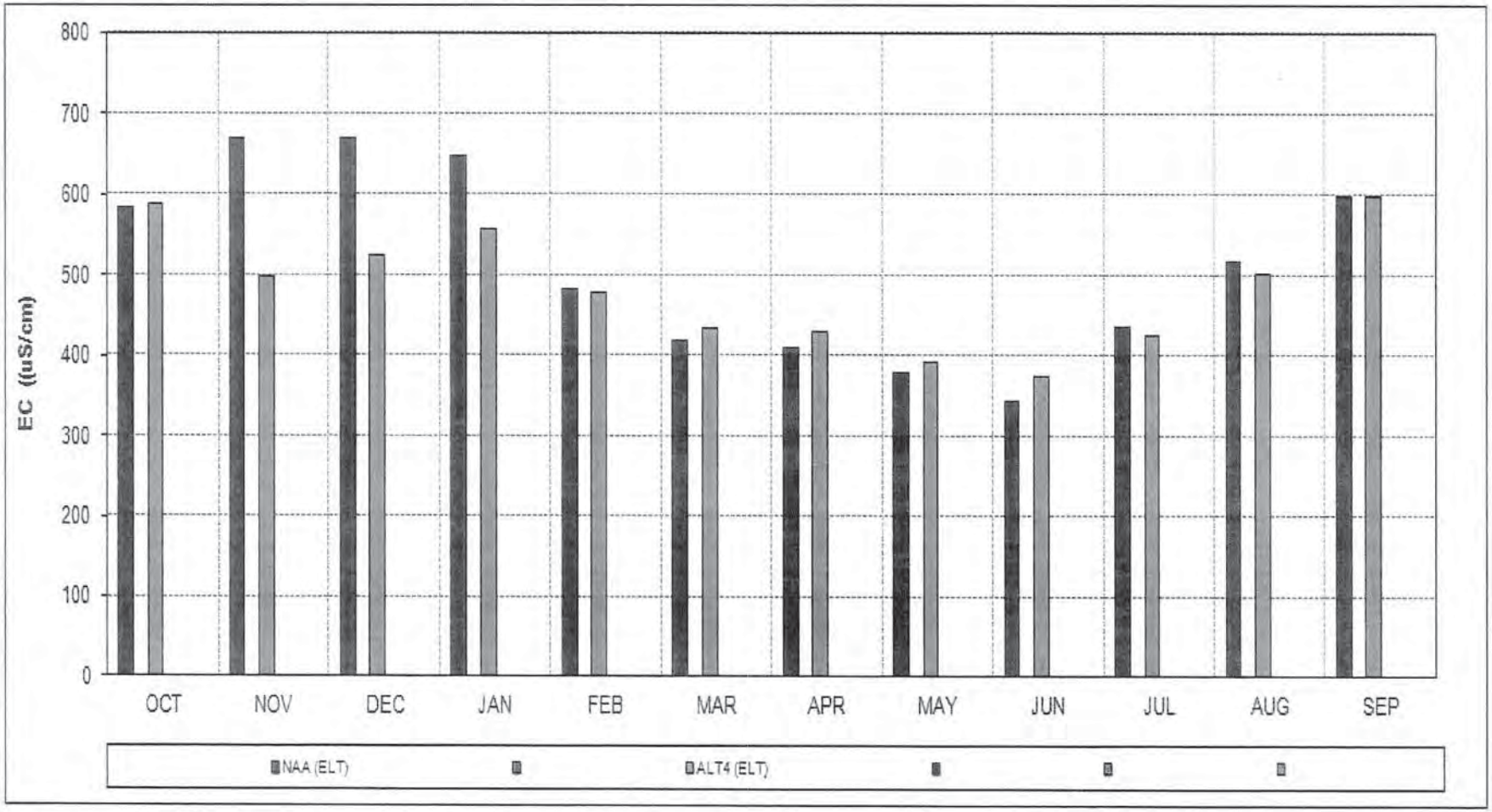
Old River @ RS

Rock Slough (EC) DSM2 (1976-1991)



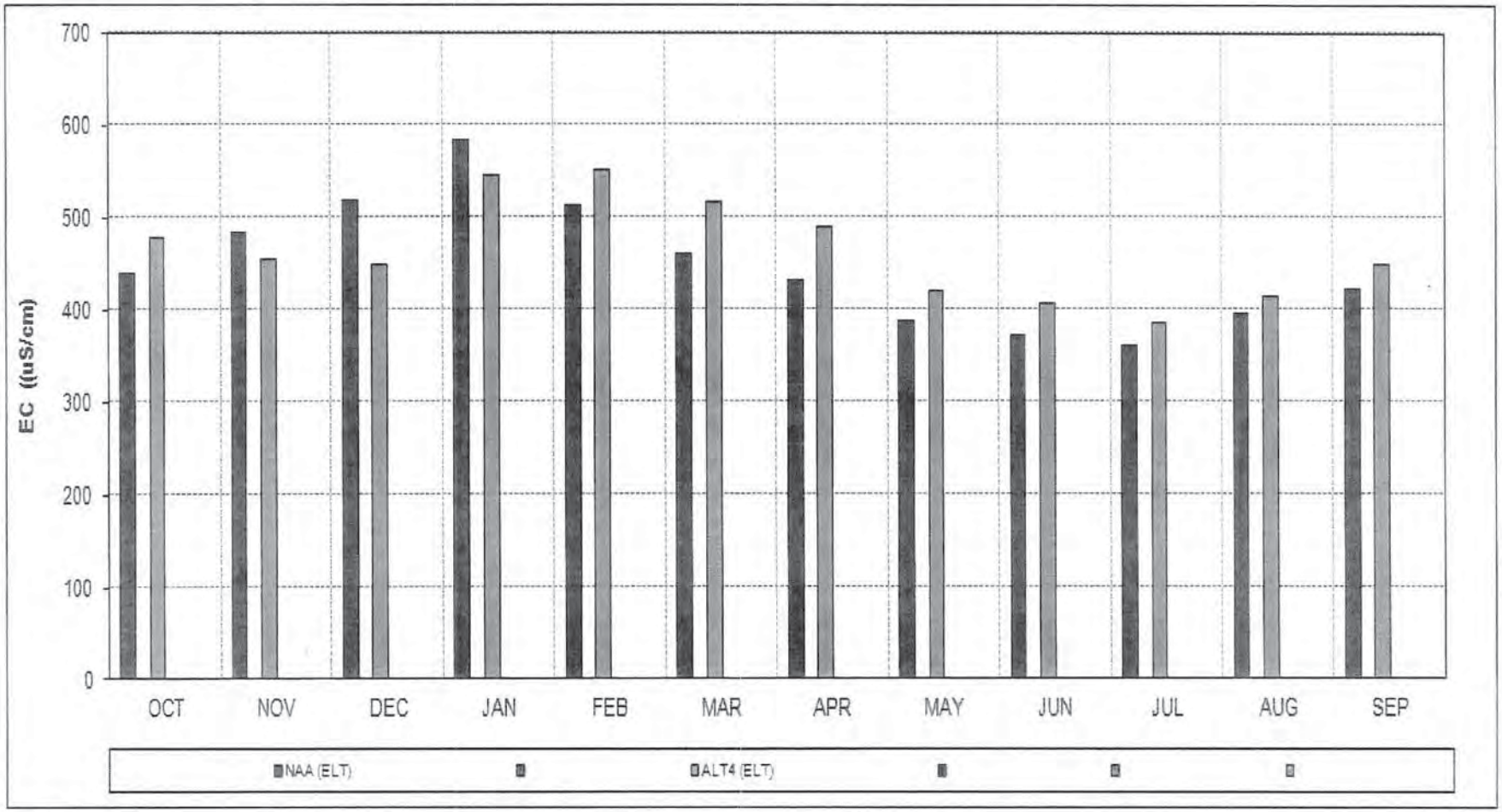
BDCP1563.

Old River Intake (EC) DSM2 (1976-1991)



BDCP1563.

Victoria Canal Intake (EC) DSM2 (1976-1991)



BDCP1563.

Modified Approach

- Redo CalSim II based on DSM2 EC Results (Use LV Module in a "Static Mode")
- Revisit EC-Chloride Relationship

BDCP1563.

EC-Chloride Conversion (CCWD)

- EC > 282 Cl = 0.285*EC - 50 Assuming seawater salt
- EC < 282 Cl = 0.15*EC - 12 Assuming Land Salt

(Equation was originally used for Rock Slough and Old River Intake). Use of the these equations is questionable for Victoria Canal Intake

BDCP1563.

Revised methodology for Victoria Canal Intake only

- Use DSM2 fingerprinting Coefficients as a guide
- If seawater Volume Contribution >0.4% use the Seawater Salt Formula
- Otherwise use the Land Salt Formula

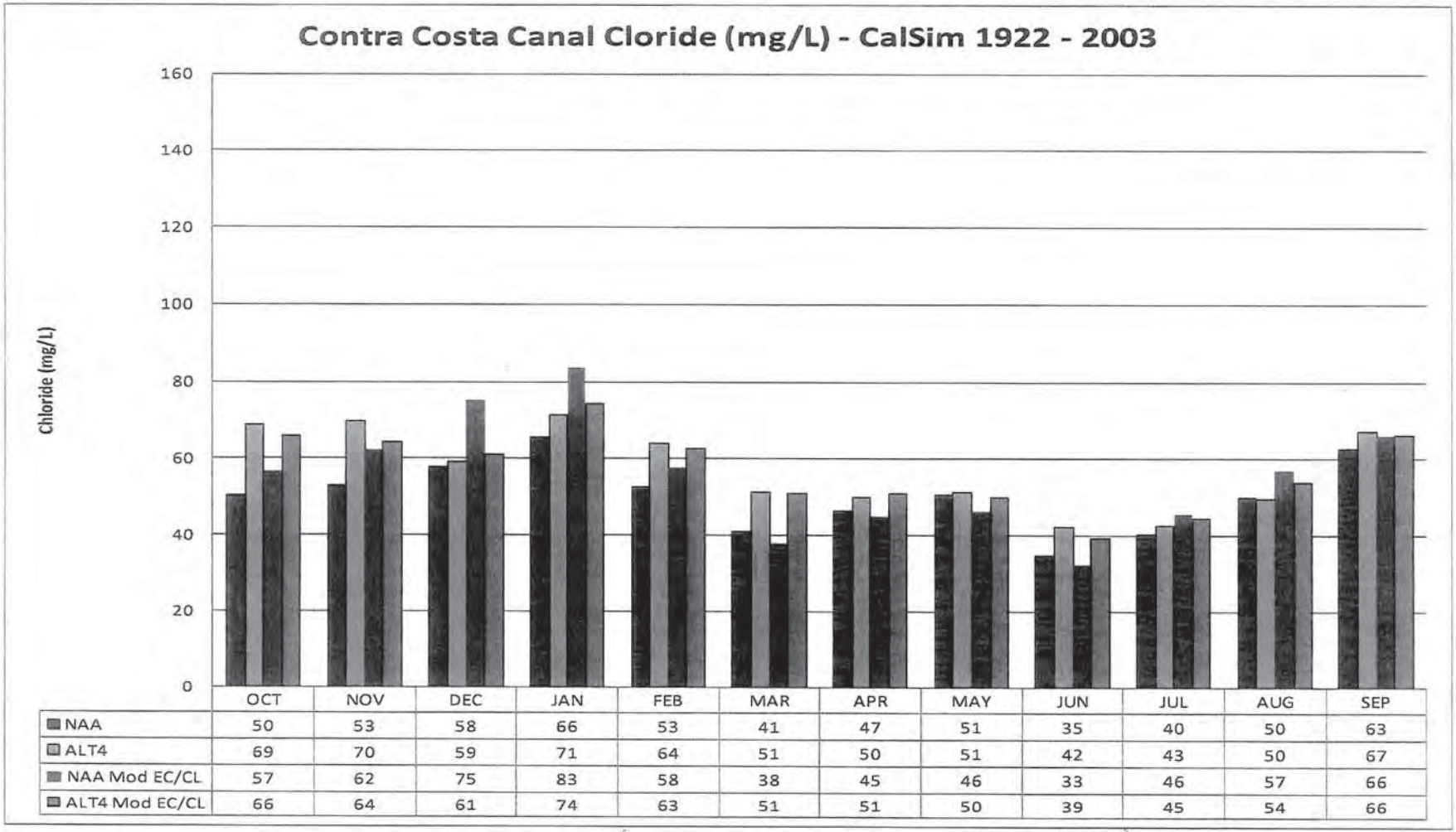
BDCP1563.

Revised CalSim II run based on DSM2 CCWD EC output and modified EC/Chloride relationship

BDCP1563.

82 year Analysis (1922-2003)

(still see some impact, but lower than before)

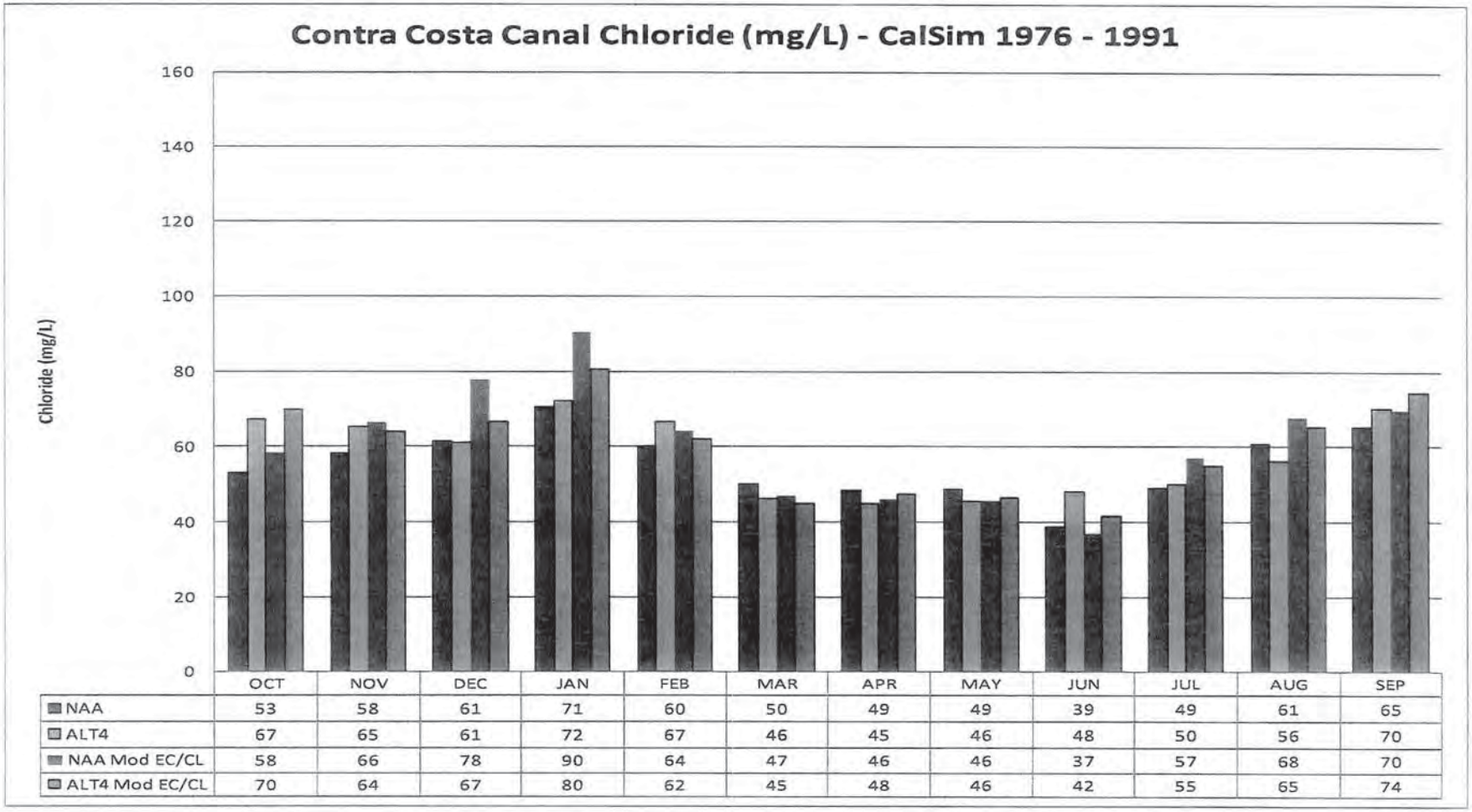


	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	50	53	58	66	53	41	47	51	35	40	50	63
ALT4	69	70	59	71	64	51	50	51	42	43	50	67
NAA Mod EC/CL	57	62	75	83	58	38	45	46	33	46	57	66
ALT4 Mod EC/CL	66	64	61	74	63	51	51	50	39	45	54	66

Impacts still exist

BDCP1563.

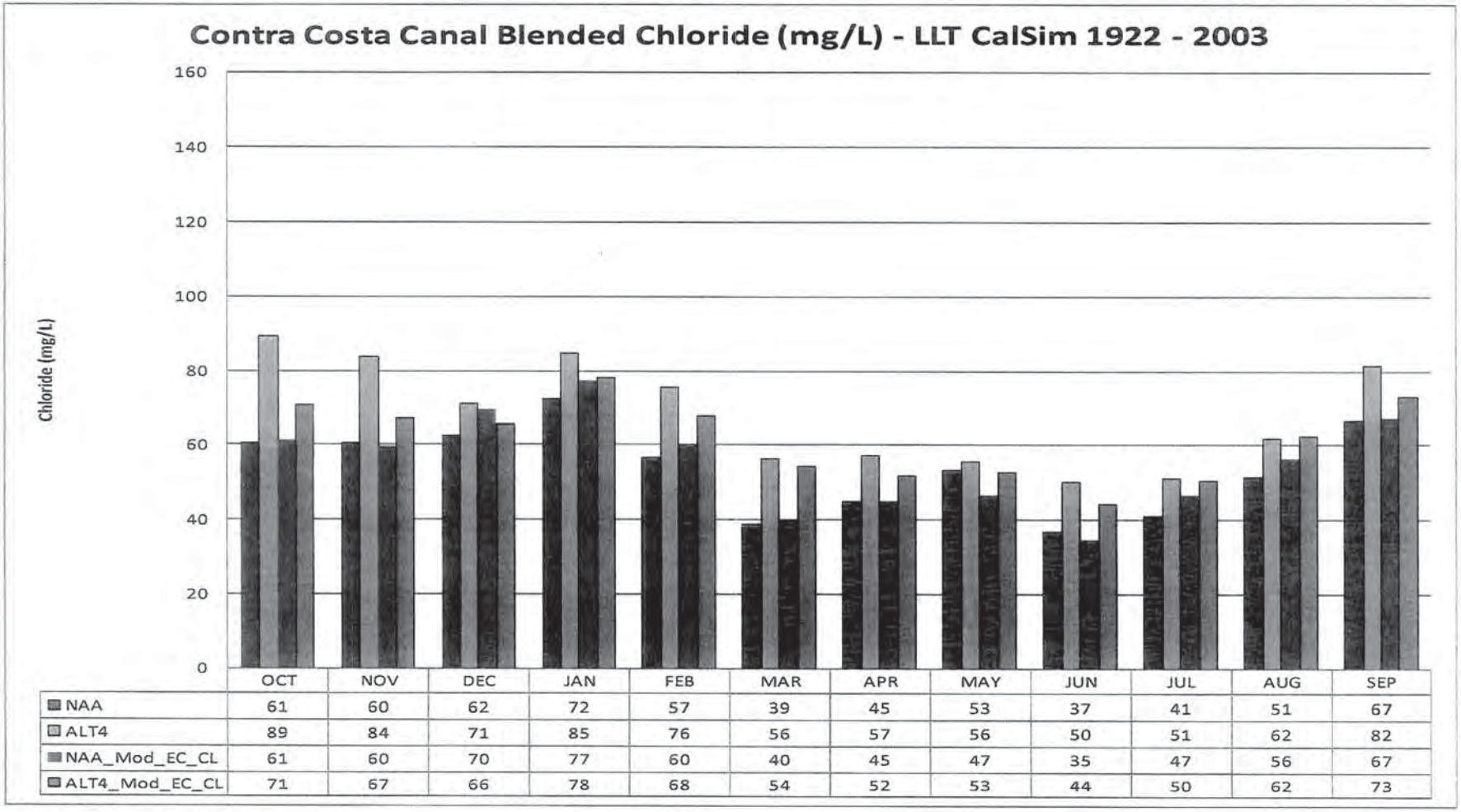
16 year Analysis (1976-1991) (Overall no/little impact)



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	53	58	61	71	60	50	49	49	39	49	61	65
ALT4	67	65	61	72	67	46	45	46	48	50	56	70
NAA Mod EC/CL	58	66	78	90	64	47	46	46	37	57	68	70
ALT4 Mod EC/CL	70	64	67	80	62	45	48	46	42	55	65	74

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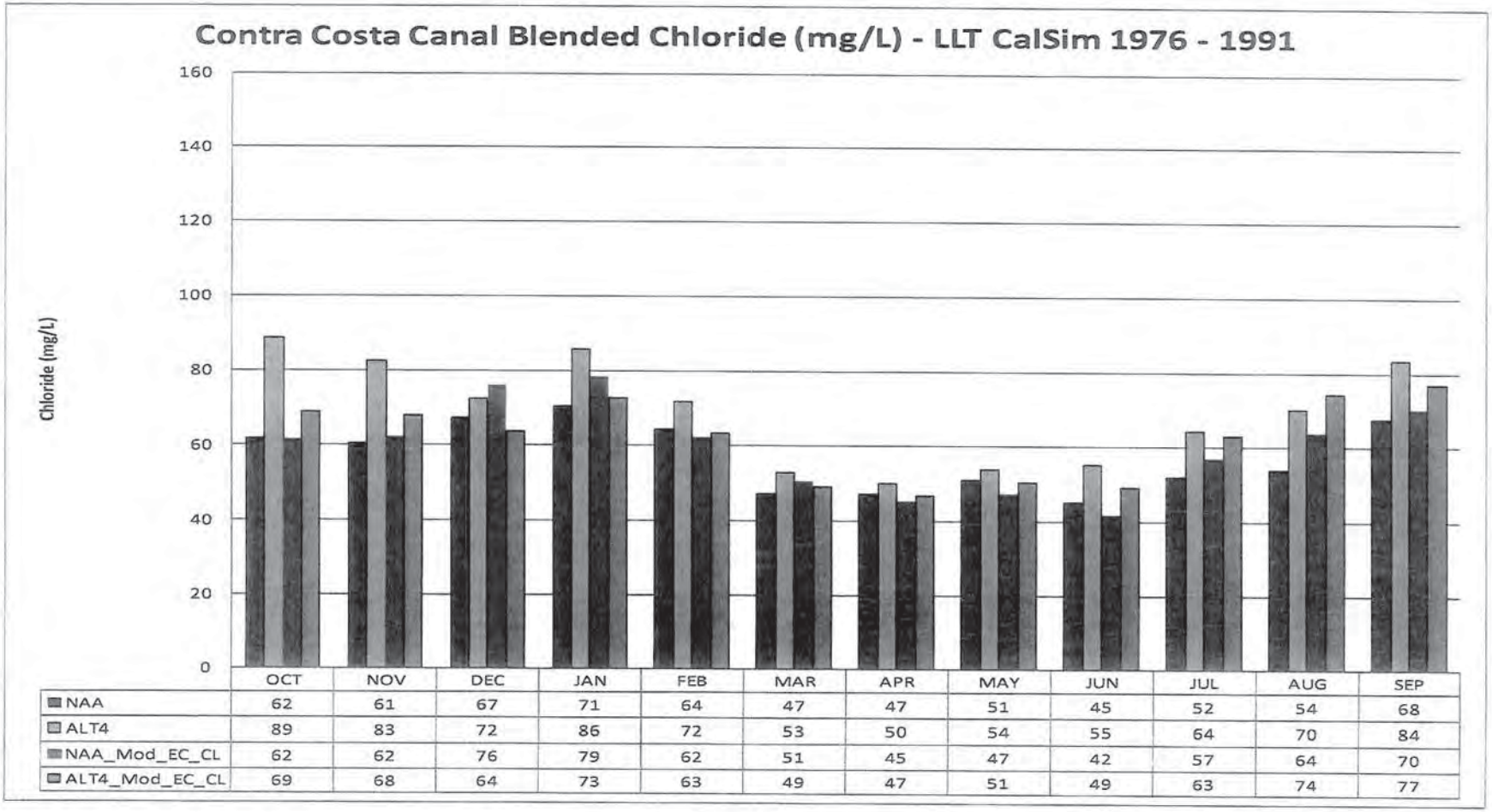
Repeat Analysis for LLT conditions (82 years)



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	61	60	62	72	57	39	45	53	37	41	51	67
ALT4	89	84	71	85	76	56	57	56	50	51	62	82
NAA_Mod_EC_CL	61	60	70	77	60	40	45	47	35	47	56	67
ALT4_Mod_EC_CL	71	67	66	78	68	54	52	53	44	50	62	73

BDCP1563.

Repeat Analysis for LLT conditions (16 years) (lower impacts)



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	62	61	67	71	64	47	47	51	45	52	54	68
ALT4	89	83	72	86	72	53	50	54	55	64	70	84
NAA_Mod_EC_CL	62	62	76	79	62	51	45	47	42	57	64	70
ALT4_Mod_EC_CL	69	68	64	73	63	49	47	51	49	63	74	77

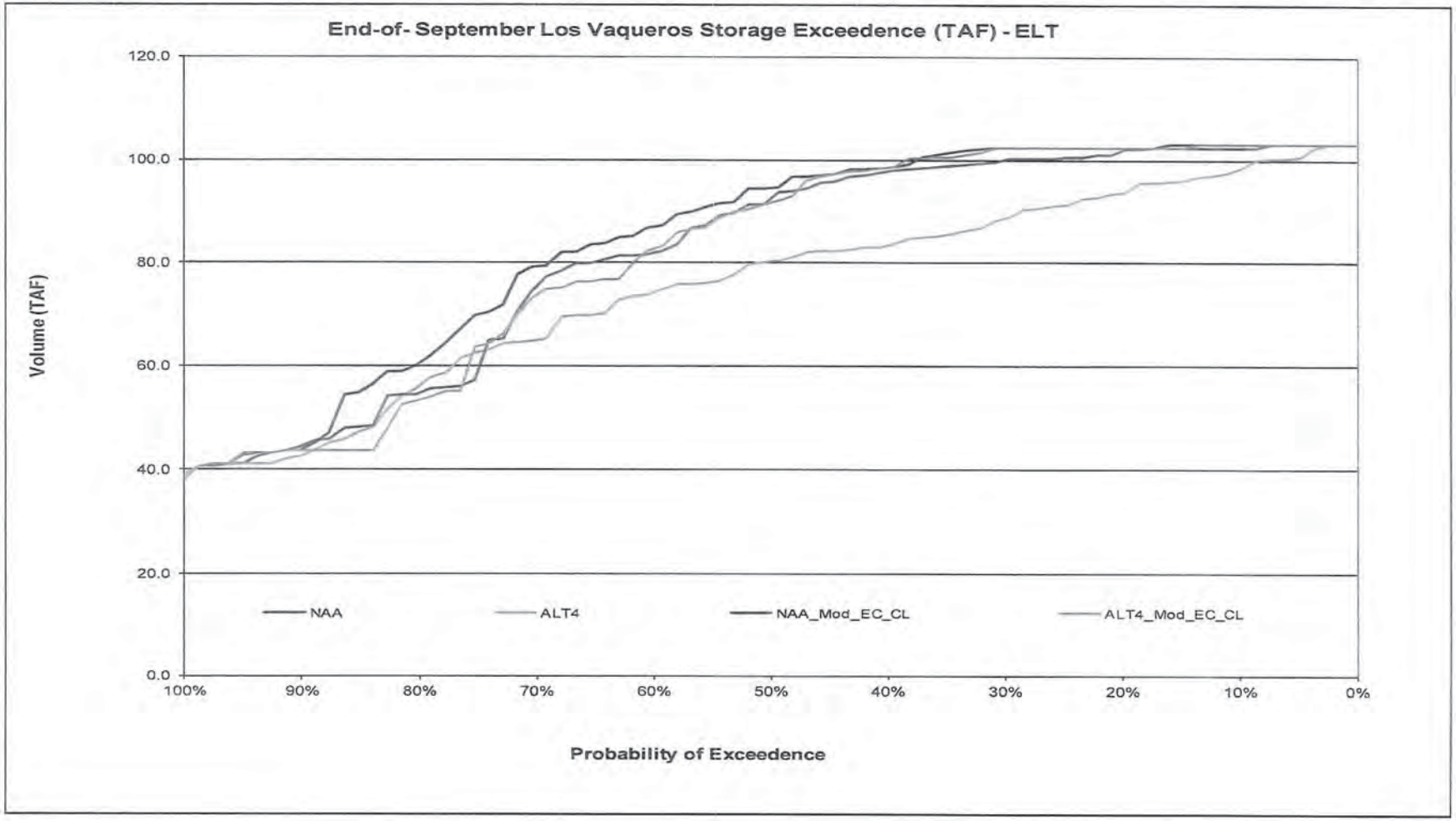
BDCP1563.

LV Storage

- Traditionally CalSim II did not include output for LV Storage.
- CCWD typically performed their own analysis to determine impact(??)
- LV Module offered an approach to estimate LV storage directly as an output from CalSim II

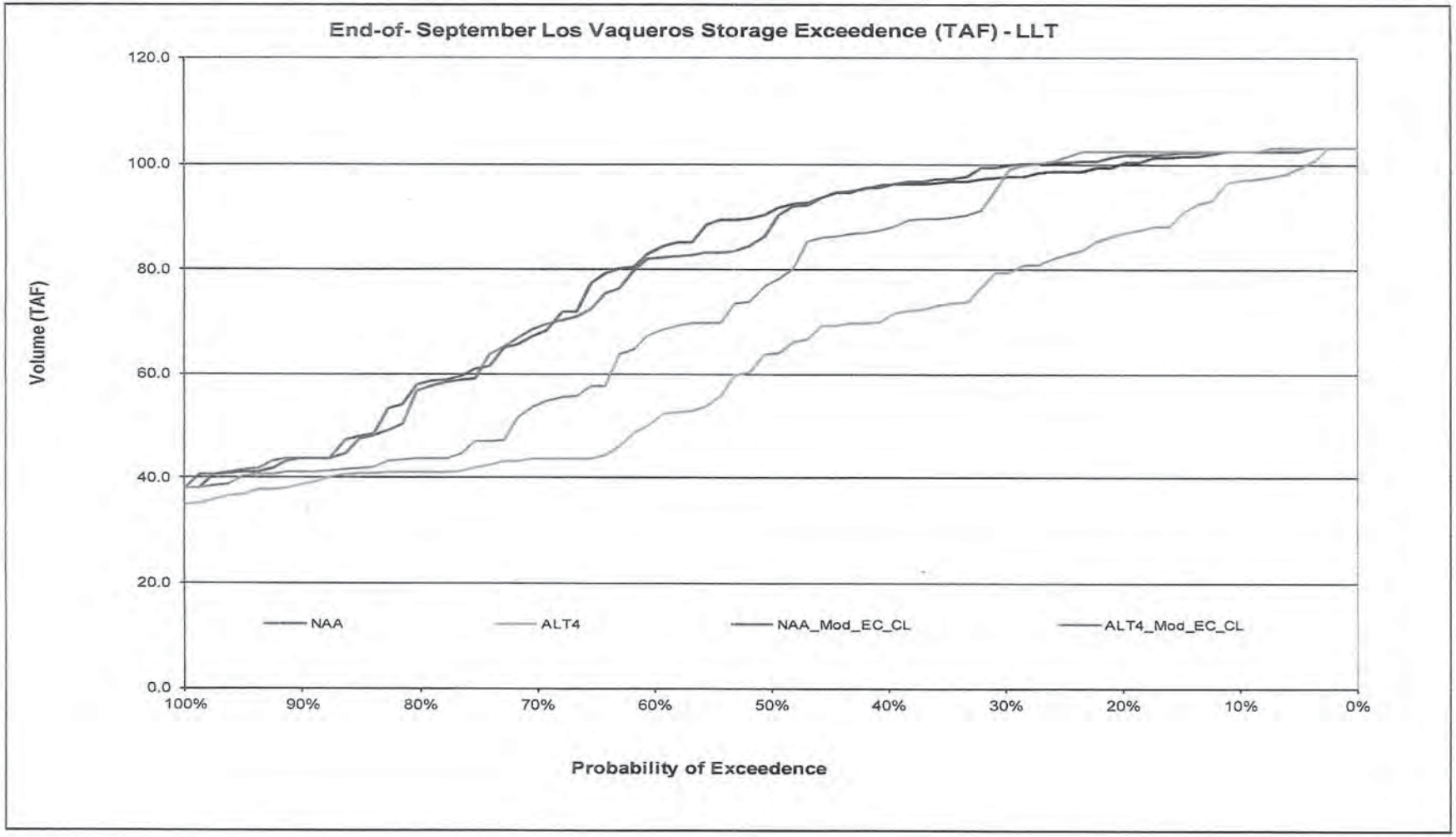
BDCP1563.

Use of DSM2 results for WQ conditions at CCWD intakes lead to substantially reduced impacts (ELT) compared to those predicted directly from LV Module.



BDCP1563.

Use of DSM2 results for WQ conditions at CCWD intakes lead to substantially reduced impacts (LLT), however, impacts are noticeable.



BDCP1563.

Conclusions

- Use of CalSim ANN salinity not appropriate to quantify CCWD water quality impacts
- Low/moderate impacts under ELT scenario
- Higher impacts under LLT scenario
- Higher salinity impacts under 82 years (versus 16 years)
- LV Storage impacts are overestimated using LV Module (in combination with ANN).

BDCP1563.

Deanna Sereno

From: Heiland, Brian@DWR <Brian.Heiland@water.ca.gov>
Sent: Thursday, March 28, 2013 2:56 PM
To: Deanna Sereno; Sanchez, Arnold@DWR
Cc: Stein, Russell@DWR; Morrow, Michelle@DWR
Subject: RE: BDCP modeling files
Attachments: BDCP_Alts_Crosswalk_102711.pdf

Hi Deanna, we can transfer all the files. Your numbering scheme is correct – I have also attached our Crosswalk. Yes, the modeling still uses the "old" numbering scheme.

BG

From: Deanna Sereno [mailto:dsereno@ccwater.com]
Sent: Wednesday, March 27, 2013 10:33 AM
To: Heiland, Brian@DWR; Sanchez, Arnold@DWR
Cc: Stein, Russell@DWR; Morrow, Michelle@DWR
Subject: RE: BDCP modeling files

Hi BG –

If it's okay, I'd prefer to get all the modeling files at once, even if they haven't changed. I believe the hard drive I sent should have enough space (500 GB), but let me know if it doesn't. Arnold should get the hard drive today. Here is the tracking info in case there is a problem:

Tracking number: 799375886465

Also, I've attached an excel spreadsheet with my interpretation of the old and new numbering schemes. It would be great if DWR could review this to make sure I'm interpreting the naming schemes properly. The modeling files (at least the prior two releases that I received) used the old numbering scheme, so this is critical to interpreting the results in context of the EIR/S.

Thanks,
~ Deanna

From: Heiland, Brian@DWR [mailto:Brian.Heiland@water.ca.gov]
Sent: Tuesday, March 26, 2013 4:19 PM
To: Deanna Sereno; Sanchez, Arnold@DWR
Cc: Stein, Russell@DWR; Morrow, Michelle@DWR
Subject: RE: BDCP modeling files

Hi Deanna, there are only a few remaining data sets that you don't have. In your first request, you asked for Existing Conditions, No Action, and Alternatives 1-5. In your 2nd request, you asked for Alternatives 2, 4, 5, and 8.

We can provide the Calsim/DSM2/SRWQM for Alternatives 6, 7, and 9 along with the Decision Tree scenarios for Alternative 4. I will assume you only want these runs unless you reply back to me with changes.

BG

From: Deanna Sereno [mailto:dsereno@ccwater.com]
Sent: Tuesday, March 26, 2013 3:23 PM
To: Heiland, Brian@DWR; Sanchez, Arnold@DWR
Cc: Stein, Russell@DWR; Morrow, Michelle@DWR
Subject: RE: BDCP modeling files

Hi BG and Arnold –

We would like all runs that are available for release. Who should I ship the harddrive to? I can send it out FedEx tonight if I get an address. If you can get the files copied before April 4, I can pick it up when I'm in town for the BDCP public meeting.

Thanks,
~ Deanna

Deanna Sereno
Water Resources Specialist
Contra Costa Water District
(925) 688-8079

From: Heiland, Brian@DWR [mailto:Brian.Heiland@water.ca.gov]
Sent: Tuesday, March 26, 2013 12:57 PM
To: Deanna Sereno
Cc: Stein, Russell@DWR; Morrow, Michelle@DWR; Sanchez, Arnold@DWR
Subject: RE: BDCP modeling files

Deanna, I have been authorized the release (starting Wednesday 3/27) the Calsim II and DSM2 data for all the BDCP Alternatives including the decision tree scenarios. We will not require a Disclaimer to be signed now that Chapter 5 of the BDCP is going to be released.

Please:

- Let me know which runs you are requesting.
- Coordinate with Arnold Sanchez (CC'd here) to provide him with an external hard drive (with at least 300 GB of storage).
- Make sure (consult & confirm with your IT staff) that the external hard drive is formatted in NTFS format instead of the default FAT32 file system or others. The reason for this is that some individual files are larger than 3GB will not be copied to that hard drive if it's not formatted accordingly.

Let me know if you have any questions.

BG

****

Brian "BG" Heiland, P.E.
Supervising Engineer, Water Resources
Executive Advisor to the Chief Deputy Director

Department of Water Resources
Executive Office

Phone: (916) 657-4389
Cell: (916) 207-6620

mailto:Brian.Heiland@water.ca.gov
****

From: Deanna Sereno [mailto:dsereno@ccwater.com]
Sent: Thursday, March 21, 2013 9:29 AM
To: Stein, Russell@DWR
Cc: Meral, Jerry@CNRA; Moon, Laura K.@DWR
Subject: BDCP modeling files

Hi Russ –

In the meeting yesterday, Jerry Meral said that the modeling files are now available to the public. While I understand that it might not be available until Ch. 5 is released (per you and Laura), the release is scheduled for next Wed, so I'd like to get the process started. Is there any paperwork that we need to sign? Who should I ship the hard drive to?

Thanks,
~ Deanna

Deanna Sereno
Water Resources Specialist
Contra Costa Water District
(925) 688-8079

ICF Proposed Alternatives Presentation for EIR/EIS

Alternative		Alignment /		ND Diversion	
Old	**New**	Conveyance	Intakes	Capacity (cfs)	Operations
1	**1A**	Tunnel / dual	1, 2, 3, 4, 5; *alts 1, 2, 3, 4, 5*	15,000	BDCP Steering Comm.
	1B	East canal / dual	1, 2, 3, 4, 5; *alts 1, 2, 3, 4, 5*	15,000	BDCP Steering Comm.
	1C	West canal / dual	1, 2, 3, 4, 5 (west side intakes)	15,000	BDCP Steering Comm.
1A	**2A**	Tunnel / dual	1, 2, 3, 4, 5[1]; *alts 1, 2, 3, 4, 5*	15,000	Scenario 6 / Fall X2
	2B	East canal / dual	1, 2, 3, 4, 5[1]; *alts 1, 2, 3, 4, 5*	15,000	Scenario 6 / Fall X2
	2C	West canal / dual	1, 2, 3, 4, 5 (west side intakes)	15,000	Scenario 6 / Fall X2
2	**3**	Tunnel / dual	1, 2; *alts 1, 2*	6,000	BDCP Steering Comm.
2A	**4**	Tunnel / dual	1, 2, 3; *alts 1, 2, 3*	9,000	Scenario 6 / Fall X2
2B	**5**	Tunnel / dual	1; *alt 1*	3,000	ND per BDCP Steering Comm.; SD per existing BOs (Fall X2, Old & Middle River flows, SJ E/I ratios)
3	**6A**	Tunnel / isolated	1, 2, 3, 4, 5; *alts 1, 2, 3, 4, 5*	15,000	BDCP Steering Comm.; no SD intakes; Fall X2
	6B	East canal / isolated	1, 2, 3, 4, 5; *alts 1, 2, 3, 4, 5*	15,000	BDCP Steering Comm.; no SD intakes; Fall X2
	6C	West canal / isolated	1, 2, 3, 4, 5 (west side intakes)	15,000	BDCP Steering Comm.; no SD intakes; Fall X2
4	**7**	Tunnel / dual	2, 3, 5; *alts 2, 3, 5*	9,000	BDCP Steering Comm.; modified to enhance aqu conservation
4A	**8**	Tunnel / dual	2, 3, 5; *alts 2, 3, 5*	9,000	≤ 1.5 MAF increased Delta outflow
5	**9**	Through Delta/ channel modifications	Screened intakes at Delta Cross Channel and Georgiana Slough	15,000	BDCP Steering Comm.

[1] Under Alternatives 2A and 2B, a total of five intakes would be constructed and operated. Intakes 4 and 5 may be substituted with

ND = North Delta

SD = South Delta

SJ = San Joaquin River



DW o e

BDO o e

South Delta

Organi ation

Ad inistration Progra Control

Delta Conveyance

odeling Support

South Delta



Bay-Delta Office
Depart ent of Water esources

1416 9th Street,
Sacramento, Ca 95814

Mailing Address:
P. O. Box 942836,
Sacramento, Ca 94236-0001



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Clifton Court Forebay Diversions cfs

Clifton Court Forebay Diversions cfs

State Water Pro ect Operations at Clifton Court Forebay and arvey O Banks Pu ping Plant

The discussion below provides a background on the SWP and CVP operations, including a description of how the SWP's CCF and SWP Banks currently work, as well as annual, weekly, and daily operations, and information on DWR's Corps permit and joint point of diversion (JPOD).

Annual Operations Planning

DWR and Reclamation estimate the amount of water that will be provided to their respective contractors each year, existing and forecasted, based on rainfall, existing storage, available data export and conveyance capacity, and beginning snowpack measurements of each year. This amount is usually a percentage of the contractors' full contractual amount. As the year progresses and forecasted data is replaced with actual data, those allocations may be revised.

Weekly Operations Planning

To plan weekly project operations, Bay-Delta tides are estimated using the National Oceanic and Atmospheric Administration's (NOAA's) forecasted tides and regression relationships with flow and salinity at various Delta locations. Based on the best estimates of weather conditions and past experience, a target Delta outflow is determined that is expected to meet the controlling water quality standard as well as other standards. DWR and Reclamation coordinate reservoir releases to meet the target outflows (California Department of Water Resources and Bureau of Reclamation 1996a).

Daily Operations

During actual daily project operations, data are transmitted hourly to DWR and Reclamation hydrometeorological systems in their water management control centers in Sacramento. These data consist of river flows, tides, salinity, and wind speed/direction at various Delta locations. If the data indicate a significant deviation from the planned conditions, one or more of the three following operational changes can be implemented: (1) adjust project reservoir releases; (2) adjust Delta export levels; and (3) close or open the Delta Cross Channel gates. Reservoir releases are most effective for meeting Sacramento River salinity criteria (most frequently at Emmaton) or Delta outflow criteria. San Joaquin River salinity criteria (most frequently at Jersey Point) are most effectively met by adjusting the amount of export pumping.

ivers and arbors Act

CCF and SWP Banks operate under a nationwide permit issued by the Corps under Section 10 of the Rivers and Harbors Act for construction and operation of facilities prior to 1968. Since 1968, four pumps were added to SWP Banks. DWR subsequently requested that the Corps provide a new permit under the Rivers and Harbors Act. In 1981, in Public Notice 5820A, Amended (Public Notice), dated October 13, 1981, the Corps determined that

operation of the expanded facility such that future diversions into the forebay do not exceed the historical maximum one-day and three-day diversion rates would have no increased effect on navigable capacity of the Delta waterways. Therefore, no additional permit will be required under Section 10 of the River and Harbor Act of 1899 provided that the historical maximum diversion rates

are not exceeded.

The Public Notice notes that those maximum diversion rates into CCF are 13,870 acre-feet (af) daily (and 13,250 acre-feet over a 3-day average). DWR also presented the Corps with plans to increase diversions by one-third of the San Joaquin River flow at Vernalis during the period from mid-December to mid-March, provided that flows at Vernalis exceed 1,000 cfs. The Corps' Public Notice states that

analysis of this proposed operation indicated that there would be no additional reduction in water levels at Clifton Court Ferry because any increased drawdown would be off-set by higher stages caused by increased San Joaquin River flows.

The Corps concluded that "diverting one-third of the flow at Vernalis during the timeframe proposed would have no effect on navigable capacity, and no Section 10 permit is required for this operation." Under all the SDIP proposed operational scenarios, the maximum diversion capacity would be higher than the currently permitted 6,680 cfs. Therefore, increased diversions would require a new Rivers and Harbors Act Section 10 permit from the Corps.

oint Point of Diversion

The CVP and SWP historically have shared Delta export pumping facilities to assist with project deliveries and to aid each project during times of facility outages. The sharing of these facilities is referred to as JPOD. In 1978, DWR agreed to, and the State Water Board permitted, the CVP to use the SWP Banks facility to export up to 195,000 acre-feet annually to replace pumping capacity lost at the CVP Tracy facility because of striped bass pumping restrictions in D-1485. In 1986, Reclamation and DWR formally agreed that "either party may make use of its facilities available to the other party for pumping and conveyance of water by written agreement" and that the SWP would pump CVP water to make up for striped bass protection measures (California Department of Water Resources 2003a). Per D-1641, use of JPOD is subject to an operations plan that protects fish and wildlife and other legal users of water. Thus, such joint point pumping essentially occurs only under conditions acceptable to NOAA Fisheries, DFG, USFWS, and the State Water Board, among other considerations. Although JPOD would continue to be implemented as it is currently, the operational scenarios under SDIP provide additional JPOD opportunities in the winter and summer periods. However, it could not be assumed that JPOD could provide the CVP with increased certainty and allow for increased water allocations to CVP contractors south of the Delta earlier in the year.

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SAN LUIS RESERVOIR *(SNL)*

Elevation: 543' · SAN LUIS CR basin · Operator: CA Dept of Water Resources

Provisional data, subject to change.

Query executed Wednesday at 11:42:57

ESE O S O A E (5634)

Date / Time	*STORAGE* **AF**
10/1968	619400
11/1968	844940
12/1968	1025100
01/1969	1345140
02/1969	1600780
03/1969	1798510
04/1969	1923100
05/1969	2009570
06/1969	2003740
07/1969	1996280
08/1969	1988830
09/1969	1981260
10/1969	1976470
11/1969	1956850
12/1969	1964390
01/1970	1975840
02/1970	1998680
03/1970	1988200
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05/1970	1959870
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07/1970	1801430
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03/1972	1895550
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12/1985	1595959
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02/1986	1974334
03/1986	2024787
04/1986	2025803
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09/1986	1481259
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12/1986	1916471
01/1987	1996408
02/1987	2021105
03/1987	2025295
04/1987	1914602
05/1987	1583809
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07/1987	715058
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12/1987	1267855
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03/1988	1781370
04/1988	1842590
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12/1988	854053
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SHASTA DAM (USBR) *(SHA)*

Elevation: 1067' · SACRAMENTO R basin · Operator: US Bureau of Reclamation

Provisional data, subject to change.

Query executed Wednesday at 11:41:10

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06/2003	4088097
07/2003	3547162
08/2003	3258552
09/2003	3159376 r

10/2003	3090889
11/2003	3090196
12/2003	3345962 r
01/2004	3606500
02/2004	3868600
03/2004	3905184
04/2004	4059792
05/2004	3863800
06/2004	3360818
07/2004	2802297 r
08/2004	2410369
09/2004	2182851
10/2004	2158914
11/2004	2124248
12/2004	2417193
01/2005	2832031
02/2005	3168056
03/2005	3827041
04/2005	4207234
05/2005	4467986
06/2005	4217184
07/2005	3639214
08/2005	3271767
09/2005	3034837
10/2005	2855374
11/2005	2896041
12/2005	3754767
01/2006	3586074
02/2006	3834224
03/2006	3853900
04/2006	4057305
05/2006	4467101
06/2006	4249102
07/2006	3784113
08/2006	3377701
09/2006	3205145
10/2006	3119405
11/2006	3127097
12/2006	3334767
01/2007	3374275
02/2007	3772193
03/2007	4010994
04/2007	3901137
05/2007	3601174
06/2007	3140631
07/2007	2559821
08/2007	2133899
09/2007	1879144
10/2007	1800690
11/2007	1729679
12/2007	1784100
01/2008	2179031
02/2008	2641041
03/2008	2990558
04/2008	2954112
05/2008	2806832
06/2008	2402186
07/2008	1905819
08/2008	1570784
09/2008	1384481
10/2008	1282770
11/2008	1331169
12/2008	1361975
01/2009	1416145
02/2009	1960458
03/2009	2880614
04/2009	2998247
05/2009	3118941

06/2009	2797114
07/2009	2325795
08/2009	1936123
09/2009	1773947
10/2009	1707930
11/2009	1673687
12/2009	1777112
01/2010	2596882
02/2010	3380147
03/2010	3868648
04/2010	4390774
05/2010	4464744
06/2010	4279177
07/2010	3841140
08/2010	3491704
09/2010	3318779
10/2010	3272489
11/2010	3224150
12/2010	3489195
01/2011	3490198
02/2011	3784113
03/2011	4032173
04/2011	4266264
05/2011	4486848
06/2011	4401530
07/2011	4034923
08/2011	3619135
09/2011	3341094
10/2011	3226770
11/2011	3150229
12/2011	3094584
01/2012	3107334
02/2012	3169235
03/2012	3853414
04/2012	4440094
05/2012	4299311
06/2012	3880716
07/2012	3271045
08/2012	2794523
09/2012	2591560
10/2012	2466130
11/2012	2564273
12/2012	3318052
01/2013	3473687
02/2013	3610647
03/2013	3771133
04/2013	3788352
05/2013	3362531
06/2013	2938227
07/2013	2433819
08/2013	2101287
09/2013	1905985
10/2013	1744200
11/2013	1695999
12/2013	1673380
01/2014	1655800
02/2014	1773314
03/2014	2198728
04/2014	2408810
05/2014	2177212
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Warning! This data is preliminary and subject to revision.

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Station ID	Sensor Number		Duration Code				Start date	End date	
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BDCP1563.

About Water Use Efficiency

ABOUT WATER USE EFFICIENCY



- Provides expertise to local agencies and individuals regarding agricultural and urban water and energy conservation, reclamation and reuse of water, land and water use, and drainage management.
- Manages the California Irrigation Management Information System (CIMIS), which collects data from over 140 automated weather stations throughout the State. CIMIS provides reference evapotranspiration (ETo) and weather data to the public for irrigation scheduling and other purposes such as water balance analyses, pest management, energy generation, fire fighting, weather forecasting, and scientific research.
- Assists in establishing mobile laboratories that conduct irrigation system evaluations.
- Carries out data analysis, demonstration projects, and research to achieve energy and water use efficiency.
- Provides loans and grants to make more efficient use of water and energy resources.

LATEST NEWS

The Governor's Drought State of Emergency Proclamation reporting for measure #2

- Water Shortage Emergency Rate Structures Webinar – Meeting Announcement (.pdf)
- Recording of Water Shortage Emergency Rate Structure Webinar
- Local urban water suppliers and municipalities are called upon to implement their local water shortage contingency plans immediately in order to avoid or forestall outright restrictions that could become necessary later in the drought season. Local water agencies should also update their legally required urban and agricultural water management plans, which help plan for extended drought conditions. The Department of Water Resources will make the status of these updates publicly available.

Agricultural Water Suppliers

- Agricultural water suppliers must prepare and adopt an Agricultural Water Management Plan (AWMP) no later than December 31, 2012, update it on December 31, 2015, and on or before December 31 every five years thereafter. Agricultural water suppliers that supply water to more than 25,000 irrigated acres, less supplied recycled water, are required to submit AWMP's. AWMP contents are outlined in Section 10826 of the Water Code. Agricultural water suppliers also are required by the Water Code §10608.48(d) to report on EWMPs that have been implemented and those that are planned to be implemented, an estimate of efficiency improvements achieved, and efficiency improvements expected in the next five and ten years and report to the Department of Water Resources. As of January 29, 2014, 29 plans were received of the estimated 55 water agencies required to submit representing 53 percent compliancy. Another 12 suppliers voluntarily submitted AWMP's. The results are

BDCP1563.

outlined in the table and maps below.

- 2012 Agricultural Water Management Plans Received
  - Click Here for Full PDF Version of Plans
  - Printable Full Color Map of Agricultural Water Management Plan Compliance
  - Printable Black and White (water suppliers shown in partial color) of Agricultural Water Management Plan Compliance

Urban Water Management Plans

- The 2010 UWMPs must be adopted by July 1, 2011 and submitted to DWR by August 1, 2011. Usually, UWMPs are due on December 31 of years ending in 0 and 5, but a 6-month extension has been granted for submittal of the 2010 UWMPs to provide additional time for water suppliers to address the SB X7-7 requirements(Division 6 Part 2.6 of the Water Code §10610 - 10656). Every urban water supplier that either provides over 3,000 acre-feet of water annually or serves more than 3,000 connections is required to assess the reliability of its water sources over a 20-year planning horizon considering normal, dry, and multiple dry years. This assessment is to be included in its UWMP, which is to be prepared every 5 years and submitted to the Department of Water Resources.

  Below is the status of Urban Water Management Plan review as of March 26, 2014, including a link to a list of the submittal status for each individual agency.

  - 43 plans have not been submitted
  - 240 plans submitted and addressed Water Code requirements
  - 85 plans submitted and awaiting or under review
  - 70 plans submitted, reviewed and status pending
  - 1 plan submitted and Water Code requirements not addressed

- 2010 Urban Water Management Plan Submittal Status March 26, 2014

[Federal Register Volume 74, Number 194 (Thursday, October 8, 2009)]
[Notices]
[Pages 51850-51862]
From the Federal Register Online via the Government Printing Office [www.gpo.gov]
[FR Doc No: E9-24287]

ENVIRONMENTAL PROTECTION AGENCY

[EPA-HQ-OW-2007-1189 FRL-8963-6]
RIN 2040-AD99

Drinking Water Contaminant Candidate List 3--Final

AGENCY: Environmental Protection Agency (EPA).

ACTION: Notice.

SUMMARY: The Environmental Protection Agency is publishing the third Contaminant Candidate List (CCL 3) since the Safe Drinking Water Act (SDWA) amendments of 1996. The CCL 3 is a list of contaminants that are currently not subject to any proposed or promulgated national primary drinking water regulations, that are known or anticipated to occur in public water systems, and which may require regulation under SDWA. Today's final CCL 3 includes 104 chemicals or chemical groups and 12 microbiological contaminants.

ADDRESSES: EPA has established a docket for this action under Docket ID No. EPA-HQ-OW-2007-1189. All documents in the docket are listed on http://www.regulations.gov. Although listed in the index, some information is not publicly available. For example, confidential business information or other information whose disclosure is restricted by statute is not publicly available. Certain other material, such as copyrighted material, is not placed on the Internet and is only in hard copy form. Publicly available docket materials are available either electronically through http://www.regulations.gov or in hard copy at the Water Docket, EPA/DC, EPA West, Room 3334, 1301 Constitution Ave., NW., Washington, DC. The Public Reading Room is open from 8:30 a.m. to 4:30 p.m., Monday through Friday, excluding legal holidays. The telephone number for the Public Reading Room is (202) 566-1744, and the telephone number for the EPA Docket Center is (202) 566-2426.

FOR FURTHER INFORMATION CONTACT: For information on chemical contaminants contact Thomas Carpenter, Office of Ground Water and Drinking Water, Standards and Risk Management Division, at (202) 564-4885 or e-mail carpenter.thomas@epa.gov. For information on microbial contaminants contact Tracy Bone, Office of Ground Water and Drinking Water, at (202) 564-5257 or e-mail bone.tracy@epa.gov. For general information contact the EPA Safe Drinking Water Hotline at (800) 426-4791 or e-mail: hotline-sdwa@epa.gov.

Abbreviations and Acronyms

CASRN--Chemical Abstract Services Registry Number
CDC--Centers for Disease Control and Prevention
CCL--Contaminant Candidate List
CCL 1--EPA's First Contaminant Candidate List
CCL 2--EPA's Second Contaminant Candidate List
CCL 3--EPA's Third Contaminant Candidate List
CERCLA--Comprehensive Environmental Response, Compensation, and Liability Act
CFR--Code of Federal Regulations
CSF--Cancer Slope Factor
DBP--disinfection byproduct
EPA--United States Environmental Protection Agency
ESA--ethanesulfonic acid
FDA--United States Food and Drug Administration
FIFRA--Federal Insecticide, Fungicide, and Rodenticide Act
FR--Federal Register
HRL--Health Reference Level
ICR--Information Collection Request
IUR--Inventory Update Rule
MCL--maximum contaminant level
MCLG--maximum contaminant level goal
NCFAP--National Center for Food and Agricultural Policy
NDWAC--National Drinking Water Advisory Council
NDMA--N-nitrosodimethylamine
NIRS--National Inorganic Radiological Survey
NRC--National Academies of Science's National Research Council
NPDWR--national primary drinking water regulation
OPP--Office of Pesticide Programs
PCCL--Preliminary CCL
PFOA--perfluorooctanoic acid
PFOS--perfluorooctane sulfonic acid

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PWS--public water system
RAISHE--Risk Assessment Information System, Health Effects

RDX- Cyclotrimethylenetrinitramine
RfD--reference dose
RTECS--Registry of Toxic Effects for Chemical Substances
SAB--EPA Science Advisory Board
SDWA--Safe Drinking Water Act
TRI--Toxics Release Inventory
TNT--2, 4, 6-trinitrotoluene
UCMR--Unregulated Contaminant Monitoring Regulation
UCMR 1--First Unregulated Contaminant Monitoring Regulation
UCMR 2--Second Unregulated Contaminant Monitoring Regulation
UCM R1/2--Unregulated Contaminant Monitoring Round \1/2\
U.S.--United States of America
USGS--United States Geological Survey
WBDO--waterborne disease outbreak
WHO--World Health Organization

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B. What Is the Purpose of this Action?
C. SDWA Risk Management Provisions
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1. Data Sources for the Contaminant Candidate Lists
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IV. Data Needs for CCL 3 Contaminants
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1. Health Effects
2. Occurrence
3. Analytical Methods
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V. Next Steps/Future Contaminant Candidate Lists
VI. References

I. General Information

A. Does This Action Impose Any Requirements on My Public Water System?

The final Contaminant Candidate List 3 (CCL 3) will not impose any requirements on anyone. Instead, this action notifies interested parties of the availability of U.S. EPA's final CCL 3, and provides information on the Agency's next steps to evaluate these contaminants.

B. What Is the Purpose of This Action?

The purpose of this action is to present the final CCL 3, a summary of the comments received on the draft CCL 3, and a description of the Agency's process for identifying contaminants to be placed on the list. Pursuant to section 1412(b)(1)(B)(i) of SDWA, as amended in 1996, EPA is required to publish a list of contaminants (1) that are currently unregulated, (2) that are known or anticipated to occur in public water systems, and (3) which may require regulations under the Safe Drinking Water Act (SDWA). This section briefly summarizes the statutory requirements for CCL 3, and related activities surrounding the contaminants included on the final CCL 3.

C. SDWA Risk Management Provisions

1. Contaminant Candidate List 3

SDWA section 1412(b)(1) requires that in the development of the CCL, EPA consider specific data sources and include the scientific community. EPA must evaluate substances identified in section 101(14) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 and substances registered as pesticides under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). SDWA also requires the Agency to consider the National Contaminant Occurrence Database established under section 1445(g) of SDWA. SDWA directs the Agency to consult with the scientific community, including the Science Advisory Board (SAB). In addition it directs the Agency to consider the health effects and occurrence information for unregulated contaminants to identify those contaminants that present the greatest public health concern related to exposure from drinking water.

EPA interprets the criterion that contaminants are known or anticipated to occur in public water systems broadly. In evaluating this criterion, EPA considers not only public water system monitoring data, but also data on ambient concentrations in surface and ground waters, and releases to the environment (e.g., Toxics Release

Inventory). While such data may not establish conclusively that contaminants are known to occur in public water systems, EPA believes these data are sufficient to anticipate that contaminants may occur in public water systems and to place them on the CCL. Once contaminants have been placed on the CCL, EPA identifies if there are any additional data needs, including gaps in occurrence data.

In selecting contaminants for the CCL 3, each of the above requirements was met. The Agency considered adverse health effects that may pose a greater risk to life stages and other sensitive groups which represent a meaningful portion of the population. Adverse health effects associated with infants, children, pregnant women, the elderly, and individuals with a history of serious illness were evaluated for both chemicals and microbes.

2. Regulatory Determinations

SDWA section 1412(b)(1) requires EPA to determine whether to regulate at least five contaminants from the CCL every five years. SDWA specifies that EPA shall regulate a contaminant if the Administrator determines that:

The contaminant may have an adverse effect on the health of persons;

The contaminant is known to occur, or there is a substantial likelihood that the contaminant will occur in public water systems with a frequency and at levels of public health concern; and

In the sole judgment of the Administrator, regulation of such contaminant presents a meaningful opportunity for health risk reduction for persons served by public water systems.

EPA interprets these criteria as more rigorous than what is used to place contaminants on the CCL. Section IV of this notice presents the current data needs for regulatory determination for the CCL 3 contaminants.

If EPA makes a determination that a national primary drinking water regulation is needed, then the Agency has 24 months to publish a proposed Maximum Contaminant Level Goal (MCLG) \1\ and a proposed National Primary Drinking Water Rule (NPDWR).\2\ After the proposal, the Agency has 18 months to publish a final

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MCLG and promulgate a final NPDWR (SDWA 1412(b)(1)(E)).\3\

\1\ An MCLG is the ``maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health of persons would occur, and which allows an adequate margin of safety. Maximum contaminant level goals are non-enforceable health goals'' (40 CFR 141.2).

\2\ An NPDWR is a legally enforceable standard that applies to public water systems. An NPDWR sets a legal limit (called a maximum contaminant level or MCL) or specifies a certain treatment technique (TT) for public water systems for a specific contaminant or group of contaminants.

\3\ The statute authorizes a nine month extension of this promulgation date.

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3. Unregulated Contaminant Monitoring

SDWA provides EPA with the authority to require all large and a subset of small systems to monitor for up to 30 unregulated contaminants every five years under the Unregulated Contaminant Monitoring Regulation (UCMR). The second unregulated contaminant monitoring rule (UCMR 2), which was promulgated on January 4, 2007 (72 FR 367; USEPA, 2007a), requires monitoring for several pesticides and pesticide degradates, five polybrominated diphenyl ether (PBDE) flame retardants, a group of nitrosamines, and two munitions (TNT and RDX). All of the chemicals on UCMR 2 were included among the contaminants evaluated for CCL 3.

Data collected under the UCMR are an important source of occurrence information for both the CCL and Regulatory Determination processes. There is an additional discussion of the relationship between CCL and UCMR in Section III. D of this Federal Register (FR) notice.

II. What Is on EPA's Drinking Water Contaminant Candidate List 3?

The draft CCL 3 was published on February 21, 2008 (73 FR 9628; USEPA 2008a), and included 93 chemicals or chemical groups and 11 microbiological contaminants. EPA provided information and sought comment on its efforts to expand and strengthen the underlying CCL listing process, the draft list, and EPA's efforts to improve the contaminant selection process for future CCLs.

In developing the draft CCL 3, EPA implemented a new process from that used for CCL 1 and CCL 2. This new process builds on evaluations from previous CCLs, and was based on substantial expert input and recommendations from various groups, including the National Academy of Science's National Research Council (NRC) and the National Drinking Water Advisory Council (NDWAC). This process is summarized in the draft CCL 3 FR notice.

In general, the criteria for including a contaminant on the CCL consisted of determining whether the occurrence or anticipated occurrence of a contaminant was likely at levels of concern to human health. The draft CCL 3 notice solicited input from the public, and specifically requested comments on (1) the approach EPA used to create the list; (2) contaminants on the list; and (3) on specific contaminants such as pharmaceuticals, perfluorinated compounds, and microbes.

The final CCL 3 includes 104 chemicals or chemical groups and 12 microbiological contaminants (Exhibit 1). The list includes, among

others, pesticides, biological toxins, disinfection byproducts, chemicals used in commerce, and waterborne pathogens. The Agency considered the best available data and information on health effects and occurrence to evaluate 7,500 unregulated contaminants and selected 116 candidates for the final CCL 3, which have the potential to present health risks through drinking water exposure.

Exhibit 1. Final Contaminant Candidate List 3:

Chemical Contaminants

CASRN	Common name--registry name
630206	1,1,1,2-Tetrachloroethane.
75343	1,1-Dichloroethane.
96184	1,2,3-Trichloropropane.
106990	1,3-Butadiene.
99650	1,3-Dinitrobenzene.
123911	1,4-Dioxane.
57910	17 alpha-Estradiol.
71363	1-Butanol.
109864	2-Methoxyethanol.
107186	2-Propen-1-ol.
16655826	3-Hydroxycarbofuran.
101779	4,4'-Methylenedianiline.
30560191	Acephate.
75070	Acetaldehyde.
60355	Acetamide.
34256821	Acetochlor.
187022113	Acetochlor ethanesulfonic acid (ESA).
184992444	Acetochlor oxanilic acid (OA).
107028	Acrolein.
142363539	Alachlor ethanesulfonic acid (ESA).
171262172	Alachlor oxanilic acid (OA).
319846	Alpha-Hexachlorocyclohexane.
62533	Aniline.
741582	Bensulide.
100447	Benzyl chloride.
25013165	Butylated hydroxyanisole.
133062	Captan.
14866683	Chlorate.
74873	Chloromethane (Methyl chloride).
110429624	Clethodim.
7440484	Cobalt.
80159	Cumene hydroperoxide.
NA	Cyanotoxins.
141662	Dicrotophos.
55290647	Dimethipin.
60515	Dimethoate.
298044	Disulfoton.
330541	Diuron.
517099	Equilenin.
474862	Equilin.
114078	Erythromycin.
50282	Estradiol (17-beta estradiol).
50271	Estriol.
53167	Estrone.
57636	Ethinyl Estradiol (17-alpha Ethynyl Estradiol).
13194484	Ethoprop.
107211	Ethylene glycol.
75218	Ethylene oxide.
96457	Ethylene thiourea.
22224926	Fenamiphos.
50000	Formaldehyde.
7440564	Germanium.
74975	Halon 1011 (bromochloromethane).
75456	HCFC-22.
110543	Hexane.
302012	Hydrazine.
72333	Mestranol.
10265926	Methamidophos.
67561	Methanol.
74839	Methyl bromide (Bromomethane).
1634044	Methyl tert-butyl ether.
51218452	Metolachlor.
171118095	Metolachlor ethanesulfonic acid (ESA).
152019733	Metolachlor oxanilic acid (OA).
2212671	Molinate.
7439987	Molybdenum.
98953	Nitrobenzene.
55630	Nitroglycerin.
872504	N-Methyl-2-pyrrolidone.
55185	N-Nitrosodiethylamine (NDEA).
62759	N-nitrosodimethylamine (NDMA).
621647	N-Nitroso-di-n-propylamine

	(NDPA).
86306	N-Nitrosodiphenylamine.
930552	N-nitrosopyrrolidine (NPYR).
68224	Norethindrone (19-Norethisterone).
103651	N-Propylbenzene.
95534	O-Toluidine.
75569	Oxirane, methyl-.
301122	Oxydemeton-methyl.
42874033	Oxyfluorfen.
14797730	Perchlorate.
1763231	Perfluorooctane sulfonic acid (PFOS).
335671	Perfluorooctanoic acid (PFOA).
52645531	Permethrin.
41198087	Profenofos.
91225	Quinoline.
121824	RDX.
135988	Sec-Butylbenzene.
7440246	Strontium.
107534963	Tebuconazole.
112410238	Tebufenozide.
13494809	Tellurium.
13071799	Terbufos.
56070167	Terbufos sulfone.
59669260	Thiodicarb.
23564058	Thiophanate-methyl.
26471625	Toluene diisocyanate.

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78488	Tribufos.
121448	Triethylamine.
76879	Triphenyltin hydroxide (TPTH).
51796	Urethane.
7440622	Vanadium.
50471448	Vinclozolin.
137304	Ziram.

Microbial Contaminants

Adenovirus
Caliciviruses
Campylobacter jejuni
Enterovirus
Escherichia coli (0157)
Helicobacter pylori
Hepatitis A virus
Legionella pneumophila
Mycobacterium avium
Naegleria fowleri
Salmonella enterica
Shigella sonnei

III. What Comments Did EPA Receive on the Draft CCL 3 and How Did the Agency Respond?

EPA received comments from 177 individuals or organizations on the draft CCL 3. Commenters identified several issues on the draft CCL 3 and the process used to select contaminants for the list. Many commenters noted the substantial effort, overall improvement, improved scientific rigor, and increased stakeholder involvement employed by EPA to develop the draft CCL 3. Commenters also provided information and recommendations for the Agency to consider as it finalized the CCL 3. The Agency has provided responses to individual comments in the ``Final Comment Response Document for the Third Drinking Water Contaminant Candidate List 3 (Categorized Public Comments)'' document that is available in the docket (USEPA 2009c).

A. Advisory From the EPA Science Advisory Board

The EPA SAB and its Drinking Water Committee reviewed the draft CCL 3 during 2008, and provided an advisory to the Administrator on January 29, 2009. EPA staff met with the SAB to provide an overview of the draft CCL 3, to answer questions from the Drinking Water Committee, and to clarify questions from the full SAB. The Agency also participated in teleconferences with SAB during the development of the ``SAB Advisory on EPA's Draft Third Drinking Water Contaminant Candidate List (CCL 3)'' (USEPA 2009d). SAB comments on the overall CCL 3 process and documentation are summarized in the following paragraphs.

The SAB noted that the process used to develop the draft CCL 3 represents a major improvement over the previous CCL processes and recognized the adaptive management strategies employed by EPA as an appropriate approach that should continue to be used in future CCLs. However, the SAB also believes the documentation of the process used to develop the draft CCL 3 lacks transparency. For example, one suggestion stated that EPA should document and justify why each of the contaminants from previous CCL lists were excluded from the draft CCL

3.

The SAB also stated that the current list may be too large for chemicals, and it may include too few pathogens. The SAB acknowledged that the CCL 3 has dual goals of developing regulatory determinations and identifying longer-term research needs. They also recommended that EPA prioritize the list to better identify regulatory priorities, research needs, and longer term needs for the next CCL.

EPA Response to SAB Recommendations

The Agency has updated the technical support documents for the CCL 3 to increase the transparency of the process that was used to determine which contaminants to include on the final CCL 3. Several specific suggestions to improve the transparency of the process are addressed in the supporting documents and identified in Section III of this notice. Documents describing the process and tables that identify the data used to select contaminants can be found on EPA's Web site at: http://www.epa.gov/safewater/ccl/index.html. More detailed information on the contaminants, such as the ``Final CCL 3 Contaminant Information Sheets.'', (USEPA, 2009e) and the ``Final Contaminant Candidate List 3 Microbes: PCCL to CCL Process'' can be found in the docket (USEPA, 2009g) and on EPA's Web site.

In Section IV of this FR notice, the Agency has also identified which contaminants will need additional data and information on their occurrence, health effects, and analytical methods. As the Agency continues to evaluate contaminants on the CCL 3, we will work with EPA and non-EPA scientists to develop and collect the best available science to support decision making for future regulatory determinations.

B. Chemical Contaminants

EPA evaluated data and information on chemical contaminants provided by commenters and collected by the Agency after the draft CCL 3 was published. EPA used the same process described in the draft CCL 3 FR notice (73 FR 9628, USEPA 2008a) to evaluate contaminants for which data became available after the publication of the draft CCL 3. Based on these analyses, EPA is taking the following actions on chemical contaminants: EPA is removing two pesticides from the CCL 3 that are no longer used in the United States, and the Agency is adding 13 chemical contaminants to the final CCL 3. EPA concluded that one antibiotic (erythromycin), nine hormones (17 alpha-estradiol, 17 beta-estradiol, equilenin, equilin, estriol, estrone, ethinyl estradiol, mestranol, and norethindrone), two potential disinfection byproducts (DBP) (Halon 1011 (bromochloeromethane) and chlorate), and one perfluorinated compound (Perfluorooctanoic sulfonic acid (PFOS)) should be included on the CCL 3 based on their potential adverse health effects and potential for occurrence in public water systems. The Agency has summarized the comments and information used to evaluate these contaminants in this section of the FR notice. The specific data used to evaluate these contaminants can be found in the response to comment document (USEPA, 2009c) and the ``Final CCL 3 Contaminant Information Sheets'' in the docket (USEPA, 2009e).

1. Pesticides and Degradates

EPA received more than 65 public comments on pesticides and their related degradates. Some commenters were concerned about the number of pesticides listed on the draft CCL 3. One commenter states, ``* * * in the process of narrowing the universe of 7,500 unregulated chemicals down to 93 * * * EPA selected nearly half (42 out of 93) to be pesticides or pesticide degradates.'' This and other commenters viewed the listing of pesticides as a selection bias and noted that EPA has not clearly demonstrated, in the process used to derive the draft CCL 3, that these 42 pesticides and degradates pose the greatest public health concern. In addition, this commenter believed that the inclusion and proportional share of pesticides and their degradates on the draft CCL 3 should take into account the Agency's regulatory determination findings where none of the pesticides or degradates evaluated were ultimately determined to provide a meaningful opportunity to provide public health protection. In contrast, some commenters were in agreement with the pesticides included on the draft CCL 3, and in some cases, commenters

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suggested placing additional pesticides on the final CCL 3.

EPA Response: EPA does not agree with the commenter's statement that there is a selection bias for pesticides. The CCL 3 process was developed to evaluate contaminants from a broad universe of chemicals in accordance with the NRC and NDWAC recommendations. The chemicals are subject to consistent screening and evaluation based on chemical specific factors such as physical properties, health effects data, and their potential to occur in public water systems. SDWA requires EPA to evaluate substances registered as pesticides under FIFRA. All pesticides identified in the universe of chemicals were evaluated by EPA using the same process as other chemicals. Previous regulatory determinations not to develop a NPDWR for 10 pesticides or degradates in Regulatory Determinations 1 and 2 are irrelevant to other pesticides on the CCL 3. The regulatory determination process, like the CCL process, is data driven. To make a regulatory determination, EPA evaluates the available occurrence and health effects data for that contaminant against the criteria in SDWA Section 1412 (b)(1)(a). The Agency has responded to comments on specific pesticides in the response to comment document (USEPA, 2009c).

2. Cancelled Pesticides Registrations

SAB and other public commenters suggested that specific pesticide active ingredients (Nitrofen and Ethion) should be removed from the CCL 3 because they are no longer used in registered pesticides. The SAB also commented that EPA should consider removing pesticides from the

CCL 3 that are no longer registered products or are in the process of being phased out of use. The pesticides identified by the commenters, Nitrofen and Ethion, are not included on the final CCL 3. The evaluation of these two pesticides is summarized in the following paragraphs.

a. Nitrofen

EPA received comment from the public and the SAB that Nitrofen should not be included on the final CCL 3. Commenters noted that the available information on use, release, and potential environmental occurrence of Nitrofen indicate that it should not be anticipated to occur in public water systems (PWS).

EPA Response: EPA agrees with the commenters that Nitrofen should be removed from the CCL 3. It is no longer manufactured or sold in the United States. Its inclusion on the draft list was based on a reported TRI release which, when investigated, indicated that Nitrofen stocks were recently found in a warehouse and properly disposed of in accordance with the Resource Conservation and Recovery Act Subtitle C landfill regulations. TRI requires that information on landfill releases, even releases in compliance with regulations, be reported; therefore, the Nitrofen release was incorporated in the total TRI data used in the CCL process. Based on this information, Nitrofen is not anticipated to occur in PWSs, and the Agency has not included Nitrofen on the final CCL 3.

b. Ethion

Commenters noted that the registration for Ethion was cancelled and therefore EPA should not include Ethion on the final CCL 3.

EPA Response: EPA agrees with the commenters and has not included Ethion on the final CCL 3. On March 22, 2002, EPA published a cancellation order discontinuing the manufacture of Ethion containing products as of October 1, 2003, and prohibiting the use of existing stocks after December 31, 2004 (67 FR 13328; USEPA, 2002). A July 23, 2004 action revoked the remaining Ethion tolerances, as of October 1, 2008 (69 FR 43918; USEPA, 2004). EPA notes that SDWA criteria consider whether a contaminant is known or anticipated to occur in PWSs and may have an adverse effect. It is possible for a contaminant to occur in a PWS even after its uses are canceled if it is very persistent in the environment. Ethion is moderately persistent in the environment, but is not likely to contaminate surface water through dissolved runoff. Based on laboratory and field data, including monitoring data compiled in EPA's Pesticides in Ground Water Database, EPA does not expect that Ethion will contaminate ground water (USEPA, 2001). Based on Ethion's discontinued registration status, prohibited use of stocks, and moderate persistence, the Agency does not anticipate that it will occur in PWSs; therefore, it is not included on the final CCL 3.

3. Perfluorinated Compounds

In the draft CCL 3 FR notice, EPA sought comments on its proposed decisions to include perfluorooctanoic acid (PFOA) and not to include PFOS on the draft CCL 3 (73 FR 9652, USEPA 2008a). The majority of commenters agreed with the inclusion of PFOA on the CCL 3. Commenters pointed out that PFOA warrants inclusion on the CCL due to its known occurrence in drinking water supplies and systems and its potential adverse health effects. A number of these commenters also wrote in support of regulating PFOA under SDWA. The SAB also stated that PFOA should be a high priority for consideration by the Agency for the CCL 3. One commenter argued that EPA did not use the most relevant information in the CCL 3 process to characterize PFOA's health effects and occurrence. Some of the commenters who were in support of including PFOA on the CCL also recommended adding PFOS and other perfluorinated compounds to the list. The SAB noted that perfluorochemicals may be a class of contaminants that the Agency should consider as a group based on their similar structures and chemical makeup.

EPA Response: The Agency agrees with commenters that potential health effects based on animal studies and the occurrence of PFOA in drinking water supplies warrant its inclusion on the CCL 3. The Agency used the best available science and information to evaluate and list drinking water contaminant candidates. PFOA has been detected in a number of drinking water supplies and ambient waters. It is also highly persistent in the environment and has been shown to be toxic in animal studies. Based on these potential adverse health effects and occurrence information, EPA concludes that PFOA is known or anticipated to occur in public water systems and may require regulation. Therefore EPA has included PFOA on the final CCL 3.

PFOS was not included on the draft CCL 3, but has been included on the final CCL 3. A major factor in EPA's decision to not include PFOS on the draft CCL 3 was the voluntary phase-out of production of PFOS in the U.S. between 2000 and 2002 (FR 73 9652; USEPA 2008a). However, EPA has evaluated new information from the October 9, 2007, significant new use rule (SNUR) that shows there are ongoing uses of PFOS that could lead to its occurrence in water (FR 72 57222-57235; USEPA 2007b). The Agency concluded, based upon this potential to occur in PWSs, existing data on environmental persistence, and toxicity in animal studies, that PFOS is known or anticipated to occur in public water systems and may require regulation. Therefore, EPA has included this compound on the final CCL 3.

The Agency continues to analyze the data and information related to the possible adverse health effects associated with PFOA and PFOS. As noted in the draft CCL 3 FR notice, the SAB completed a review of a draft PFOA risk assessment in 2006 and made

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recommendations for the further development of the risk assessment (USEPA, 2006a). A number of important studies are underway, and the Agency continues to participate in research regarding the toxicity of related perfluorochemicals, as well as research to help identify routes of human exposure. EPA is evaluating additional research and has not

made any definitive conclusions on the risk assessment at this time. The Agency also issued ``Provisional Health Advisories for PFOA and PFOS'' (USEPA 2009f) to provide technical information to State and local officials, and PWSs for consideration in addressing local contamination of drinking water to protect public health. This information has been included in the docket and the ``Final CCL 3 Contaminant Information Sheets'' for PFOA and PFOS (USEPA, 2009e).

While the Agency did not specifically seek comment on other perfluorinated compounds in the draft CCL 3 FR notice, some of these compounds were included in the CCL 3 Universe. However, the Agency had only limited data on the potential occurrence of these compounds and potential adverse health effects. Commenters did not provide additional occurrence or health effects data than those already evaluated by the Agency; therefore, they are not listed on the CCL at this time. The Agency will continue to evaluate perfluorinated compounds to ascertain whether they possess similar toxicological properties and if they are anticipated or known to occur in public water systems.

4. Pharmaceuticals

In the draft CCL 3 FR notice (73 FR 9652; USEPA, 2008a), EPA explained how pharmaceuticals were evaluated in the CCL 3 process, and sought additional data and information on the concentrations of pharmaceuticals in finished or ambient water. EPA also requested comment on how pharmaceuticals have been considered in the CCL 3 process. In addition, EPA sent a letter to State public health and environmental departments requesting information on the States' activities and initiatives involving pharmaceuticals. The Agency specifically requested information on pharmaceuticals in the areas of occurrence, human health effects research, analytical methods development, and stewardship. EPA received a number of comments on pharmaceuticals and the CCL 3. Commenters pointed out that additional research is needed to address the health effects and occurrence of pharmaceuticals in drinking water. Commenters also noted that the contaminants were detected at low levels. Commenters differed on whether pharmaceuticals should be included on the CCL 3. Some commenters provided references from the published literature on the occurrence of pharmaceuticals in water and on the health effects of pharmaceuticals. In its comments, the SAB noted that pharmaceuticals may be a class of contaminants that need special attention when considering them for CCL 3 or future CCLs, and recommended that EPA use additional data on occurrence of pharmaceuticals in water from the United States Geological Survey (USGS), or studies in the peer-reviewed literature (USEPA, 2009d).

EPA Response: EPA is actively working to evaluate the potential risks to human health and aquatic life posed by trace amounts of pharmaceuticals and personal care products in water, and to identify measures to minimize their occurrence. The Agency has a number of activities underway and will continue to add activities as appropriate. All of these activities are described in further detail on our Web site located at http://www.epa.gov/waterscience/ppcp. Additional information on the Agency's research related to pharmaceuticals can be found at http://www.epa.gov/ppcp.

In the CCL 3 process, EPA evaluated the potential adverse health effects of pharmaceuticals and their occurrence in public drinking water systems to determine if pharmaceuticals should be added to the list. Since the draft CCL 3 was published, several publications have focused on the occurrence of pharmaceuticals in ambient water and drinking water. In response to comments, EPA has conducted additional data collection efforts to comprehensively review recent published information from USGS and other sources, including those cited by commenters, to identify the best available occurrence information for pharmaceuticals. EPA identified new occurrence data for 81 contaminants from 22 sources. The Agency also conducted additional literature reviews to identify the best available health effects information and identified data from sources including: EPA Office of Pesticide Programs, the Food and Drug Administration (FDA) Center for Veterinary Medicine, the Joint Food and Agriculture Organization/World Health Organization (WHO) Expert Committee on Food Additives, and the European Medicines Agency, and the FDA Center for Drug Evaluation and Research. EPA used the new data in the same process that was described in the draft CCL 3 FR notice to further evaluate pharmaceutical contaminants.

Based upon this re-evaluation with new data, EPA concluded that one antibiotic (erythromycin) and nine hormones (17 alpha-estradiol, 17 beta-estradiol, equilenin, equilin, estriol, estrone, ethinyl estradiol, mestranol, and norethindrone), should be included on the CCL 3 because these contaminants are known or anticipated to occur in public water systems and may require regulation. The specific data used to evaluate these contaminants can be found in the ``Final CCL 3 Contaminant Information Sheets'' (USEPA, 2009e).

5. Perchlorate

EPA received several comments on perchlorate in response to the draft CCL 3. Commenters noted that perchlorate should be included on the final CCL 3 and provided occurrence and health effects data. Commenters also identified potential sources of perchlorate in the environment.

EPA Response: EPA included perchlorate on the first CCL in 1998 and on the second CCL in 2005. EPA is including perchlorate on CCL 3 while the Agency continues to evaluate scientific information related to a regulatory determination.

EPA published a preliminary regulatory determination for perchlorate in the FR on October 10, 2008 (73 FR 60262; USEPA, 2008b). In this notice, EPA solicited public comment on its preliminary determination not to regulate perchlorate. The Agency issued an interim health advisory for perchlorate to provide technical information to State and local officials and PWSs for consideration in addressing local contamination of drinking water (USEPA, 2008c).

EPA received more than 32,000 comments on the preliminary

regulatory determination (73 FR 60262; USEPA 2008b). The majority of comments were submitted by individuals opposed to the decision. There were also unique comments that recommended further scientific evaluation of the information EPA used to make the preliminary determination. These commenters included EPA's NDWAC, SAB, and Children's Health Protection Advisory Committee. All of the comments received on the preliminary regulatory determination FR notice can be reviewed on www.regulations.gov. Refer to docket number EPA-HQ-OW-2008-0692.

6. Disinfection Byproducts (DBP)

EPA received several comments on unregulated disinfection byproducts.

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Most comments supported the inclusion of N-nitrosodimethylamine (NDMA) and the other N-nitrosamines (N-nitrosodiethylamine, N-nitroso-di-n-propylamine, N-nitrosodiphenylamine, N-nitrosopyrrolidine) on CCL 3, citing the evidence for their carcinogenicity and the overarching need to evaluate this risk. The SAB advised EPA to consider N-nitrosamines as a group because of their similar toxicities and likelihood to occur together. One commenter expressed concern that two N-nitrosamines: N-nitroso-di-n-butylamine and N-nitroso-methylethylamine (which are included in UCMR 2) are not listed on the draft CCL 3. Several commenters expressed concern about the overall lack of DBPs on the draft CCL 3, citing their assumed presence as a result of drinking water disinfection. One commenter requested that the remaining halo-acetic acids not covered under the current DBP regulation (bromochloroacetic acid, dibromochloroacetic acid, bromodichloroacetic acid, and tribromoacetic acid) be added to the CCL 3. Several commenters mentioned groups of chemicals, such as halo-nitriles, halo-aldehydes, halo-nitromethanes, and other nitrogenous DBPs that they believed should be included on the CCL 3.

EPA Response: The CCL 3 process took into consideration the potential formation of DBPs in disinfected and treated drinking water. Potential DBPs with available health information were added to the CCL Chemical Universe even if they did not have measured occurrence data. This is because DBPs were considered to have ``default'' occurrence for the Universe since they are potentially formed in treated drinking water supplies (USEPA 2009a). In screening chemicals from the Universe to the Preliminary CCL (PCCL), EPA added DBPs to the PCCL that lacked quantitative occurrence data but were in the Toxicity Category 1 or Toxicity Category 2 groupings because of their potential presence in disinfected and treated drinking water (USEPA 2009b). EPA attempted to identify additional health effects and occurrence data for these DBPs to determine whether to include them on the CCL 3. Quantitative occurrence data were needed in order for DBPs to be evaluated for inclusion on the CCL 3. The Agency sought comment on the approach and the data used to select contaminants in the draft CCL 3.

EPA evaluated 85 chemicals in the groups of potential DBPs mentioned by the commenters, but the available data showed that most DBPs had limited or low levels of occurrence, or lacked health effects data. For example, the two UCMR 2 nitrosamines that are not on CCL 3 lacked sufficient occurrence information for inclusion on the list. There is additional discussion of the interrelationship between the CCL and UCMR in Section III.D of this FR notice.

Several commenters mentioned chemicals that were not included in the Universe data compilation, but they did not submit the health effects and/or occurrence information that would be necessary to support their inclusion on the final CCL 3.

In addition to the data used by the Agency in the draft CCL 3, such as the May 14, 1996, DBP Information Collection Rule (ICR) (61 FR 24354, USEPA 1996), EPA used drinking water occurrence data from the State of California Department of Health Services ICR and studies cited by commenters (Krasner et al., 2006) to evaluate the occurrence of DBPs. The Agency also sought and identified new health effects information. A study EPA requested during the development of the Stage 2 Rule on chlorate was completed (NTP 2008) and occurrence information on bromochloromethane (Halon 1011) was also identified. EPA concluded that chlorate and bromochloromethane are known or anticipated to occur in PWSs and may require regulation. Therefore the Agency added these two contaminants to the CCL 3.

EPA continues to participate in research concerning the toxicity, occurrence, exposure, and treatment of unregulated disinfection byproducts. This research will inform the development of future CCLs and the regulatory determination process, as well as future reviews of existing drinking water regulations.

C. Microbial Contaminants

EPA is including twelve pathogens on the final CCL 3, one more than the eleven pathogens on the draft CCL 3. The Agency is adding Adenovirus, Enterovirus, and Mycobacterium avium to the final CCL 3, and is removing Vibrio cholerae and Entamoeba histolytica from the final CCL 3.

The protocol EPA used to select the microbial contaminants for the CCL 3 is described in detail in the draft CCL 3, notice (73 FR 9631, 9644; USEPA, 2008a). Except for a minor change discussed in Section III.C.1, the protocol for selecting pathogens for the final CCL 3 remains the same as the protocol for the draft CCL 3; EPA selected the pathogens based on their health effects and occurrence in drinking water.

Based on public comment, EPA modified the waterborne disease outbreak (WBDO) protocol. The Agency removed older, Centers for Disease Control (CDC) reported WBDOs (prior to 1990) from the occurrence analysis to account for the impact of drinking water regulations that

have been implemented since 1990. This change in the WBDO protocol resulted in the exclusion of Vibrio cholerae and Entamoeba hystolitica from the final CCL 3 and the inclusion of Adenovirus and Enterovirus to the final CCL 3.

Based on public comment, EPA reviewed the health score for Mycobacterium avium. After re-evaluating the health effects information, EPA determined that a higher health effects score was appropriate for this pathogen.

1. Using the CDC WBDO's as a Scoring Criterion

A commenter recommended the use of outbreak data tied to the implementation of the SDWA and its amendments (i.e., after 1990). The commenter, as well as SAB, also encouraged EPA to develop its own occurrence database instead of relying on CDC reported WBDOs. A few commenters noted that, in general, the information on occurrence of pathogens in drinking water is limited, and that EPA should develop more occurrence information.

EPA Response: EPA agrees in part with this recommendation, and recognizes that after implementation of SDWA and its amendments, PWSs should have changed their practices resulting in fewer outbreaks. Therefore, early outbreaks (i.e., before 1990) may not represent the current situation and controls at PWSs operating under these regulations. EPA removed CDC WBDOs prior to 1990 from the occurrence analysis. This change resulted in the exclusion of Vibrio cholerae and Entamoeba hystolitica from the final CCL 3 because their WBDO scores were reduced due to the removal of older documented WBDOs from consideration (USEPA, 2009e).

EPA disagrees with abandoning the CDC database and continues to use the CDC documented WBDOs in the CCL 3 pathogen scoring process. CDC collects statistical data on WBDOs every year (since 1920). CDC has consistently applied a definition for WBDO as well as consistently investigated and verified epidemiological information related to illnesses. This consistency in definitions and methods allows EPA to consistently compare the WBDO data. In contrast, individual research studies on isolated outbreaks may have different methods and goals, and therefore disparate study designs, making evaluation of the results difficult from a

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national perspective. No other national database on drinking-water related illnesses exists.

EPA contributes and collaborates with CDC on the Morbidity and Mortality Weekly Report's annual surveillance summary, and is confident of the quality of the information in the report. EPA agrees with the commenter that there is a need for more information on occurrence of pathogens in drinking water; however, EPA believes that the CDC WBDO data is the best available information at this time.

2. Mycobacterium Avium

EPA received more than a dozen comments requesting that EPA re-examine the health effects score for Mycobacterium avium and to include the pathogen on the final CCL 3. Commenters pointed to the long treatment duration and the severity of the disease particularly for the elderly population. Commenters also cited the increased incidence of disease, particularly amongst the elderly.

EPA Response: EPA re-evaluated Mycobacterium avium's health effects information and increased the health effects score for one of the sensitive life stages, or populations; specifically, the elderly. The Agency agrees with commenters that the potential health effects on the elderly and the occurrence of Mycobacterium avium in drinking water supplies warrant its inclusion on the CCL 3. The health effects score was increased based on the severity and treatment duration on the elderly as described in Murray 2007 (USEPA, 2009g). Based on this information, EPA anticipates that Mycobacterium avium may occur in PWSs and require regulation. Therefore the Agency has included Mycobacterium avium on the final CCL 3.

3. Vibrio cholerae and Entamoeba hystolitica

EPA received a few comments recommending the exclusion of both Vibrio cholerae and Entamoeba hystolitica from the final CCL 3. Commenters recommended that EPA not include these pathogens because cholera and amebiasis are currently rare in the United States, even though they are still common in other countries. Also, commenters felt that current treatment practices (i.e., disinfection) will provide sufficient protection against Vibrio cholerae. However, one commenter supported keeping Vibrio cholerae because its occurrence is likely to increase and expand as climate change continues.

EPA Response: Based on public comment discussed earlier, EPA changed the WBDO protocol. The Agency removed older, CDC reported WBDOs (prior to 1990) from the occurrence analysis to account for recently implemented regulations (e.g., Surface Water Treatment Rule, Total Coliform Rule). This change in the WBDO protocol resulted in the reduction of the WBDO score for both Vibrio cholerae and Entamoeba hystolitica, and their exclusion from the final CCL 3. However, EPA did not consider treatment as one of the parameters for inclusion or exclusion of a pathogen onto the CCL 3 because many public water systems are not required to treat, as discussed in the draft CCL 3 FR notice (73 FR 9648; USEPA, 2008a). Further, EPA acknowledges the potential impact climate change may have on water quality; however, at this time EPA does not have enough information to assess the risk.

D. Other Comments

1. Data Sources for Contaminant Candidate Lists

Several commenters noted that EPA used occurrence data sources that could only identify a contaminant's potential to occur in PWSs. These included data from the TRI, National Center for Food and Agricultural Policy (NCFAP), modeled occurrence data for pesticides, and chemical

production data. While some commenters urged EPA to rely on this type of data, other commenters suggested that production data should only be used to identify chemicals for initial consideration (i.e., inclusion on the CCL 3 Universe) and more rigorous data should be used to screen or include chemicals on the CCL.

EPA response: The Agency used data from the TRI and modeled occurrence data for pesticides developed by the Office of Pesticide Programs (OPP) to support the inclusion of contaminants on the CCL 3, but EPA did not rely on the Chemical Update System (CUS) and the Inventory Update Rule (IUR) data (i.e., production volume).

In developing the CCL, SDWA requires that EPA consider unregulated contaminants that are known or anticipated to occur in PWSs and may require regulation. EPA believes that the TRI and the OPP data are sufficient for it to anticipate that a contaminant that is released into the environment may occur in a PWS. The Agency coupled these data with health effects information to evaluate contaminants. The NRC (2001) and NDWAC (2004) reports included specific recommendations on data and information that the Agency could use to anticipate the occurrence of contaminants in PWSs. Both of these panels cited the importance of identifying contaminants that did not yet have occurrence information indicating detections in source waters or drinking water. NDWAC recognized that the Agency could apply a hierarchy to the use of detected occurrence over potential occurrence, but also noted that the use of these types of data enables the Agency to be proactive in protecting public health.

EPA also conducted several reviews of the data sources and information used to develop the CCL 3. EPA sought contaminants for the Agency to consider in its FR notice, seeking nominations (71 FR 65573, USEPA 2006b). The Agency published a list of data sources including the TRI, CUSIUR, and NCPAP. Many of the nominated contaminants are chemicals included solely on those lists. The Agency also conducted several expert panels to review the types of data and information it used to evaluate contaminants. While these panels provided recommendation to qualify these types of data, which the Agency implemented, the panels did not recommend excluding these data sources. Based on this input from stakeholders and expert reviews, the Agency included 51 contaminants with TRI and/or modeled occurrence data for pesticides to support inclusion on the CCL 3 because EPA anticipates that these contaminants may occur in PWSs and may require regulation.

2. Contaminant Candidate List and Unregulated Contaminant Monitoring Regulation

Several commenters requested clarification on the interrelationship between the UCMR and the CCL. Commenters wanted to know whether the CCL draws from chemicals on the UCMR, or the UCMR draws from chemicals on the CCL to develop the respective lists. One commenter encouraged EPA to ``improve correlation between the CCL and the UCMR.''

EPA response: The 1996 amendments to SDWA instituted the CCL and UCMR programs to provide information EPA needs to determine which drinking water contaminants have the greatest potential to present a meaningful opportunity to reduce health risk through a NPWDR. The CCL is the primary mechanism for the identification of contaminants that may require regulation, while UCMR provides EPA with the data necessary to determine if a contaminant occurs at a frequency and at levels of public health concern. The CCL and UCMR are parts

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of the risk management process, and they support and inform each other.

The UCMR sampling program was designed to consider the technical difficulty and expense of analyzing up to 30 contaminants as well as their potential to occur in treated drinking water at levels of public health concern. The UCMR approach includes three different sampling design options, with the determination of the appropriate option for each contaminant based primarily on the difficulty and expense of the analytical methods used, and the associated issue of laboratory capacity. The sampling designs described below are discussed in detail in the proposed UCMR 2 (70 FR 49094; USEPA 2005). Assessment monitoring is the most extensive, and is used when the technology of the analytical methods is in common use in drinking water laboratories. Screening monitoring relies more on identifying a statistically valid representation of the universe of PWSs in order to reduce the number of utilities impacted by the monitoring. It is designed to assure the necessary laboratory capacity in those cases where the analytical technology is more complex and/or expensive. The pre-screening monitoring option detailed in the UCMR program is based on assessing the vulnerability of selected PWSs and may be used when the analytical techniques are so complex that commercial laboratory capacity is severely limited; this option has not been exercised to date.

EPA promulgated UCMR 2 on January 4, 2007 (72 FR 367; USEPA 2007a). The UCMR program was developed in coordination with the development of the CCL. Both programs consider the adverse health effects a contaminant may pose through drinking water exposures.

Sixteen contaminants on the UCMR 2 monitoring list are also on the final CCL 3. The final CCL 3 includes acetochlor and its degradates, alachlor degradates, dimethoate, 1,3-dinitrobenzene, metolachlor and its degradates, RDX, terbufos sulfone, and four of the nitrosamines that are a part of UCMR 2. In addition to the health effects data and potential occurrence, the UCMR 2 also considers analytical method availability and cost, availability of analytical standards, and laboratory capacity to support a nationwide monitoring program in selecting contaminants.

The UCMR 2 includes nine contaminants that are not on the final CCL 3. The five polybrominated flame retardants can be measured by the same analytical method used for terbufos sulfone. The polybrominated flame retardants are listed on UCMR 2 because of concern that these have become more widespread environmental contaminants (Darnerud et al.,

2001). The polybrominated flame retardants lacked sufficient occurrence information to be listed on final CCL 3 (73 FR 9628; USEPA 2008a). This UCMR 2 monitoring data will provide information for future CCLs. Similarly, 2,4,6-trinitrotoluene (TNT) and two of the nitrosamines not on CCL 3 are also measured by an analytical method in the UCMR 2. Alachor was listed on UCMR 2 for monitoring along with its degradates to allow for the measurement of co-concurrence between the parent compound and its degradates. It was removed from consideration for CCL 3 because it is currently regulated. The Agency will use the results from UCMR 2 as a source of occurrence information during the development of CCL 4, as well as for CCL 3 regulatory determinations.

IV. Data Needs for CCL 3 Contaminants

After the listing process, the CCL 3 contaminants are evaluated further to determine if a contaminant has sufficient data to meet the regulatory determination criteria set forth in SDWA section 1412(b)(1) and previously outlined in Section I.C of this notice. If the data are sufficient, a regulatory determination may be made. EPA must make regulatory determinations on at least five CCL 3 contaminants every five years.

The SAB and other commenters have indicated that the CCL 3 may be too large and recommended additional priority ranking of contaminants to focus resources. EPA acknowledges that many contaminants on the CCL 3 have substantial data and information needs that will have to be met before the Agency can make a regulatory determination in accordance with SDWA 1412 (b)(1)(A). Currently, several of the CCL 3 contaminants have data or information needs. These are described in the following section.

A. Chemical Contaminants

EPA assessed the data and information gathered on the CCL 3 chemical contaminants and generated a table (Exhibit 2) to help identify data/information needs for further regulatory determination evaluations. In general, EPA characterized each chemical contaminant included on the final CCL 3 for their data needs in three categories; health effects, occurrence, and analytical methods. The data needs were characterized as no data needs, specific data needs, or substantial data needs. The health effects, occurrence, and analytical methods data/information used to classify data needs are featured in the supporting documentation and in the ``Final CCL 3 Contaminant Information Sheets'' in the docket (USEPA, 2009e). Blank cells in Exhibit 2 generally indicate that there is no data need for that contaminant in that category. Cells with a ``2'' indicate that the data are under evaluation by EPA and the contaminant has a specific need. Cells with a ``1'' indicate that there is a data need for that contaminant, and that need may be substantial. The following sections describe the types of data or information gaps outlined in Exhibit 2 and provide examples.

1. Health Effects

EPA categorized the health effects data needs for Exhibit 2 using the following set of assumptions. Any chemical that had an existing EPA quantitative assessment (Reference Dose (RfD) or Cancer Slope Factor (CSF)) for the oral route of exposure is identified on the table as not having a health effect data need based on the assumption that EPA will be able to use the existing data along with more recent studies to develop a quantitative health effects assessment. These chemicals are designated with a blank cell in the health effects column. There may well be opportunities to further elucidate mode of action or to reduce uncertainty for the analyses associated with these contaminants, but such data would not be necessary to develop an assessment. Similarly, any chemical that has an assessment being developed by EPA is not identified on the table as having a data need, and is represented by a blank cell because that work is currently ongoing.

The next category of chemicals with health effects data needs have quantitative assessments conducted by other government agencies such as WHO, and Agency for Toxic Substances and Disease Registry. These chemicals are designated with a ``2'' in the health effects column on the table, signifying that an EPA assessment is needed and sufficient information may be available to initiate the assessment. These data apply to oral exposures that can be used to support a quantitative assessment of risk; however, EPA has not yet thoroughly evaluated the existing risk assessment to determine if it and the supporting data meet EPA data quality guidelines and is compatible with EPA risk assessment policies. For example, at times there may be an RfD-equivalent for oral exposures based on inhalation data (i.e., California EPA), which is an approach EPA does not typically use unless there is a physiologically-based

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pharmacokinetic model that supports the cross route extrapolation. The Agency is currently evaluating whether this type of model information and results are available. For a few chemicals marked with the ``2'' designation in the health effects column, there is no assessment by another agency, but EPA identified a critical study suitable for quantification of likely cancer risk during the development of the CCL 3 process. In these cases, an assessment is needed based on the data identified.

The final group of chemicals on Exhibit 2 is designated with a ``1'' in the health effects column of the table. For these chemicals, the CCL process used data from a small group of studies identified through the Registry of Toxic Effects for Chemical Substances (RTECS), a provisional Risk Assessment Information System Health Effects assessment, and/or a limited literature search for the health effects

component of the CCL 3 evaluation. These chemicals have the most substantial health effects data gaps and information collection needs.

2. Occurrence

EPA categorized the occurrence data needs for Exhibit 2, after evaluating data availability from UCMR 1 and 2, Unregulated Contaminant Monitoring Round 1 and 2 (UCM R1/2), National Inorganic Radiological Survey (NIRS), NAWQA, TRI, NCFAP, and other supplemental data sources.

Chemicals with finished water occurrence data from UCMR 1, UCMR 2, or UCM R1/2 were generally characterized as not having an occurrence data gap because these data are considered nationally representative; therefore, they have sufficient occurrence data to be further evaluated if it is consistent with the health effects information. These chemicals are designated with a blank cell in the occurrence column of Exhibit 2.

Contaminants from data sources with limited PWS monitoring data (i.e., ground water systems only), spatial or geographical data limitations, and/or a small sample size were identified as having a data gap because additional monitoring data may be needed for further evaluation as part of the regulatory determinations process. These were given a ``2'' in the occurrence column of Exhibit 2, and examples of data sources with this type of data include the UCMR screening survey, NIRS, DBP ICR data, and others.

Chemicals from occurrence data sources with ambient monitoring data, environmental release data, or modeled data were given a ``1'' in the occurrence column because there are substantial additional data needs to be considered and evaluated as part of the regulatory determinations process. Examples of data sources with this type of data include USGS's NAWQA, National Reconnaissance of Emerging Contaminants, TRI, and others with similar data.

3. Analytical Methods

To conduct nationally representative drinking water occurrence studies, and support a regulatory determination, EPA must have an analytical method that is suitable for the drinking water matrix and is robust enough to be used by many laboratories to conduct national studies and/or compliance monitoring. The analytical method should be sensitive enough to allow for quantitation of the chemical at a concentration below the HRL, or as close to the HRL as practically feasible.

EPA categorized available analytical methods for the CCL chemicals to define the data needs presented in Exhibit 2. EPA reviewed the methods to assess if they had been developed for drinking water and then evaluated estimated reporting levels for the chemical by that method. When available, method-specific reporting levels, lowest concentration minimum reporting levels, and promulgated minimum reporting levels were also used to measure method sensitivity. When this was not possible, EPA used a value of five times the method detection limit or detection limit; this approach has been used in the past.

Chemicals with blanks in the analytical methods column of Exhibit 2 are generally those chemicals for which EPA has an established drinking water method, with estimated reporting levels that are adequate for analysis relative to the HRL. However, in some cases, a blank may also signify that EPA is currently in the process of developing a method that it believes will have adequate reporting levels. Chemicals with a ``2'' in the analytical method column of Exhibit 2 have a drinking water method that is under development by EPA. EPA has evaluated the available methods for each of these chemicals and determined that the reporting level does not allow for quantitation of the chemical at a concentration below the HRL or as close to the HRL as practical. Therefore, EPA has designated that these methods require further development to increase their sensitivity and lower the estimated method reporting level or method detection level. Those chemicals listed as a ``1'' in the methods column do not have an established method for drinking water or a method that is suitable for a national drinking water occurrence study.

Key to Exhibit 2

The following key is a reference guide to reading Exhibit 2 and interpreting the data presented in the table.

Note: Categories are based on the extent of available data for each contaminant.

1. Health Effects:

1 = Substantial data needs (RTECS, RAISHE, and other small study data); 2 = Assessments exist from other government agencies. Sufficient information may exist to conduct an EPA assessment; Blank = Existing or ongoing EPA quantitative assessment (e.g., IRIS)

2. Occurrence:

1 = No comprehensive drinking water occurrence data (e.g., often only environmental release data such as TRI, or ambient water data), 2 = Limited available drinking water monitoring data; however, data may be limited by scope and sample size (e.g., UCMR 1 Screening Survey, NIRS); Blank = EPA has more extensive national drinking water monitoring data (e.g., UCMR, UCM R1/2)

3. Analytical Method:

1 = No analytical method suitable for national drinking water occurrence studies; 2 = Drinking water method in development or being re-evaluated for comparison with new health effects information; Blank = EPA has a method or is in the process of developing a method that could be used for national drinking water monitoring.

Exhibit 2. Regulatory Determination Data/Information Needs for CCL 3 Chemicals

CASRN	Common name	Health effects	Occurrence	Analytical methods

630206	1,1,1,2-Tetrachloroethane			
75343	1,1-Dichloroethane	1		2
96184	1,2,3-Trichloropropane			
106990	1,3-Butadiene	1	1	2
99650	1,3-Dinitrobenzene			

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123911	1,4-Dioxane		1	
71363	1-Butanol		1	1
109864	2-Methoxyethanol	2	1	1
107186	2-Propen-1-ol		1	1
16655826	3-Hydroxycarbofuran	2		
101779	4,4'-Methylenedianiline	2	1	1
30560191	Acephate		1	2
75070	Acetaldehyde		2	
60355	Acetamide	2	1	1
34256821	Acetochlor			
187022113	Acetochlor ethanesulfonic acid (ESA).	2		
184992444	Acetochlor oxanilic acid (OA)	2		
107028	Acrolein		1	1
142363539	Alachlor ethanesulfonic acid (ESA).	2		
171262172	Alachlor oxanilic acid (OA)	2		
319846	alpha-Hexachlorocyclohexane		1	2
64285069	Anatoxin-a		1	2
62533	Aniline	2	1	1
741582	Bensulide		1	1
100447	Benzyl chloride		1	1
25013165	Butylated hydroxyanisole	2	1	2
133062	Captan		1	2
14866683	Chlorate		2	
74873	Chloromethane (Methyl chloride).	2		
110429624	Clethodim		1	2
7440484	Cobalt		2	
80159	Cumene hydroperoxide	1	1	1
143545908	Cylindrospermopsin		1	2
141662	Dicrotophos		1	2
55290647	Dimethipin		1	2
60515	Dimethoate			
298044	Disulfoton		2	
330541	Diuron		2	
114078	Erythromycin	2	1	1
13194484	Ethoprop		1	2
107211	Ethylene glycol		1	1
75218	Ethylene oxide	1	1	1
96457	Ethylene thiourea		1	2
22224926	Fenamiphos		1	2
50000	Formaldehyde		2	
7440564	Germanium	1	2	2
74975	Halon 1011 (bromochloromethane).	1		2
75456	HCFC-22	1	1	2
110543	Hexane	1	1	1
302012	Hydrazine		1	1
10265926	Methamidophos		1	2
67561	Methanol		1	1
74839	Methyl bromide (Bromomethane)			
1634044	Methyl tert-butyl ether			
51218452	Metolachlor			
171118095	Metolachlor ethanesulfonic acid (ESA).	2		
152019733	Metolachlor oxanilic acid (OA)	2		
101043372	Microcystin-LR		1	2
2212671	Molinate			
7439987	Molybdenum		2	
98953	Nitrobenzene			
55630	Nitroglycerin	2	1	1
872504	N-Methyl-2-pyrrolidone	2	1	1
55185	N-Nitrosodiethylamine (NDEA)			
62759	N-nitrosodimethylamine (NDMA)			
621647	N-Nitroso-di-n-propylamine (NDPA).			
86306	N-Nitrosodiphenylamine		1	1
930552	N-nitrosopyrrolidine (NPYR)			
103651	n-Propylbenzene	1		2
95534	o-Toluidine	2	1	2
75569	Oxirane, methyl-		1	1
301122	Oxydemeton-methyl		1	2
42874033	Oxyfluorfen		1	2
14797730	Perchlorate			
1763231	Perfluorooctane sulfonic acid (PFOS).	2	1	
335671	Perfluorooctanoic acid (PFOA)	2	1	

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52645531	Permethrin		1	2
41198087	Profenofos		1	2
91225	Quinoline		1	2
121824	RDX			
135988	sec-Butylbenzene	1		2
7440246	Strontium		2	

107534963	Tebuconazole		1	2
112410238	Tebufenozide		1	1
13494809	Tellurium	1	2	2
13071799	Terbufos		2	
56070167	Terbufos sulfone	2		
59669260	Thiodicarb		1	2
23564058	Thiophanate-methyl		1	2
26471625	Toluene diisocyanate	2	1	1
78488	Tribufos		1	2
121448	Triethylamine	1	1	1
76879	Triphenyltin hydroxide (TPTH)		1	1
51796	Urethane	2	1	1
7440622	Vanadium	2	2	
50471448	Vinclozolin		1	2
137304	Ziram		1	1
57910	17alpha-estradiol	1	1	1
517099	Equilenin	1	1	1
474862	Equilin	1	1	1
50282	Estradiol (17-beta estradiol)	2	1	
50271	Estriol	1	1	2
53167	Estrone	1	1	2
57636	Ethinyl Estradiol (17-alpha ethynyl estradiol)	1	1	2
72333	Mestranol	1	1	1
68224	Norethindrone (19-Norethisterone)	1	1	1

B. Microbial Contaminants

EPA intends to look at the over-arching risk posed by pathogens in drinking water. To this end, EPA is planning to evaluate the CCL 3 pathogens in the context of the existing drinking water regulatory program to determine the sufficiency of the barriers that help to prevent exposure.

Commenters noted a need for information on the national occurrence of pathogens in drinking water. Development of such data would aid EPA in determining the likelihood that pathogens will occur in public water systems and thus clarify the extent to which they represent a significant public health threat. One aspect of determining the occurrence of any contaminant is the availability of a method to monitor for that contaminant. While there are many methods for monitoring the CCL 3 pathogens available from scientific papers and consensus organizations, not all of them may be appropriate for use in drinking water or for a national monitoring effort. Of the CCL 3 pathogens, only enterovirus has an EPA-approved method for drinking water. EPA is working on developing and approving drinking water methods for some of the pathogens, and is considering the need for additional occurrence information. In addition, EPA is evaluating the suitability of current microbial indicators as well as the reliability of other indicators for CCL pathogens.

Furthermore, the Agency is actively working with stakeholders on additional information on distribution system issues needed to inform national risk management actions such as regulations and guidance. Based on currently available information, EPA and other stakeholders have identified the following issues as being the most relevant to protecting public health and maintaining the integrity of drinking water distribution systems for future consideration: cross connections and backflow of contaminated water; storage facility design, operation, or maintenance; main installation, repair or rehabilitation practices; intrusion due to pressure conditions; significance and control of biofilm and microbial growth; nitrification issues; and accumulation and release of contaminants from distribution system scales and sediments. These issues may be applicable to chemicals as well as microbial contaminants.

V. Next Steps/Future Candidate Contaminant Lists

The CCL process is a critical input to shaping the future direction of the drinking water program. The Agency will continue to gather information and evaluate contaminants on the CCL 3 to make a regulatory determination for at least five contaminants by 2013. The Agency will also continue to refine the CCL process and gather more data to identify contaminants for the fourth CCL by 2014. EPA will also continue to work to prioritize contaminants on the CCL 3, both for regulatory determination and for additional research and data collection.

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MIXING in Inland and Coastal Waters

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in writing Eq. (6.17) we are assuming that the wind stress is transmitted directly to the upper layers of the water and that none of the stress is lost by surface wave radiation and subsequent dissipation at the lake boundaries.

As the water becomes very shallow, less than 2.5 m, the longer waves will not be able to develop fully and the water surface will remain smoother. Hicks *et al.* (1974) showed that for such conditions C_D remains close to 1.0×10^{-3} for all wind speeds.

The stability of the air column also has a strong influence on the value of C_D. Warm winds blowing over a cold water body are stabilized by the temperature difference which in turn results in less friction. The value of C_D can be reduced by as much as 40% for stable conditions and increased equally by up to 40% for very unstable air flows. Hicks (1975) suggested an iterative procedure designed to correct for the effects of stability, without requiring sensors at more than one elevation.

McBean and Paterson (1975) and Bean *et al.* (1975) give data for the variation of surface stresses over Lake Ontario. Great variability was observed both spatially and temporally, many times greater than the variation introduced by the changes in C_D due to stability, wind speed, or lake depth.

Thus from a practical point of view, since the normal lake site usually has only a remotely located land based meteorological station, the only consistent action is to assume C_D equal to a constant. For a station with a wind sensor located 10 m above the ground or above the lake's surface, an average value of 1.3×10^{-3} is appropriate for most engineering calculations.

The rate of working W by the wind on the water surface is given by

$$W = \tau u_w, \tag{6.18}$$

where u_w is the drift velocity of the water near the surface and the stress τ is given by Eq. (6.17). The drift velocity has rarely been measured directly, but as in boundary layer flow u_w may be expected to scale with shear velocity $u^* = (\tau/\rho_0)^{1/2}$. How much of the work given by Eq. (6.18), appears as kinetic and potential energy of surface waves, as kinetic energy of a mean drift current, or as kinetic energy of eddy motions below the wave zone, is still poorly understood. We shall return briefly to this matter in Section 6.3.2, but the reader may also wish to consult the book by Phillips (1977) for a more penetrating discussion of this subject.

6.2.2 Surface Thermal Energy Transfer

Once again specification of the thermal transfer of heat by evaporation, conduction, and radiation is complicated by the great variability of meterological conditions encountered and by the usually poor availability of reliable meteorological data. An excellent summary of the formulas pertaining to transfers from a lake surface is given in the TVA publication (1972).

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In general the heat flux due to conduction, called the sensible heat transfer H_s, and the loss of heat due to evaporation H_L, may be written in a form similar to that for the surface stress.

In particular, the dominant influences are incorporated if we write

$$H_s = C_s \rho_A C_p U(T_0 - T) \tag{6.19}$$

and

$$H_L = C_L \rho_A L_W U(Q_0 - Q), \tag{6.20}$$

where C_s and C_L are coefficients incorporating the same variability influences as described for the wind stress, C_p is the specific heat of air, T_0 the water surface temperature, T the temperature at 10 m, L_W the latent heat of evaporation, Q_0 the saturation specific humidity (kilograms of water moister/kilograms of air–water moisture) at T_0, and Q the specific humidity at 10 m.

For neutrally stable boundary layers Hicks (1972) recommends $C_s \approx C_L = 1.45 \times 10^{-3}$. Friehe and Schmitt (1976) collated all available ocean and lake data and determined an average value of 1.4×10^{-3} for C_s and 1.3×10^{-3} for C_L, but it should be noted that the stability (see Hicks, 1975) has a large effect on these values. Normal meteorological changes over a lake could easily cause variations from 0.8×10^{-3} for very stable conditions to 1.6×10^{-3} at very unstable conditions. The TVA report (1972) recommends values of $C_s \approx C_L = 1.5 \times 10^{-3}$ for estimates from remote land based meteorological stations. As a rule of thumb, it is always better to use a value verified for local meteorological and atmospheric conditions rather than ones which are perhaps more general, but which have not been verified locally.

The long wave radiation from the water vapor in the sky is given by TVA (1972)

$$H_1 = -5.18 \times 10^{-13}(1 + 0.17C^2)(273 + T)^6 \tag{6.21}$$

and the back radiation from the water surface

$$H_2 = 5.23 \times 10^{-8}(273 + T_0)^4, \tag{6.22}$$

where C is the fraction of the sky covered by cloud.

These formulas are based on average values of reflectance and the reader is referred to the TVA report for further details.

The direct short wave radiation H_{sw} incident at the lake's surface may again be estimated from a knowledge of the radiation outside the atmosphere and the conditions of the atmosphere (see TVA, 1972), but since radiometers are relatively cheap and reliable it is better to measure this flux directly.

Example 6.1. Table 6.1 gives values of meteorological variables recorded on 9 February (day 76040) 1976 near the Wellington Reservoir, Western Australia. Use these values to compute the instantaneous heat fluxes at the water surface. Assume that the sky was cloudless for the whole period, the values

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TABLE 6.1
Meteorological Variables Recorded on February 9, 1976, near the Wellington Reservoir, Western Australia

	Given Quantities						Derived Quantities		
Time (h)	Short wave, H_{sw} (W/m^2)	Air temp. at 10 m T (°C)	Water temp. T_0 (°C)	Vapor conc. at 10 m, $Q \times 10^2$	Vapor conc. (saturation), $Q_0 \times 10^2$	Wind speed at 10 m, U (m/sec)	H_L (W/m^2)	H_S (W/m^2)	$H_1 + H_2$ (W/m^2)
1.0	0	17.0	24.4	1.0	1.9	0.2	7.6	2.6	101
2.0	0	17.0	24.5	1.0	1.9	0.5	19.1	6.6	101
3.0	0	16.9	24.4	1.1	1.9	0.1	3.4	1.3	101
4.0	0	16.8	24.4	1.0	1.9	0.4	15.3	5.3	101
5.0	0	16.4	24.4	1.0	1.9	0.8	30.5	11.2	105
6.0	0	17.0	24.3	1.1	1.9	0.3	10.2	3.8	101
7.0	−18	18.6	24.3	1.0	1.9	0.4	15.3	4.0	90
8.0	−230	23.0	24.3	0.9	1.9	0.1	4.2	0.3	60
9.0	−444	28.8	24.3	0.7	1.9	0.9	45.8	−7.1	17
10.0	−628	29.3	24.4	0.7	1.9	0.2	10.2	−1.7	14
11.0	−769	29.8	24.4	0.7	1.9	0.1	5.1	−0.9	10
12.0	−859	31.8	24.4	0.7	1.9	0.8	40.7	−10.4	−6
13.0	−889	34.6	24.5	0.7	1.9	1.0	50.8	−17.7	−30
14.0	−863	35.0	24.7	0.8	1.9	0.5	23.3	−9.0	−31
15.0	−720	34.2	24.9	0.9	1.9	3.2	135.6	−52.2	−23
16.0	−650	33.4	25.1	0.9	1.9	2.3	97.5	−33.5	−15
17.0	−403	32.2	25.2	0.8	1.9	4.1	191.2	−50.3	−6
18.0	−180	30.3	25.2	1.0	1.9	3.4	129.2	−30.4	10
19.0	−23	28.6	25.1	0.9	1.9	3.2	135.6	−19.6	23
20.0	0	25.0	24.6	1.0	1.9	2.8	106.8	−2.0	47
21.0	0	23.9	24.5	0.9	1.9	1.4	59.3	1.5	55
22.0	0	20.2	24.5	1.0	1.9	1.8	68.7	13.6	81
23.0	0	18.1	24.5	1.0	1.9	1.1	37.3	12.4	95
24.0	0	18.0	24.5	1.0	1.9	0.8	27.1	9.1	95

of the coefficients $C_s = C_L = 1.45 \times 10^{-3}$, $\rho_A = 1.20$ kg/m^3, $L = 2.4 \times 10^6$ J/kg, and $C_p = 1012$ J/kg °C.

Solution. See Table 6.1 and Fig. 6.6. ■

The heat fluxes calculated in Example 6.1 are all immediately absorbed by the water at the surface, except the short wave radiation which is able to penetrate to appreciable depths. Depending on the color and clarity of the water some of the incident radiation will be felt at depths as far as 10–15 m below the surface. There are again numerous empirical formulas which correlate the light attenuation with the turbidity of the water. Generally a relationship of the form

$$H_z/H_{sw} = e^{-\eta(H-z)} \tag{6.23}$$

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is found to fit the data, where H_z is the radiation remaining at a height z and η is a coefficient of extinction. The TVA (1972) report summarizes available data and it is seen that η ranges from 0.2 m^{-1} for very clear lakes to 4.0 m^{-1} for turbid eutrophied lakes. The actual value obviously depends greatly on the biological growth in the lake. The exact extinction coefficient is not important for mixing models in the cooling phase since wind stirring and convective overturn at night usually mix the heat gained from the sun to a depth greater than the penetration depth. However, on the heating part of the cycle the value of η controls the gain in stability of the upper layers and thus strongly influences the depth of the thermocline.

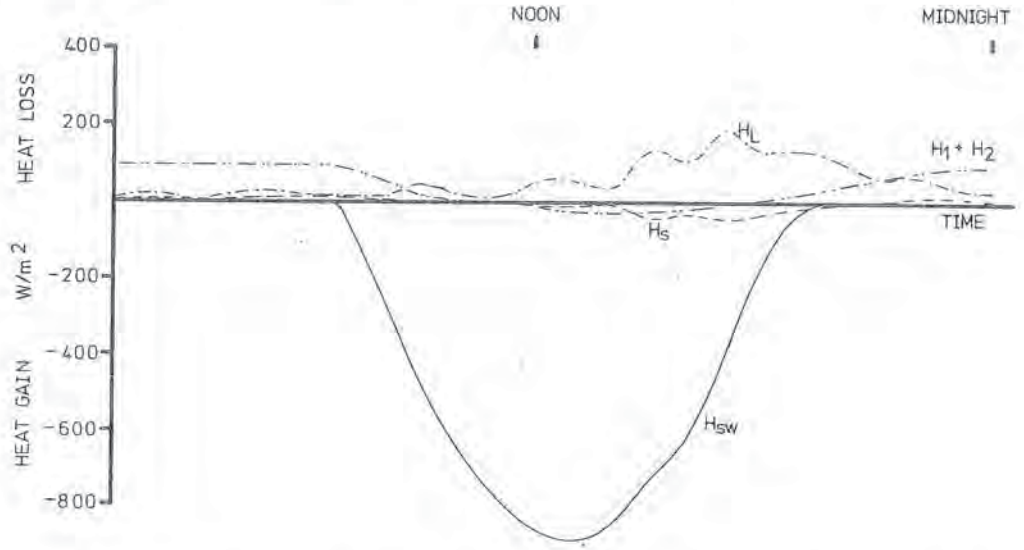


Figure 6.6 Graph showing shortwave radiation H_{sw}; net longwave radiation H_1 and H_2; sensible heat exchange H_s and the latent heat transfer H_L for February 9, 1976, at the Wellington Reservoir.

Example 6.2. Given the incident energies of the previous examples, calculate the change in temperature in the top 10 m of the water column. Use one meter intervals in your calculation and assume that $\eta = 0.35\ m^{-1}$.

Solution. The long wave radiation, sensible heat transfer, and the evaporative heat losses all effect only the upper 1 m. The short wave radiation will be distributed according to Eq. (6.23). Measuring from the surface down the net heat input over the whole day may be tabulated as shown in Table 6.2.

This calculation indicates that cooling in the evening leads to cold surface waters overlying warmer water. Such a situation is unstable and we might expect to see rather vigorous "convective" stirring or mixing as evening approaches. Such mixing occurs very often and is responsible for stirring the heat gained during the day into the epilimnion. ■

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TABLE 6.2
Absorption of Thermal Energy with Depth

Depth ($H - z$) (m)	Short wave energy at z (J/m^2) $\times 10^{-7}$	Net short wave energy absorbed in slab $z - 1$ to z (J/m^2) $\times 10^{-7}$	Surface transfers (J/m^2) $\times 10^{-7}$	Temp. change[a] (°C)
0	−2.4			
1	−1.7	−0.7	0.8	−0.3
2	−1.2	−0.5		+1.2
3	−0.8	−0.4		+0.9
4	−0.6	−0.2		+0.5
5	−0.4	−0.2		+0.5
6	−0.3	−0.1		+0.3
7	−0.2	−0.1		+0.3
8	−0.15	−0.05		+0.1
9	−0.10	−0.05		+0.1
10	−0.007	−0.03		+0.07

[a] This column shows the corresponding temperature changes in the water column induced by the energy absorption.

6.2.3 Inflow Energy Available for Mixing

A stream enters a reservoir with a finite velocity and is often cooler than the resident water in the reservoir which has been warmed by the sun. Thus apart from bringing in a mass of water into the reservoir, the stream also introduces kinetic and potential energy.

The flux of kinetic energy K_1 introduced is given by the integral

$$K_1 = \int_A \frac{1}{2} \rho_1 u^3 \, dA, \tag{6.24}$$

where A is the cross-sectional area of the entering river at a sufficient distance upstream to be away from the influence of the reservoir itself, ρ_1 the density of the stream water, and u the velocity of the water.

The introduction of potential energy from a stream is most conveniently illustrated by considering a very much simplified model of a reservoir inflow. Figure 6.7 shows a reservoir with a length of river equal to say one day's inflow. Let us assume that the reservoir water has a constant density $\rho_0 < \rho_1$. The energy due to buoyancy differences released and possibly available for mixing may be estimated by calculating the decrease in mean potential energy as the river water flows to the bottom exchanging without mixing its place with reservoir water (Fig. 6.7).

The potential energy P_i of a system before the inflow has taken place is given by

$$P_i = \rho_0 V_0 g \bar{z}_0 + \rho_1 V_1 g \bar{z}_1, \tag{6.25}$$

Sacramento-San Joaquin Delta

The sinking heart of the state



S.E. Ingebritsen
U.S. Geological Survey, Menlo Park, California

Marti E. Ikehara
National Geodetic Survey, Sacramento, California

The Sacramento-San Joaquin Delta of California was once a great tidal freshwater marsh. It is blanketed by peat and peaty alluvium deposited where streams originating in the Sierra Nevada, Coast Ranges, and South Cascade Range enter San Francisco Bay.

In the late 1800s levees were built along the stream channels and the land thus protected from flooding was drained, cleared, and planted. Although the Delta is now an exceptionally rich agricultural area (over $500 million crop value as of 1993), its unique value is as a source of freshwater for the rest of the State. It is the heart of a massive north-to-south water-delivery system. Much of this water is pumped southward for use in the San Joaquin Valley and elsewhere in central and southern California.

The leveed tracts and islands help to protect water-export facilities in the southern Delta from saltwater intrusion by displacing water and maintaining favorable freshwater gradients. However, ongoing subsidence behind the levees increases stresses on the levee system, making it less stable, and thus threatens to degrade water quality in the massive north-to-south water-transfer system. Most subsidence in the Delta is caused by oxidation of organic carbon in peat soils.

THE DELTA MARSHES TEEMED WITH WILDLIFE

When Spanish explorers first viewed the Delta from Mount Diablo in 1772, the Sacramento and San Joaquin Rivers were in flood, and they mistook it for a great inland sea. In fact, the prehistoric Delta consisted largely of "tule" (bulrush) and reed marshes that were periodically submerged, with narrow bands of riparian forest on the natural levees along major stream channels. Exceptionally abundant fish and game supported a large


(The Nature Conservancy)

Native American population. When the Spanish first set foot in the Delta, they found the deer and tule elk trails to be so broad and extensive that they first supposed that the area was occupied by cattle. Similarly, American soldiers exploring the Delta in the 1840s found waterfowl to be so abundant and tame that they were mistaken for domestic fowl. The Native Americans were also able to harvest abundant local shellfish and the salmon that migrate through the Delta en route to spawning grounds in streams of the Sierra Nevada and southern Cascades.

The tule marshes of the Delta once teemed with migratory birds and fish.



(The Nature Conservancy)

Trappers from the Hudson Bay Company and elsewhere visited the Delta periodically between 1827 and 1849, drawn by the initially abundant beaver and river otter. By the beginning of the California Gold Rush in 1849, the Native American population of the Delta had been nearly destroyed by intermittent warfare with the Spanish and Mexicans and great epidemics of malaria (?) and cholera (1833) and smallpox (1839) (Dillon, 1982). Shortly after the Gold Rush, a great effort to control and drain the Delta for agriculture began. Levees were built along the stream channels, and the land thus protected from flooding was drained, cleared, and planted. The results of such reclamation seemed miraculous—in a letter to a friend, early settler George McKinney reported cabbages weighing 53 pounds per head and potatoes 33 inches in circumference (Dillon, 1982).

Agriculture and water now dominate the landscape

Today, the Delta is largely devoted to agriculture, and includes about 55 islands or tracts that are imperfectly protected from flooding by over 1,000 miles of levees. Many of the islands in the central Delta are 10 to nearly 25 feet below sea level because of land subsidence associated with drainage for agriculture. There are also numerous smaller, unleveed islands that remain near sea level. Remnants of the natural tule marsh are found on the unleveed "channel" or "tule" islands and along sloughs and rivers. The strips of natural riparian forest have nearly vanished, except on some of the larger channel islands, but relicts can be viewed at the Nature Conservancy's Cosumnes River Preserve in the northeastern Delta.

Although the Delta is an exceptionally productive agricultural area, its unique value to the rest of the State is as a source of freshwater. The Delta receives runoff from about 40 percent of the land area of California and about 50 percent of California's total streamflow. It is the heart of a massive north-to-south water-delivery system whose giant engineered arterials transport water southward. State and Federal contracts call for export of up to 7.5 million acre-feet per year from two huge pumping stations in the southern Delta near the Clifton Court Forebay (California Department of Water Resources, 1993). About 83 percent of this water is used for agriculture and the remainder for various urban uses in central and southern California. Two-thirds of California's population (more than 20 million people) gets at least part of its drinking water from the Delta (Delta Protection Commission, 1995).

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Delta waterways pass through fertile farmland.

(California Department of Water Resources)

The Delta soils are composed of mineral sediments delivered by the rivers and of peat derived from decaying marsh vegetation. The peat began accumulating about 7,000 years ago and, prior to settlement, accumulated at a rate just sufficient to keep up with the average postglacial sea-level rise of about 0.08 inches per year (Atwater, 1980). The total thickness of peat was as large as 60 feet in the extreme western areas. The mineral sediments are more abundant on the periphery of the Delta and near the natural waterways, whereas the peat soils are thickest in former backwaters away from the natural channels—that is, towards the centers of many of the current islands.

The waterways of the entire Delta are subject to tidal action—tidal surges from San Francisco Bay are observed 5 hours later along the Cosumnes River in the eastern Delta. The position of the interface between the saline waters of the Bay and the freshwaters of the Delta depends upon the tidal cycle and the flow of freshwater through the Delta. Before major dams were built on rivers in the Delta watershed, the salinity interface migrated as far upstream as Courtland along the Sacramento River (California Department of Water Resources, 1993). Today, releases of freshwater from dams far upstream help reduce landward migration of the salinity interface during the summer months. A complicated formula agreed upon by all relevant parties attempts to maintain the two parts per thousand salinity interface near Chipps Island at the western edge of the Delta.

RECLAMATION FOR AGRICULTURE LED TO SUBSIDENCE

Sustained, large-scale agricultural development in the Delta first required levee-building to prevent frequent flooding. The levee-surrounded marshland tracts then had to be drained, cleared of tules, and tilled. The labor force for the initial levee-building effort consisted mainly of Chinese immigrants who arrived in large numbers upon completion of the Transcontinental Railroad in 1869. Between 1860 and 1880, workers using hand tools reclaimed about 140 square miles of Delta land for agriculture. The Chinese labor force was paid about a dollar per day, or at a piecework rate of 13 cents per cubic yard of material moved. After about 1880 the clamshell dredge, still in use today, became the dominant reclamation tool.



Chinese laborers built many of the early levees in the Delta.

(Overland Monthly, 1896)



A clamshell dredge operates near Sherman Island, ca. 1907.

(National Maritime Museum, San Francisco)



"Watch that first step!"

The land surface has subsided beneath a Delta house, 1950.

Levees and drainage systems were largely complete by 1930, and the Delta had taken on its current appearance, with most of its 1,150-square-mile area reclaimed for agricultural use (Thompson, 1957).

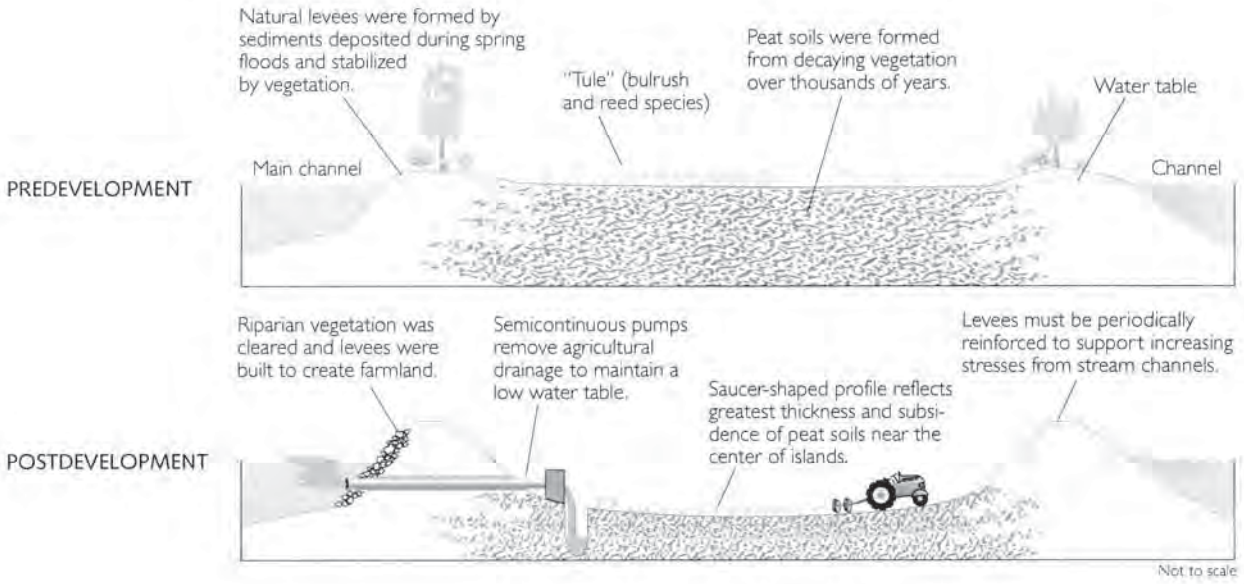
Reclamation and agriculture have led to subsidence of the land surface on the developed islands in the central and western Delta at long-term average rates of 1 to 3 inches per year (Rojstaczer and others, 1991; Rojstaczer and Deverel, 1993). Islands that were originally near sea level are now well below sea level, and large areas of many islands are now more than 15 feet below sea level. The land-surface profile of many islands is somewhat saucer-shaped, because subsidence is greater in the thick peat soils near their interior than in the more mineral-rich soils near their perimeter. As subsidence progresses the levees themselves must be regularly maintained and periodically raised and strengthened to support the increasing stresses on the levees that result when the islands subside. Currently, they are maintained to a standard cross section at a height 1 foot above the estimated 100-year-flood elevation.

Water levels in the depressed islands are maintained 3 to 6 feet below the land surface by an extensive network of drainage ditches, and the accumulated agricultural drainage is pumped through or over the levees into stream channels. Without this drainage the islands would become waterlogged.



(California Department of Water Resources)

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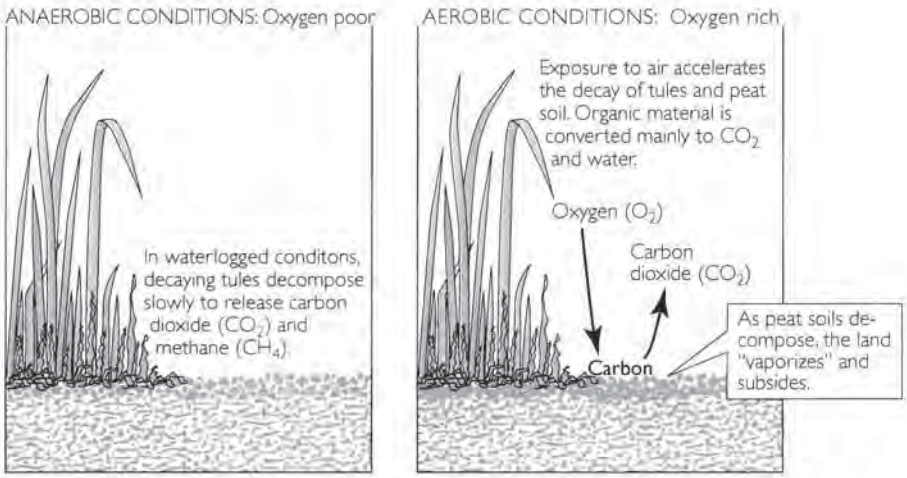


Decomposing peat soils are the main cause of subsidence

The dominant cause of land subsidence in the Delta is decomposition of organic carbon in the peat soils. Under natural waterlogged conditions, the soil was anaerobic (oxygen-poor), and organic carbon accumulated faster than it could decompose. Drainage for agriculture led to aerobic (oxygen-rich) conditions. Under aerobic conditions microbial activity oxidizes the carbon in the peat soil quite rapidly. Most of the carbon loss from the soil occurs as a flux of carbon-dioxide gas to the atmosphere.



Pumps, such as these on Twitchell Island, remove agricultural drainage while maintaining the water table at a level low enough to sustain agriculture.



Scientists resolve subsidence mechanisms

There has been some debate as to the causes and mechanisms of subsidence in the Delta. Possible causes include deep-seated compaction related to the removal of subsurface fluids (oil, gas, and water) and the near-surface oxidation and mass wasting of organic soils. This debate seems to have been resolved in favor of the carbon oxidation/gas flux hypothesis. Extensometer measurements have shown that deep-seated subsidence due to natural-gas production and ground-water withdrawal is minimal. Further, pockets of unreclaimed marshland on channel islands remain at sea level. Age-dating of sediment cores from these islands indicates low sedimentation rates and, by inference, minimal subsidence in unreclaimed areas (Rojstaczer and others, 1991). These studies made it clear that Delta subsidence is a near-surface process, but did not establish how the carbon loss takes place. Further studies by the USGS, in cooperation with the California Department of Water Resources, resolved this issue by simultaneously measuring subsidence and carbon fluxes at several sites (Deverel and Rojstaczer, 1996). The increased gaseous flux of carbon dioxide was sufficient to explain most of the carbon loss and measured subsidence, whereas the dissolved organic carbon (DOC) pumped from the islands in agricultural drainage could account for only about 1 percent of the carbon loss.

The USGS experiments also showed that rates of carbon-dioxide production increase with increasing temperature and decrease with increasing soil moisture. These results are consistent with field and laboratory measurements from the Florida Everglades, where subsidence is occurring by the same mechanism, albeit at a smaller rate of about 1 inch per year.

These transmission towers on Sherman Island show evidence of subsidence



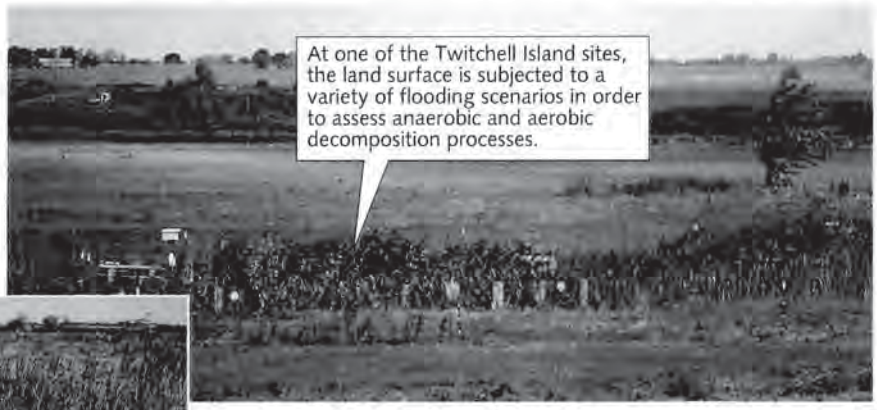
The rate of subsidence has decreased

The best evidence for long-term rates of subsidence comes from two sources—measurements of the exposure of transmission-line

How to slow or reverse subsidence

Scientists look for answers with controlled experiments

Investigations on various islands in the Sacramento-San Joaquin Delta have shown that microbial decomposition of organic-rich soils is causing the land to "vaporize" and disappear. Ongoing experiments at two sites on Twitchell Island in the western Delta focus on assessing the factors that affect the rate and timing of carbon-dioxide production.





At the other site (not shown), which will be permanently flooded, the effects of vegetative cover on the potential for biomass accumulation will be assessed.

Tules will be planted on subsets of this site and will spread throughout the site. They will decompose relatively slowly under flooded conditions. It is anticipated that plant-litter accumulations will become peat-like material over time and eventually increase land-surface elevations measured relative to stable markers set in mineral soil beneath the peat.

FUTURE STRATEGIES

Possible long-term management strategies for various Delta islands include:

1. Shallow flooding to slow peat oxidation and reverse subsidence through biomass accumulation.
2. Shallow flooding combined with thin-layer mineral deposition (a possibly beneficial reuse of dredge material).
3. Continued agricultural use of areas with shallow peat and/or low organic-matter content, under the assumption that the maximum additional subsidence will not destabilize the levees.
4. Blending mineral soil with peat soil to decrease the rate of carbon dioxide (CO_2) release and allow continued agricultural use.
5. Addition of thick layers of mineral soil, possibly using controlled levee breaches or deposition of dredge material, to slow peat oxidation and raise land-surface elevation.
6. Deep flooding to create freshwater reservoirs.

These strategies may be implemented in a mosaic throughout the Delta that creates a substantial diversity of wildlife habitat—uplands, open water, shallow permanent wetlands, and seasonal wetlands.

foundations on Sherman and Jersey Islands in the western Delta and repeated leveling surveys on Mildred and Bacon Islands and Lower Jones Tract in the southern Delta (Weir, 1950; Rojstaczer and others, 1991). The transmission lines in the western Delta were installed in 1910 and 1952. They are founded on pylons driven down to a solid substrate, so that comparison of the original foundation exposure with the current exposure allows estimates of soil loss. The southern Delta transect was surveyed 21 times between 1922 and 1981; in 1983 further surveys were precluded when Mildred Island flooded. Both data sets indicate long-term average

subsidence rates of 1 to 3 inches per year, but also suggest a decline in the rate of subsidence over time, probably due to a decreased proportion of readily decomposable organic carbon in the near surface (Rojstaczer and Deverel,1993). In fact, rates of elevation loss measured at three selected sites in 1990 to 1992 were less than 0.4 inches per year, consistent with the inferred slowing of subsidence (Deverel and Rojstaczer, 1996). However, all of these sites were near island edges, and likely underestimate the average island-wide elevation loss.

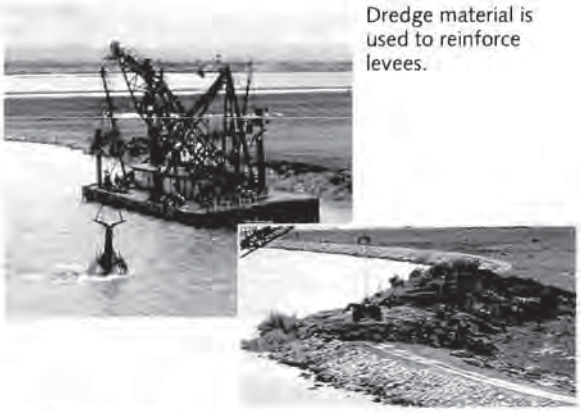
MANY MANAGEMENT ISSUES ARE RELATED TO SUBSIDENCE

The management issues raised by land subsidence range in scale from those faced by individual farmers to the possible global-scale

Living with possible levee failure

Approximately 1,100 miles of levees need to be maintained

Levee failure has been common in the Sacramento-San Joaquin Delta since reclamation began in the 1850s. Each of the islands and tracts in the Delta has flooded at least once, with several flooding repeatedly. About 100 levee failures have occurred since the early 1890s. Initially, most of the failures were caused by overtopping during periods of spring flooding. Although construction of upstream reservoirs since the 1940s has reduced the threat of overtopping, it has not reduced the incidence of levee failure.



Dredge material is used to reinforce levees.

Tyler Island levee was breached in a 1986 flood.



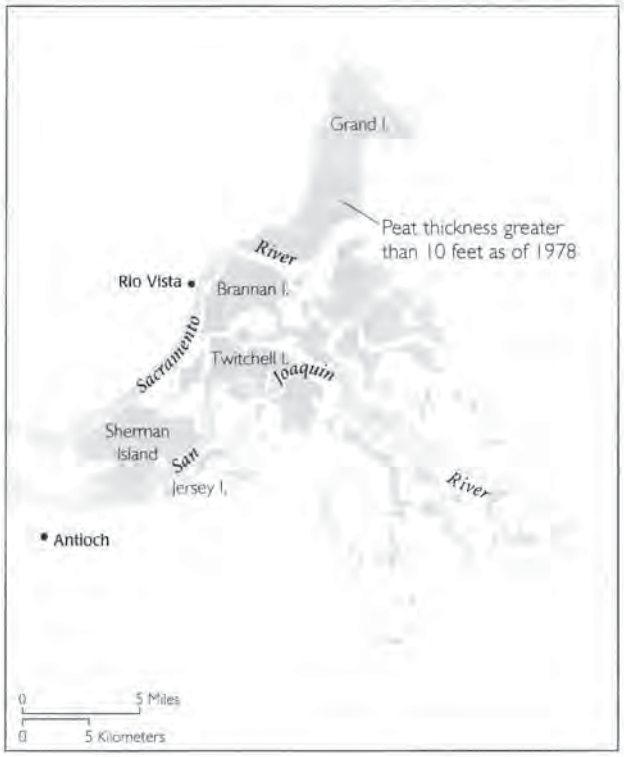
(California Department of Water Resources)

EARTHQUAKES

The Delta sits atop a blind fault system on the western edge of the Central Valley. Moderate earthquakes in 1892 near Vacaville and in 1983 near Coalinga demonstrate the seismic potential of this structural belt.

The increasing height of the levee system has prompted growing concern about the seismic stability of the levees. The concern is based on the proximity of faulting, the nature of the levee foundations, and the materials used to build the levees. Many levees consist of uncompacted weak local soils that may be unstable under seismic loading. The presence of sand and silt in the levees and their foundations indicates that liquefaction is also a possibility. Although no historic examples of seismically induced levee failure are known in the Delta, the modern levee network has not been subjected to strong shaking. Levees were either smaller or nonexistent in 1906 when the region was strongly shaken by the great San Francisco earthquake.

Areas with peat thickness over 10 feet have a great potential for continued subsidence.



(Peat-thickness estimates are from the California Department of Water Resources, written communication, 1998)

issue posed by the carbon-dioxide flux, with its possible link to climate change. At the most local level, individual farmers or reclamation districts must maintain drainage networks on the islands and pump the agricultural drainage back into waterways. These costs increase gradually as subsidence progresses.

As subsidence continues, levees must be enlarged

The costs of levee construction and maintenance are borne by the State of California and the Federal government, as well as by local reclamation districts. These costs also increase as subsidence progresses, forcing levees to be built higher and stronger. In 1981 to 1986 the total amount spent on emergency levee repairs related to flooding was about $97 million, and in 1981 to 1991 the amount spent on routine levee maintenance was about $63 million (California Department of Water Resources, 1993). Thus the annual cost of repair and maintenance of Delta levees in the 1980s averaged about $20 million per year.

The fertile soils of the Delta are vulnerable to flooding.



(California Department of Water Resources)

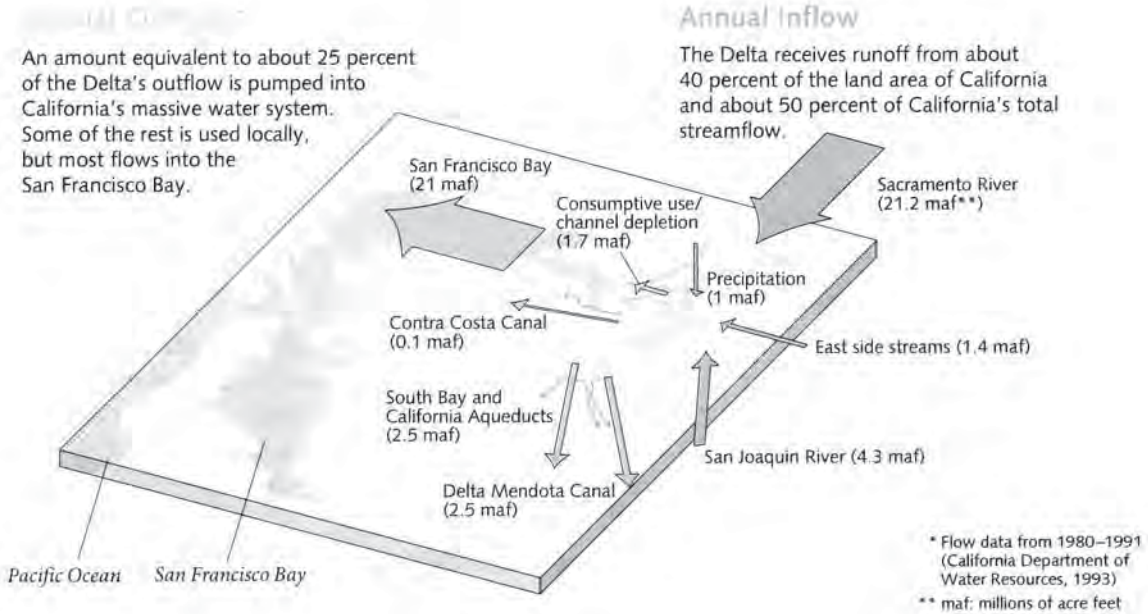
Subsidence could affect California's water system

Much larger costs might be incurred if land subsidence indirectly affects the north-to-south water-transfer system, which is predicated on acceptable water quality in the southern Delta. The western Delta islands, in particular, are believed to effectively inhibit the inland migration of the salinity interface between Bay and Delta. If these are flooded, the water available to the massive pumping facilities near the Clifton Court Forebay might become too saline to use.

Sacramento-San Joaquin Delta

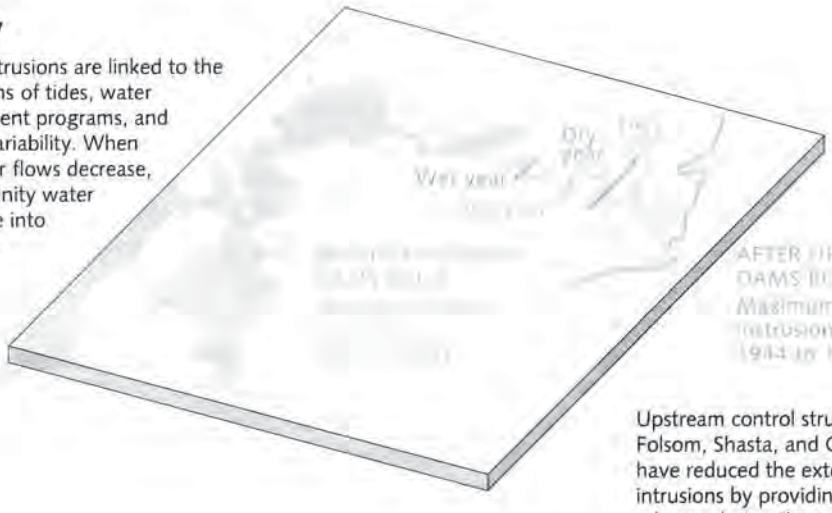
The heart of California's water systems

An artificial balance is maintained in the water exchanged between the Delta and the San Francisco Bay. Freshwater inflows regulated by upstream dams and diversions supply water to the Delta ecosystems and to farms and cities in central and southern California. Subsidence of Delta islands threatens the stability of island levees and the quality of Delta water. Delta levee failures would tip the water-exchange balance in favor of more saltwater intrusion, which can ruin the water for agriculture and domestic uses. Several aqueducts would be affected. Any reductions in the supply of imported Delta water could force water purveyors in many parts of the State to meet water demand with groundwater supplies. And this, in turn, could renew land subsidence in Santa Clara and San Joaquin Valleys and exacerbate subsidence in the Antelope Valley and other areas currently reliant on imported Delta water supplies and prone to aquifer-system compaction.



Salinity

Salinity intrusions are linked to the interactions of tides, water management programs, and climatic variability. When freshwater flows decrease, higher salinity water can move into the Delta.



Upstream control structures, such as Folsom, Shasta, and Oroville Dams, have reduced the extent of salinity intrusions by providing freshwater releases during the summer and fall.

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[California Department of Water Resources]

The Harvey O. Banks pumping plant at the southern edge of the Delta lifts water (lower right) into the California aqueduct (center left). The white towers on the upper left are wind turbines that generate electricity.

The timing of levee breaks and flooding is critical in this regard. Fortunately, most flooding occurs in winter and spring, when major saltwater intrusion is less likely. However, there are occasional levee failures under low-flow conditions. These can cause major short-term water-quality problems, even if the flooded areas are later reclaimed. During one island flooding under low-flow conditions, chloride levels reached 440 parts per million (ppm) at the Contra Costa Canal intake, well above the California standard for drinking water of 250 ppm (California Department of Water Resources, 1995).

The statewide water-transfer system in California is so interdependent that decreased water quality in the Delta might lead to accelerated subsidence in areas discussed elsewhere in this Circular. Both the Santa Clara and San Joaquin Valleys rely, in part, on imported water from the Delta to augment local supplies and thereby reduce local ground-water pumpage and arrest or slow subsidence. Degradation of the Delta source water could well lead to increased ground-water use, and renewed subsidence, in these and other areas in California.

Peat soil agriculture plays a minor role in climate change

The fact that most subsidence in the Delta, and in other drained wetlands, is caused by carbon oxidation suggests that such subsidence might affect atmospheric carbon-dioxide levels. The worldwide annual production of atmospheric carbon due to agricultural drainage of organic soils has been estimated to be as much as 6 percent of that produced by fossil fuel combustion (Tans and others, 1990). However, current rates of carbon-dioxide production in the Delta are likely to be significantly less than those caused by the initial agricultural expansion into virgin areas (Rojstaczer and Deverel, 1993). The gradual slowing of subsidence is associated with a declining rate of carbon-dioxide production.

THE FUTURE OF THE DELTA POSES MANY CHALLENGES

In cases where subsidence is due to aquifer-system compaction, it can often be slowed or arrested by careful water-use management. In cases where subsidence is due to peat oxidation, such as the Delta, it can be controlled only by major changes in land-use practice. In standard agricultural practice, the ultimate limiting factor is simply the total peat thickness; that is, the availability of organic carbon in the soil. In the Florida Everglades, the original peat thickness was less than 12 feet, and most of the potential subsidence has already been realized. In much of the cultivated area of the Delta, however, substantial thicknesses of peat remain, so that there is great potential for further subsidence.

Like the Everglades, the Delta is currently the subject of a major Federal-State restoration effort that includes attempts to improve wildlife habitat. These attempts have focused on the periphery of the Delta, avoiding the central areas with significant amounts of subsidence. As in the Everglades, much of the extensively subsided area is impractical to restore and will continue to be intensively managed.

As subsidence progresses, the levee system will become increasingly vulnerable to catastrophic failure during floods and earthquakes. The interrelated issues of Delta land subsidence, water quality, and wildlife habitat will continue to pose a major dilemma for California water managers.

This view of the Delta was taken looking westward with Mount Diablo on the horizon.



(California Department of Water Resources)

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PERGAMON

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Different effects of peat degradation on dissolved organic carbon and nitrogen

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Abstract

The dynamics of dissolved organic matter (DOM) are closely related to organic matter processes such as decomposition, humification, and stabilization of organic matter in soils. Nevertheless, it is unknown whether dissolved organic carbon (DOC) and nitrogen (DON) have an equal response to these processes. We analyzed DOC and DON concentrations of topsoil, groundwater, and surface water of six differently used sites characterized by differences in peat degradation. Carbon (^{13}C, ^{14}C) and nitrogen (^{15}N) isotopes of DOM were related to a humification index in order to detect differences between DOC and DON at different stages of humification. The results show that intact peatlands had higher DOC concentrations than degraded peatlands. Clearly, DOC concentration depends on soil organic carbon content and therefore on the degree of peat degradation. However, intact and degraded peatlands showed similar DON and inorganic N concentrations suggesting that DON release is dependent on soil inorganic N rather than the organic N pool. Moreover, a high degree of peat degradation resulted in lower DOC/DON ratios than the C/N ratio of the solid phase indicating a preferential release of DON from soil organic matter. Further, $\delta^{13}C$ ratios and the radiocarbon age of DOM increase with peat degradation and humification indicating a high C turnover, an increased microbial modification and age of DOC. On the other hand $\delta^{15}N$ ratios decrease, probably as a result of N fertilization. The promoting effect of inorganic N on DON release and a high humification of DOM at sites treated with inorganic N fertilizers suggest that N fertilization promotes a release of amino acids depleted in ^{15}N and subsequent condensation with carbohydrates to humic substances. © 2002 Elsevier Science Ltd. All rights reserved.

1. Introduction

Dissolved organic matter (DOM) in soils plays an important role in the biogeochemistry of carbon, nitrogen, and phosphorus, as summarized by Kalbitz et al. (2000a). It affects the pedogenesis, the mobilization, and transport of pollutants in soils (Dawson et al., 1978; Kalbitz et al., 1997; Temminghoff et al., 1997; Raulund-Rasmussen et al., 1998; Marschner, 1999). DOM is generally regarded as a continuum of organic molecules of various sizes and structure. Only small proportions of DOM have been identified (Thurman, 1985; Herbert and Bertsch, 1995).

Although the pool of DOM in soils is only 0.04–0.22% of soil organic carbon (Zsolnay, 1996), it represents the most mobile part of it. Therefore, DOM might be a useful indicator for processes affecting the C and N cycles. Numerous studies have also shown effects of environmental factors and management activities on DOM (Kalbitz et al., 2000a).

Usually, DOM is quantified by the analysis of dissolved organic carbon (DOC) but little is known about the N component of DOM, the dissolved organic nitrogen (DON). It is often assumed that DOC and DON have similar behavior in soils and aquatic ecosystems. However, in field and laboratory studies of the dynamics

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of DOM, there are indications of the decoupling of the C and N cycle by environmental changes (Kalbitz et al., 2000a). For instance, Prechtel et al. (2000) showed a distinct increase of DON release after drought, whereas DOC was hardly affected. Furthermore, Williams and Silcock (2000) reported a higher seasonal variability of DON compared with DOC. Causes and mechanisms for these different behaviors of DOC and DON are largely unknown.

Decomposition, humification, and stabilization of SOM are closely related to DOM dynamics (Zech et al., 1997). The main transformations occurring during litter decomposition and humification are loss of polysaccharides and phenolic moieties, modification of lignin structures, and enrichment in recalcitrant, non-lignin aromatic structures (Zech et al., 1997). However, effects of an increased decomposition and humification of litter and SOM on DOM have been examined little so far. There was no clear effect of decomposition of different deciduous foliage on the dynamic of DOC and DON release over a period of 15 weeks (Magill and Aber, 2000).

In previous studies we observed that long-term intensive land use (50 to $\geqslant$ 200 years) of peat soils resulted in enhanced peat decomposition and in increasing amounts of aromatic structures and polycondensation of dissolved organic molecules (Kalbitz et al., 1999). Isotopic ratios of water-soluble fulvic acids (FA) were also affected by differences in peat decomposition due to land use (Kalbitz et al., 2000b). Therefore, land use impacts altered the soil conditions for DOM release, i.e. a changed amount and composition of soil organic matter. These studies supported the concept that DOM can serve as an indicator for processes in soils affecting the C and N cycle like decomposition and humification. However, it is unknown whether DOC and DON have an equal response to these processes. The known degrees of humification of DOM within an area characterized by similar environmental conditions offers the unique possibility to study the different effects of humification on DOC and DON.

The main objective of this study was to test the hypothesis that a change in the degree of humification of DOM caused by a different peat degradation has different effects on DOC and DON. We tested this hypothesis by (1) analyzing DOC and DON concentrations in soil and water and by (2) relating the degree of humification of DOM to the natural variation of carbon (^{13}C, ^{14}C) and nitrogen (^{15}N) isotopes of DOM.

2. Materials and methods

2.1. Study area and sites

Samples were taken at the "Droemling" area located in Northeast Germany (28,000 ha, 55–58 m above sea level, 570 mm mean annual precipitation, 8.4 °C mean annual temperature). The sampling sites have been described in detail by Kalbitz et al. (1999, 2000b). Six sampling sites with different land use were selected (Table 1). The soils of the degraded peatlands (sites 1–3) contain only relict amounts of peat as a result of agricultural use for the last 50–200 years. These sites have got considerable amounts of mineral fertilizers, up to 150–200 kg mineral N ha^{-1} $year^{-1}$ (Kalbitz et al., 2000b). The land use pattern of site 3 was changed into unimproved grassland at the beginning of this study in 1996. At the relatively intact peatlands (sites 4–6) peat degradation was much lower than at the degraded peatlands as seen by higher content of organic matter (Table 1).

2.2. Sampling, analyzing, and statistics

Details of sampling and analysis are described by Kalbitz et al. (1999). Briefly, topsoils (0–25 cm depth), groundwater and surface water were sampled from spring 1996 to fall 1998 every 3 weeks. Aqueous saturation extracts of the topsoil were prepared with a relatively narrow soil-to-water ratio (soil/water: 0.3–1.1; w/v) similar to in situ soil solution. Groundwater samples were collected from wells (1–2 m depth) and surface water was directly pumped from the adjacent draining ditch into a container.

All aqueous samples were 0.45 μm filtrated (polysulfon, Fa. Gelman), then analyzed for DOC on a Shimadzu TOC 5050, for total-N by a modified Kjeldahl procedure (VDLUFA, 1991), for nitrate and nitrite by ion chromatography (Dionex DX 100), and for ammonium by colorimetrical analysis using sodium dichloroisocyanurate and sodium salicylate by Spectroquant 118. DON concentration was calculated as the difference between total-N and inorganic-N. Before running the ANOVA procedure (SPSS for Windows 8.0) and multiple comparison tests (Tukey test, $\alpha < 0.05$), data were pooled in two distinct groups, degraded peatlands and intact peatlands, in order to examine the effects of a different degree of peat degradation on DOC and DON. The homogeneity of variance was tested by the Bartlett test.

The degree of humification of DOM was related to the natural variation of carbon (^{13}C, ^{14}C) and nitrogen (^{15}N) isotopes as follows: for isotopic analysis we extracted fulvic acids (FA) from aqueous extracts of the topsoil, from groundwater and surface water by adsorption chromatography on XAD-8 resin at three sampling dates. Details on the isotopic measurements are given by Kalbitz et al. (2000b) who presented these data in detail. Briefly, $\delta^{13}C$ and $\delta^{15}N$ of the freeze-dried FA were determined using a C/N analyser (Carlo Erba 1108) coupled to a continuous flow isotope ratio mass spectrometry (delta C Finnigan MAT). ^{14}C measurements of the freeze-dried FA were made by accelerator

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mass spectrometry (IsoTrace laboratory, University of Toronto) (Beukens, 1992). The ^{14}C concentration is given in pmC (% modern C) and referred to 94.9% of the activity concentration of the NBS oxalic acid standard in 1950. The results are corrected for natural and sputtering fractionation to a base of $\delta^{13}C = -25‰$ (Stuiver and Polach, 1977). In addition to the FA isotopes we recorded synchronous fluorescence spectra of the corresponding water sample to compute a humification index by calculating the ratio of fluorescence intensities at a longer (390 nm) and a shorter (355 nm) wavelength (Kalbitz et al., 2000c). The calculation of this humification index is based on the fact that a shift in the fluorescence intensity from shorter to longer wavelengths is associated with an increasing number of highly substituted aromatic nuclei (Senesi et al., 1989; Miano and Senesi, 1992). After the analysis linear regressions of isotopic data and humification indices were calculated. Total organic carbon (TOC) and nitrogen (TON) content of the soil were analyzed on an elemental analyzer (LECO CHN-1000).

3. Results and discussion

3.1. DOC concentrations

Dissolved organic carbon (DOC) concentrations in topsoil, groundwater and surface water were significantly higher at the intact peatlands (46–87 mg C l^{-1}) than at the degraded peatlands (25–35 mg C l^{-1}, Table 2). These findings emphasize the importance of soil organic matter (SOM) as the main source of DOC (McDowell and Likens, 1988; Zsolnay, 1996). Clearly, DOC release depends on soil organic matter content and therefore on peat degradation.

Table 1
Land use, soil type and some properties of topsoil horizons of the study area ("Droemling", Germany)

Site	Land use	Soil depth (cm)	TOC[a] (g kg^{-1})	TON[b] (g kg^{-1})	TOC/TON	DON[c] (mg N l^{-1})
Degraded peatlands—Mollic Gleysols						
Site 1	Intensive arable land	0–18	41.8	3.60	11.6	6.8 (0.9)
Site 2	Intensive grassland	0–32	47.2	3.65	12.9	8.1 (1.6)
Site 3	Changing land use[d]	0–26	46.2	2.58	17.9	8.5 (1.1)
Relatively intact peatlands—Terric Histosols						
Site 4	Unimproved grassland	0–37	205.6	11.80	17.4	12.0 (1.4)
Site 5	Grassland in natural succession	0–28	86.8	8.76	9.9	6.4 (1.4)
Site 6	Almost natural woodland	0–30	452.7	30.70	14.7	6.8 (0.6)

[a] Total organic carbon content of the soil.
[b] Total organic nitrogen content of the soil.
[c] DON concentration in aqueous extracts of the topsoil (mean and standard error of 41 sampling dates from May 1996 to December 1998).
[d] Changing land use from intensive crop production to unimproved grassland in Spring 1996.

Table 2
DOC concentrations (mg C l^{-1}) and DOC/DON ratios of topsoil (aqueous extracts), ground and surface water (mean of 41 sampling dates)

Site	DOC (mg C l^{-1})			DOC/DON		
	Topsoil	Groundwater	Surface water	Topsoil	Groundwater	Surface water
Degraded peatlands[a]	34.7±0.8	24.9±0.6	29.4±2.8	9.5±1.2	9.4±1.1	12.3±2.1
Site 1	33.1	28.8	10.5	7.7	8.1	7.1
Site 2	38.6	19.8	61.8	12.5	12.7	23.2
Site 3	32.4	26.1	26.5	7.9	8.0	6.5
Relatively intact peatlands[a]	87.1±4.5	46.0±3.7	52.6±3.2	16.2±1.5	17.5±2.4	14.6±1.6
Site 4	57.8	24.9	21.7	8.8	5.6	5.3
Site 5	59.5	37.1	75.1	15.5	23.4	21.1
Site 6	144.1	76.0	72.8	25.9	29.7	23.6

[a] Mean and standard error of the three sites.

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3.2. DON concentrations and DOC/DON ratios

While total organic nitrogen (TON) concentrations of topsoils were much higher in intact peatlands (9–31 g kg^{-1} soil) relative to the degraded peatlands (3–4 g kg^{-1} soil) dissolved organic nitrogen (DON) concentrations did not show any significant difference (6–12 mg l^{-1}, Table 1). Furthermore, organic and inorganic N of aqueous extracts from topsoils were in the same concentration range (5–12 mg l^{-1}) as reported by Murphy et al. (2000) for agricultural soils. Moreover, we found similar concentrations of inorganic N in the same samples for degraded (~5.6 mg l^{-1}, $n=109$) versus intact peatlands (~5.1 mg l^{-1}, $n=108$). Therefore, DON release in the topsoil seems to be affected by the smaller pool of inorganic N rather than by the large pool of soil organic N.

The promoting effect of soil inorganic N on the release of DON becomes also evident looking at C/N ratios of the solid and the liquid phase. These ratios showed that degraded peatlands topsoil are depleted in C versus N in the water phase (Fig. 1). Thus, our results are explained by a preferential release of DON from the solid phase of soil organic matter in degraded peatlands possibly due to the input of 150–200 kg mineral N ha^{-1} $year^{-1}$. Neff et al. (2000) reported that N fertilization increased DON fluxes by 50% and decreased the DOC/DON ratio in a soil sample with a low nitrogen content. Also Williams et al. (1999) found that the amount of DON in water extracted from moss increased linearly with the amount of inorganic N added. However, this added inorganic nitrogen was not directly incorporated in DON as indicated by an applied ^{15}N tracer (Williams et al., 1999). Furthermore, in forest soils, DON concentrations and fluxes increased after nitrogen addition, whereas DOC concentrations and fluxes remained unchanged (Currie et al., 1996; McDowell et al., 1998). It is, therefore, suggested that DON release is promoted when inorganic nitrogen is added to the soil.

3.3. Carbon and nitrogen isotopes in relation to DOM humification

3.3.1. $\delta^{13}C$ ratios in relation to DOM humification

An enhanced humification of DOM could be related to an enrichment of ^{13}C in DOM as shown in Fig. 2. Melillo et al. (1989) and Bol et al. (1999) have shown a ^{13}C enrichment with increased decomposition of organic matter which could be attributed to enhanced microbial contribution of ^{13}C enriched (re)synthesized compounds (Huang et al., 1996, 1998). In a previous study, Kalbitz et al. (2000b) showed that strong peat degradation resulted in a ^{13}C enrichment as indicated by higher values at the degraded peatlands compared with the intact peatlands. Haider (1999) emphasizes the outstanding role of microbes for decomposition and humification of plant residues. Therefore, we conclude that an increasing degree of humification of DOM is related to an increasing microbial modification of water-soluble organic carbon compounds.

The positive relationship between humification of DOM and its $\delta^{13}C$ ratios supports the findings that the relative concentration of ^{13}C depleted lignin-derived aromatics are decreasing whereas the portion of ^{13}C enriched O-alkyl compounds remains more or less constant during humification (Haider, 1999; Schulten and Gleixner, 1999; Kracht and Gleixner, 2000). The positive relationship between humification of DOM and its $\delta^{13}C$ ratio also indicates an increasing formation of microbial biomass during humification, which is enriched in ^{13}C (Kracht and Gleixner, 2000).

3.3.2. ^{14}C contents in relation to DOM humification

The significant correlation between the ^{14}C content and the humification index of DOM in Fig. 3 shows that the humification degree of DOM increases with its age. As reported for $\delta^{13}C$ ratios strong peat degradation resulted in an increasing radiocarbon age (decreasing ^{14}C values) of DOC. This is indicated by higher values at the degraded peatlands compared with the intact peatlands (Kalbitz et al., 2000b). Bol et al. (1999) concluded that decomposition of SOM is linked to an increased radiocarbon age. This conclusion can be extended to humification of DOM.

The significant increase of the ^{14}C content after a short-term land use change (Fig. 3) is not linked with decreasing humification indices as expected from the relationship presented above (Fig. 3). The input of newly synthesized organic carbon with modern ^{14}C values after this land use change reflects a changed C turnover probably by an increased microbial activity. On the other hand, these newly synthesized organic compounds should be characterized by a similar humification. The positive relationship between humification and age of DOM seems to exists after this land use change with a constant slope but shifted to a different level.

3.3.3. $\delta^{15}N$ ratios in relation to DOM humification

In contrast to the $\delta^{13}C$ ratios and ^{14}C values, the high humification index of the degraded peatlands is linked to low δ^{15} N ratios as shown in Fig. 4. That means, in opposite to DOC, an increased humification of DOM did not result in an increased microbial change of DON. An increased humification of DOM is rather linked to the incorporation of isotopically light N into DON. Furthermore, strong peat degradation resulted in a ^{15}N depletion as indicated by lower values at the degraded peatlands compared with the intact peatlands (Kalbitz et al., 2000b). These low $\delta^{15}N$ ratios support the hypothesis of a low microbial modification of DON because microbes prefer light N (Desjardins et al., 1996; Martinelli et al., 1996; Högberg, 1997; Novák et al.,

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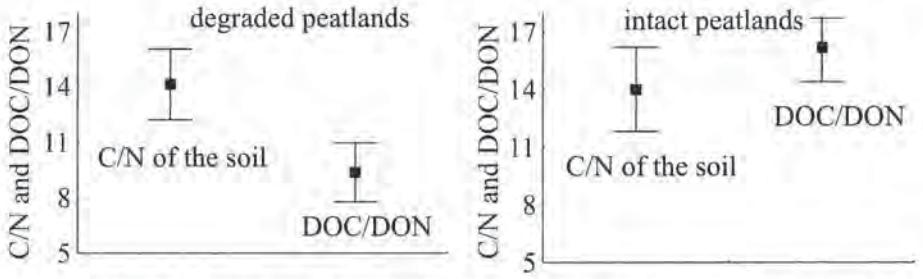


Fig. 1. C/N ratio of the solid and the liquid phase (DOC/DON) of the degraded and the intact peatlands (mean and standard error of 3 sites; solid phase: one sampling date per site of the topsoil horizon; liquid phase: mean and standard error include data of 41 sampling dates for each site).

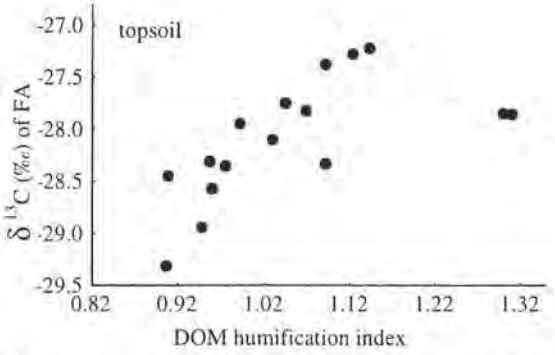


Fig. 2. Dependence of $\delta^{13}C$ ratios of water-soluble fulvic acids on DOM humification index (ratio of fluorescence intensities at 390/355 nm; $r = 0.63$).

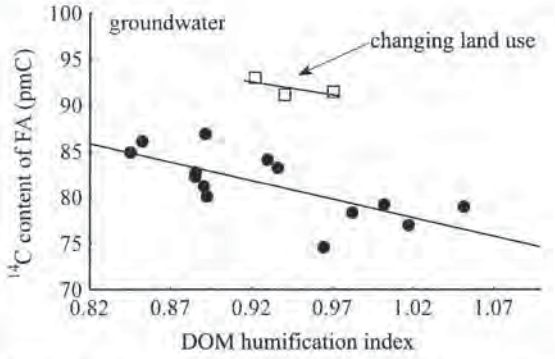


Fig. 3. Dependence of ^{14}C contents of water-soluble fulvic acids on DOM humification index (ratio of fluorescence intensities at 390/355 nm; $r = -0.72$). The ^{14}C contents of site 3 were not included in these regressions because of changed isotopic values and unchanged humification indices after the short-term land use change at this site.

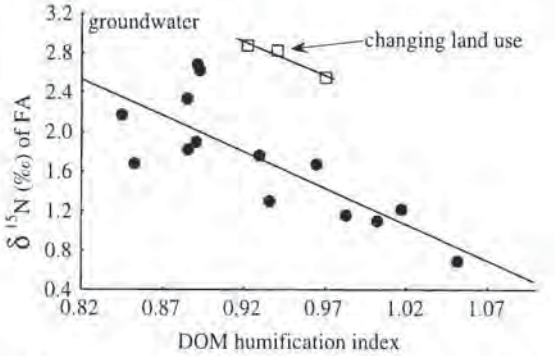


Fig. 4. Dependence of $\delta^{15}N$ ratios of water-soluble fulvic acids on DOM humification index (ratio of fluorescence intensities at 390/355 nm; $r = -0.80$). The $\delta^{15}N$ ratios of site 3 were not included in these regressions because of changed isotopic values and unchanged humification indices after the short-term land use change at this site.

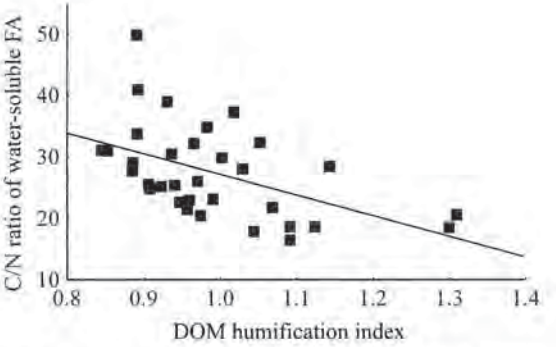


Fig. 5. C/N ratio of water-soluble fulvic acids (topsoil, groundwater, surface water) in dependence on DOM humification index (ratio of fluorescence intensities at 390/355 nm; $r = -0.50$).

1999). An enrichment of ^{13}C and a depletion of ^{15}N could be explained by a different response of DOC and DON to peat degradation and DOM humification.

Besides, an increased humification of DOM is also related to a selective preservation of nitrogen as indicated by a linear correlation (Fig. 5) using the published C/N ratios of water-soluble FA (Kalbitz et al., 1999) and the humification indices of DOM (Kalbitz et al., 2000c).

The isotopically light N of FA from the degraded peatlands might derive from the added mineral fertili-

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zers. According to Clark and Fritz (1997), the $\delta^{15}N$ ratios of mineral fertilizers are often lower than soil organic N. However, a direct incorporation of this fertilizer N into DON is not likely because in ^{15}N tracer experiments in a bog peat and in a grassland soil less than 0.1% of added inorganic N could be detected in DON (Williams et al., 1999; Shand et al., 2000). A promoting influence of the inorganic N pool on DON release is more likely (see above). At the moment we can only speculate about mechanisms for this promoting effect of the inorganic N pool. Qualls (2000) emphasized that microbial dissolution of organic compounds like proteins is important for the production of DON. This microbial dissolution could be promoted by an addition of inorganic N (see Section 3.2.). Then, the Maillard reaction in which amino acids (released during the hydrolysis of proteins) and carbohydrates condense to form humic substances, could be responsible for increasing DON release (Qualls, 2000). This pathway of humic substances formation is supported by higher humification indices at sites with an addition of inorganic N (degraded peatlands). Higher contents of amino acids in soils treated with inorganic N than in untreated soils also support this hypothesis (Bol et al., 1998a). However, these amino acids vary in the $\delta^{15}N$ ratios in a broad range (−12 to +26‰) (Bol et al., 1998b). The $\delta^{15}N$ ratios of bulked amino acids can be higher or lower than the $\delta^{15}N$ of the soil (Bol et al., 1998b; Ostle et al., 1999). A determination of individual amino acids (content, $\delta^{15}N$ ratio) of degraded and intact peatlands would allow to test our hypothesis of a promoting influence of added inorganic N on the release of amino acids.

Similar to the ^{14}C contents increasing $\delta^{15}N$ ratios after a changing land use (Fig. 4) indicated that an increased microbial activity do not result in an increased humification of DOM. However, the increasing $\delta^{15}N$ ratios mean that the released DON after this land use change was strongly microbial altered (Högberg, 1997; Novák et al., 1999). On the other hand, the ^{14}C values show a release of newly synthesized organic carbon. Also in this case DOC and DON show a different pattern.

4. Conclusions

DOC release depends on soil organic matter content and therefore on peat degradation whereas DON release is independent of it. The inorganic N pool affects the release of DON rather than the pool of soil organic nitrogen. Therefore, degraded peatlands characterized by a high degree of peat decomposition and an addition of inorganic N fertilizer release DON from SOM preferentially. High humification of DOM is linked with a high C turnover and high microbial modification and age of DOC but with low $\delta^{15}N$ ratios of DOM. It is suggested that an addition of mineral N fertilizer increases the microbial mobilization of amino acids followed by a condensation with carbohydrates to humic substances. The different response of DOC and DON to enhanced peat degradation and DOM humification emphasizes the necessity to consider DON besides DOC in further DOM research.

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Farming the Delta's high-organic (peat, muck) soils provides a grower with a unique set of problems and limitations. Today, the most widely grown crop on these organic soils is field corn. The next most common are wheat, barley, and asparagus. Sunflowers are the Delta's most colorful crop. Potatoes, once widely grown, have lost their importance, as has grain sorghum. Minor vegetable crops—carrots, radishes, and onions—are occasionally found, as are alfalfa and sugar beets.

Plants usually grow well on peat soils, which warm up early in spring because their dark color absorbs heat. With warm weather, they mineralize relatively large quantities of nitrogen. Peat soils, light and nonabrasive, are easy to work, with relatively low power requirements for machinery and little wear on tillage equipment. Often, they can be worked early in spring or shortly after a rain.

There are, however, problems that go along with the advantages. Not only do crops grow well; so do weeds. Weeds start early and have a ready supply of nutrients and moisture all season. For this reason, the crops grown most widely in the Delta must be tolerant of at least some post-emergence herbicides and must generally compete well against weeds.

Water storage

Peat soils have a high water-holding capacity and conduct water well. High water tables are common in the Delta, and some areas may remain so wet that even the peat soils cannot be worked in early spring. Excessive moisture may create anaerobic conditions in the soil, leading to denitrification and consequent nitrogen deficiency early in the season.

At the other extreme, the soil may dry out at the surface, creating fine organic dust picked up by spring winds. Clouds of peat dust for many miles downwind were of serious concern some years ago, but they are generally under control today. However, dusty conditions continue to make labor recruitment difficult, and air-conditioned cabs on farm equipment have become common.



Dark organic soils of the Delta warm up rapidly in the spring, permitting early production of asparagus.



In preparation for the first irrigation of the season, a trencher cuts a spud ditch through a corn field in Delta peatlands.

Subsurface irrigation by means of spud ditches is commonly used in Delta peat soils (See page 5.) This system, so well adapted to shallow-rooted crops, also creates problems. By raising the water table, it rots the lower roots and accumulates salts near the soil surface during the cropping season. These salts may be leached out by winter rains and flooding.

Nutrient requirements

The nutrient most often deficient in peat soils is phosphorus, followed by zinc and potassium. Under wet conditions, where denitrification occurs, nitrogen responses have been recorded. In addition, nitrogen is increasingly needed in areas where the peat overlying mineral soils has oxidized away and insufficient nitrogen is released from the organic material for crop production. When fertilizers are applied, they are banded under the seeds. The high amounts of nitrogen available in peat soils, especially later in the season, mean that sugar beet crops generally have high yields but relatively low sugar content.

For most crops Johnsongrass, a perennial weed, is a severe problem. Other weeds include annual grasses, annual and perennial broad-leaved weeds, and nutsedge. Rotating corn with winter cereals, such as wheat or barley, gives growers an opportunity to plow, disc, and flood Johnsongrass-infested fields during summer. In severe cases, two years of wheat before returning to corn have been helpful. Herbicides used on corn and wheat are chosen to complement the competitive cover provided by these two crops.

In past years, burning the top layer of peat soils destroyed weed seeds and disease organisms, and provided potassium. The practice of burning has been discontinued, and other weed and disease control methods are used today.

Asparagus, no longer a major crop, is still important in both peat and mineral areas. The heat-absorptive capacity of peat soils promotes early yields. In the 1930s, white celery was a big crop; with changes in taste and better yields elsewhere, it is no longer grown. Potatoes were also once important, but today only a remnant of the former acreage produces market and seed potatoes.

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THE STABILITY OF GEOSMIN AND MIB AND THEIR DEUTERATED ANALOGUES IN SURFACE WATERS AND ORGANIC SOLVENTS

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ABSTRACT

Deuterated geosmin [trans-1,10-[$^2H_3$]-dimethyl-9α-decalol] and deuterated methylisoborneol [2-exo-hydroxy-2-[$^2H_3$]-methylbornane] were synthesised and evaluated as alternatives to 1-chloroalkanes as internal standards in the determination of geosmin and MIB in surface waters. Geosmin and MIB were stored as dilute solutions in methanol, ethanol, acetone, hexane or carbon disulfide for >6 months without deterioration. Dichloromethane caused substantial decomposition of MIB. When added at the time of sampling, the labelled standards compensated for losses of analyte by physical, chemical and biological processes during sample storage. The labelled compounds were effective internal standards for the determination of other odorous metabolites such as the carbonyl compounds β-cyclocitral, β-ionone, geranylacetone and 6-methylhept-5-en-2-one.

KEY WORDS

geosmin, 2-methylisoborneol, deuterium labelling, analysis, internal standards.

INTRODUCTION

The two compounds most commonly implicated in imparting an earth/musty taste and odour to drinking water are geosmin and 2-methylisoborneol (MIB). They are of particular concern to water managers as they are resistant to normal water treatment processes and can be perceived by the general public at very low levels, typically 10 and 30 ng/l for MIB and geosmin respectively (Tyler *et al.*, 1978; Yasuhara and Fuwa, 1979; Persson, 1980; Bartels *et al.*, 1989). To avoid consumer complaints water authorities generally monitor their source water supply and implement a management strategy while the concentration of either or both of these compounds is still low enough to make an early treatment option viable. To determine these concentrations a sensitive and accurate analytical procedure is required.

Several analytical techniques are now available for the analysis of the two compounds. Our laboratory quantifies geosmin and MIB using a salted closed loop stripping analysis procedure (CLSA) based on that of Hwang *et al.*(1984) and described in our previous paper (Korth *et al.*, 1991). Although most procedures utilize gas chromatography-mass spectrometry (GC-MS) or GC-flame ionization detector (FID) to quantify the analyte, they differ substantially with respect to sample extraction and concentration.

For accurate quantification the use of an appropriate internal standard is necessary and the diversity of internal standards used to date indicates the difficulty in finding the "ideal internal standard" (Johnsen and Jui Chang , 1987; Hwang *et al.*, 1984). Other workers (Yasuhara and Fuwa, 1979; Tabacheck and Yurkowski,

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1976; Dupuy *et al.*, 1987;) resort to the slower standard addition technique. Most laboratories currently use a series of linear 1-chloroalkanes with the CLSA procedure as the best compromise. However, chloroalkanes have a number of disadvantages. They strip at a faster rate than MIB and geosmin, are less sensitive to changes in CLSA parameters than MIB and geosmin (Hwang *et al.*, 1984), require frequent calibration and do not compensate for losses of analyte during sample storage. To overcome these problems deuterated analogues of geosmin and MIB were synthesized. The ring-junction methyl group of geosmin was labelled with three deuterium atoms and the methyl group at C_2 in MIB.

Deuterium labelled internal standards have been shown to offer many advantages compared with conventional standards for the determination of MIB and geosmin in surface water (Korth *et al.*, 1991). The identical physical and chemical behaviour of MIB and geosmin to their labelled analogues make the deuterated compounds ideal internal standards when using CLSA-GC-MSD. Variations in CLSA parameters such as stripping time, bath temperature, size and shape of stripping bottle, stripping with or without salt, air flow through the carbon filter, sparging rate or air leaks have no effect on the accuracy of the determination.

The insensitivity to changes in CLSA parameters results in a great deal of time saving because unknowns do not have to be analysed with and without spikes and frequent calibration is not necessary for accurate determinations. If the concentration is sufficiently high the stripping time can be reduced to half an hour or less without affecting the result or having to recalibrate the system. A busy laboratory could easily triple its output, with respect to the analyses of these two compounds, without sacrificing accuracy.

In the present study we planned to measure the stability of standard solutions of geosmin and MIB in various organic solvents and to explore the validity of using (±)-geosmin-d_3 (added at the time of sampling) to quantify (-)-geosmin present in river water, with the analysis being performed after varying extents of biodegradation. The suitability of (±)-geosmin-d_3 and (-)-MIB-d_3 as internal standards for the quantification of other odorous algal metabolites was also investigated.

MATERIALS AND METHODS

Synthetic (±) geosmin, MIB, synthetic (±) geosmin-d_3, MIB-d_3, 1-chlorooctane, 1-chlorodecane, 1-chlorododecane, carbon disulphide, acetone, and dichloromethane were obtained as previously described (Korth *et al.*, 1991) and 6-methylhept-5-en-2-one, geranyl acetone, β-ionone and β-cyclocitral were generously donated by Prof. F. Jüttner.

The CLSA equipment and CLSA-GC-mass sensing detector (MSD) technique used for sample extraction and analysis was as previously described (Korth *et al.*, 1991). GC-FID conditions and equipment used were: GC, Varian 3400; detector, FID (attenuation $4x10^{-11}$); column, Alltech ECONO-CAP SE 30, 0.25 mm ID, 0.25 µm film; temperature program, 25°C for 1.5 min., then to 250°C at 10°C/min., hold for 5 min.; splitter off 1.5 min.; split flow 50 ml/min.; carrier gas, helium; injector, 260°C; detector, 260°C. Chiral GC was performed with a 50 m J&W Cyclodex-B column with either hydrogen (FID) or helium (MSD) as carrier gas. Temperature program was 30°C hold for 1.5 min. with splitter off, then 30°C/min. with splitter on up to 127°C, hold at 127°C for 38 min., then 30°/min. up to 230°C then held for 5 min. Ions monitored and the quantifying ions, in brackets, for the four additional odour compounds were as follows: 6-methylhept-5-en-2-one 43, (108), 111, 126; β-ionone 135, (177), 192; β-cyclocitral 109, 123, (137), 152; geranyl acetone 43, 125, 136, (151).

Storage of MIB and geosmin in organic solvents

A stock solution of MIB (460 ng/µl), geosmin (450.6 ng/µl), 1-chlorooctane (619.3 ng/µl), 1-chlorodecane (426 ng/µl), 1-chlorododecane (587.3 ng/µl), n-tridecane (446.9 ng/µl) and n-pentadecane (448.9 ng/µl) was prepared in acetone. An aliquot (50 µl) of this solution was added to each of six 4 ml amber screw cap vials containing 2 ml of acetone, dichloromethane, ethanol, methanol, hexane and carbon disulphide respectively. Each solution was mixed thoroughly and analysed immediately. The solutions were split into 2 sets of

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duplicate aliquots (1 ml) and stored. The 1st set was stored at -15^0 C in the dark and the 2nd set at room temperature (22^{0}C) under normal light conditions. All solutions were analysed at various time intervals (GC-FID) and the area of each compound was normalised relative to the area of n-tridecane.

Chemical degradation of MIB

MIB (180 mg) was added to CH_2Cl_2 (1 ml) in a 4 ml amber screw cap vial. An aliquot (1 drop) of this solution was transferred to another vial containing CH_2Cl_2 (2 ml) and analysed by GC-FID. To the initial solution 1N $HCl_{(aq)}$ (1 ml) was added and the vial placed in a wrist action shaker (48 hrs.). After 27 h a further 0.9 ml of 10M HCl was added to increase the HCl concentration to 5M. The degradation was monitored as follows: at various time intervals aliquots (1 drop) were added to CH_2Cl_2 (2 ml) and 5% $NaHCO_{3(aq)}$ (2 ml) in a 4 ml amber screw cap vial. The mixture was vortexed (1 min) and allowed to settle until the phases separated. The aqueous phase was removed and Na_2SO_4 was added to dry the organic layer. This layer was analysed using GC-FID.

Biodegradation Trials

Additional Odour Compounds vs geosmin-d_3 and 1-ClC_{10}. Murrumbidgee River water (5 l) was collected and chloroalkanes and labelled geosmin were added to an aliquot (900 ml) as internal standards. This was then stripped and analysed as a blank. The remaining river water (4 l) was spiked with the following: 6-methylhept-5-en-2-one (3560 ng/l); geranyl acetone (3570 ng/l); β-ionone (6280 ng/l) and β-cyclocitral (315 ng/l). The spiked water was then split into two equal portions A and B (2x2 l Schott bottles). To portion B geosmin-d_3 was added (1000 ng/l) and both bottles were stored at room temperature (22^{0}C) and under normal light conditions. Sub-samples were taken at ~12 hour time intervals over the next 130 hours and stripped in duplicate.

Prior to stripping sub-samples from bottle A, a chloroalkane (90 ng/l, 1-ClC_{10}) and geosmin-d_3 (100 ng/l) were added, whereas prior to stripping sub-samples from bottle B only the chloroalkane (90 ng/L, 1-ClC_{10}) was added. Response factors for each of the four odour compounds and geosmin-d_3 relative to 1-ClC_{10} as well as each of the four odour compounds and 1-ClC_{10} relative to geosmin-d_3 were determined from the duplicate strips of sub-samples from each bottle at time = 0. These response factors were used to follow the biodegradation of the four odour compounds added using either 1-ClC_{10} or geosmin-d_3 as internal standards.

Natural (-)-geosmin vs synthetic (±)-geosmin-d_3. Natural (-)-geosmin produced in culture by *Anabaena circinalis* (strain designation 852E) was used to spike Murrumbidgee River water. An aliquot of the *A. circinalis* culture (200 ml) was probe sonicated (6x30 sec.) and centrifuged (6000 rpm) for 15 minutes to clarify. The clarified supernatant was then used to spike raw water.

River water (5 l) was collected and chloroalkanes and labelled geosmin were added to an aliquot (900 ml) as internal standards. This was then stripped and analysed as a blank. To a portion of the remaining river water (2 l) all of the clarified supernatant of *A. circinalis* was added. This solution was mixed and made up to volume (4 l) with raw water to give a final concentration for (-)-geosmin of 1290 ng/l.

The spiked raw water (4 l) was split into two portions A and B (2x2 l Schott bottles) and portion B was spiked with geosmin-d_3 to give a final concentration of 1000 ng/l. Both 2 l portions were stored at room temperature (22^{0}C) and under normal light conditions. A sub-sample (50 ml) was taken from each bottle preserved with $HgCl_2$ (40 mg/l) and stored under the same conditions next to the 2x2 l portions. Further sub-samples were taken at ~ 12 hour time intervals over the next 90 hours, preserved with $HgCl_2$ and stored in a cold room (4^{0}C) until ready for stripping. Each sub-sample was stripped in duplicate and each strip analysed in duplicate by GC-MSD.

Prior to stripping sub-samples from bottle A, a chloroalkane (90 ng/l, 1-ClC_{10}) and geosmin-d_3 (100 ng/l) were added as internal standards, whereas only the chloroalkane (90 ng/l, 1-ClC_{10}) was added prior to stripping sub-samples from bottle B. Response factors for 1-ClC_{10} relative to geosmin-d_3 were calculated at

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each time interval from the duplicate strips of sub-samples of bottle A. These response factors were used to determine the concentration of natural (-)-geosmin and synthetic (±)-geosmin-d_3 of the sub-samples from bottle B.

RESULTS AND DISCUSSION

Storage of MIB and geosmin in organic solvents

The chemical stability of MIB and geosmin in six commonly used laboratory solvents was evaluated using n-C_{13} and n-C_{15} as internal standards (see materials and methods section). The area of each compound was normalised to the area of n-C_{13}. A decrease in this ratio to that obtained for each compound at day 0 indicated a breakdown of the compound. If the internal standard degrades then the ratio of all compounds relative to n-C_{13} would increase.

All compounds were found to be stable when stored at -15°C in the dark and all except MIB were stable when stored at room temperature (22° C) under normal light conditions. In dichloromethane, MIB degrades (see Fig.1).

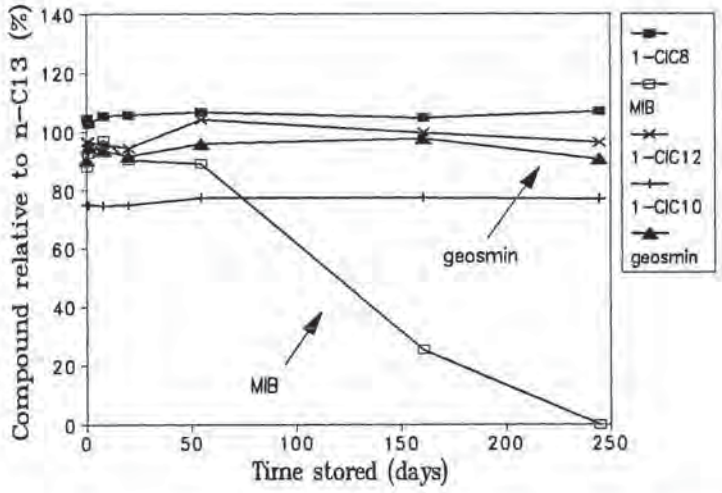


Figure 1 Stability of geosmin, MIB and chloroalkanes in CH_2Cl_2 at room temperature.

Chemical degradation of MIB

The breakdown of MIB is assumed to be due to acid catalysed dehydration in the presence of HCl formed by the photolytic breakdown of CH_2Cl_2. A similar breakdown of MIB could be observed by shaking MIB in CH_2Cl_2 with 1N HCl (see materials and methods section). The disappearance of MIB and the appearance of two earlier eluting breakdown products was also identical with those observed for the original solution (see Fig.2).

The mass spectra of the two breakdown products showed a molecular ion at m/z 150 (168 for MIB) which is consistent with the loss of water and were identical with published mass spectra of 2-methylenebornane and 2-methyl-2-bornene (Martin *et al.*, 1988). Prior to the formation of the two breakdown products the chromatographic peak for MIB was observed to split into two almost co-eluting peaks. The right hand side

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of the doublet had the characteristic MIB mass spectrum however the left hand side (LHS) differed. Although the molecular ion was still at m/z 168 for the LHS peak it was lower in intensity and the base peak had changed to m/z 107 from the usual m/z 95. The LHS peak may be 2-methylborneol: the MIB could protonate and dehydrate to a carbocation which could then either lose H^+ to give the mixture of alkenes or re-hydrate and lose H^+ to form the epimeric alcohol.

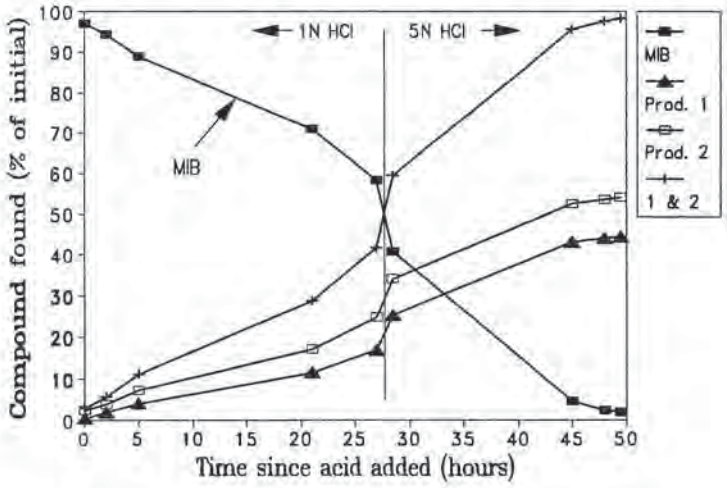


Figure 2 Acid catalysed decomposition of MIB.

Biodegradation Trials

Additional odour compounds vs geosmin-d_3 and 1-ClC_{10}. The suitability of the labelled internal standards for the determination of other odorous algal metabolites was also investigated. Murrumbidgee River water spiked with four odour compounds (see materials and method) was analysed with addition of chloroalkanes, MIB-d_3 and geosmin-d_3 prior to stripping. The labelled compounds were as effective as chloroalkanes when added at the time of stripping giving comparable concentrations for each of the odour compounds. However, as for chlorodecane, the biodegradation rates of all compounds (i.e., target compounds and internal standards) differ sufficiently to preclude addition of the labelled standards at the time of sampling. The rapid loss of the four carbonyl compounds in our river water, also observed for lake water in Germany (Jüttner, 1984), suggests that these compounds may be less troublesome pollutants than MIB or geosmin because they biodegrade more rapidly (see Fig.3).

Natural geosmin vs synthetic geosmin-d_3. To be suitable as an internal standard that can be added in the field at the time of sampling, the rates of biological loss of a target compound and the internal standard must be identical. In our previous paper (Korth *et al.*, 1991) we showed synthetic MIB-d_3 could be added as an internal standard at the time of sampling. Because the synthetic compound is prepared from a chiral precursor ((+)-camphor), it is optically pure and has the same configuration (-) as MIB from natural sources (Wood and Snoeyink, 1977). Both materials were therefore biodegraded at the same rate. The synthetic geosmin-d_3 was racemic and, when added to a water sample spiked with synthetic geosmin, both materials were biodegraded at the same rate. However, one cannot assume that the rates of biodegradation of (+) and (-) geosmin are the same, and so an experimental study was made of the comparative rates of biodegradation of (-)-geosmin and (±)-geosmin-d_3. Geosmin from natural sources is (-) (Gerber, 1965). An aqueous solution of (-)-geosmin from a culture of *A. circinalis* was used to spike a Murrumbidgee River water sample, together

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with (±)-geosmin-d_3. 1-chlorodecane was added as internal standard at the time of analysis. The ratio of m/z 185/182 (molecular ion geosmin-d_3, molecular ion geosmin) increased slowly with storage time (by ca. 10% after 40 h). By measuring the residual concentration of (-)-geosmin and (±)-geosmin-d_3, the residual concentration of (+)-geosmin-d_3 and of (-)-geosmin-d_3 at each storage time can be calculated. Fig. 4 shows that the (+) enantiomer is biodegraded at a slightly lower rate than the (-) enantiomer. Thus, the initial concentrations were: (-)-geosmin 1238 ng/l and (±)-geosmin-d_3 1049 ng/l (i.e. 525 ng/l of (+)-geosmin-d_3 and 525 ng/l of (-)-geosmin-d_3). After 43 h the concentration of (-)-geosmin had fallen 41%, so the concentration of (-)-geosmin-d_3 must also have fallen 41%. The concentration of (-)-geosmin-d_3 after 43 h = 525 x 0.59 = 309 ng/l. The concentration of (±)-geosmin-d_3 at 43 h = 683 ng/l. Hence the concentration of (+)-geosmin-d_3 at 43 h = 683 - 309 = 374 ng/l. This had the effect of increasing the ratio of m/z 185/182 (and hence lowering the apparent initial concentration of (-)-geosmin in the water) with increasing storage times. However, such errors do not become serious until the geosmin concentration has been greatly reduced by biodegradation during storage and hence does not preclude the addition of the racemic labelled standard at the time of sampling.

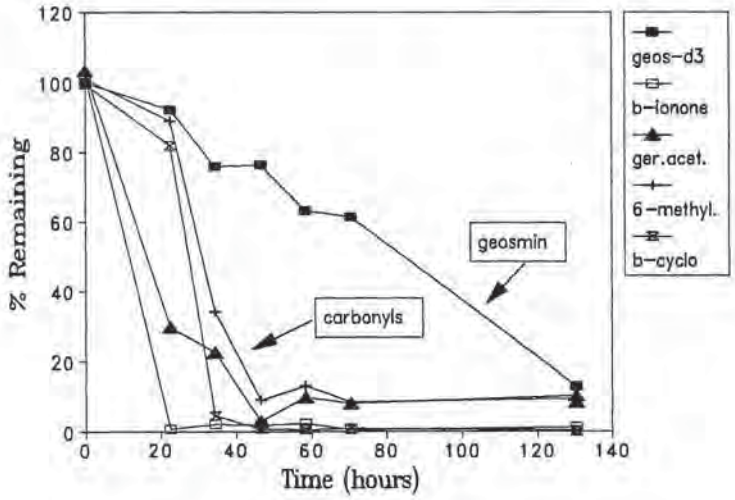


Figure 3 Biodegradation of carbonyl odour compounds and geosmin-d_3 in Murrumbidgee River water.

Even if the concentration of natural geosmin was allowed to degrade to 5% of the initial value an apparent concentration of 80% of the initial value could still be obtained. If however the degradation was kept below 10%, by storing the sample in the cold and in the dark, an apparent concentration greater than 95% of the initial value is achievable (see Fig.4). This source of error could potentially be avoided by using pure (-)-geosmin as the internal standard (obtained by stereoselective synthesis or by formation and separation of diastereoisomers at a suitable point in the geosmin-d_3 synthesis). Alternatively, a chiral GC column could be used to resolve the (+) and (-) enantiomers of geosmin-d_3 (or even of unlabelled (±)-geosmin).

We planned to test the chiral GC approach by using the labelled racemic geosmin as an internal standard added at the time of sampling to a water sample containing a known concentration of (-)-geosmin. A chiral column (J&W Cyclodex-B) was to be used to separate the optical isomers remaining after storing the water sample for varying times. The rate of biodegradation of the natural (-)-geosmin is the same as that of the (-)-geosmin-d_3 enantiomer of the racemic geosmin-d_3; the more slowly degraded (+)-geosmin-d_3 was expected to give a separate peak and thus not affect the m/z 185/182 ratio of the (-) enantiomer peak. Unfortunately

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initial experiments gave only partial separation of the racemate so the biodegradation trials could not proceed. Despite this, we were able to establish that commercial geosmin (from WAKO) and our synthetic geosmin (both labelled and unlabelled) are racemic. We were also able to establish that natural geosmin as produced in culture by *A. circinalis* (852E) is optically pure and elutes as the second peak on this column. Because the primary mode of separation of the cyclodextrin columns is by shape recognition (Nowotny *et al.*, 1989) the greater the difference in the shape of one enantiomer to the other the better the separation achievable. The lack of baseline resolution of racemic geosmin on this column indicates that the difference in shape between the 2 geosmin enantiomers is minimal. The reason for this is most likely due to the almost spherical shape of the molecule and the fact that the racemic carbon is towards the centre of the molecule. We are continuing our work in this area in an effort to increase the resolution of the two enantiomers. However even if the resolution of geosmin itself cannot be improved, these chiral columns potentially offer a unique opportunity to quantify other optically pure natural compounds using the opposite enantiomer of the synthetic racemic compound as an internal standard. If the synthetic racemate is labelled, then the same enantiomer could be used to quantify the natural unknown employing mass spectrometry to distinguish between the labelled and unlabelled enantiomers.

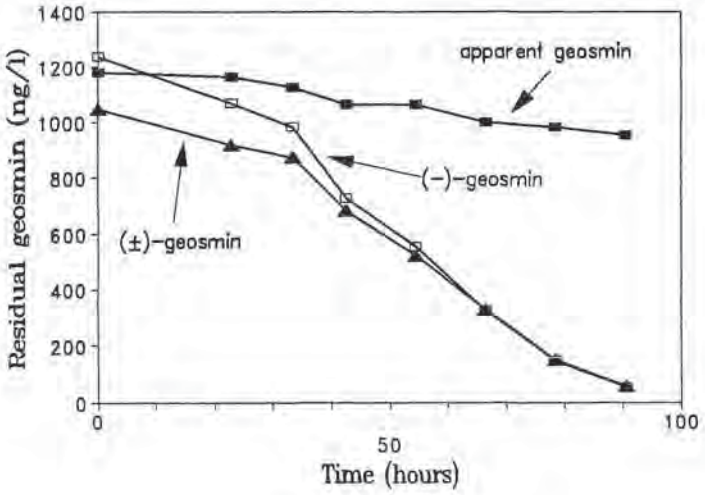


Figure 4 Geosmin biodegradation in Murrumbidgee River water stored at room temperature under normal light conditions.

CONCLUSION

We have extensively evaluated the suitability of MIB-d_3 and geosmin-d_3 and believe them to be ideal internal standards for the determination of MIB and geosmin in surface water using CLSA-GC-MS. Both geosmin and MIB may be stored as dilute solutions in acetone, ethanol, methanol, hexane or carbon disulphide for long periods without decomposition. Sunlight decomposes MIB dissolved in dichloromethane to give 2-methylenebornane and 2-methyl-2-bornene.

Standard solutions of geosmin-d_3 or MIB-d_3 in acetone can be added at the time of stripping to determine the concentration of other volatile compounds and provide results which are comparable with those obtained using

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chloroalkanes. They can be added at the time of sampling and will compensate for loss of MIB and geosmin during sample transport and storage. Even though some biological discrimination against the synthetic (+) enantiomer of geosmin is evident for our river water, it is not significant unless the sample is allowed to degrade substantially. These labelled compounds would also make excellent internal standards for the determination of MIB and geosmin in other matrices. Their identical physical and chemical behaviour during extraction procedures employed to isolate and concentrate them would mean that the precision and accuracy of the determination is maximized.

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Dissolved Organic Nitrogen as a Precursor for Chloroform, Dichloroacetonitrile, *N*-Nitrosodimethylamine, and Trichloronitromethane

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Nitrogen-containing disinfection byproducts (N-DBPs) are potentially toxic. This study assessed the formation of three N-DBPs (dichloroacetonitrile (DCAN), trichloronitromethane (TCNM), and *N*-nitrosodimethylamine (NDMA)) and one regulated DBP (chloroform) upon adding free chlorine and monochloramine into solutions containing different fractions (hydrophobic, transphilic, hydrophilic, and colloidal) of dissolved organic matter (DOM) isolates ($n = 17$). We hypothesized that N-DBP formation would increase for organic matter enriched in organic nitrogen. Formation potential tests were conducted with free chlorine or preformed monochloramine. Chloramination formed, on average, 10 times lower chloroform concentrations, but 5 times higher DCAN concentrations, as compared with free chlorine addition. The formation of the two halogenated N-DBPs (DCAN and TCNM) increased as the dissolved organic carbon (DOC) to dissolved organic nitrogen (DON) ratio decreased upon adding free chlorine, but the N-DBP formation was relatively constant upon adding monochloramine. NDMA, a nonhalogenated N-DBP, formed on average 0.26 nmol per mg of DOC (4.5 nmol per mg of DON) upon adding monochloramine; no NDMA formation occurred upon adding free chlorine. NDMA formation increased as the DOC/DON ratio decreased (i.e., increasing nitrogen content of DOM). NDMA formation also increased as the amino sugar to aromatic ratio of DOM increased. The results support the hypothesis that DON promotes the formation of N-DBPs.

Introduction

Chlorine and chloramines are widely used low-cost disinfectants in water treatment plants, distribution systems, and wastewater effluents. These disinfectants, however, form halogenated and nonhalogenated disinfection byproducts (DBPs) of potential human health concerns (*1*, *2*). Chloramination forms lower concentrations of regulated DBPs (i.e., trihalomethanes (THMs) and haloacetic acids (HAAs)) than chlorination but forms a larger percentage of unidentified total organic halides (TOX) (*3*–*7*).

In addition to the currently regulated DBPs, occurrence of nitrogen-containing DBPs (N-DBPs) (e.g., haloacetonitriles, halonitromethanes, and nitrosamines) has been reported (*8*–*10*). Although N-DBPs generally form at lower concentrations than THMs or HAAs, N-DBPs have been shown to be more carcinogenic and mutagenic than the currently regulated DBPs (THMs and HAAs) (*11*–*13*). Thus, N-DBPs are an emerging concern during the disinfection of drinking water, wastewater, and reclaimed water.

Dissolved organic matter (DOM) reacts with chlorine or chloramines to form N-DBPs. Numerous formation mechanisms, based largely on model compound studies, have been proposed for individual N-DBP species. Dichloroacetonitrile (DCAN) and other haloacetonitriles can be produced from the chlorination of free amino acids (*14*), heterocyclic nitrogen in nucleic acids (*15*), proteinaceous materials, and combined amino acids bound to humic structures (*16*, *17*). Many organic nitrogen compounds and humic acids have been shown to be trichloronitromethane (TCNM) precursors in drinking water (*18*). Generally, the accepted formation mechanisms of *N*-nitrosodimethylamine (NDMA) and related nitrosamines are nitrosation of organic nitrogen precursors (e.g., dimethylamine) by nitrous acid and/or nitrite (*19*, *20*) or a reaction between monochloramine and organic amines (e.g., dimethylamine) (*21*, *22*). NDMA formation is theoretically governed by a rate-limiting step involving the oxidation of DOM (*23*) and is generally enhanced when monochloramine is used for disinfection as compared to free chlorine (*21*, *22*).

Although some studies have suggested organic nitrogen moieties of DOM (i.e., measured in bulk as dissolved organic nitrogen (DON)) as the likely precursors for N-DBPs in drinking water (*16*–*18*, *24*), controlled studies are lacking for N-DBP formation from chlorination versus chloramination of DOM. DON analysis is more analytically challenging to quantify than dissolved organic carbon (DOC) (*25*). Therefore, most studies of DBP formation rely upon DOC and/or UV absorbance measurements to quantify DBP organic precursors (*26*, *27*). Little is known about the role of DON in DBP formation, and precursors leading to N-DBP formation in the water treatment system remain unclear.

This study assessed the role of DON in the formation of N-DBPs (DCAN, TCNM, and NDMA) and a regulated DBP (chloroform) upon adding free chlorine or monochloramine. Under controlled laboratory conditions for chlorination or chloramination, formation potential experiments were conducted with solutions containing different fractions (hydrophobic, transphilic, hydrophilic, and colloidal) of DOM isolates, dissolved in nanopure water with only a pH buffer added (i.e., no bromide or inorganic nitrogen). To determine if DOM characteristics affect N-DBP formation, we correlated DBP yields with DOC/DON ratios, amino acid contents, and pyrolysis gas chromatography-mass spectrometry (pyrolysis GC-MS) analysis data.

Experimental Procedures

DOM Isolates and Solutions. DOM was isolated at the Université de Poitiers on a variety of source waters from the U.S. and France. Methods detailing the DOM isolation procedures and isolate characterization are provided elsewhere (*28*). Solutions containing DOM were prepared by dissolving fractionated DOM isolates in deionized water (NANOpure Infinity) and sonicated prior to filtration through

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TABLE 1. DOC/DON Ratios, SUVA Values, THAA Content, and Pyrolysis GC-MS Analysis of DOM Isolate Solutions[a]

						proportion (%) in the pyrolysis GC-MS analysis				
sample ID	source	type of fraction	DOC/DON (mg of C/mg of N)	SUVA $(m^{-1}(mg/L)^{-1})$	THAA content (nmol/mg of DOC)	aromatics (%)	polysaccharides (%)	amino sugars (%)	proteins (%)	unknown (%)
1	Britanny River	HPO	19	3.4	159	43	12	10	15	20
2	Colorado River	HPO	36	2.2	n/a	34	15	5	25	21
3	Naintre WWTP Effluent	HPO	14	2.4	912	25	5	14	31	25
4	Ribou Reservoir	HPO	21	2.3	204	25	21	6	33	15
5	Seine River	HPO	15	3.0	848	29	8	28	23	12
6	South Platte River	HPO-A	26	3.0	157	45	13	6	19	19
7	Nordic Lake	FA	58	5.0	n/a	n/a	n/a	n/a	n/a	n/a
8	Britanny River	TPI	11	1.5	557	14	13	25	36	12
9	Colorado River	TPI	15	1.0	n/a	19	16	23	27	15
10	Ribou Reservoir	TPI	9	1.3	264	n/a	n/a	n/a	n/a	n/a
11	Nordic Lake	TPI-A	45	4.0	n/a	n/a	n/a	n/a	n/a	n/a
12	Suwannee River	TPI-A	40	3.5	143	n/a	n/a	n/a	n/a	n/a
13	South Platte River	TPI-N	6	0.9	n/a	13	4	17	57	9
14	Suwannee River	TPI-N	28	2.8	471	40	35	7	11	7
15	Suwannee River	HPIA+N	28	2.2	n/a	45	15	5	20	15
16	Naintre WWTP Effluent	colloids	9	4.6	4529	12	11	38	32	7
17	Ribou Reservoir	colloids	10	3.7	n/a	6	34	30	24	6

[a] HPO: hydrophobic; HPO-A: hydrophobic acid; FA: fulvic acid; TPI: transphilic; TPI-A: transphilic acid; TPI-N: transphilic neutral; and HPIA+N: hydrophilic acid plus neutral.

ashed (at 500 °C) glass fiber filters (GF/F; pore size = 0.7 μm; Millipore Corp.). The colloidal DOM isolates were not filtered. Table 1 summarizes the sources and characteristics of DOM isolates. DOC/DON ratios of DOM isolates ranged from 6 to 58 mg of DOC per mg of DON. Specific ultraviolet absorbance (SUVA) values ranged from 1 to 5 $m^{-1}(mg/L)^{-1}$. SUVA, the measurement of UV absorbance at 254 nm divided by the DOC concentration, indicates the degree of aromaticity of DOM (*29*). Solutions were bromide-free; nitrate, nitrite, and ammonia concentrations of solutions were measured to be less than the detection limits, 5 μg/L as N.

Chlorination and Chloramination of DOM Isolates. Hypochlorite solutions (Fisher Scientific) were diluted and used to prepare free chlorine and to preform monochloramine stock solutions. Monochloramine stock solutions were prepared daily by mixing hypochlorite and ammonia chloride solutions (both solutions preadjusted to pH 8.3) at a ratio of 0.8 mol/mol. The monochloramine stock solution was refrigerated for at least 3 h before use. Solutions containing DOM isolates at a DOC concentration of 3 mg/L were chlorinated and chloraminated in sealed 1 L amber glass bottles at 20 °C in darkness. Free chlorine DBP formation potential experiments were conducted following the approach of Reckhow et al. (*17*), using a dose of 5 mg of Cl_2 per mg of DOC with a reaction time of 7 days (pH 7.0 with 5 mM phosphate buffer). Monochloramine DBP formation potential experiments were conducted following the approach of Mitch et al. (*30*), using a high dose of 45 mg of Cl_2 per mg of DOC with a reaction time of 10 days (pH 7.0 with 10 mM phosphate buffer), which was based upon logic similar to that behind the THM formation potential test. When the preformed monochloramine was added into DOM solutions at pH 7, part of the monochloramine converted to dichloramine (<5%); however, the majority of chloramines was still monochloramine. Because of the limited amount of DOM, duplicated DBP formation potential tests were conducted on only one select DOM isolate (#3).

Analytical Methods. At the end of the chlorine or chloramine reaction, residual disinfectants were measured by the total and free DPD (*N,N*-diethyl-*p*-phenylenediamine) colorimetric method 4500-Cl G (*31*). The disinfectant residuals were quenched with ammonium chloride, and the aliquots were preserved at pH 4.8–5.5 (phosphate buffer) for the subsequent THM, haloacetonitrile (HAN), and TCNM analyses. For NDMA analysis, the disinfectant residuals were quenched with sodium thiosulfate, and the aliquots were preserved at pH < 2 (hydrochloric acid). DBPs were analyzed by the City of Phoenix Laboratory Services using EPA Method 551.1 (*32*) for THMs (chloroform, bromoform, and total THM), HANs (dichloroacetonitrile, trichloroacetonitrile, dibromoacetonitrile, and bromochloroacetonitrile), and TCNM (also known as chloropicrin). NDMA was analyzed by the MWH Laboratory Services using a GC-MS based on EPA Method 1625/625 that was modified (*33*). In brief, the method consists of continuous liquid–liquid extraction including the addition of NDMA-d_6 as an isotope dilution standard. The final extract was analyzed by chemical ionization mass spectrometry (GC-MS-SIM). Detection limits for THMs, HANs, TCNM, and NDMA are 21, 4, 3, and 0.03 nmol/L, respectively.

Ultraviolet spectroscopy was measured by a Shimadzu UV–vis spectrophotometer, MultiSpec-1501 (Shimadzu Corp.). A Shimadzu TOC-V_{CSH} analyzer (high-temperature combustion at 720 °C; nondispersive infrared detection) with a TNM-1 TN unit (chemiluminescence detection) (Shimadzu Corp.) simultaneously measured DOC and total dissolved nitrogen (TDN). The DON concentration was calculated by the difference in TDN and dissolved inorganic nitrogen (ammonia, nitrate, and nitrite). Ammonia was measured by the automated phenate method (SM 4500-NH_3 G) (*31*) using a TRAACS 800 autoanalyzer (Bran-Luebbe). Nitrate and nitrite were measured using a Dionex DX-120 ion chromatography system (Dionex Corp.). Ammonia, nitrate, and nitrite concentrations of all the DOM isolate solutions were below the detection limit, 5 μg/L as N.

Amino acid and pyrolysis GC-MS analysis were conducted at the Université de Poitiers. Hydrolyzable amino acids were analyzed by HPLC after acid hydrolysis (6 N HCl for 6 h) and precolumn derivatization using the 6-aminoquinolyl-*N*-hydroxysuccinimidyl carbamate (AQC) derivatization agent. The reaction between AQC and amino acids (primary and secondary amino acids) leads to the formation of highly fluorescent complexes that can be analyzed using fluorescence emission detection (*34*). Pyrolysis of DOM samples was conducted using a Pyroprobe 2000 Chemical Data Systems filament pyrolyzer according to the procedure of Gadel and Bruchet (*35*). Other details of the configuration and setup of the HPLC and pyrolysis GC-MS systems and operational conditions are described elsewhere (*34*).

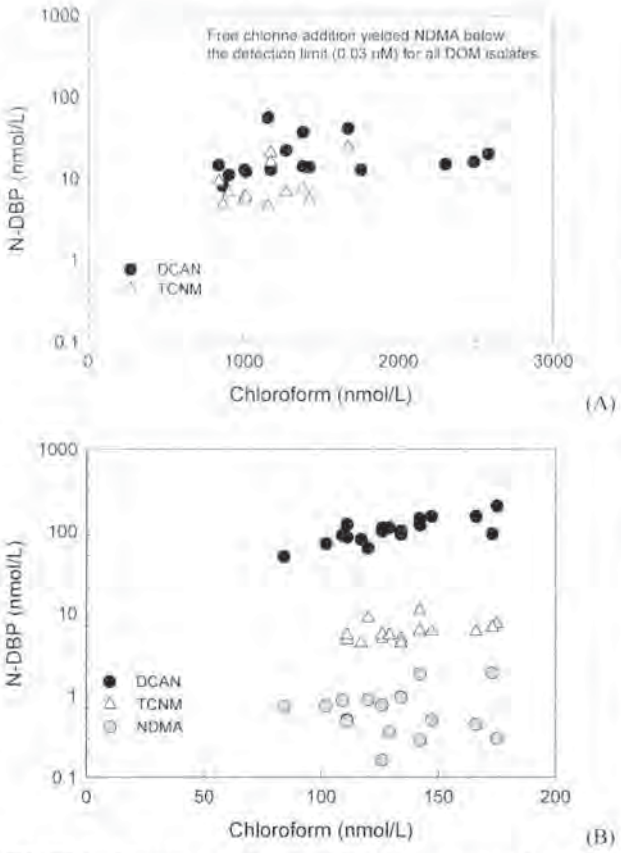


FIGURE 1. Nitrogenous DBPs vs chloroform concentrations from (A) chlorination (dose = 5 mg of Cl_2/mg of DOC; 7 days at pH 7.0) and (B) chloramination (dose = 45 mg of Cl_2/mg of DOC; 10 days at pH 7.0) of DOM isolate solutions. Five samples from (A) chlorination and three samples from (B) chloramination exhibited TCNM concentrations below the detection limit (3 nM).

Results

Residual free chorine or monochloramine concentrations were measured at the end of the formation potential incubation times. The residual concentrations of monochloramine were relatively constant in all samples: 3−10 mg/L as Cl_2. Free chlorine consumption was slightly higher in colloids (2.7 mg of Cl_2/mg of DOC) than in other fractions:−transphilic (TPI) (2.4 mg of Cl_2/mg of DOC), hydrophilic (HPI) (2.2 mg of Cl_2/mg of DOC), and hydrophobic (HPO) (2.1 mg of Cl_2/mg of DOC). DBP concentrations for each DOM isolate after formation potential tests are summarized in the Supporting Information Table 1. From both chlorination and chloramination, only chlorinated (not brominated) analogues were observed. Chloroform was the only THM species formed; DCAN was the only HAN species formed. The relative standard deviation from the selected duplicated experiment (isolate #3) was <5% each on chloroform, DCAN, and NDMA and <10% on TCNM. Chloroform, DCAN, NDMA, and TCNM concentrations of chlorinated and chloraminated nanopure water (blank) were below the detection limits.

DCAN, TCNM, and NDMA concentrations upon chlorination or chloramination of DOM isolate solutions were plotted as a function of chloroform formation potentials (Figure 1). Overall, no significant correlation was observed between N-DBP and chloroform formation potential. Only the DCAN formation potential correlates with chloroform upon chloramination (correlation coefficient, $r = 0.75$). On a molar basis, chloroform was the dominant DBP formed upon chlorination of DOM isolate solutions. Chloroform concentrations formed upon chlorination were, on average, 10 times higher than levels formed during chloramination.

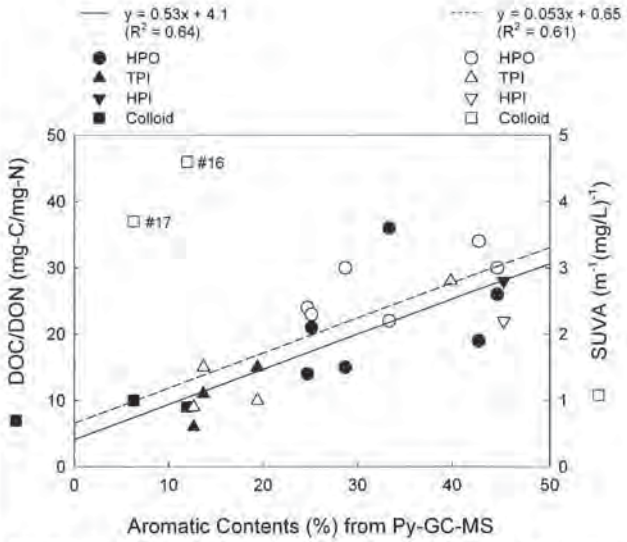


FIGURE 2. DOC/DON ratios (solid symbol, solid line) and SUVA (open symbol, dashed line; colloids are excluded) as a function of percentage of aromatic compounds.

Among N-DBPs, DCAN concentrations were highest, followed by TCNM and NDMA. DCAN concentrations from chlorination were 5 times lower than for chloramination. Average chloroform and DCAN concentrations upon chloramination were 130 and 106 nmol/L, respectively. NDMA concentrations upon adding monochloramine in DOM isolate solutions ranged from 0.16 to 1.87 nmol/L, with an average of 0.74 nmol/L. Free chlorine addition in DOM isolate solutions resulted in NDMA below the detection limit (0.03 nmol/L) for all DOM isolates. TCNM concentrations formed during both chlorination and chloramination were similar (~6 nmol/L).

Table 1 summarizes the amino acid content and pyrolysis GC-MS analysis data of each DOM isolate. Isolates obtained from wastewater treatment plant effluents (isolates #3 and #16) exhibited a higher total hydrolyzable amino acid (THAA) content than other DOM isolates. Detailed analysis data for 17 amino acids for each isolate are presented in the Supporting Information Table 2. The TPI fraction was more enriched in neutral amino acids as compared to its corresponding HPO fraction. The HPO fraction was more enriched in acidic amino acids as compared with its corresponding TPI fraction.

The pyrolysis GC-MS analysis indicated that both TPI and colloid fractions were enriched with amino sugars and proteins, while HPO fractions were enriched with aromatic compounds. Colloid fractions contained less aromatic compounds than we expected from their SUVA values, suggesting a scattering of UV light at 254 nm by colloids rather than UV absorbance by carbon−carbon double bonds. Excluding colloid fractions, SUVA values positively correlated ($r = 0.78$) with the proportion of aromatic compounds from the pyrolysis GC-MS analysis (Figure 2). The DOC/DON ratio correlated ($r = 0.80$) with the proportion of aromatic compounds. DOM isolates with higher SUVA values and DOC/DON ratios contained larger amounts of aromatic compounds. Therefore, DOM isolates enriched with organic nitrogen (low DOC/DON ratio) had lower SUVA values, lower aromaticity, and greater amounts of amino acids and proteinaceous materials.

Discussion

Chloroform Yields. Since DBP formation potential tests were conducted at specific doses of free chlorine or monochloramine per DOC, the DBP formation potential is discussed based on yields relative to DOC. The chlorination of DOM isolates

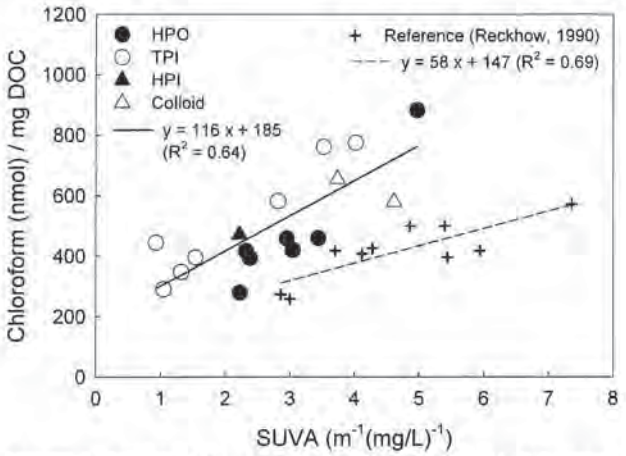


FIGURE 3. Specific chloroform yields as a function of SUVA values from chlorination of DOM isolate solutions (dose = 5 mg of Cl_2/mg of DOC; 7 days at pH 7.0).

formed 273−882 nmol/mg of DOC of chloroform with an average of 500 nmol/mg of DOC. The chloroform yields were independent of the nitrogen content (i.e., DOC/DON ratio) of the isolates. Instead, the chloroform yields correlated with SUVA values ($r = 0.80$ (R^2 for regression = 0.64) with all data (Figure 3) and $r = 0.82$ ($R^2 = 0.67$) excluding colloids (Supporting Information Figure 1)). The aromatic compound content of DOM from pyrolysis GC-MS analysis is less correlated with chloroform yields ($r = 0.40$) (Table 2). Colloids ($n = 2$) were excluded for the correlation analysis because of their extremely high THAA content and misleading SUVA values. As expected from previous studies (*26, 27*), hydrophobic compounds are likely to form chloroform upon adding free chlorine to DOM solutions. The results from ref *17* with similar chlorination conditions but shorter contact times (3 days) than our study (7 days) exhibited similar trends on chloroform yields over SUVA values (Figure 3). The difference in chloroform yields was related to the reaction duration and is discussed further in the following section together with DCAN formation.

Monochloramination of DOM isolates formed much lower levels of chloroform than free chlorine and was independent of nitrogen content; the chloroform yields ranged from 35 to 60 nmol/mg of DOC with an average of 46 nmol/mg of DOC. Neither DOC/DON ratios nor DOM fraction types exhibited a relationship with chloroform yields from chloramination. SUVA values positively correlated with chloroform yields ($r = 0.62$). Overall, the SUVA value was a better parameter than DOC, DON, and the DOC/DON ratio to estimate chloroform yields from chlorination or chloramination of DOM.

Halogenated N-DBP (DCAN and TCNM) Yields. Two colloidal (#16 and #17) and one TPI (#13) DOM isolates

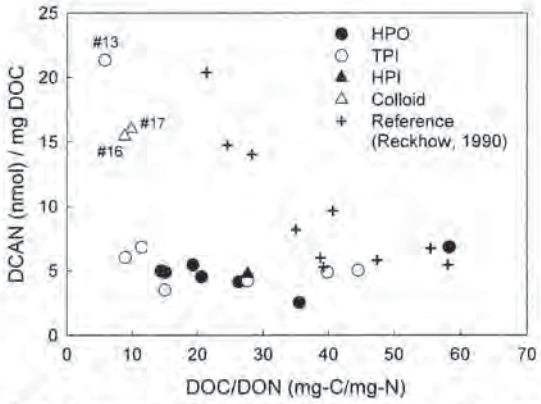


FIGURE 4. Specific DCAN yields from chlorination of DOM isolates (dose = 5 mg of Cl_2/mg of DOC; 7 days at pH 7.0).

exhibited higher DCAN yields (15−21 nmol/mg of DOC) than other isolates (3−7 nmol/mg of DOC) (Figure 4). The three isolates were enriched with organic nitrogen (DOC/DON ratios of 6−10 mg of C/mg of N) as compared to the other isolates. The results from ref *17* for HPO isolates also exhibited similar trends on DCAN yields over DOC/DON ratios. Pyrolysis GC-MS analysis data showed that proteins and protein/aromatic ratios positively correlated with DCAN yields (Table 2). The results indicate that organic nitrogen moieties of DOM are precursors for DCAN upon chlorination. Unlike the previous studies with model compounds (*36, 37*), however, our findings exhibited no significant correlation between DCAN yields and THAA for each amino acid species. DCAN yields upon adding monochloramine ranged from 20 to 70 nmol/mg of DOC with an average of 38 nmol/mg of DOC, which are higher than the yields upon adding free chlorine. DCAN yields upon adding monochloramine did not correlate with organic nitrogen content or with amino acid content of DOM, which suggests that the nitrogen from monochloramine is important in DCAN formation upon chloramination.

Figure 5 presents the chloroform/DCAN yield ratios as a function of the DOC/DON ratios. Upon adding free chlorine, the ratio of chloroform/DCAN increased as a function of the DOC/DON ratio. Therefore, DOM isolates with a higher nitrogen content had a lower chloroform and higher DCAN formation as compared to DOM isolates with a smaller nitrogen content. The results from ref *17* with similar chlorination conditions but shorter (3 days) contact times than our study (7 days) exhibited a similar trend on chloroform/DCAN over DOC/DON ratios, but the chloroform/DCAN values were lower than those in our study. DCAN in the presence of free chlorine slowly reacts to form dichloroacetamide, which then hydrolyzes to form dichloroacetic acid (*24*). Thus, over time, DCAN levels lead to higher chloroform/DCAN ratios. The correlation observed between

TABLE 2. Summary of Correlation Coefficients (r) from Correlation Analysis of DBP Formation Results with Amino Acid Content ($n = 9$) and Pyrolysis GC-MS Analysis ($n = 11$)[a]

	DBP yields (DBP/DOC)						
	HOCl addition			NH_2Cl addition			
component	chloroform	DCAN	TCNM	chloroform	DCAN	TCNM	NMDA
THAA/DOC	−0.33	0.11	0.29	0.33	0.03	0.55	0.38
aromatics (%)	0.40	−0.52	−0.19	−0.11	0.57	0.00	−0.71[b]
polysaccharides (%)	0.38	−0.46	−0.19	−0.30	−0.07	−0.11	−0.05
amino sugars (%)	−0.23	0.22	0.46	0.45	−0.09	0.68[b]	0.41
proteins (%)	−0.26	0.82[b]	0.03	−0.07	−0.49	−0.37	0.48
amino sugars/aromatics	−0.25	0.49	0.16	0.30	−0.36	0.27	0.69[b]
protein/aromatics	−0.13	0.88[b]	−0.06	−0.02	−0.46	−0.33	0.55

[a] Colloid fractions were excluded for the correlation analysis. [b] Significant at 95% confidence level.

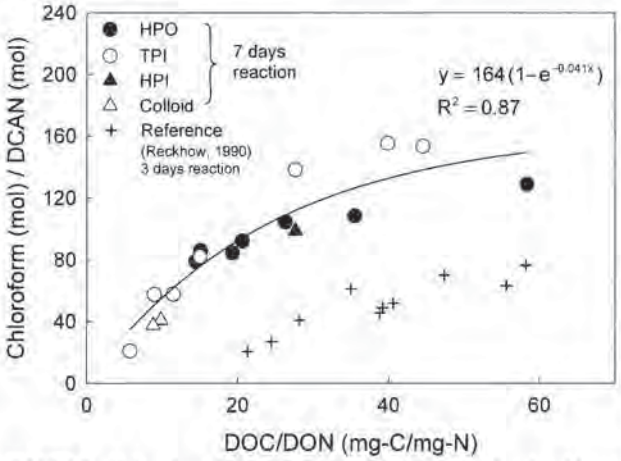


FIGURE 5. Chloroform/DCAN vs DOC/DON from chlorination (dose = 5 mg of Cl_2/mg of DOC; 7 days at pH 7.0).

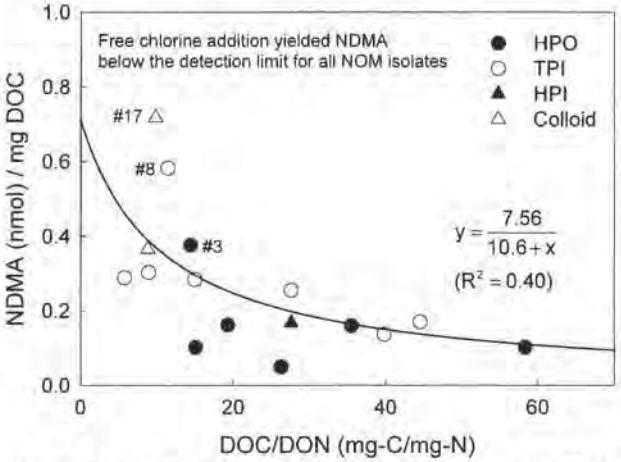


FIGURE 6. Specific NDMA yields from chloramination of DOM isolates (dose = 45 mg of Cl_2/mg of DOC; 10 days at pH 7.0).

chloroform/DCAN and DOC/DON for free chlorine was not observed during monochloramine experiments. Upon adding monochloramine, chloroform/DCAN ratios were relatively constant at 1.4 mol of chloroform/mol of DCAN (i.e., chloroform yields were proportional to the DCAN yields) regardless of DOC/DON ratios. Monochloramine does not react with DCAN, so DCAN accumulates.

TCNM yields (TCNM/DOC) averaged 2 nmol/mg of DOC on both chlorination and chloramination. TCNM yields upon adding free chorine were higher, with lower DOC/DON ratios; these are similar to DCAN yields. Upon adding monochloramine, TCNM yields exhibited no distinct relationship with DOC/DON ratios. Instead, they correlated ($r = 0.68$) with the amino sugar content (Table 2).

Nonhalogenated N-DBP (NDMA) Yields. NDMA exhibited a different pattern from the halogenated DBPs (DCAN and TCNM). NDMA did not form upon adding free chlorine to the DOM isolate solutions; NDMA formed on average 0.26 nmol/mg of DOC upon adding monochloramine to the DOM isolate solutions (Figure 6). This observation confirms that in the absence of NO_3^-, NO_2^-, or NH_4^+, monochloramine is essential in forming NDMA. Previous studies using model organic nitrogen compounds indicate NDMA formation upon adding free chlorine to the dimethylamine (DMA) solution (*22*, *38*). However, this was not the case with chlorination of bulk organic nitrogen (DON) based upon our results. The presence of free chlorine may enhance the NDMA formation with nitrite present through nitrosation mechanisms (*38*). Our study goals did not include investigating the role of nitrite on NDMA formation during chlorination or chloramination of DOM. High NO_2^- concentrations are unlikely to occur in most drinking water systems. The results imply that the reaction between DOM and monochloramine can form NDMA without nitrous acid or nitrite present and that increasing the DON content will likely form more NDMA.

On the basis of the chloramination results, the organic nitrogen content of DOM correlated with the NDMA formation potential (Figure 6). The NDMA yield decreased as a function of an increasing DOC/DON ratio (i.e., decreasing nitrogen content) of the DOM isolates. The colloidal DOM isolates, and other nitrogen-enriched isolates, exhibited the highest NDMA yields as compared to hydrophobic acid isolates. In addition to the DOC/DON ratio, NDMA formation positively correlated with amino sugar/aromatic ratios ($r = 0.69$ excluding colloids; $r = 0.81$ with all data) (Supporting Information Figure 2) but negatively correlated with the aromatic compound content ($r = -0.71$ excluding colloids; $r = -0.79$ with all data). It is not possible to compare our results with data from ref *30* on which the chloramination conditions were based because the authors did not report DOC or DON concentrations of their samples. Overall, nitrogen moieties of both DOM and monochloramine play important roles in NDMA formation.

Implication. DON can serve as a precursor material for N-DBPs. More nitrogen incorporated into DCAN and NDMA with monochloramine than with free chlorine. From chlorination, the percentages of nitrogen converted from DOM into DCAN and TCNM were 0.1−0.6 and <0.01−0.2%, respectively. Upon chloramination, the percentages of N incorporated into DCAN, TCNM, and NDMA were 0.2−5.6, <0.01−0.2, and 0.004−0.021%, respectively. Overall, the nitrogen content of DOM affects chlorinated N-DBP yields, and the DOC/DON ratios could be simply applied to estimate the formation. The application of chloramines can reduce chloroform formation but elevate N-DBP formation. The presence of nitrogen can elevate the toxicity of DBPs (*11*−*13*), and this could be one of the major drawbacks of chloramine application in drinking water systems. Clearly, a key to controlling N-DBP formation is treating the nitrogen-enriched DOM fractions prior to chloramination.

N-DBP formation upon chloramination is possibly more complicated than chlorination since both inorganic and organic nitrogen can contribute to DBP formation. The literature lacks information on the role of inorganic and organic nitrogen in N-DBP formation. Further investigation using isotopes (e.g., N^{15} labeled compounds) may require differentiating the role of organic and inorganic nitrogen in N-DBP formation during chloramination.

Acknowledgments

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Supporting Information Available

Two tables (DBP concentrations after formation potential tests and amino acid content of DOM isolates) and two figures (specific chloroform yields as a function of SUVA values and NDMA yields from chloramination of DOM isolates vs amino sugars/aromatics ratios). This material is available free of charge via the Internet at http://pubs.acs.org.

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PRIMARY RESEARCH PAPER

The influence of environmental conditions on the seasonal variation of *Microcystis* cell density and microcystins concentration in San Francisco Estuary

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Abstract A bloom of the cyanobacteria *Microcystis aeruginosa* was sampled over the summer and fall in order to determine if the spatial and temporal patterns in cell density, chlorophyll *a* (chl *a*) concentration, total microcystins concentration, and percent microcystins composition varied with environmental conditions in San Francisco Estuary. It was hypothesized that the seasonal variation in *Microcystis* cell density and microcystin concentration was ecologically important because it could influence the transfer of toxic microcystins into the aquatic food web. Sampling for *Microcystis* cell density, chl *a* concentration, total microcystins concentration and a suite of environmental conditions was conducted biweekly at nine stations throughout the freshwater tidal and brackish water regions of the estuary between July and November 2004. Total microcystins in zooplankton and clam tissue was also sampled in August and October. *Microcystis* cell density, chl *a* concentration and total microcystins concentration varied by an order of magnitude and peaked during August and September when P_m^B and α^B were high. Low streamflow and high water temperature were strongly correlated with the seasonal variation of *Microcystis* cell density, total microcystins concentration $(\text{cell})^{-1}$ and total microcystins concentration $(\text{chl } a)^{-1}$ in canonical correlation analyses. Nutrient concentrations and ratios were of secondary importance in the analysis and may be of lesser importance to seasonal variation of the bloom in this nutrient rich estuary. The seasonal variation of *Microcystis* density and biomass was potentially important for the structure and function of the estuarine aquatic food web, because total microcystins concentration was high at the base of the food web in mesozooplankton, amphipod, clam, and worm tissue during the peak of the bloom.

Keywords *Microcystis* · Estuary · Microcystins · Food web · Seasonal variation

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Introduction

Microcystis aeruginosa (*Microcystis*) is a common freshwater cyanobacterium in freshwater lakes and reservoirs worldwide (Federal Environmental Agency, 2005). It also occurs in rivers that form estuaries including the Potomac River and the Neuse River in the USA, the Swan River in Australia and the Guadiana River in Spain and Portugal (Sellner et al., 1988; Pearl, 1988; Rocha et al., 2002; Orr et al., 2004).

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Microcystis is considered a cyanobacterial harmful algal bloom (CHAB) species because it produces surface scums that impede recreation sports, reduce aesthetics, lower dissolved oxygen concentration and cause taste and odor problems in drinking water (Carmichael, 1995). *Microcystis* also produces toxic microcystins that are powerful hepatotoxins associated with liver cancer and tumors in humans and wildlife (Carmichael, 1995).

The toxicity of *Microcystis* blooms negatively impact phytoplankton, zooplankton, and fish production directly or indirectly through the transfer or accumulation of toxins in the food web (Kotak et al., 1996; Ibelings et al., 2005; Sedmak & Elersek, 2005; Malbrouck & Kestemont, 2006). *Microcystis* also affects aquatic community structure and function by impacts on feeding success or food quality for zooplankton and fish (Rohrlack et al., 2005; Malbrouck & Kestemont, 2006). The abundance of cyanobacteria further affects total carbon production by causing a shift from large to small zooplankton species (Fulton & Pearl, 1987; Smith & Gilbert, 1995).

Microcystis blooms vary over the summer and fall in response to environmental factors that influence bloom initiation and those that sustain bloom growth. Since *Microcystis* does not contain heterocysts that produce nitrate from atmospheric nitrogen, both high nitrogen, and phosphorus are needed for blooms to develop (Pearl et al., 2001). Bloom initiation requires water temperature above 20°C (Jacoby et al., 2000), but accumulation of high biomass, requires long residence time for this slow growing species (Reynolds, 1997). Blooms also develop faster in vertically stable environments that allow the buoyant *Microcystis* colonies to rise to the surface of the water column where they out compete other phytoplankton for light (Huisman et al., 2004). Other factors such as high pH and turbidity or low carbon dioxide concentration enhance growth of *Microcystis* over other phytoplankton once the bloom is established, but are not required for bloom initiation or growth (Shapiro, 1990). Most of the information on the importance of environmental factors for *Microcystis* bloom development and persistence is obtained from freshwater lakes and reservoirs, less is known about the relative importance of environmental factors in estuaries, particularly nutrient-rich estuaries like San Francisco Estuary (SFE).

The cause of *Microcystis* blooms and their potential impact on estuarine productivity is an important concern for SFE where a bloom of *Microcystis* first appeared in 1999 (Lehman et al., 2005). Little is known about the seasonal variation of *Microcystis* cell density, biomass and toxic microcystin concentration, the environmental factors that affect the seasonal variation of the bloom or its impact on the structure and function of the estuarine food web. Data from a single sampling day in October 2003 indicated *Microcystis* was widely distributed across the freshwater to brackish water reaches of the estuary and contained the hepatotoxic microcystin-LR (Lehman et al., 2005). The bloom was associated with high and non-limiting nitrogen and phosphorus concentration, high water temperature and high water transparency but values from this single sampling day were not sufficient to assess the importance of these variables. The presence of total microcystins in zooplankton and clam tissue also suggested the toxins in the bloom might impact the aquatic food web.

The purpose of this study was to quantify the seasonal variation of *Microcystis* cell density, chlorophyll *a* (chl *a*) concentration, microcystins concentration and the presence of microcystins in the tissues of lower aquatic food web organisms and to determine how these variables are influenced by environmental conditions in SFE. Understanding the influence of environmental conditions on the seasonal variation of the *Microcystis* bloom and its associated microcystins concentration is potentially important for management of fishery production in SFE, where the food web is dependent on phytoplankton and zooplankton production and characterized by a long-term decrease in fish, zooplankton and diatom carbon (Lehman, 2004; Sommer et al., 2007).

Materials and methods

Study area

SFE consists of an inland delta that flows into a chain of downstream marine bays—Suisun, San Pablo and San Francisco—and creates one of the largest estuaries on the west coast of North America (Fig. 1). The inland delta formed by the Sacramento River (SAC) on the north and the San Joaquin River (SJR)

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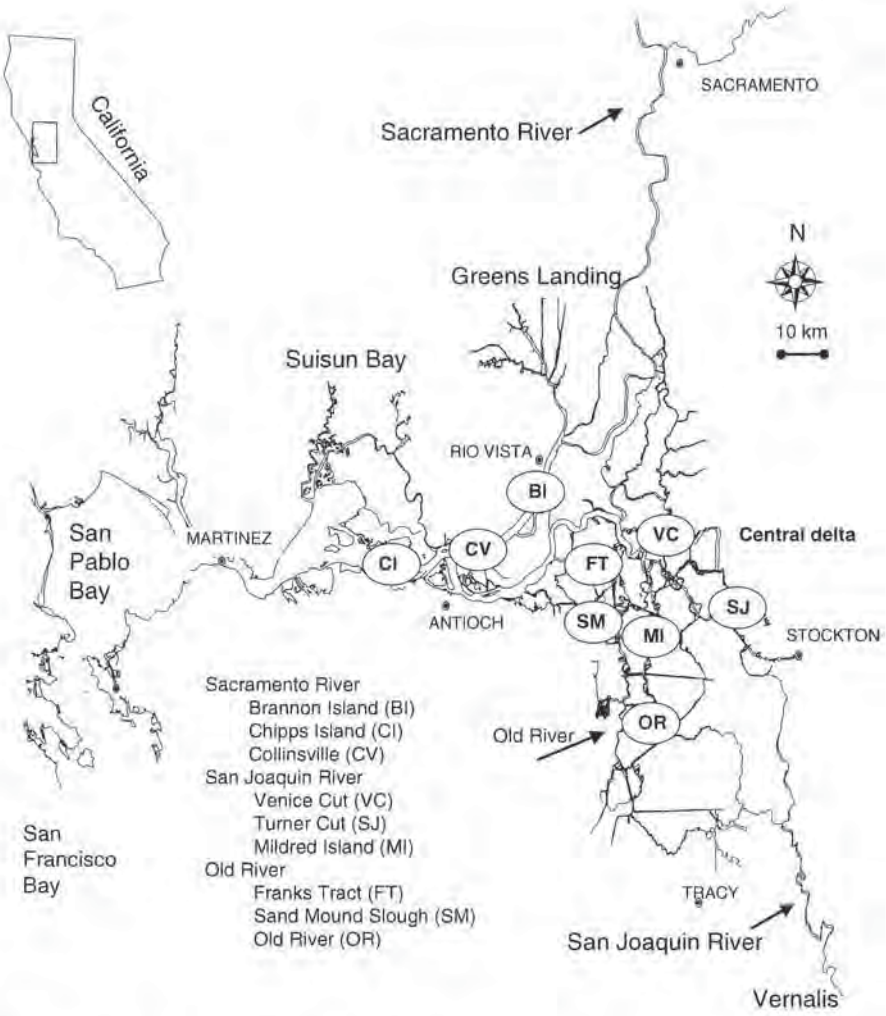


Fig. 1 Map of San Francisco Estuary showing location of sampling stations

on the south contains 200 km^2 of waterways. SAC is the largest of the rivers with an average discharge of 4795 $m^3 s^{-1}$ compared with 400 $m^3 s^{-1}$ for SJR over the July through October period of this study. Other rivers influence streamflow in the delta including the Mokelumne (MOKE) and Cosumnes (CSR) Rivers with average discharge of 21 $m^3 s^{-1}$and 6 $m^3 s^{-1}$, respectively. An important feature of the delta is the large amount of water removed for agriculture that causes average reverse streamflow of 1578 $m^3 s^{-1}$ in Old River (ODR) and 1339 $m^3 s^{-1}$ in SJR during August and September (http://www.waterdata.usgs.gov/nwis). Depth varies in the delta from a few meters in the flooded islands in the center of the delta to 13 m in the main river channels. Tides in the delta reach 2 m in height with tidal velocities up to 30 cm s^{-1} and tidal excursions of 10 km.

Field and laboratory sampling

Chl *a* concentration, *Microcystis* cell density and microcystin (total and individual) concentration were sampled biweekly between July 13 and November 3, 2004 at nine stations throughout the freshwater to brackish water reaches of SFE. Selected stations represented different habitat types or beneficial use including recreational swimming (BI), shallow water habitat (MI and FT), deep river channel (CV, VC and SM), native fish habitat (SJ and CI) and agricultural and drinking water supply (OR; Fig. 1). *Microcystis* colonies were sampled by horizontal surface tows of a 0.72 m diameter plankton net fitted with a 75-μm mesh screen (Lehman et al., 2005). Use of a smaller mesh net (40 μm) was not possible because the net became clogged with heavy sediment. Water

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temperature, specific conductance, pH, dissolved oxygen, and turbidity were also measured at each station using a Yellow Springs Instrument (YSI) 6600 sonde. Depth of the euphotic zone was estimated from Secchi disk depth. Photosynthetically active surface irradiance (PAR) was measured at 15 min intervals in Langleys at Antioch, CA using an Eppley phyrohelliometer (http://www.iep.water.ca.gov). Langleys were converted to mole quanta using linear correlation with LiCOR quantum sensor values ($r^2 = 0.91$; $P < 0.01$).

Surface water samples were collected by van Dorn water sampler and immediately stored at 4°C. Algal biomass was filtered within 2 h onto Millipore APFF glass fiber filters (0.7 μm pore diameter). Filters for microcystins analysis were folded, wrapped in aluminum foil and frozen at −80°C until analysis. Filters for chl *a* (corrected for phaeophytin) and phaeophytin analysis were treated with 1 ml of saturated magnesium carbonate solution as a preservative and frozen at −14°C until analysis (method 10200H, APHA et al., 1998). Phytoplankton for identification and enumeration were preserved and stained with Lugol's iodine solution and species were counted at 700X using the inverted microscope technique (Utermöhl, 1958). Sample replication was 10%.

Water samples for dissolved ammonium, nitrate-plus-nitrite, soluble reactive phosphorus, and silicate concentration were filtered through 0.45 μm pore size Millipore HATF04700 nucleopore filters. Filtered samples plus raw water samples for total phosphorus were stored at −14°C until analysis by colorimetric techniques (US EPA, 1983; USGS, 1985). Total suspended solids concentration was determined by standard methods (APHA et al., 1998). Daily average streamflow, air temperature, and water temperature were obtained from hourly data collected by the Interagency Ecological Program (http://www.iep.water.ca.gov).

Net primary productivity and community respiration (phytoplankton and bacteria) were measured for a single station each sampling day by 4–6 h incubations at 0.075 m depth near Antioch, CA (Fig. 1) using the dissolved oxygen light and dark bottle incubation technique (Vollenweider, 1974). Values obtained from incubating bottles in a light gradient were used to compute the photosynthetic capacity from the chl *a* specific light saturated rate of photosynthesis (P_m^B, mg C (mg chl *a*)$^{-1}$ h^{-1}), the photosynthetic efficiency from the chl *a* specific initial slope (α^B; mg C (mg chl *a*)$^{-1}$ (mole quanta m^{-2})$^{-1}$) and the photoinhibition parameter from the chl *a* specific negative slope of the P–I curve above light saturation (β^B, mg C (mg chl *a*)$^{-1}$ (mole quanta m^{-2})$^{-1}$; Lehman et al., 2007). These parameters were used to compute integrated gross (GP_{ez}, mg C m^{-2} h^{-1}) and areal (GP_{ez}) primary productivity of the euphotic zone.

Zooplankton including mesozooplankton, amphipods, worms, and jellyfish were sampled at CV, SM, SJ, and MI by horizontal tows of a 0.7 m diameter plankton net fitted with a 150 μm mesh. Zooplankton tissue was kept at 4°C and separated by pipette from *Microcystis* in the water sample using a dissecting microscope within 48 h of sampling. The final zooplankton tissue sample was rinsed in distilled water and frozen at −80°C until analysis. Clams were collected using a ponar dredge. The muscle tissue was removed from the shell, rinsed in distilled water and frozen at −80°C until analysis.

Microcystin analysis

Filters and animal tissue for microcystin analysis were extracted and assessed for total microcystins using the protein phosphate inhibition assay (PPIA). Samples with high levels of total microcystins were further analyzed by high pressure liquid chromatography (HPLC) to identify the specific microcystins in the sample (Lehman et al., 2005).

Statistical analysis

Statistical analyses included correlation and single and multiple comparisons using analysis of variance. Kruskal-Wallis nonparametric analysis of variance was used when the assumptions of the analysis (normally distributed data and homogeneity of variance) were not met. Canonical correlation analysis was computed using log-transformed values in order to minimize differences in variance produced by differences in absolute size and adjust for nonhomogeneity of variance among variables. All statistical analyses were computed using Statistical Analysis System software (SAS Institute Inc., 2004).

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Results

Microcystis spatial and temporal variation

Chl *a* concentration and *Microcystis* cell density in the net tow samples were greatest in SJR (Fig. 2). Average chl *a* concentration was 7-fold greater ($P < 0.05$) in SJR compared with SAC ($P < 0.05$; mean 97 ± 70, 34 ± 36, and 14 ± 18 ng l^{-1} for SJR, ORD and SAC, respectively). Among stations, chl *a* concentration was greatest ($P < 0.05$) at the shallow flooded island and slow moving river channel stations MI and SJ in SJR and lowest at the fast flowing river channels CI and CV in SAC. *Microcystis* cell density varied in a similar fashion to chl *a* concentration among rivers and was greatest ($P < 0.05$) in SJR followed by ODR and SAC (Fig. 2). Cell densities were low in the net tows and exceeded 20,000 cells ml^{-1} only three times at MI, two times at SJ and VC in SJR and once at OR and

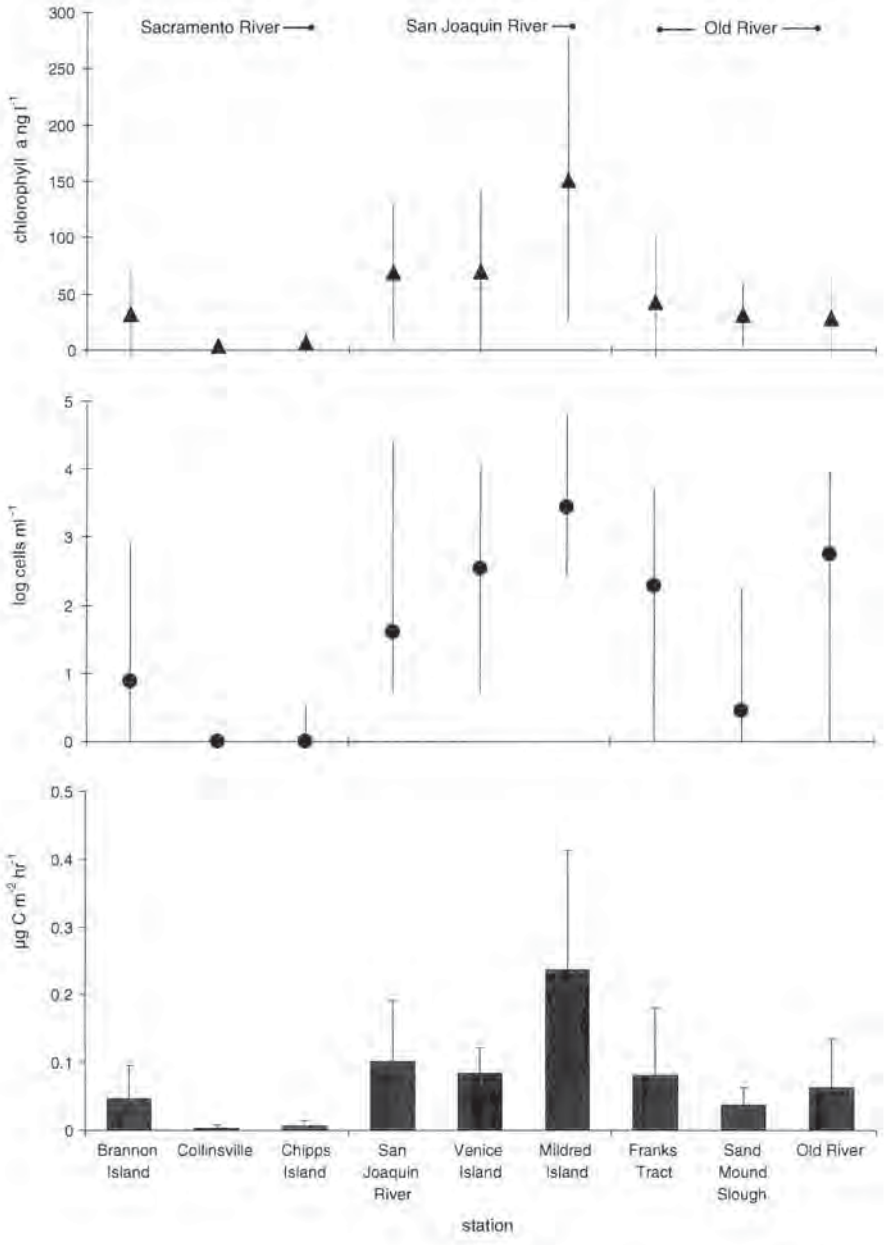


Fig. 2 Mean and standard deviation (vertical bar) of chlorophyll *a* concentration in the >75 µm algal size fraction, log *Microcystis* cell density and areal gross primary productivity in the euphotic zone at stations in San Francisco Estuary between July and October 2004

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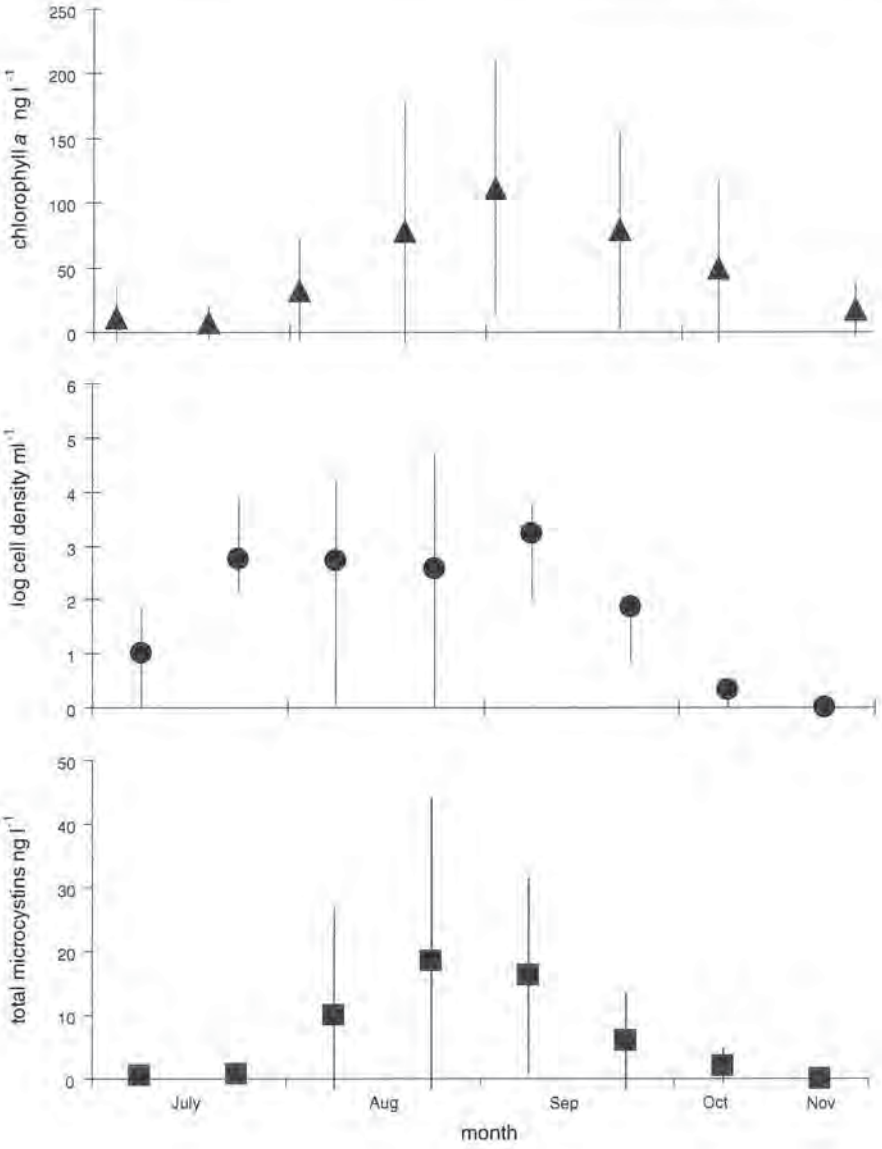


Fig. 3 Mean and standard deviation (vertical bar) of chlorophyll *a* concentration in the >75 μm algal size fraction, log *Microcystis* cell density ml^{-1} and total microcystins concentration among months between July and November 2004 in San Francisco Estuary

FT in ODR. The maximum cell density was 22,480,000 cells ml^{-1} at MI.

Average chl *a* concentration was 3-fold greater ($P < 0.05$) in August and September than July, October and November (75 ± 66 ng l^{-1} and 22 ± 29 ng l^{-1}, respectively; Fig. 3). This pattern differed somewhat among rivers, with peak chl *a* concentration occurring earlier ($P < 0.05$) in SJR (August) than SAC (September). Chl *a* concentration was equally high in August and September for ODR. Chl a concentration did not vary with *Microcystis* cell density which was consistently high ($P < 0.05$) between late July and early September (Fig. 3). *Microcystis* cell density also did not have a strong seasonal pattern among rivers except in SJR where cell density was greatest ($P < 0.05$) in August and September.

Areal GP_{ez} was greater ($P < 0.01$) at stations in SJR and ODR than SAC (141 ± 70, 67 ± 26 and 19 ± 24 ng C m^{-2} h^{-1}, respectively; Fig. 2) but did not differ among rivers when normalized to chl *a* concentration. Areal GP_{ez} and GP_{ez} normalized to chl *a* concentration were also greatest ($P < 0.01$) in September even though respiration $(\text{chl } a)^{-1}$ was highest that month. The seasonal variation of GP_{ez} mirrored changes in the photosynthetic parameters P_m^B, α^B and β^B which were high in August and

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Table 1 Photosynthetic parameters and respiration normalized to chlorophyll *a* concentration computed from the photosynthesis-irradiance curve and light and dark bottle dissolved oxygen incubations for three stations sampled between August and October, 2004

Date	Sampling station	P_m^B mg C (mg chl *a*)$^{-1}$ hr^{-1}	α^B mg C (mg chl *a*)$^{-1}$ (mole quanta m^{-2})$^{-1}$	β^B mg C (mg chl *a*)$^{-1}$ (mole quanta m^{-2})$^{-1}$	Respiration mg C (mg chl *a*)$^{-1}$ hr^{-1}
August 27	Franks Tract	1.15 ± 0.12	2.52 ± 0.15	0.11 ± 0.07	−0.73 ± 0.06
September 9	Old River	2.38 ± 0.33	1.54 ± 0.26	0.11 ± 0.11	−1.76 ± 0.07
September 28	Mildred Island	2.13 ± 0.50	0.88 ± 0.37	–	−0.88 ± 0.03
October 18	Old River	0.36 ± 0.03	0.42 ± 0.10	0.06 ± 0.01	−0.10 ± 0.07

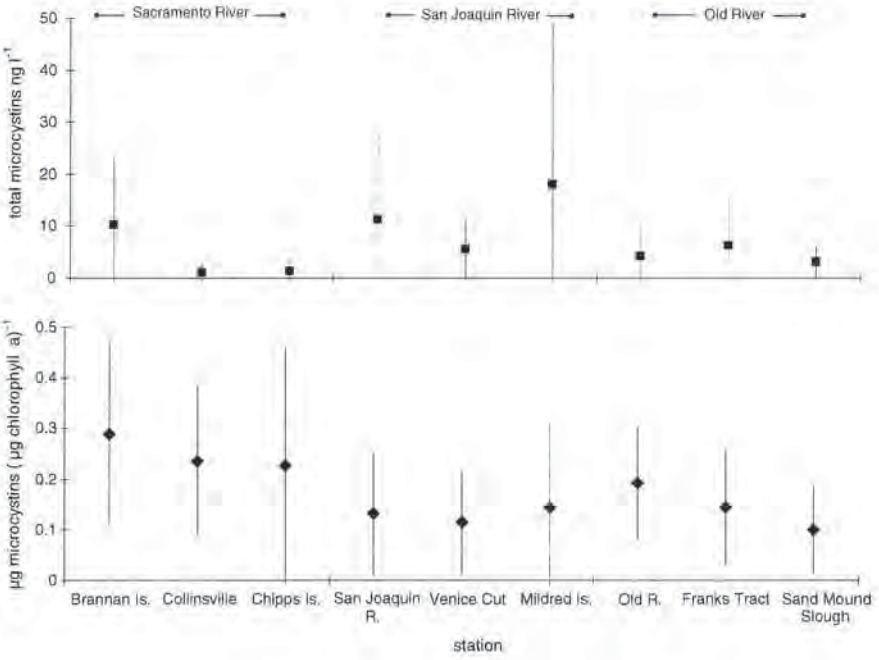


Fig. 4 Mean and standard deviation (vertical bar) of total microcystins concentration and total microcystins (chl *a*)$^{-1}$ for stations in the San Francisco Estuary between July and November 2004

September (Table 1). However, the seasonal variation in primary productivity and the photosynthetic parameters was large. Areal GP_{ez} varied by two orders of magnitude while P_m^B and α^B varied 6-fold (Fig. 4; Table 1). By comparison, there was a little seasonal variation in β^B which varied by a factor of 2.

Microcystins concentration

Total microcystins concentration ranged from 0.01 ng l^{-1} to 81 ng l^{-1} in net tows and was 2-fold greater ($P < 0.05$) in SJR than the other rivers (Fig. 4). This contrasted with total microcystins concentration (chl *a*)$^{-1}$ which was 2-fold greater ($P < 0.05$) in SAC compared with SJR. Among months, average total microcystins concentration was an order of magnitude greater ($P < 0.05$) in August and September for the whole estuary (12.64 ± 17.46 ng l^{-1} and 0.85 ± 1.56 ng l^{-1}, respectively; Fig. 3), but the monthly pattern differed among rivers. Total microcystins concentration was greatest ($P < 0.05$) in August for SJR and September for SAC and was equally high in August and September for ODR. Total microcystins (chl *a*)$^{-1}$ did not differ among months for SAC and ODR but was greater ($P < 0.05$) in August for SJR.

A suite of 11 microcystins contributed to the spatial and temporal variation in total microcystins concentration (Fig. 5). Microcystin-LR comprised the greatest percent (54%) of the total microcystins at all stations followed by microcystin-unknown 1 (14%) and microcystin-LA (11%). The percent

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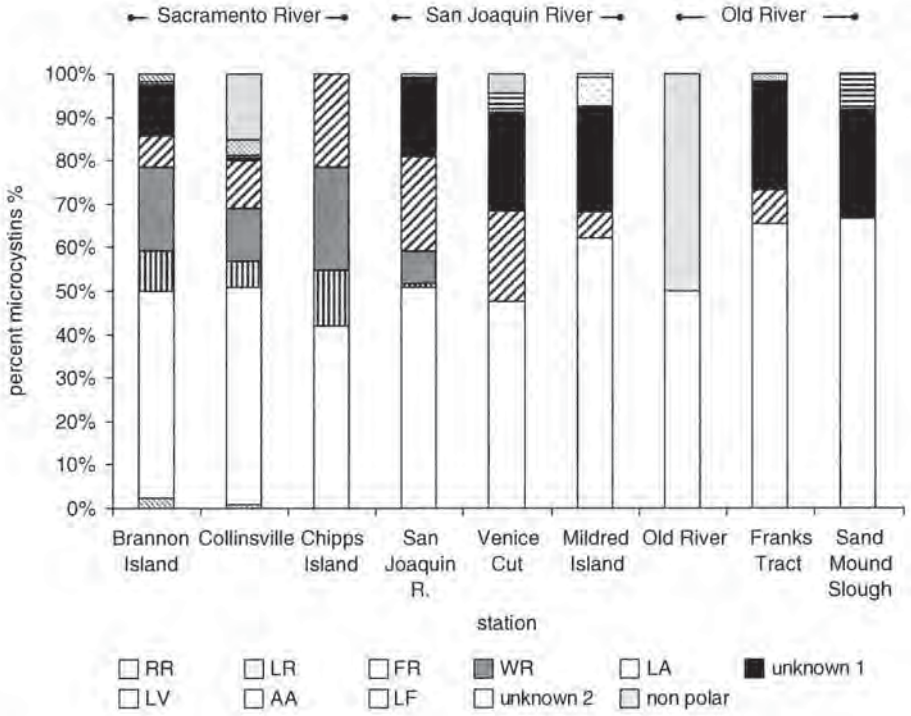


Fig. 5 Average percent composition of microcystin congeners in algal tissue between July and November 2004 in San Francisco Estuary

composition of most microcystins did not differ significantly among rivers, except for microcystin-FR and microcystin-WR which were an order of magnitude greater ($P < 0.01$) in SAC and microcystin-LA which was at least 2-fold greater ($P < 0.05$) in SJR than ODR.

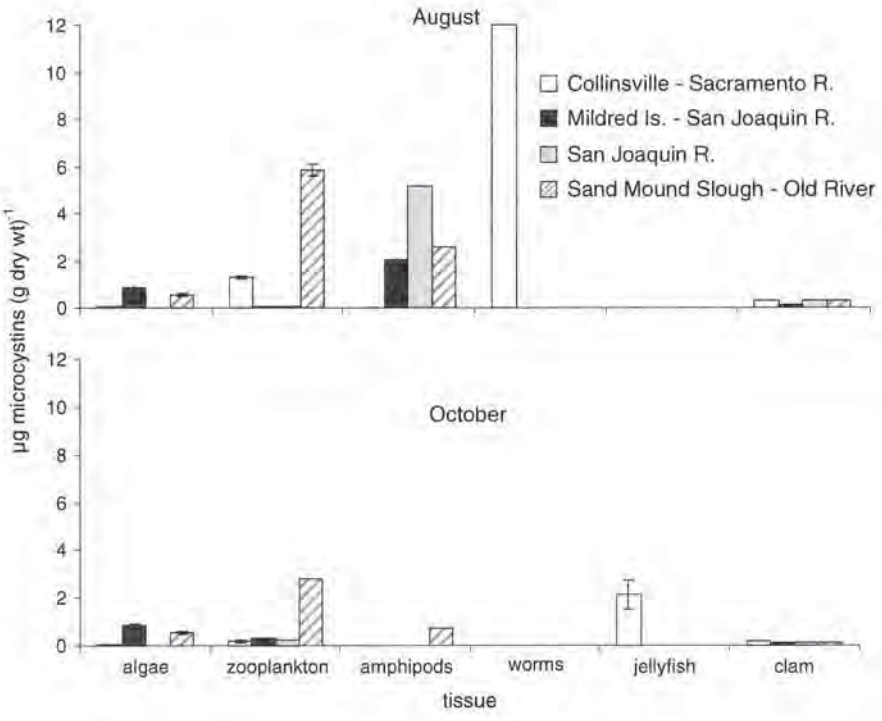


Fig. 6 Total microcystins concentration in algal and animal tissue at four stations in the San Francisco Estuary during August and October 2004

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The microcystin composition was also seasonally variable among rivers. Microcystin-LA was greatest ($P < 0.05$) in July for SJR. Both microcystin-FR and microcystin-WR were greatest ($P < 0.05$) in October for SAC while microcystin-LR was greatest ($P < 0.05$) in October for SJR and ODR. Further, the number of microcystins present at the stations varied over the season with a larger average number ($P < 0.01$) of microcystins occurring between September and November (2.0 ± 1.4) than between July and August (1.3 ± 1.8).

The total microcystins in the tissues of lower food web animals was generally greater in August during the peak of the bloom and lowest in October during the decline of the bloom (Fig. 6). Total microcystins in animal tissue also varied widely among animals and was often higher in worms and amphipods than mesozooplankton (12 ± 0.00, 2.62 ± 1.88, 1.34 ± 2.05 μg microcystins (g dry wt.)$^{-1}$, respectively). However, average total microcystins concentration in mesozooplankton tissue (e.g, *Eurytemora affinis* and *Pseudodiaptomus forbesii*) was still 3–6 fold greater than in the algae (*Microcystis* and surface algae) and clam tissue (0.50 ± 0.37 and 0.21 ± 0.10 μg microcystins (g dry wt.)$^{-1}$, respectively). Among rivers, total microcystins concentration in mesozooplankton tissue appeared to be greater in ODR than SAC and SJR (5.8 ± 1.70, 0.18 ± .65, 0.15 ± 11 μg microcystins (g dry wt.)$^{-1}$, respectively). A more quantitative statistical comparison of the spatial and temporal variation in total microcystins content in animal tissue was precluded by small sample size; two samples per animal type per station.

Environmental factors

Chl *a* concentration and *Microcystis* cell density varied with physical and chemical conditions among rivers. The greatest chl *a* concentration and cell density occurred in SJR which had the lowest chloride, low total suspended solids and soluble reactive phosphorus concentration and high nitrate concentration (Table 2). The second highest chl *a* concentration and cell density occurred in ODR which like SJR had low chloride and total suspended solids concentration, but also had relatively low nitrogen and phosphorus concentration and high specific conductance. SAC with the greatest total microcystins concentration (chl *a*)$^{-1}$ had the highest chloride, total suspended solids and dissolved nitrogen and phosphorus concentration and the lowest specific conductance among rivers. These differences in chemical conditions were accompanied by differences in streamflow which was an order of magnitude greater ($P < 0.05$) for SAC than SJR. Water temperature was not significantly different among rivers.

Microcystis growth rate in the euphotic zone also varied with physical and chemical conditions. GP_{ez}

Table 2 Mean and standard deviation of physical and chemical variables measured for the Sacramento, San Joaquin and Old Rivers between July and November 2004

Variable	Sacramento River	San Joaquin River	Old River	Significance at $P < 0.05$ level
Chloride (mg l^{-1})	1259.81 ± 1175.95	34.91 ± 21.21	121.54 ± 48.64	1, 2, 3
Specific conductance (μS cm^{-1})	4.18 ± 3.72	66.25 ± 126.24	123.92 ± 261.17	1&2, 2&3
Secchi disk depth (cm)	60.67 ± 20.50	129.37 ± 37.66	139.73 ± 26.29	1, 2, 3
Total suspended solids (mg l^{-1})	20.60 ± 11.14	3.80 ± 2.06	3.79 ± 1.75	1&2, 1&3
Water temperature (°C)	19.84 ± 2.83	21.03 ± 3.68	20.95 ± 3.52	None
Nitrate (mg l^{-1})	0.32 ± 0.07	0.36 ± 0.22	0.19 ± 0.10	1&3, 2&3
Ammonia (mg l^{-1})	0.06 ± 0.03	0.05 ± 0.04	0.02 ± 0.02	1, 2, 3
Total phosphorus (mg l^{-1})	0.10 ± 0.02	0.08 ± 0.03	0.06 ± 0.01	1, 2, 3
Soluble reactive phosphorus (mg l^{-1})	0.08 ± 0.09	0.05 ± 0.01	0.05 ± 0.01	1&2, 1&3
N:P molar ratio	12.19 ± 3.63	15.97 ± 7.49	9.25 ± 4.59	1&3, 2&3
S:N molar ratio	20.76 ± 4.88	24.07 ± 10.59	35.93 ± 13.89	1&3, 2&3

Significant differences between rivers at the $P < 0.05$ level are indicated by a comma

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increased with water temperature ($r = 0.56$, $P < 0.01$) and decreased with specific conductance and chloride ($r = -0.49$, $P < 0.01$ and $r = -0.68$, $P < 0.01$, respectively). GP_{ez} was also correlated with streamflow but the direction of the correlation differed among rivers with a positive correlation for SAC ($r = 0.46$, $P < 0.01$) and a negative correlation for SJR ($r = -0.51$, $P < 0.01$). The difference in these correlations may be due to the correlation between streamflow, dissolved salts, and water temperature. Streamflow was positively correlated with water temperature and negatively correlated with specific conductance and chloride ($r = 0.70$, $P < 0.01$; $r = -0.45$, $P < 0.01$; $r = -0.30$, $P < 0.01$, respectively) in SAC. In contrast, streamflow was negatively correlated with water temperature and positively correlated with specific conductance in SJR ($r = -0.74$, $P < 0.01$ and $r = 0.32$, $P < 0.01$). The streamflow pattern also differed between SAC and SJR with consistently low streamflow ($P < 0.05$) in SJR, but a gradual decrease in streamflow ($P < 0.05$) over the bloom season in SAC. GP_{ez} was also negatively correlated with total irradiance in the euphotic zone as suggested by the negative correlation between GP_{ez} and Secchi disk depth ($r = -0.24$, $P < 0.05$). This contrasted with the negative correlation between total suspended solids or dissolved solids and GP_{ez} ($r = -0.35$, $P < 0.01$ and $r = -0.67$, $P < 0.01$, respectively). GP_{ez} was also negatively correlated ($P < 0.05$) with ammonium, nitrate and soluble reactive phosphorus concentration and the N:P ratio. Nutrient concentration (Table 2) remained above limiting values for dissolved inorganic nitrogen, soluble reactive phosphorus and silica of 0.02 mg l^{-1}, 0.002 mg l^{-1} and 0.15 mg l^{-1}, respectively (Jassby, 2005). Average N:P ratios were also less than 16 between July and November and less than 10 during the peak of the bloom in August and September.

Canonical correlation analysis

Microcystis cell density was strongly correlated with streamflow and water temperature in canonical correlation analysis. Eleven water quality and seven streamflow variables that were significantly ($P < 0.05$) correlated with *Microcystis* cell density were included in the canonical correlation analysis (Table 3). The canonical environmental variable created from these variables was significant and described 59% ($P < 0.01$) of the variation in *Microcystis* cell density between July and November. Standardized coefficients for each variable suggested high streamflow in the eastern delta, low streamflow in the SJR, SAC and MOKE, high water diversion near the city of Contra Costa and high water temperature accounted for most of the variability in cell density. However, correlation between individual environmental variables and the canonical environmental variable suggested water temperature ($r = 0.56$, $P < 0.01$), Si:N ratio ($r = -0.52$, $P < 0.01$), ammonium concentration ($r = -0.51$, $P < 0.01$) and streamflow in the MOKE and SJR ($r = -0.50$, $P < 0.01$ and $r = -0.45$, $P < 0.01$, respectively) contributed to the variance described by the canonical environmental variable.

Table 3 Standardized coefficients for variables on the first significant canonical environmental variable computed by canonical correlation analysis to describe the variability of *Microcystis* cell density for data collected between July and November 2004

Variable	Standardized coefficient
Microcystis cell density	
East side streamflow	4.77
Contra Costa Canal pumping	1.31
Water temperature	1.04
Total dissolved solids	0.92
Silica:phosphorus molar ratio	0.48
Old River agricultural diversion	0.46
Total phosphorus	−0.05
Nitrate	−0.12
Ammonia	−0.17
Specific conductance	−0.21
N:P molar ratio	−0.43
Total suspended solids	−0.48
Miscellaneous agricultural diversions	−0.54
Chloride	−0.73
SI:N molar ratio	−0.78
Mokelumne River streamflow	−1.99
Sacramento River streamflow	−2.20
San Joaquin River streamflow	−3.03
Variance explained	59%

The streamflow variables in the canonical analysis were correlated ($P < 0.05$) with a larger set of measured and computed streamflow variables

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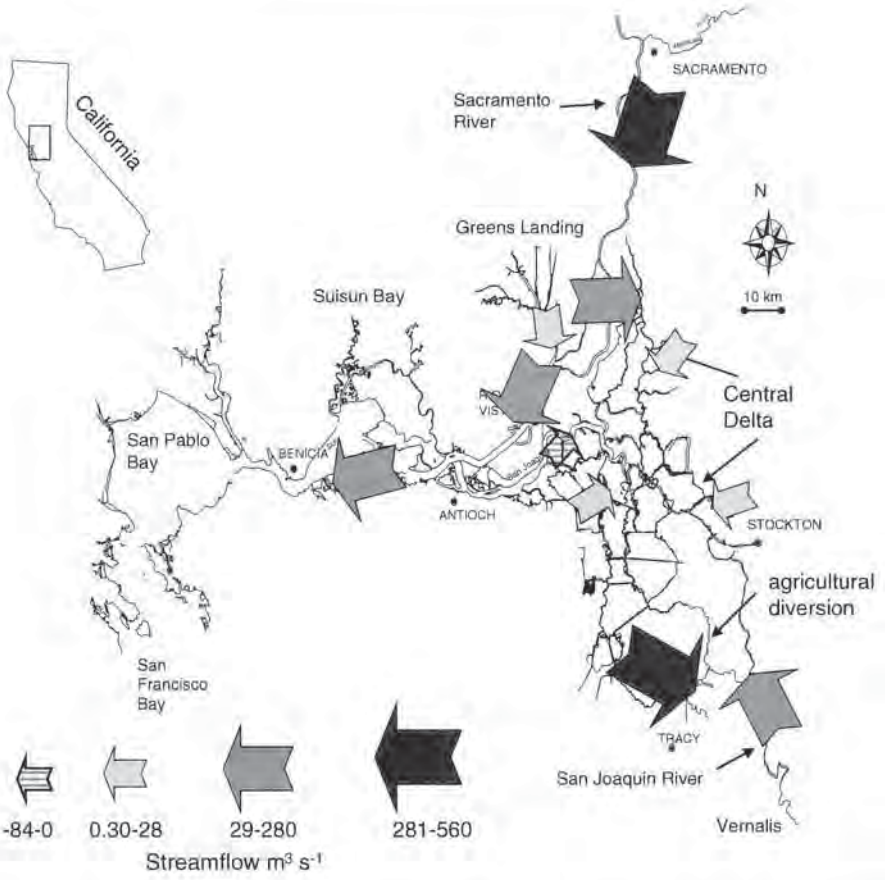


Fig. 7 Map of San Francisco Estuary indicating the mean of selected streamflow variables for August and September 2004

available for the estuary including the Sacramento, Cosumnes, Mokelumne, and San Joaquin Rivers flow, east side tributary flow, Contra Costa, State Water Project and Central Valley Project water diversion flow and streamflow past Jersey Point, and Rio Vista (http://www.iep.water.ca.gov). When these streamflow variables were averaged over August and September, high *Microcystis* cell density coincided with relatively low streamflow in the central delta, high streamflow in SAC, moderate streamflow in SJR and reversed (upstream arrow) streamflow in the southern delta produced by high diversion flow (Fig. 7).

The correlation between environmental conditions and *Microcystis* cell density varied among rivers. In SJR, *Microcystis* cell density was positively correlated with MOKE streamflow ($r = 0.52$, $P < 0.01$) and negatively correlated with agricultural diversion near the city of Tracy and the N:P ratio ($r = -0.67$, $P < 0.01$; $r = -0.47$, $P < 0.05$). In ODR, *Microcystis* cell density was negatively correlated with streamflow in the MOKE ($r = -0.52$, $P < 0.01$) and SJR ($r = -0.52$, $P < 0.01$) and positively correlated with water temperature ($r = 0.52$, $P < 0.01$) and Secchi disk depth ($r = 0.42$, $P < 0.05$). In SAC, *Microcystis* cell density was positively correlated with both water temperature ($r = 0.65$, $P < 0.01$) and Secchi disk depth ($r = 0.47$, $P < 0.05$).

Microcystis also occurred within a narrow range of environmental conditions. *Microcystis* cells first appeared when water temperature reached 20°C. *Microcystis* cells were present at total suspended solids concentrations between 100 mg l^{-1} and 500 mg l^{-1}, specific conductance between 0.1 mS cm^{-1} and 0.3 mS cm^{-1}, Si:N ratios between 20 and 50 and ammonium concentration between 0.01 mg l^{-1} and 0.03 mg l^{-1}. *Microcystis* cells also occurred, when streamflow was 28.32–35.40 m^3 s^{-1} in SJR and 0.85–1.13 m^3 s^{-1} in MOKE.

Total microcystins concentration $(cell)^{-1}$ and total microcystins $(chl\ a)^{-1}$ were also strongly correlated with streamflow in separate canonical correlation

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Table 4 Standardized coefficients for variables on the first significant canonical environmental variable computed by canonical correlation analysis to describe the variability of total microcystins $(cell^{-1})$ and total microcystins $(chlorophyll\ a)^{-1}$ for data collected between July and November 2004

	Standardized coefficient
Microcystins $(cell)^{-1}$	
East side streamflow	4.77
Contra Costa Canal pumping	1.31
Water temperature	1.04
Total dissolved solids	0.92
Silica:phosphate molar ratio	0.48
Old River agricultural diversion	0.46
Total phosphorus	−0.05
Nitrate	−0.12
Ammonia	−0.17
Variance explained	59%
Microcystins $(chlorophyll\ a)^{-1}$	
Specific conductance	−0.21
Nitrogen:phosphate molar ratio	−0.43
Total suspended solids	−0.48
Miscellaneous agricultural diversions	−0.54
Chloride	−0.73
Silica:nitrogen molar ratio	−0.78
Mokelumne River streamflow	−1.99
Sacramento River streamflow	−2.20
San Joaquin River streamflow	−3.03
Variance explained	32%

analyses (Table 4). Nine water quality and streamflow variables that were significantly ($P < 0.05$) correlated with total microcystins concentration $(cell)^{-1}$ produced a significant ($P < 0.01$) canonical environmental variable that described 32% ($P < 0.01$) of the variation in total microcystins $(cell)^{-1}$. Large standardized coefficients within the canonical environmental variable suggested east side streamflow, municipal water diversion at the city of Contra Costa and water temperature were positively correlated with microcystins concentration $(cell)^{-1}$. A somewhat different set of nine water quality and streamflow variables were correlated with total microcystins $(chl\ a)^{-1}$. These variables described 59% ($P < 0.01$) of the variance in total microcystins concentration $(chl\ a)^{-1}$. Large standardized coefficients on the significant canonical environmental variable indicated total microcystins concentration $(chl\ a)^{-1}$ was greater at low streamflow in SJR, SAC, and MOKE.

Environmental constancy

Environmental variability may further influence the seasonal variation of *Microcystis* cell density and total microcystins concentration. *Microcystis* cell density was greater in August and September when the variance in daily streamflow was low ($P < 0.05$; Table 5). The greatest number of microcystins occurred in September and October ($P < 0.01$)

Table 5 Coefficients of variation computed for daily streamflow and water temperature between July and October for locations throughout the estuary

	Coefficient of variation			
	July (%)	August (%)	September (%)	October (%)
Streamflow				
San Joaquin River	9	10	6	36
Sacramento River	5	6	10	18
Mokelumne River	64	16	9	23
East streamflow	8	8	6	35
Agricultural diversion	5	6	10	17
Total agricultural export	12	5	8	21
Significantly different	*			*
Water temperature				
San Joaquin River	2	2	5	9
Sacramento River	2	2	5	9
Significantly different			*	*

Significant difference in variance at the $P < 0.01$ level are indicated by a star (*)

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during the decline of the bloom when the variance in daily water temperature was highest ($P < 0.01$). The variance in daily water temperature was influenced by daily air temperature which were correlated at Stockton on the San Joaquin River ($r = 0.50$, $P < 0.01$, $n = 96$) and Rio Vista on the Sacramento River ($r = 0.56$, $P < 0.01$, $n = 97$) between July and November 2004.

Discussion

Distribution

Microcystis occurred throughout SFE from freshwater habitats in SJR and ODR to brackish water habitats in SAC during the summer and fall of 2004. *Microcystis* was probably more widely distributed than the 2004 study suggests because *Microcystis* cells were found as far seaward as Martinez in 2003 (see Fig. 1 for location; Lehman et al., 2005). The consistently higher *Microcystis* cell density in SJR and ODR compared with SAC suggests optimum conditions for *Microcystis* growth occurred in the central delta. It is unlikely that *Microcystis* grew outside of the freshwater habitats in the central delta where salinities are commonly less than 5 ppt (Lehman et al., 2005) because *Microcystis* does not grow at salinities above 7 ppt (Robson & Hamilton, 2003). Instead, *Microcystis* cells were probably transported from the central delta with streamflow, wind and tide to more brackish water habitats downstream where they might survive, but not grow (Pickney et al., 1997). Low cell density in SAC was probably a combination of dilution and cell death at high chloride. High salinity conditions encountered during seaward transport could cause *Microcystis* colonies to lyse, aggregate, and settle to the bottom in Chesapeake Bay (Sellner et al., 1988; Orr et al., 2004).

Microcystis cell density and chl *a* concentration peaked during the summer and fall between August and September in 2004. *Microcystis* cell density and biomass commonly peak during the summer and fall when they occur in freshwater lakes and reservoirs (Watson et al., 1997). *Microcystis* also occurs during the summer and fall in the low salinity regions of some estuaries including the Swan River estuary, Australia, the Los Platos Estuary, Brazil, and the Potomac and Neuse River estuaries in the USA (Pearl, 1988; Robson & Hamilton 2003; Sellner et al., 1993; Yunes et al., 1996). In SFE, peak *Microcystis* chl *a* concentration and cell density in August and September were associated with high GP_{ez} and characterized by high P_m^B, α^B and low β^B. Warm water temperature during August and September may have contributed to high P_m^B which is correlated with high water temperature for *Microcystis* populations in lakes (Robarts & Zachary 1987). August and September are also characterized by high streamflow in SAC and low streamflow in SJR that promote the warm water temperature, low salinity and low specific conductance conditions associated with high GP_{ez}.

Total microcystins concentration was highest in SJR during August and September when *Microcystis* cell density and chl *a* concentration were high, but was poorly correlated with either. Total microcystins concentration and chl *a* concentration were also poorly correlated for the single-day survey conducted in SFE during October 2003 (Lehman et al., 2005). The lack of a correlation between total microcystins concentration and chl *a* concentration is common because cellular microcystins content is uncoupled from growth rate (Utkilen & Gjølme, 1992). Total microcystins concentration was probably influenced by the relative growth of *Microcystis* strains or "genotypes" that contain different kinds of microcystins as well as the direct influence of environmental conditions on microcystin formation in *Microcystis* cells or "chemotypes" (Ouellette et al., 2006). Significant differences in the microcystins composition in SJR and SAC suggest there were at least two different genotypes or chemotypes contributing to the total microcystins concentration.

The variation of total microcystins concentration suggested the potential toxicity of *Microcystis* was variable. Eleven microcystins varied by eight orders of magnitude during the bloom in SFE. This level of variation might not be unusual because it was similar to the variation measured for *Microcystis* blooms in German lakes and reservoirs where 14 microcystins varied by four orders of magnitude (Fastner et al., 1999). The potential toxicity of the *Microcystis* bloom in SFE was strongly influenced by the presence of the hepatotoxic microcystin-LR which comprised about 54% of the total microcystins. However, the full toxicity of the bloom depends on the remaining 46% of the microcystins for which a

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little is known (Zurawell et al., 2004). It is likely that the potential toxicity of the microcystins in SAC was higher than the other rivers because it had the highest total microcystins (chl a)$^{-1}$.

Environmental factors

Streamflow was a major factor controlling *Microcystis* cell density in SFE and probably influenced development of the *Microcystis* bloom directly and indirectly through a suite of environmental conditions. Since *Microcystis* has a relatively slow growth rate, long water residence time is needed for biomass to accumulate (Reynolds, 1997). Low streamflow in the central delta region coupled with high GP_{ez}, P_m^B, and α^B in August and September probably facilitated accumulation of *Microcystis* cells in SFE. Accumulation rather than growth was supported by the similar GP_{ez} (chl a)$^{-1}$ among rivers. Flushing rate was also a key factor affecting the seasonal variation of *Microcystis* blooms in the Swan River Estuary and in the Neuse River estuary where *Microcystis* blooms only develop when streamflow is below 13–15 $m^3 s^{-1}$ (Christian et al., 1986; Robson & Hamilton, 2003). A streamflow threshold was similarly suggested for SFE where M*icrocystis* only occurred when SJR streamflow was 28–32 $m^3 s^{-1}$.

Microcystis probably grew well in the shallow-flooded island habitats in the central delta region of SFE where low streamflow helps to keep vertical mixing low (Jacoby et al., 2000). Low vertical mixing enables *Microcystis* colonies to float to the surface of the water column where they out compete other phytoplankton for light (Huisman et al., 2004). Such an adaptation was probably important in SFE, where phytoplankton growth is light limited due to high suspended sediment concentration (Jassby et al., 2002) and may partially explain the negative correlation between *Microcystis* cell density and Secchi disk depth. Low vertical mixing in the central delta region may also enhance phytoplankton metabolic activity and cell viability which are reduced at high mixing rates (Huisman et al., 2004; Regel et al., 2004). Low vertical mixing in the central delta was suggested by abundant large 2–3 cm wide colonies in MI, a shallow-flooded island in the center of the delta and small 1-cm wide colonies in the middle of the fast flowing and turbulent river channels where *Microcystis* cell density was low (Lehman, personal observation). Large colonies were shown to rapidly break apart under turbulent conditions in laboratory tests (O'Brien et al. 2004).

Microcystis cell density was also positively correlated with water temperature in SFE. *Microcystis* growth begins in early summer, when water temperature above 20°C stimulates esterase activity in vegetative cells on the surface of the sediment and ceases in the fall when water temperature declines to below 20°C (Latour et al., 2004). Water temperature similarly contributed to the seasonal pattern in *Microcystis* cell density in SFE where *Microcystis* cells only occurred above 20°C. Maximum chl a concentration occurred during mid-summer when water temperature reached 25°C, but this may not represent maximum growth rate of *Microcystis* which was higher at 29–32°C in laboratory studies (Robarts & Zohary, 1987). Water temperature probably influenced the spatial and temporal variation in *Microcystis* cell density among rivers because it reached 20°C sooner in SJR and ODR than SAC.

The importance of water temperature for microcystin development was suggested by the large coefficient for water temperature on the canonical environmental variable in canonical correlation analysis for total microcystins (cell)$^{-1}$. In lab studies, total microcystins concentration varied more with water temperature than irradiance and was highest at 20–24°C (Van der Wethuizen & Eloff, 1985; Wiedner et al., 2003); water temperatures similar to those measured in SFE during mid-summer. Water temperature primarily influences total microcystins concentration through its impact on growth rate, because cellular microcystins are only produced during log-phase growth (Lyck, 2004). The greater total microcystins concentration during mid-summer in SFE may be influenced by the high P_m^B and a^B during this time.

It is possible environmental variability contributed to the seasonal variation in *Microcystis* cell density and the quantity and quality of microcystins in SFE. Chl a and total microcystins concentration peaked in August and September when the variance in streamflow was low. Low daily variance in streamflow may promote the accumulation of *Microcystis* cells and the growth of relatively few *Microcystis* genotypes. In contrast, the high daily variance of water

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temperature in September and October may contribute to the increased number of microcystins in these months through differential growth and survival of *Microcystis* genotypes or chemotypes (Ouellette et al. 2006). Daily water temperature is linked to seasonal changes in air temperature with streamflow dominating water temperature early in the season at high streamflow and air temperature dominating water temperature late in the season at low streamflow. This impact is supported by decadal change in water temperature in SFE that was inversely correlated with streamflow and positively correlated with air temperature in SJR and SAC (Lehman, 2004).

Nutrient concentration was not a driving force for variation of the *Microcystis* bloom in SFE. The high nutrient concentrations in SFE were a necessary condition for initiation of the *Microcystis* bloom because *Microcystis* requires both high nitrogen and phosphorus concentration for growth (Paerl et al., 2001). However, the persistence and variation of the bloom was not nutrient driven because nutrient concentrations were consistently an order of magnitude greater than limiting values throughout the water column in SFE (Jassby 2005). Nutrient ratios are generally important for cyanobacterial bloom formation (Paerl et al., 2001) with *Microcystis* blooms occurring at an N:P ratio <15 (Jacoby et al. 2000). The average N:P ratio of 10 (range 6–10) in August and September was favorable for *Microcystis* growth in SFE. The lesser influence of nutrients on *Microcystis* cell density and total microcystins concentration was supported by the low coefficients for nutrient concentration and nutrient ratios in the canonical correlation analyses.

Food web impact

The spatial and temporal variation of *Microcystis* cells might affect the presence of toxic microcystins in the estuarine food web in SFE. The high concentration of total microcystins in lower food web organisms during the peak of the *Microcystis* bloom suggested there was a direct link between microcystins in algal tissue and microcystins in the tissue of aquatic animals. Microcystins concentration was also high in the tissue of food web animals during the peak of the bloom in central Alberta Lakes, Canada (Kotak et al., 1996). Microcystins in zooplankton and other lower food web animals can occur from active and passive ingestion of algal tissue, even though *Microcystis* may not be selectively grazed (DeBernardi & Giussani, 1990; DeMott & Moxter, 1991; Sellner et al., 1993).

The greater microcystins concentration in animal than algal tissue suggested microcystins were transferred and perhaps biomagnified through the aquatic food web in SFE. Microcystins were also transferred through food web organisms in the Alberta Lakes, Canada, Lake Ijsselmeer, the Netherlands and Lakes Rotoiti and Rotoehu in the Czech Republic (Kotak et al., 1996; Ibelings et al., 2005; Wood et al., 2006). Detritus feeders may be an important transfer agent of microcystins into the SFE food web because total microcystins concentrations were high in amphipod and worm tissue. Detrital grazers were also thought to be the primary pathway for the transfer of microcystins into the food web in Alberta lakes (Kotak et al., 1996). Unexpectedly, clams which fed directly on phytoplankton may not be an important source of microcystins to the food web in SFE. Clam tissue had the lowest total microcystins content among the animals tested in 2004 and low microcystins content compared with zooplankton tissue in 2003 (Lehman et al., 2005). Mollusks could accumulate microcystins, but tissue content is often low due to the rejection of *Microcystis* colonies or rapid depurgation of toxins from tissue (Prepas et al. 1997).

The *Microcystis* bloom probably did not cause acute toxicity to aquatic food web organisms in SFE. Total microcystins concentration in zooplankton tissue was below the value of 10–18 μg (g dry wt.)$^{-1}$ associated with acute death in Daphnia during laboratory feeding studies (Rohrlack et al., 2005). However, even at low concentrations, *Microcystis* can affect zooplankton community structure and function by sublethal toxicity or non-toxin related factors such as feeding inhibition or providing phytoplankton food of poor quality or low digestibility (DeMott & Mueller-Navarra, 1997; Rohrlack et al., 2005). Further, dissolved microcystins released from lysed *Microcystis* cells at the end of the bloom are toxic and can reduce feeding success for zooplankton (Pietsch et al., 2001). Large zooplankton such as Daphnia are sensitive to dissolved microcystins and demonstrate reduced growth and fecundity in

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the presence of *Microcystis* (Reinikainen et al., 1999). More information on these potential impacts are needed for SFE.

Management strategies

The worldwide impact of *Microcystis* blooms on ecosystem structure and function and human health through drinking water and recreation suggests the potential need for management of *Microcystis* populations in SFE (White et al., 2005). Because the spatial and temporal variability of *Microcystis* cell density and total microcystins concentration is high in SFE, management might require consideration of physical, chemical, and biological factors at both large and small spatial and temporal scales (Donaghay & Osborn, 1997). Although there are many management strategies for control of *Microcystis* and its toxins (Pearl et al., 2001), regulation of streamflow may be the most important for SFE. High streamflow would prevent accumulation of *Microcystis* biomass in stable backwater sloughs or shallow-flooded islands, where residence time is long and vertical mixing is low. High streamflow would also increase vertical mixing which decreases colony viability and the competitive advantage of *Microcystis* colonies to obtain light by floating on the surface of the water column (Huisman et al., 2004). Streamflow could further be managed to influence water quality conditions such as water temperature and salinity that initiate and sustain bloom biomass and affect microcystins concentration (Jacoby et al. 2000). A decline in the density and biomass of fish, zooplankton, mysid shrimp, and diatoms has left the food web in SFE vulnerable to any adverse impact so that even a small change in the impact of *Microcystis* and its associated toxins on the food web may be important for fishery production (Lehman, 2004; Sommer et al. 2007).

Conclusion

Microcystis and its associated toxin microcystin varied spatially and temporally over the bloom season in SFE. Significant differences in cell density and chl *a* concentration were associated with the *Microcystis* bloom among months, rivers and stations. Differences in *Microcystis* cell density and total microcystins concentration per cell^{-1} and microcystins concentration chl a^{-1} were correlated with environmental conditions, particularly streamflow and water temperature. These environmental conditions were correlated with differences in areal growth rate within the euphotic zone and probably driven by high P_m^B and α^B during the peak of the bloom. The variation of the bloom and its associated toxin concentration is potentially important ecologically because total microcystins are present in the tissues of the lower food web animals, mesozooplankton, amphipods, worms, jellyfish and clams. Although the bloom contains hepatotoxic microcystins, the present concentrations are low and probably not acutely toxicity to food web animals. However, the higher concentration of total microcystins in some animals and higher total microcystins concentration in animal than algal tissue suggests biomagnification or accumulation could increase the impact of these toxins on the aquatic community.

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PRIMARY RESEARCH PAPER

Long-term trends and causal factors associated with *Microcystis* abundance and toxicity in San Francisco Estuary and implications for climate change impacts

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Abstract The impacts of climate change on *Microcystis* blooms in San Francisco Estuary are uncertain because factors associated with the abundance and distribution of *Microcystis* blooms since their inception in 1999 are poorly understood. Discrete and continuous data collected between 2004 and 2008 were used to assess what factors controlled bloom initiation and persistence, if there was an impact of the bloom on mesozooplankton abundance and toxicity or dissolved organic carbon concentration, and how these might vary with climate change. *Microcystis* abundance was greater in dry years than wet years and both total microcystins concentration and the microcystins content of mesozooplankton tissue increased with abundance. The bloom began in the upstream portions of the estuary and spread farther west during dry years. Bloom initiation required water temperature above 19°C and surface irradiance in the visible range above 100 W m^{-2}. The bloom persisted during a wide range of water quality conditions but was closely correlated with low turbidity. The intensity of *Microcystis* blooms will likely increase with climate change due to increased water temperature and low streamflow during droughts. Elevated water temperature earlier in the spring could also extend the duration of *Microcystis* blooms by up to 3 months.

Keywords *Microcystis* · Climate change · Microcystins · Cyanobacteria · Environmental factors · Estuary

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Introduction

Cyanobacteria are common in freshwater aquatic ecosystems worldwide and are an increasing concern due to their long-term increase in frequency and intensity since the 1960s (Carey et al., 2012). *Microcystis*, the most common cyanobacterium in freshwater, has also spread into estuaries including Chesapeake Bay, San Francisco Bay, and Neuse River Estuaries in the United States; the Swan River Estuary in Australia; and the Guadiana River Estuary in Spain and Portugal (Paerl, 1988; Sellner et al., 1988; Rocha et al., 2002; Robson & Hamilton, 2003; Lehman et al., 2005). *Microcystis* is a local health threat to humans and wildlife directly in contact with the blooms because it usually contains microcystins, hepatotoxins that

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promote tumor and liver cancer (Zegura et al., 2003; International Agency for Research on Cancer, 2006; Ibelings & Havens, 2008). However, *Microcystis* toxins can also be a regional health threat. In southern California, microcystins flushed seaward from an inland freshwater lake concentrated in marine mollusks and caused liver cancer in sea otters which rely on mollusks as a food source (Miller et al., 2010). The surface scum produced by *Microcystis* blooms is also well known to affect water quality conditions by impeding recreation, reducing esthetics, lowering dissolved oxygen concentration, and causing taste and odor problems in drinking water (Paerl et al., 2001).

The abundance, frequency, and distribution of *Microcystis* and other cyanobacteria are expected to increase with climate change (Carey et al., 2012). The high Q_{10} of *Microcystis* allows it to grow rapidly compared with other primary producers at high water temperature which is expected to increase with the increased frequency, intensity, and duration of heat waves in North America (Carey et al., 2012; Paerl & Paul, 2012). High water temperature also increases thermal stratification which in turn enhances nutrient limitation near the surface and reduces vertical mixing. Such conditions favor buoyant species like *Microcystis* that can vertically migrate to harvest nutrients throughout the water column (O'Neil et al., 2012). Vertical migration to the surface and tolerance of high light conditions also enable *Microcystis* to adapt to limiting light conditions during blooms which are expected to increase with warmer water temperature (Reynolds, 2006). Similarly vertical migration to the surface enables *Microcystis* to use atmospheric carbon dioxide when dissolved inorganic carbon in the water column becomes limiting during blooms (Reynolds, 2006; Elliott, 2012). Climate change is also expected to increase the frequency, intensity, and duration of high precipitation events as well as droughts (IPCC, 2007). These conditions will further promote *Microcystis* and other cyanobacteria over other primary producers because of their ability to compete well for increased nutrients associated with high runoff from precipitation and to tolerate increased light, salinity, water temperature, stratification, and bloom conditions during drought (Elliott, 2012; O'Neil et al., 2012; Paerl & Paul, 2012).

In San Francisco Estuary (SFE), *Microcystis* colonies have formed widespread surface scums or blooms at varying levels each year since they first became established in 1999 (Lehman et al., 2005, 2008, 2010). Blooms commonly begin in the central delta and spread seaward into brackish water environments with streamflow and tide (Lehman et al., 2005). *Microcystis* blooms pose a threat to human and ecosystem health in SFE because they commonly contain the highly toxic hepatotoxin, microcystin-LR, and microcystins are present throughout the lower food web in clams, mesozooplankton, and juvenile fish (Lehman et al., 2005, 2008, 2010; Acuna et al., 2012a, b). Laboratory bioassays demonstrated that both short and long-term exposure to dissolved and dietary microcystins impact the health and survival of native zooplankton and fish (Ger et al., 2009; Deng et al., 2010; Acuna et al., 2012a, b). Further, the presence of *Microcystis* was associated with a shift in phytoplankton and cyanobacteria species composition, suggesting it may affect the structure as well as the function at the base of the food web (Lehman et al., 2010). Persistent elevated nutrient concentrations in SFE and poor correlation between nutrient concentration and cell abundance suggest that nutrients do not control the year to year variations in *Microcystis* (Lehman et al., 2008). Instead, physical factors such as streamflow and water temperature appear to be of greater importance (Lehman et al., 2008). The importance of environmental factors is confounded by the multiple genotypes and strains of *Microcystis* in SFE (Moisander et al., 2009; Baxa et al., 2010).

It is unknown how *Microcystis* blooms will vary with climate change in SFE. It is hypothesized that *Microcystis* bloom intensity and duration will increase with the elevated water temperature (Paerl & Huisman, 2008). Continuous monitoring data have already demonstrated an increase in water temperature at multiple stations in the Delta since 2000 (Brooks et al., 2012). Models suggest that this long-term increase in water temperature will continue (Cloern et al., 2011). It is further hypothesized that *Microcystis* blooms will increase with the projected increase in the frequency and intensity of drought conditions throughout California with climate change (Cloern et al., 2011). Understanding the current and future causes of *Microcystis* blooms are particularly important in SFE where the blooms are hypothesized to be a contributing factor in the decline of many species of interest including striped bass, the endangered delta smelt, longfin smelt, and mesozooplankton since 2000 (Sommer et al., 2007).

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The purpose of this study was to characterize the trend in *Microcystis* blooms and the associated physical, chemical, and biological factors between 2004 and 2008 and to use this information to gain insight into the causal factors and the potential future variation of *Microcystis* blooms and their toxins with climate change. The study will address the questions: (1) Did *Microcystis* abundance, microcystin toxin concentration or dissolved organic carbon concentration vary with wet and dry conditions? (2) Did the toxin content in the lower food web animals vary with wet and dry conditions? (3) What environmental factors controlled initiation and persistence of the blooms? To address these questions, physical, chemical, and biological data were compiled from five stations sampled monthly to semimonthly during four independent research studies conducted on the *Microcystis* bloom in 2004, 2005, 2007, and 2008; only the data from 2004 and 2005 have been published previously. Additional water temperature and surface irradiance data were obtained from a fixed continuous monitoring station located near Antioch.

Methods

Site description

The SFE consists of an inland delta that flows into a chain of marine bays downstream—Suisun, San Pablo, and San Francisco—and creates one of the largest estuaries on the west coast of North America. The estuary is formed by two rivers, the Sacramento River on the north and the San Joaquin River on the south. These rivers converge to form a delta with 200 km^2 of waterways (Fig. 1). The estuary contains many kinds of habitats from freshwater shallow flooded islands that are 2 m deep in the center of the delta, wide brackish water bays in Suisun Bay, and deep river channels 13 m deep. Water flow in the



Fig. 1 Location of five stations sampled during *Microcystis* blooms in summers between 2004 and 2008

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channels is influenced by the semidiurnal tide which commonly has a 1.5-m amplitude and up to 6 km excursion. A combination of tide, streamflow, and agricultural diversion keeps the river channels and brackish bays mixed to the bottom. The estuary is turbid with maximum photic zone depth of 2 m. *Microcystis* blooms occur throughout the freshwater and brackish water regions of the estuary between June and October (Lehman et al., 2005). Elevated *Microcystis* abundance usually occurs in the center of the delta in association with the San Joaquin River but the greatest abundance on any given day can occur anywhere throughout the region.

Sampling

Data used in this analysis were combined from research studies that sampled the same five stations (CI, AT, CV, SJ, and OR) biweekly during the summers of 2004, 2005, 2007, and 2008 (Fig. 1). Sampling was conducted between June and October for 2004, 2007, and 2008 and August and September for 2005. For each study, *Microcystis* tissue was collected from the first 0.5 m of the water column using a surface-water tow of a 0.50–0.75-m diameter plankton net fitted with a 75 μm mesh. A net tow was used for collection to get a representative sample of *Microcystis* colonies that were widely dispersed. Use of a wide diameter mesh allowed capture of most of the cyanobacterium colonies that were often 50 mm in diameter while reducing clogging of the net from heavy suspended sediment. Surface water for chemical analysis was collected at 0.3 m by a van Dorn or diaphragm pump sampler.

Concentrated samples from the net tow sample were filtered through GF/F glass fiber filters and processed for pigment or toxin concentration, with final concentration based on the volume of the net tow. Filters for chlorophyll *a* analysis were treated with 1% magnesium carbonate solution to prevent acidity, immediately frozen on dry ice and stored at −4°C until analysis for chlorophyll *a* and pheophytin concentration. Pigments were extracted in 90% acetone and measured using spectrophotometry (American Public Health Association et al., 1998). Filters with tissue for total microcystins analysis were immediately frozen on dry ice and stored at −80°C until processing for total toxic microcystins concentration using protein phosphate inhibition assay (PPIA; Lehman et al., 2005). The PPIA assay is an integrative bioassay that sums the inhibitory activity of all the different microcystins in the sample into a single value. The results are then expressed in terms of microcystin equivalents. For quality control purposes and to ensure that the changes in toxicity observed using the PPIA assay were not due to changes in toxin composition, 274 of the more 600 samples collected in 2007 and 2008 whose microcystin concentrations in the extract solution as determined by the PPIA assay exceeded 0.5 μg l^{-1} were also analyzed by liquid chromatography coupled with photodiode array and mass selective detection (LCMS-PDA) using established methods (Boyer, 2007).

Water samples for chloride, ammonium-N, nitrate plus nitrite-N, and SRP that were filtered through a 0.45-μm nucleopore filter as well as unfiltered whole water samples for total and volatile suspended solids and total organic carbon analysis were kept at 4°C or frozen until analysis (United States Environmental Protection Agency, 1983; United States Geological Survey, 1985; American Public Health Association et al., 1998). Water samples for dissolved organic carbon analysis were filtered through pre-combusted GF/F filters and kept at 4°C until analysis (American Public Health Association et al., 1998). Water temperature, pH, specific conductance turbidity, and dissolved oxygen concentration were measured at 0.3 m using a freshly calibrated Yellow Springs Instrument (YSI) 6600 water quality sonde. Photon flux (μmol photons m^{-2} s^{-1}) of the photosynthetically active radiation (PAR) was measured from the surface to 1% of the surface light level at 0.3 m intervals in the water column using a Li-COR spherical quantum sensor model LI-193. The total and median photon flux of PAR in the photic zone (PAR_{pz}) where *Microcystis* was most abundant was computed from the integrated (triangular) Li-COR values measured from the surface to the depth of 1% of the surface irradiance, reduced by 10% to correct for reflectance at the surface. Water transparency was also measured by Secchi disk depth.

Continuous high-frequency (15-min averaged) data were collected at a fixed monitoring station near AT. These data included water temperature measured with an YSI water quality sonde and surface irradiance (W m^{-2}) measured with an Eppley pyrheliometer (www.iep.water.ca.gov). Pyrheliometer irradiance

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was expressed as PAR by assuming PAR comprised 49% of the total surface irradiance.

Streamflow variables were obtained from the California Department of Water Resources DAYFLOW (www.water.ca.gov/dayflow) database containing both measured and computed values. Upstream San Joaquin River streamflow was described by measured streamflow past Vernalis (QSJR) while upstream Sacramento River streamflow was described by measured streamflow past Freeport (QSAC; Fig. 1). QWEST is a computed value that describes the amount of San Joaquin River streamflow that flows into the central delta past Jersey Point and reflects the inflow from the San Joaquin River and loss from water diversions between Vernalis and Jersey Point. QWEST streamflow values can be negative due to large net reverse streamflows from water diversions at the State (SWP) and Federal (CVP) pumping facilities. In a similar fashion, QRIO describes the amount of water that remains in the Sacramento River at Rio Vista after channel depletions between Freeport and Rio Vista. Unimpaired streamflows were used to classify water years 2004 and 2005 as wet versus 2007 and 2008 as dry (www.waterplan.water.ca.gov).

Biological samples

Microcystis cell abundance estimates were determined from plankton samples collected from the net tow. These samples were immediately stained and preserved with Lugol's solution. *Microcystis* cells were identified and enumerated at 700× using an inverted microscope in 2004 and 2005 (Utermöhl, 1958) or a Fluid Imaging Technologies FlowCAM digital flow cytometer in 2007 and 2008 (Sieracki et al., 1998). Microscope and FlowCAM cell abundance estimates were strongly correlated ($r = 0.88$, $P < 0.01$).

Mesozooplankton were collected by a 3 min diagonal tow of a 0.5-m diameter plankton net fitted with a 150 μm mesh. Zooplankton were kept at 4°C and separated by pipette from *Microcystis* in the water sample using a dissecting microscope within 48 h of sampling. Zooplankton tissue was rinsed in distilled water and frozen at −80°C until toxin analysis by protein phosphatase inhibition assay (PPIA). Zooplankton for identification and enumeration were dyed and preserved in 10% buffered formalin with rose Bengal dye. Species identification and enumeration were conducted using a dissecting microscope.

Data analysis

All statistical analyses were computed with non-parametric statistics using Statistical Analysis System (SAS, 2004) and Primer-e version 6 (Clarke, 1993; SAS Institute, 2004; Clarke & Gorley, 2006). SAS was used to compute simple Spearman rank correlations between single variables. PRIMER-e is a multivariate non-parametric permutation statistical method that was used to test the similarity of patterns in sample groups described by similarity matrices. Analyses mentioned in this study included determining the similarity between biological samples and suites of environmental samples with RELATE, distinguishing significant differences between groups of multivariate samples with ANOSIM, isolating the best match between biological and environmental (multivariate) similarity matrices with BEST and describing the associations among environmental variables and *Microcystis* abundance with principal components analysis (PCA). Similarity of the sample matrices is based on Spearman rank correlation coefficients.

Before PRIMER analyses, *Microcystis* cell abundance and chlorophyll *a* concentration were log transformed and then converted to similarity matrices using a Bray–Curtis Similarity Index which better represents the lack of normality and unequal variance distribution of these biological data (Clarke & Gorley, 2006). Environmental similarity matrices were computed from Euclidean distances that were computed from normalized variables (difference of the value from the mean and divided by the standard deviation). In addition, similarity matrices were only computed for variables that were not intercorrelated ($r > 0.70$). Chloride gram per liter was converted to salinity by the multiplier 1.80655 (American Public Health Association et al., 1998).

Results

Long-term trend

Microcystis abundance was greater during August and September (combined) of dry years than wet years (Fig. 2). Peak abundance occurred in August and September and median abundance exceeded ($P < 0.05$, ANOSIM) that in June or July by a factor of 1.2 (21,101 ± 2,386 cells ml^{-1} for June and July

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and 24,941 ± 32,836 cells ml^{-1} for August and September). Median *Microcystis* abundance in August and September was also greater ($P < 0.01$, ANOSIM) in the dry years 2007 and 2008 with 29,920 ± 21,433 cells ml^{-1} compared with the wet years 2004 and 2005 with 34 ± 311,506 cells ml^{-1} (Table 1). Abundance increased throughout the Delta in dry years and was greater at stations in both the central Delta (OR and SJ, $P < 0.05$) and western Delta near the confluence (AT, CI and CV, $P < 0.01$; Fig. 2).

Median chlorophyll *a* concentration within the 0.5-m surface layer was also greater in August and September during dry years ($P < 0.01$, ANOSIM; 36 ± 53 ng l^{-1} and 110 ± 132 ng l^{-1} for wet and dry years, respectively; Fig. 2 and Table 1). Among months, median chlorophyll *a* concentration was lowest for August 2004 ($P < 0.05$) but did not differ among years for September. Among stations, chlorophyll *a* concentration was greater in the central delta at SJ and OR than near the confluence at AT, CV, and CI (130 ± 82 ng l^{-1} and 20 ± 48 ng l^{-1}, respectively). Similar patterns of chlorophyll *a* concentration and *Microcystis* abundance were due to their correlation which was greater in dry years when *Microcystis* biomass increased ($r = 0.43$, $P < 0.01$ for 2004–2005 and $r = 0.78$, $P < 0.01$ for 2007–2008).

Median dissolved organic carbon concentration ranged from 1.7 to 2.3 mg l^{-1} during the peak of the bloom in August and September (Fig. 2). There was no significant difference in dissolved organic carbon concentration among all years during the peak of the bloom but abundance was greater for both months in the dry year 2008 than the wet year 2005 ($P < 0.05$; Table 1). Dissolved organic carbon concentrations also varied directly with the bloom and increased with all measures of the bloom intensity, *Microcystis* abundance, chlorophyll *a* concentration, and total microcystins concentration ($r = 0.44$, $r = 0.55$, $r = 0.60$, $P < 0.01$; respectively).

Total microcystins concentration was over an order of magnitude greater in dry years (Fig. 2; Table 1). Median total microcystins concentration was greater in 2005, 2007, and 2008 at 36 ± 55 ng l^{-1} than in 2004 at 2 ± 5 ng l^{-1} ($P < 0.01$, ANOSIM). Concentrations increased with *Microcystis* abundance and were greater for dry years when *Microcystis* was more abundant ($r = 0.81$, $P < 0.01$ for 2007–2008 and $r = 0.43$, $P < 0.01$ for 2004–2005). Median total

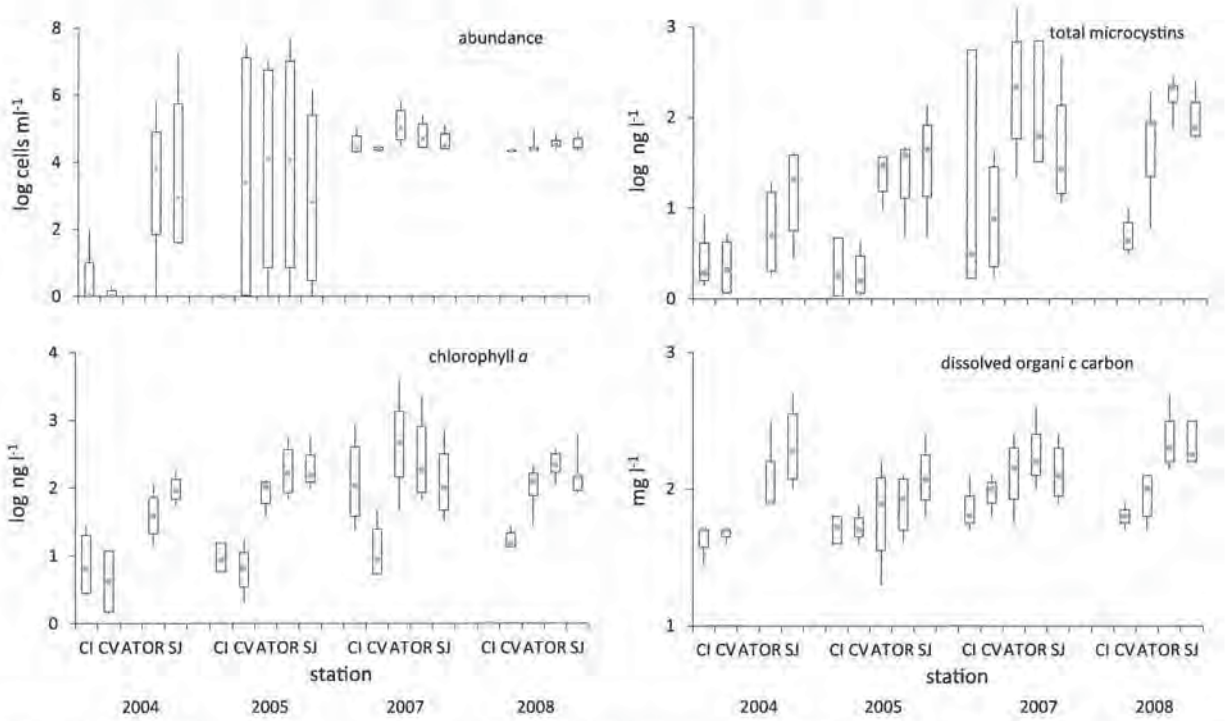


Fig. 2 Maximum, minimum, median and 25 and 75% quartiles for *Microcystis* cell abundance as well as chlorophyll *a*, total microcystins, and dissolved organic carbon concentration measured at five stations in the delta in the summer between 2004 and 2008

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microcystins concentration varied little among years during the peak of the bloom in August and September except for the greater concentration in August of 2007 ($P < 0.01$, ANOSIM). Among stations, total microcystins concentration was greater in the San Joaquin River at AT, SJ, or OR than the Sacramento River at CI or CV ($P < 0.05$, ANOSIM; 29 ± 33 ng l^{-1} and 0.79 ± 1.5 ng l^{-1}). Median total microcystins cellular content was 0.7 ± 1.4 pg $cell^{-1}$ and did not differ significantly between wet and dry years or among stations.

Although the total mesozooplankton carbon was similar among stations for the wet year 2005 and the dry year 2007 (Fig. 3), the maximum total microcystins content was somewhat greater in the dry year 2007 than the wet years 2004 or 2005 (Table 2). Mesozooplankton tissue contained 0.14–0.74 μg (g dry weight)$^{-1}$ total microcystins in 2004 and up to 1.43 μg (g dry weight)$^{-1}$ in 2005. This was lower than the maximum 2.55 and 3.14 μg (g dry weight)$^{-1}$ measured at CI and CV in the dry year 2007. High variability and the relative nature of these values limited further conclusions.

Environmental conditions

A seasonal threshold response characterized the association between *Microcystis* and water temperature or light. *Microcystis* was present only when surface water temperature was 19°C or greater (Fig. 4). Peak abundance occurred near 23°C, but relatively high abundance persisted up to the maximum recorded water temperature of 25.6°C. These water temperatures restricted the *Microcystis* bloom to the summer months between June and October. The daily average surface irradiance during this period was 167 ± 7 to 126 ± 7 W m^{-2} (Fig. 5a). Blooms disappeared in October or November once surface irradiance dropped below 98 ± 14 W m^{-2}. However, surface irradiance greater than 126 W m^{-2} occurred as early as March and suggested water temperature and not surface irradiance limited *Microcystis* growth between March and June.

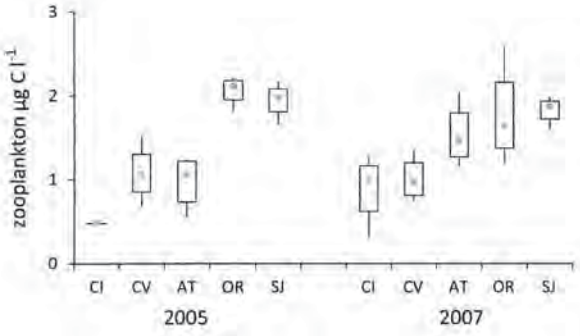


Fig. 3 Maximum, minimum, median and 25 and 75% quartiles for mesozooplankton carbon (μg C l^{-1}) collected by diagonal net tow at five stations sampled in 2005 and 2007 during the peak of the *Microcystis* bloom in August and September

Light within the water column was influenced by turbidity. *Microcystis* occurred when total suspended solids concentration was <50 mg l^{-1} (Fig. 4). These values were associated with an integrated average PARpz of over 50 μmol photons m^{-2} s^{-1}, with most blooms occurring when the average PARpz ranged between 50 and 200 μmol photons m^{-2} s^{-1} (Fig. 5b). The median extinction coefficient during blooms was 1.9 ± 0.41 m^{-1}.

In general, *Microcystis* occurred over a wide range of most physical and chemical conditions that were not linearly correlated with abundance (Fig. 4). *Microcystis* occurred in fresh to brackish water conditions where specific conductance was less than 12,000 μS cm^{-1}, salinity was between 0 and 3,500 and pH was between 7.5 and 9.6. Nutrient concentrations varied by a factor of 5 during the blooms with peak *Microcystis* abundance occurring near the low end of the range of concentrations for nitrate–N, SRP, or ammonium-N concentration (ranged from 0.1 to 0.4 mg l^{-1}, 0.03 to 0.09 mg l^{-1}, and 0.01 to 0.08 mg l^{-1}, respectively). *Microcystis* also occurred in the lower end of the range for DIN:DIP molar ratios from 5 to 22.

For streamflow, *Microcystis* was abundant in the San Joaquin River when QWEST ranged from positive 48 to negative 169 m^3 s^{-1} and QSJR ranged from 28 to 84 m^3 s^{-1} (Fig. 6). For the Sacramento River, *Microcystis* was associated with QRIO in the Delta between 113 and 3,030 m^3 s^{-1} and QSAC upstream between 300 and 600 m^3 s^{-1}. Peak abundance occurred at a narrower range of streamflows near negative 100 m^3 s^{-1} for QWEST and 250 m^3 s^{-1} for QRIO, 80 m^3 s^{-1} for QSJR and 500 m^3 s^{-1} for QSAC. Elevated chlorophyll *a* concentration occurred over an even wider range of streamflows than *Microcystis*; 20–80 m^3 s^{-1} for QSJR, negative 250–50 m^3 s^{-1} for QWEST, 200–600 m^3 s^{-1} for QSAC, and 100–450 m^3 s^{-1} for QRIO (not shown).

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Table 1 Comparison of median with 25 and 75% percentile confidence limits of physical, chemical, and biological data for the wet years 2004 and 2005 and dry years 2007 and 2008 measured during the peak of the *Microcystis* bloom in August and September

Variable	Wet year	Dry year	Significance level
Microcystis (cells ml^{-1})	34 ± 311,506	29,920 ± 21,433	0.05
Total microcystins (ng l^{-1})	3.8 ± 16.9	60.5 ± 90.9	0.01
Chlorophyll *a* (ng l^{-1})	36.4 ± 52.7	110.4 ± 132.6	0.01
Pheophytin (ng l^{-1})	7.2 ± 4.8	1.9 ± 13	ns
Water temperature (°C)	21.6 ± 1.2	21.8 ± 1.3	ns
Secchi disk depth (cm)	72 ± 42	88 ± 42	0.05
Specific conductance (μS cm^{-1})	1002 ± 2,325	1,438 ± 2,225	ns
Chloride (mg l^{-1})	232 ± 736	331 ± 671	ns
Total suspended solids (mg l^{-1})	7.5 ± 13	6 ± 4	ns
Volatile suspended solids (mg l^{-1})	2 ± 2	1 ± 1	0.01
Dissolved oxygen (mg l^{-1})	8.7 ± 0.5	8.5 ± 0.4	ns
pH	7.9 ± 0.1	8.0 ± 0.3	ns
Turbidity NTU	14.8 ± 14.4	7.1 ± 3.8	0.01
Ammonium (mg l^{-1})	0.03 ± 0.02	0.04 ± 0.01	ns
Nitrate (mg l^{-1})	0.26 ± 0.04	0.28 ± 0.06	0.05
Soluble reactive phosphorus (mg l^{-1})	0.06 ± 0.01	0.06 ± 0.01	ns
NP molar ratio	10.8 ± 1.3	12.0 ± 2.1	ns
Silica (mg l^{-1})	14.3 ± 0.75	14.5 ± 0.9	ns
Total organic carbon (mg l^{-1})	2.2 ± 0.4	2.2 ± 0.2	ns
Dissolved organic carbon (mg l^{-1})	1.8 ± 0.2	2.1 ± 0.2	0.01
Sacramento River-Freeport (m^3 s^{-1})	498 ± 28	433 ± 83	0.01
Sacramento River-Rio Vista (m^3 s^{-1})	275 ± 18	238 ± 63	0.01
San Joaquin River-Vernalis (m^3 s^{-1})	58 ± 22	28 ± 1	0.01
San Joaquin River-Jersey Point (m^3 s^{-1})	−94 ± 15	−88 ± 68	ns

Correlations between biological and environmental data

Microcystis abundance across the Delta was correlated with the suite of physical and chemical variables ($P < 0.01$, RELATE). About 72% of the variability in the environmental variables associated with the *Microcystis* bloom over time was characterized by five PCA axes (Table 3). The first two axes each described 22–23% of the variance in the environmental data with an additional 7–11% of the variation described by each of the additional three PCA axes. Of these, only PCA axes 1, 2, and 5 were significantly correlated with *Microcystis* abundance (Table 3).

An overlay of *Microcystis* abundance on the ordination of the first and fifth PCA axes suggested that *Microcystis* occurred during warm water temperature, low turbidity, and low streamflow conditions (Fig. 7). *Microcystis* abundance varied most closely with PCA axis 1 ($r = 0.41, P < 0.01$) which primarily described a combination of warm water temperature, low nitrogen concentration (total and ammonium), low QWEST flow, and low turbidity. *Microcystis* abundance was similarly correlated with axis 5 ($r = 0.39$, $P < 0.01$) which primarily described a combination of low San Joaquin River streamflow, low turbidity, and high dissolved oxygen concentration. There was also a somewhat lower, but negative correlation between *Microcystis* abundance and PCA axis 2 ($r = -0.20$, $P < 0.05$; not shown) which was largely the opposite of PCA axis 1. PCA axis 2 described conditions associated with high chloride and turbidity and low total organic carbon concentration, water temperature, and QWEST flow.

However, only a few of these variables accounted for most of the variation in *Microcystis* abundance

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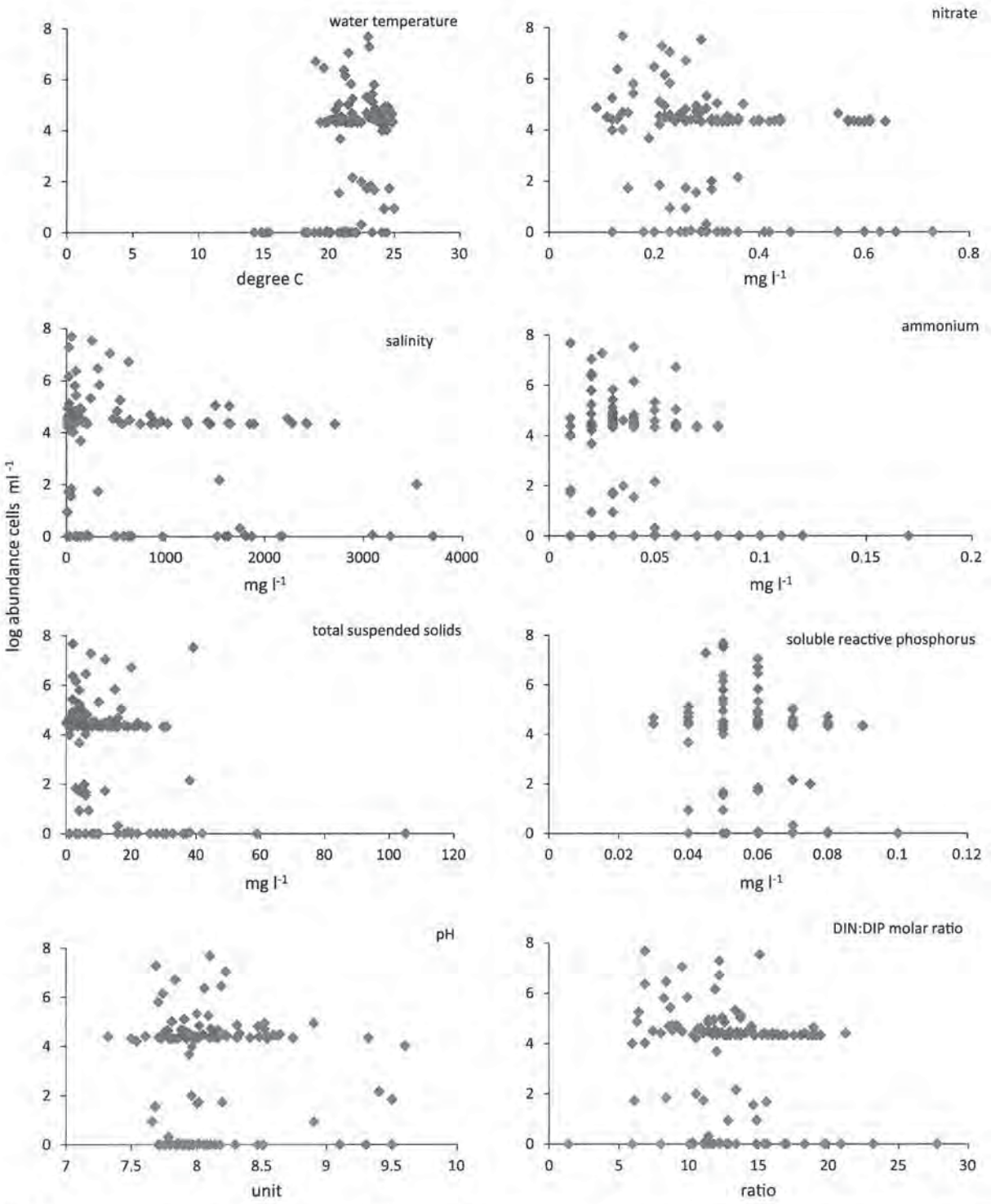


Fig. 4 Associations between *Microcystis* cell abundance and physical and chemical variables measured for five stations during summers between 2004 and 2008

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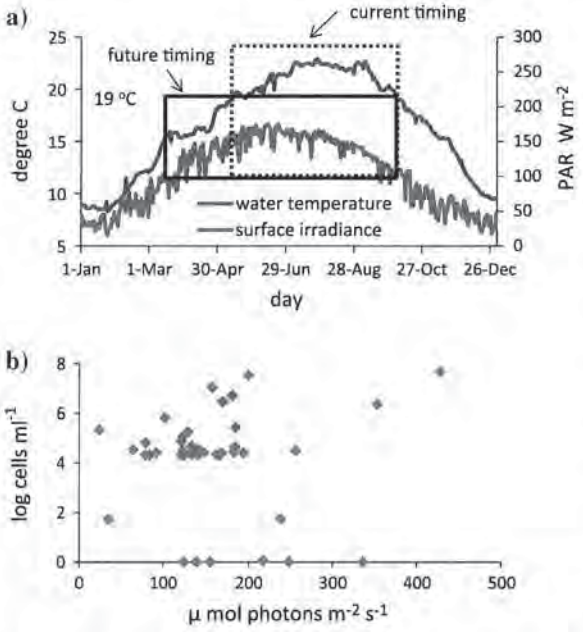


Fig. 5 **a** Average daily variation of PAR as surface irradiance (Eppley pyrheliometer) and water temperature at 1 m depth at Antioch for 2004, 2005, 2007, and 2008. **b** Average PAR (LiCOR) within the photic zone associated with *Microcystis* abundance at five stations in the Delta during summers between 2004 and 2008

based on BEST analysis which determines the best match between biotic and abiotic similarity matrices. The combination of turbidity and SJR described the largest variation in *Microcystis* abundance ($r = 0.47$, $P < 0.01$, BEST). However, most of this variation was due to the inverse correlation between *Microcystis* abundance and turbidity ($r = 0.35$, $P < 0.01$, BEST). Turbidity also accounted for most of the variation in *Microcystis* abundance during the peak of the bloom in August and September ($r = 0.40$, $P < 0.01$, BEST) and was produced by total suspended solids in the water column ($r = 0.79$, $P < 0.01$).

Chlorophyll *a* concentration was also correlated with the suite of physical and chemical variables across the Delta ($P < 0.01$, RELATE). Most of the variation was associated with turbidity and total nitrogen ($r = 0.42$, $P < 0.01$, BEST), with turbidity accounting for nearly all of the variance ($r = 0.41$, $P < 0.01$, BEST). Turbidity also described most of the variability in chlorophyll *a* concentration during the peak of the bloom in August and September ($r = 0.32$, $P < 0.01$, BEST). The inverse correlation between chlorophyll *a* concentration and turbidity occurred at all stations ($r = -0.39$ to $r = -0.65$, $P < 0.01$) except AT where chlorophyll *a* concentration was

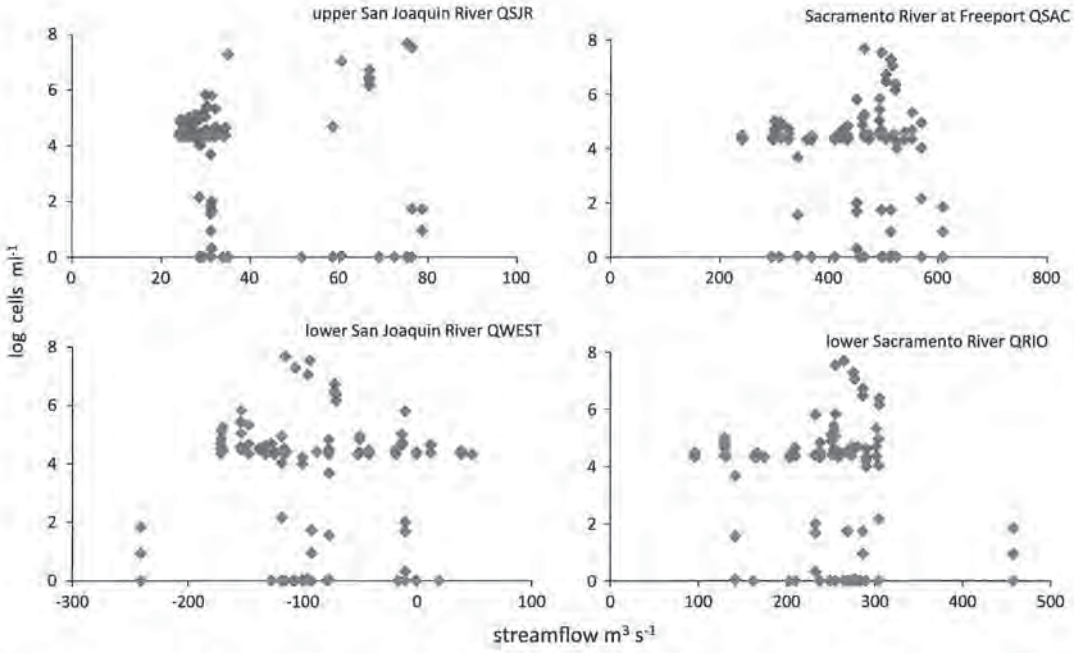


Fig. 6 Associations between *Microcystis* abundance and streamflow variables during the summer between 2004 and 2008

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Table 2 Median with 25 and 75% percentile confidence limits or detection limits for total toxic microcystins content in mesozooplankton [μg microcystins (μg dry weight)$^{-1}$] collected at five stations in 2004, 2005, and 2007

Date	Antioch	Chipps Is.	Collinsville	Old River	San Joaquin
August and October 2004			0.74 ± 0.79		0.14 ± 0.15
August and September 2005	<1.05	<3.99	<0.22	<3.14	1.43 ± 0.62
June 26, 2007	<0.67	0.25 ± 0.04	0.87 ± 0.11	<0.72	NA
July 10, 2007	<0.38	1.17 ± 0.12	<4.05	<0.81	0.68 ± 0.09
July 24, 2007	<1.58	<0.41	<15.00	<1.58	<0.66
August 7, 2007	<0.75	<12.00	<8.57	<0.87	<0.95
August 21, 2007	<0.98	<20.00	<0.52	<2.40	<0.38
September 4, 2007	<2.73	2.55 ± 0.04	3.14 ± 0.10	<3.75	<0.29
September 17, 2007	0.70 ± 0.25	<3.33	<0.40	<2.72	<0.72

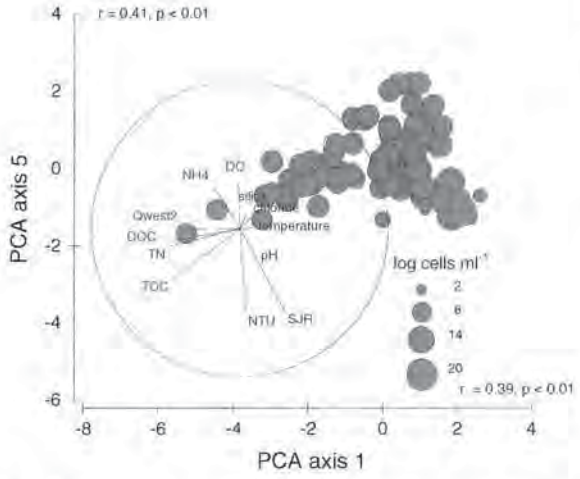


Fig. 7 Ordination of principal component axes 1 and 5 describing the associations among environmental factors overlaid with coincident *Microcystis* abundance (*circles*) for blooms in 2004, 2005, 2007, and 2008. All variables are normalized to the mean

more closely correlated with nitrate and total nitrogen concentration ($r = -0.58$ and $r = -0.60$, $P < 0.01$).

Similar to *Microcystis* abundance and chlorophyll *a* concentration, total microcystins concentration was correlated with the suite of physical and chemical variables ($P < 0.01$, RELATE) at stations across the Delta. It was also correlated with turbidity ($r = 0.19$, $P < 0.01$, BEST), but the correlation was low. The similar direction of the correlations between total microcystins or *Microcystis* abundance and environmental conditions was probably due to their strong correlation ($r = 0.68$, $P < 0.01$). In contrast, the total microcystins cellular content was not correlated with the suite of physical and chemical variables and weakly correlated with individual variables ($r = -0.21$, $r = -0.21$, and $r = -0.25$, $P < 0.05$ for dissolved oxygen concentration, turbidity, and the DIN:DIP molar ratio).

Streamflow

Streamflow probably directly affected the distribution and accumulation of *Microcystis* colonies in wet and dry years. The increased abundance of *Microcystis* in dry years was accompanied by 13–52% ($P < 0.01$) lower streamflows in both the Sacramento and San Joaquin Rivers (Table 1). The bloom also occurred when there was a combination of both cross delta streamflow from QRIO and water diversions from the south delta. The eastward movement of water across the delta from the Sacramento River into the San Joaquin River was suggested by the inverse correlation between QWEST at Jersey Point and streamflow at QRIO ($r = -0.70$, $P < 0.01$). Some of this water from QRIO replaced water diverted for agriculture in the lower San Joaquin River as suggested by the inverse correlation between QWEST and SWP or CVP ($r = -0.75$ and $r = -0.68$, $P < 0.01$). Diversions in the Delta were also linked to the overall wet and dry conditions in the Delta because agricultural water diversion increased directly with the magnitude of both QSJR and QSAC ($r = 0.84$ and $r = 0.62$, $P < 0.01$ for QSAC; and $r = 0.49$ and $r = 0.45$, $P < 0.01$ for QSJR with SWP and CVP, respectively).

Streamflow probably indirectly affected *Microcystis* abundance through impacts on the physical and chemical conditions in the Delta during wet and dry

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Table 3 Principal component analysis of non-correlated environmental variables measured during *Microcystis* blooms and the correlation between the principal component scores of these axes and *Microcystis* abundance for 2004–2008

Variable	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Water temperature	0.35	−0.26	−0.22	0.35	0.11
Dissolved oxygen	−0.11	0.11	0.00	−0.75	0.40
pH	0.06	0.05	−0.63	−0.35	−0.26
Turbidity	−0.33	0.32	−0.12	0.09	−0.44
Ammonium-N	−0.37	0.17	−0.07	0.09	0.14
Chloride	−0.27	0.42	0.03	0.10	0.01
Total dissolved inorganic nitrogen	−0.50	−0.15	0.04	0.08	−0.10
Dissolved organic carbon	−0.19	−0.54	0.03	−0.06	−0.02
Silica concentration	−0.13	0.21	−0.34	0.39	0.39
Total organic carbon	−0.27	−0.39	−0.29	−0.05	−0.35
QWEST flow	−0.34	−0.25	0.39	0.03	0.16
San Joaquin River streamflow	0.23	0.20	0.43	−0.06	−0.48
Percent variation	23	22	11	10	7
Correlation with *Microcystis* abundance	**0.41**	−0.20			**0.39**

Correlation coefficients are significant at the 0.01 level (bold text) and 0.05 level (plain text)

conditions. Water temperature decreased with streamflow in the San Joaquin River at QSJR and QWEST ($r = -0.18$, $P < 0.05$; $r = -0.27$, $P < 0.01$) and increased with streamflow in the Sacramento River QSAC and QRIO ($r = 0.28$, $P < 0.01$; $r = 0.23$, $P < 0.05$). Turbidity increased with streamflow at both QSAC and QRIO ($r = 0.26$, $P < 0.01$ and $r = 0.20$, $P < 0.05$) in the Sacramento River. Total and volatile suspended solids also increased with QRIO near the confluence at AT, CI, and CV ($r = 0.29$ and $r = 0.30$, $P < 0.05$) and with QSJR flow in the San Joaquin and Old River at stations SJ and OR ($r = 0.21$, $P < 0.01$; $r = 0.35$, $P < 0.01$). Nitrate, total nitrogen, SRP, and total and dissolved organic carbon in the Delta, increased with flow at QWEST ($r = 0.32$ to $r = 0.52$; $P < 0.01$). In contrast, nutrient concentrations decreased upstream at high streamflow. For the San Joaquin River, nitrate, total nitrogen, SRP, silica and dissolved organic carbon concentrations decreased with QSJR ($r = -0.26$ to $r = -0.33$, $P < 0.01$). Similarly, ammonium, nitrate, total nitrogen, SRP, and dissolved organic carbon decreased with high streamflow for the Sacramento River at QSAC ($r = -0.19$, $P < 0.05$; $r = -0.46$, $P < 0.01$; $r = -0.46$, $P < 0.01$; $r = -0.39$, $P < 0.01$; $r = -0.35$, $P < 0.01$) and QRIO ($r = -0.43$, $r = -0.43$, $r = -0.31$, $r = -0.36$, $P < 0.01$).

The influence of streamflow on environmental conditions may partially explain the differences in environmental conditions between wet and dry years (Table 1). Streamflow was relatively low in the upper Sacramento and San Joaquin Rivers at most locations and coupled with low water diversions for agriculture during dry years. These years were characterized by a 50% reduction in turbidity and volatile suspended solids as well as a 60% increase in specific conductance. A relatively smaller but significant increase in pH of 6% and decrease in nitrate concentration of 8% also occurred.

Discussion

Long-term trend

Microcystis abundance and toxin concentration increased over the study period and were greater during dry years. Dry years were generally characterized by low streamflow and low total suspended solids, but elevated water temperature and inorganic and organic nutrient concentrations (Lehman, 2000). These factors correlate well with *Microcystis* abundance in SFE (Lehman et al., 2008, 2010). *Microcystis* occurs in these conditions worldwide because it can outcompete other primary producers at elevated nutrient concentration and water temperature and light near the surface where it occurs during the day (Paerl et al., 2001). Dry conditions were also characterized by greater ammonium concentrations due to reduced dilution of waste water treatment discharge in the Sacramento River (Jassby, 2005). Elevated ammonium concentrations can favor *Microcystis* which

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outcompetes other primary producers for ammonium (Takamura et al., 1987; Jassby, 2005; Yoshida et al., 2007).

The increased *Microcystis* abundance in dry years was accompanied by an expansion of the spatial distribution seaward. This expanded distribution may reflect the presence of more favorable physical and chemical water quality conditions for *Microcystis* growth throughout the delta in dry years. It may also reflect decreased streamflows and increased water residence time that enable *Microcystis* colonies to accumulate throughout the delta instead of being flushed downstream. Because *Microcystis* maximum potential growth rate is slow compared with other primary producers, blooms can reflect accumulation of colonies more than elevated growth rate (Wang et al., 2010; Elliott, 2012). Previous measurements of growth rate in 24 h dissolved oxygen light and dark bottle incubation studies confirmed the average maximum specific growth rate of *Microcystis* and associated communities in surface waters of the delta ranged from 1.15 to 2.38 mg C (mg chl $a)^{-1}$ h^{-1} (Lehman et al., 2008). This is lower than the minimum 3.6–4.4 mg C (mg chl $a)^{-1}$ h^{-1} measured by similar dissolved oxygen incubation techniques for other primary producers in floodplain and riverine habitats within the delta (Lehman et al., 2008).

Microcystis may have increased in the dry years 2007 and 2008 partly because it has become better adapted to conditions in the delta over time. *Microcystis* blooms in SFE and northern California contain multiple genotypes that would allow them to adapt to environmental conditions (Moisander et al., 2009; Bozarth et al., 2010). For example, a separate genotype in the western delta suggested that *Microcystis* may have evolved to tolerate the elevated salt in this region of SFE where salinity reaches 18 (Moisander et al., 2009). It is unknown if *Microcystis* colonies grow or merely tolerate these brackish water conditions because growth is thought to stop at salinity greater than 10–12.6 (Tonk et al., 2007; Black et al., 2011). However, strains within each genotype could rapidly adjust to local environmental conditions. Quantitative PCR analysis indicated that toxic strains varied both spatially and temporally on a biweekly basis across the delta in 2007 (Baxa et al., 2010). The presence of different strains was further suggested by the presence of at least 11 different types of microcystins within *Microcystis* blooms in 2004 and 2005 (Lehman et al., 2005, 2008). Such variability is common within *Microcystis* blooms; for example, 14 different types of microcystins occurred throughout the bloom season in German lakes (Fastner et al., 1999).

The increase in toxic total microcystins concentration and dissolved organic carbon concentration in *Microcystis* blooms and within mesozooplankton tissue over time was probably due to the increase in *Microcystis* abundance and not an increase in cellular toxicity or extracellular release of dissolved organic carbon. Total microcystins concentration and *Microcystis* biomass are often poorly correlated because not all cells within *Microcystis* blooms contain microcystins (Davis et al., 2009). However in SFE, because most of the *Microcystis* tissue samples contained toxic microcystins, there was a strong correlation between total microcystins concentration and *Microcystis* cell abundance. Further, because dissolved organic carbon concentration decreased with streamflow, the increased concentration in dry years may have been due to increased *Microcystis* abundance. These relationships may change in future blooms. Toxic and non-toxic varieties of *Microcystis* respond differently to nutrient and temperature changes (Davis et al., 2009) and as the abundance increases during blooms, toxic strains are sometimes replaced by non-toxic strains with different physiological characteristics and vice versa (Briand et al., 2008, Rinta-Kanto et al., 2009). PCR analyses conducted for the 2007 bloom identified both toxic and non-toxic strains in the delta (Baxa et al., 2010).

Environmental factors

Threshold conditions

Both threshold and maintenance conditions control the seasonal initiation, persistence, and decline of *Microcystis* blooms in SFE. A threshold response for water temperature characterized the initial phase of the *Microcystis* bloom in the early summer when water temperature reached 19°C and probably initiated vertical migration of *Microcystis* vegetative cells that have been shown in other systems to remain at the bottom of the water column over the winter (Verspagen et al., 2005). A higher water temperature threshold of 20°C was reported for 2005, but this probably reflects the later start of the sampling

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program that year (Lehman et al., 2008). An initial water temperature threshold of 7–18.8°C has been measured for *Microcystis* growth in laboratory and field studies worldwide (Latour et al., 2004; Jiang et al., 2008). *Microcystis* can grow at water temperatures as high as 29–32°C, but optimum growth often occurs around 25–30°C (Robarts & Zohary, 1987; Davis et al., 2009). Because maximum water temperature in the delta is commonly 25–30°C, the bloom is probably not inhibited by an upper water temperature threshold.

The initiation of the bloom was also facilitated by a light threshold of surface irradiance in the visible range above 100 W m^{-2}, turbidity less than 50 NTU, and average integrated PAR_{pz} of over 50 μmol photons m^{-2} s^{-1}. The surface irradiance threshold is reached 3 months earlier than the water temperature threshold, making water temperature the variable that is most likely to restrict the bloom to June through September. Light is also thought to trigger the initial vertical migration of vegetative over-wintering colonies from bottom sediments to the surface in the summer and the bottom in the fall (Sigee, 2005). After initiation of the bloom, light is thought to be adequate because *Microcystis* colonies can migrate to the surface of the water column where light is available. A high-effective quantum yield allows *Microcystis* colonies to outcompete other primary producers at the high surface irradiance levels near the surface that would inhibit most other planktonic primary producers (Wu et al., 2011).

However, the strong negative correlation between *Microcystis* abundance and turbidity in this study suggested light or one of its correlates was an important environmental factor needed to maintain daily growth in SFE. Low turbidity may directly facilitate *Microcystis* growth in SFE where high turbidity creates light-limited growth for most primary producers (Jassby, 2005). Light was also found to be an important factor controlling the duration and onset time of *Microcystis* blooms in Lake Taihu, China (Zhang et al., 2012). Turbidity may also be a proxy for water residence time in the delta because turbidity decreases at low streamflow due to sedimentation of particulate matter and reduced transport of sediment from upstream in this very turbid estuary (Lehman, 2004; Wright & Schoellhamer, 2004). Turbidity could also be a proxy for vertical mixing which increases at elevated streamflow and would negatively impact *Microcystis* growth by limiting the time colonies remain in the surface layer during the day where light is elevated and transport is maximized. Vertical mixing of deep riverine channels has been associated with reduced net primary productivity in the Delta where the photic zone is shallow due to heavy sediment (Cloern, 1987). In addition, vertical mixing is physically detrimental to *Microcystis* colonies because it disaggregates large buoyant colonies into small, less buoyant ones (O'Brien et al., 2004).

Nutrients

The maintenance of *Microcystis* blooms requires the availability of the macronutrients nitrogen and phosphorus, but there was no suggestion that these nutrients or their ratio controlled the seasonal or inter-annual variation in the bloom. The nitrate concentration greater than 0.2 mg N l^{-1} and SRP concentration greater than 0.003 mg l^{-1} needed to support *Microcystis* growth in laboratory cultures (Jiang et al., 2008) was well below the average ambient nitrate and SRP concentrations in SFE of 0.32 ± 0.14 mg l^{-1} and 0.07 ± 0.04 mg l^{-1}. However, both nitrate and SRP concentrations in SFE were far lower than the 8.7 mg N l^{-1} nitrate and 0.22 mg l^{-1} SRP measured for maximum growth yield at Laguna de Bay in the Philippines or the 1.4 mg l^{-1} total nitrogen concentration needed to efficiently metabolize carbohydrate and maintain buoyancy in laboratory cultures (Brookes & Ganf, 2001; Baldia et al., 2007). This suggests that increased nutrient concentrations could increase the magnitude of the bloom in SFE.

It is also possible that nitrate may be of lesser importance as a source of nitrogen for *Microcystis* growth in SFE because of the availability of ammonium. *Microcystis* has a strong affinity for ammonium which gives it a competitive advantage over other primary producers even at low concentrations (Takamura et al., 1987). An ammonium concentration of 0.025 mg N l^{-1} was sufficient to support a *Microcystis* bloom in Lake Erie, USA while an ammonium concentration of only 0.007 mg N l^{-1} was sufficient to support a *Microcystis* bloom in Steilacoom Lake, WA (Jacoby et al., 2000; Chaffin et al., 2011). The summer time ammonium concentration of 0.04 ± 0.02 mg N l^{-1} was therefore probably sufficient to support the *Microcystis* bloom in SFE. Recent stable

isotope analyses of the $\delta^{15}N$ in particulate organic matter for 2007 and 2008 by Lehman confirmed that ammonium was the sole nitrogen source during *Microcystis* blooms in all but a few samples. The preference of ammonium and not nitrate as the primary nitrogen source for primary producers was also supported by nitrogen uptake studies in the Sacramento River (Parker et al., 2012). The often exclusive uptake of ammonium casts doubt on the importance of Redfield level DIN:DIP molar ratios on *Microcystis* growth as well (Glibert et al., 2011). Median DIN:DIP molar ratios of 11.4 (range 5.8–17.7) in SFE during the peak of the bloom in August and September were usually near or a little lower than the Redfield ratio of 16 needed for optimum phytoplankton growth but drop precipitously to a median of 1.31 (range 0.2–3.2) when ammonium is the only nitrogen source used. DIN:DIP molar ratios in SFE were also similar to those in Steilacoom Lake where peak *Microcystis* biomass occurred at DIN:DIP molar ratios less than 15 (Jacoby et al., 2000). Nitrogen and phosphorus concentrations or their ratio were also not correlated with *Microcystis* blooms in Lake Taihu, China (Zhang et al., 2012).

While the SRP concentration in SFE was not categorized as limiting for growth, it may have influenced the structure and function of the bloom. Phosphorus may be important for regulating vertical migration in SFE. The average ambient SRP concentration in SFE of 0.07 ± 0.04 mg l^{-1} was below the 0.2 mg l^{-1} upper threshold that facilitates growth of wide diameter colonies (Shen & Song, 2007). Wide diameter colonies, like those in SFE, are more buoyant and have lower half saturation constants for phosphorus uptake than small diameter colonies which make them more competitive for nutrients. Slow growth of wide diameter colonies also reduces nutrient depletion while limiting the growth of food resources that support predator populations (Raikow et al., 2004; Shen & Song, 2007).

Streamflow

Streamflow was probably the most important maintenance factor for the bloom. Low streamflows were needed to provide sufficiently long water residence time for the slow growing *Microcystis* colonies to accumulate into blooms (Reynolds, 1997). *Microcystis* blooms were associated with streamflows less than 13–15 $m^3 s^{-1}$ in the Swan River and Neuse River estuaries (Christian et al., 1986; Robson & Hamilton, 2003). Previous research in SFE suggested that *Microcystis* blooms occur when streamflow is low at 28–35 $m^3 s^{-1}$ in the San Joaquin River (Lehman et al., 2008). In this study we refined these streamflow levels to negative 240 to positive 50 $m^3 s^{-1}$ for the QWEST index and 100–450 $m^3 s^{-1}$ for QRIO. A comparatively high streamflow may be needed initially to move colonies from the upper San Joaquin River into the central delta where high residence time associated with low advective and dispersive streamflow would retain colonies in the delta. Flushing along with salinity was similarly found to be the primary driver of *Microcystis* blooms in the Volkerak Estuary, the Netherlands (Verspagen et al., 2006). Streamflow was also correlated with all of the environmental variables, particularly turbidity which was the variable most closely associated with *Microcystis* abundance, chlorophyll *a* concentration and total microcystins concentration. Importantly, it affected both water temperature and light which were key variables in the seasonal initiation and decline of the bloom.

Climate change

The increase in water temperature, light intensity, and nutrient concentration associated with future climate change will likely increase the intensity and duration of *Microcystis* blooms in SFE. *Microcystis* first appeared about 2000 when both the minimum and maximum average water temperature between 1984 and 2007 increased by 1–2°C at three continuous monitoring stations in the Delta (Brooks et al., 2012). *Microcystis* blooms could intensify as water temperature increases because *Microcystis* outcompetes other primary producers at elevated water temperature (Paerl & Huisman, 2008; Paerl & Paul, 2012). Modeling studies also suggest that increased water temperature in the spring could lead to earlier timing and duration of cyanobacteria blooms (Elliott, 2012). This would apply to *Microcystis* blooms in the Delta as well where earlier occurrence of the 19°C water temperature threshold, coupled with the already adequate surface irradiance, could extend the bloom by as much as 3 months into the spring. In fact, water temperature has already increased during the spring by at least 0.5–1°C since 1985 (Lehman, 2004). Increased maximum, minimum, and mean water temperature as

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well as light intensity were also important in extending the duration of *Microcystis* blooms in Lake Taihu, China (Zhang et al., 2012).

Increase in the frequency, intensity, and duration of both high precipitation and drought events with climate change in California (Cloern et al., 2011) could also increase *Microcystis* blooms in SFE. High precipitation would benefit *Microcystis* by increasing the availability of nutrients, particularly ammonium, from runoff and if coupled with subsequent low flow conditions, would restrict flushing and further increase bloom intensity (Paerl & Paul, 2012; Reichwaldt & Ghadouani, 2012). Conversely, the expected increased frequency and intensity of droughts could facilitate *Microcystis* blooms in SFE by reducing the flushing of *Microcystis* colonies out of the Delta and increasing light in the water column by facilitating sedimentation of particulate matter (Elliott, 2012; Reichwaldt & Ghadouani, 2012). Greater salinity and pH during droughts would also favor *Microcystis* blooms that survive over a wide range of freshwater to brackish water conditions and pH in SFE (Lehman et al., 2005). Lastly, biological feedback mechanisms could facilitate the increase in *Microcystis* bloom intensity during droughts because reduced vertical mixing would likely increase aggregation of cells into wide diameter colonies with increased buoyancy near the surface and reduce exposure to limiting light and carbon concentration within the water column (Paerl & Paul, 2012).

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Increased selenium threat as a result of invasion of the exotic bivalve *Potamocorbula amurensis* into the San Francisco Bay-Delta

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Abstract

Following the aggressive invasion of the bivalve, *Potamocorbula amurensis*, in the San Francisco Bay-Delta in 1986, selenium contamination in the benthic food web increased. Concentrations in this dominant (exotic) bivalve in North Bay were three times higher in 1995–1997 than in earlier studies, and 1990 concentrations in benthic predators (sturgeon and diving ducks) were also higher than in 1986. The contamination was widespread, varied seasonally and was greater in *P. amurensis* than in co-occurring and transplanted species. Selenium concentrations in the water column of the Bay were enriched relative to the Sacramento River but were not as high as observed in many contaminated aquatic environments. Total Se concentrations in the dissolved phase never exceeded 0.3 μg Se per l in 1995 and 1996; Se concentrations on particulate material ranged from 0.5 to 2.0 μg Se per g dry weight (dw) in the Bay. Nevertheless, concentrations in *P. amurensis* reached as high as 20 μg Se per g dw in October 1996. The enriched concentrations in bivalves (6–20 μg Se per g dw) were widespread throughout North San Francisco Bay in October 1995 and October 1996. Concentrations varied seasonally from 5 to 20 μg Se per g dw, and were highest during the periods of lowest river inflows and lowest after extended high river inflows. Transplanted bivalves (oysters, mussels or clams) were not effective indicators of either the degree of Se contamination in *P. amurensis* or the seasonal increases in contamination in the resident benthos. Se is a potent environmental toxin that threatens higher trophic level species because of its reproductive toxicity and efficient food web transfer. Bivalves concentrate selenium effectively because they bioaccumulate the element strongly and lose it slowly; and they are a direct link in the exposure of predaceous benthivore species. Biological invasions of estuaries are increasing worldwide. Changes in ecological structure and function are well known in response to invasions. This study shows that changes in processes such as cycling and effects of contaminants can accompany such invasions. © 2002 Published by Elsevier Science B.V.

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1. Introduction

Selenium is an environmental toxicant that has been responsible for adverse reproductive effects and local extinctions of fish and birds in cooling reservoirs of coal-fired power plants (Lemly, 1985), wetlands receiving agricultural drainage (Presser and Ohlendorf, 1987; Skorupa, 1998) and river ecosystems draining seleniferous agricultural lands (e.g. the Colorado River and its tributaries; Hamilton, 1999). Although selenium is nutritionally essential, the window is narrow between essential concentrations in food and concentrations that cause adverse effects (Hodson and Hilton, 1983). Selenium becomes a reproductive toxin at slightly enriched concentrations because it substitutes for sulfur in the tertiary structures of proteins and thereby causes deformities in embryos or inhibition of the hatchability of eggs (e.g. Stadtman, 1974; Diplock, 1976; Skorupa, 1998).

Assessment of selenium effects in aquatic systems is complicated by the differing bioavailability of its several oxidation states (VI, selenate; IV, selenite; O, elemental selenium; -II, selenide) and the occurrence of organic or inorganic forms within an oxidation state (Cutter and Bruland, 1984; Cutter, 1989). Biogeochemical conversion of dissolved Se to particulate forms is also complicated. Organic selenide is produced by plants (such as phytoplankton) or other primary producers (Wrench, 1978; Wrench and Measures, 1982) after uptake of selenite or selenate. Particulate elemental selenium is produced via dissimilatory reduction of selenate or selenite by bacteria (Oremland et al., 1990). Particulate selenium is a critically important phase because diet is the primary route of selenium exposure for invertebrates and other animals (Lemly, 1985; Luoma et al., 1992). Bivalves are especially effective bioaccumulators of selenium because they assimilate almost all the selenium they ingest with particulate material (e.g. from phytoplankton; Luoma et al., 1992) and they lose the element slowly (rate constants of loss are 0.01–0.03 per day; Reinfelder et al., 1997). The selenium bioaccumulated by invertebrate consumers like bivalves is efficiently transferred to their predators upon ingestion and concentrations can be biomagnified in predator tissues. Therefore, selenium most seriously threatens upper trophic level birds and fish (Lemly, 1995).

Although predators are the species of greatest concern with regard to selenium contamination, they are mobile, impractical to sample in large numbers, and generally not especially useful for routine monitoring. Consumer species like bivalves are practical to sample (Phillips and Rainbow, 1993), and they integrate the influences of environmental concentrations, speciation and transformation of selenium. Bioaccumulated selenium in consumers is the critical link in exposure of predators. Monitoring contaminant exposure in a bioindicator is not a substitute for other types of investigations, but it can help focus more complicated studies of fate and effects (Brown and Luoma, 1995).

San Francisco Bay, the largest estuary on the west coast of North America, is formed by the confluence of the Sacramento River and the San Joaquin River. The North Bay extends from the confluence of the two rivers to the Golden Gate, and is comprised of Suisun Bay toward the rivers, an intermediate, large and shallow San Pablo Bay, and Central Bay seaward (Fig. 1). The largest water management system in the world can divert 30% of the Sacramento River during high flows and 60% during the low flow season before it reaches the Bay (for agriculture and drinking water; Nichols et al., 1986). Nearly all of the San Joaquin River is recycled southward for agricultural/urban uses by the water management system, during most months, especially in dry years. Wide seasonal and year-to-year changes in freshwater inflow are linked to precipitation and water management (Nichols et al., 1986). Seasonal and year-to-year differences in river inflows control hydraulic residence times in Suisun Bay, the salinity gradient, and distributions of dissolved and

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particulate constituents like selenium (Largier, 1996; Monismith et al., 1996; Nichols et al., 1986).

San Francisco Bay is one of the few estuaries in which selenium contamination has been studied (Cutter, 1989; Johns et al., 1988). In the 1980s concentrations of selenium in birds, fish (White et al., 1988; Urquhart and Regalado, 1991) and invertebrates (Johns et al., 1988) in the Bay were high enough to be of concern (Luoma et al., 1992), despite relatively low concentrations of selenium in water (Cutter, 1989). Refineries were the predominant source of selenium during this period, especially during the season of low river discharge (Cutter and San Diego-McGlone, 1990). Saline soils rich in selenium are common in the western San Joaquin Valley (SJV). Release of selenium is accelerated by irrigation of those soils and disposal of irrigation drainage has contaminated ground water, wetlands and riverine habitats in the SJV (Presser and Ohlendorf, 1987). Selenium contamination in the San Joaquin River is well known (Presser and Ohlendorf, 1987); and San Joaquin River inputs could be a source of selenium when waters from that river reach the Bay. The selenium studies of the 1980s showed little input from this source, but those studies were conducted during a prolonged drought when little runoff from the San Joaquin River reached the Bay.

The purpose of the present paper is to contrast Se contamination in the water column and in bivalves between the mid-1980s and 1995–1997. Two changes have occurred in the intervening period that could affect Se cycling in the Bay. First, beginning in the mid-1980s, an invading species of bivalve, *Potamocorbula amurensis*, became the predominant benthic macroinvertebrate in the Bay (Carlton et al., 1990). Biological invasions of estuaries have become an increasing problem worldwide and are known to change community structure and function (Cohen and Carlton, 1998; Carlton and Geller, 1993). *P. amurensis* is a voracious feeder that has essentially eliminated the standing stock of phytoplankton from the water column of the Suisun Bay (Cloern, 1996). The result has been an increase in energy available to the benthic food web and a decrease in energy available to the water column food web (J. Thompson, USGS, personal communication). Second, greater than normal precipitation and high river runoff occurred during this study period (May 1995–November 1997), in contrast to the periods of drought that characterized earlier study periods. This could result in more selenium

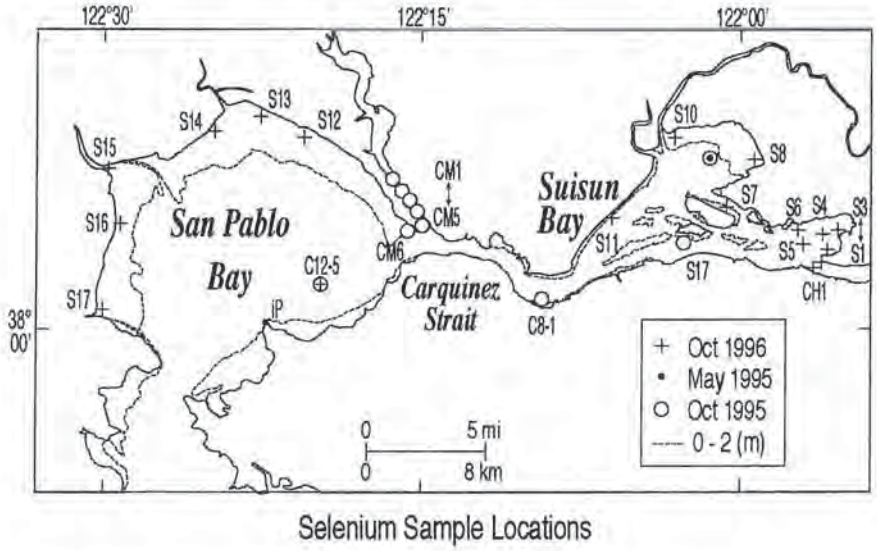


Fig. 1. Shoal (S) and Channel (C) sites sampled in North San Francisco Bay for *P. amurensis* in May 1995, October 1995 and October 1996.

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entering the Bay from the agricultural runoff than occurred previously.Our study investigates several questions:

- have selenium concentrations in the predominant benthos changed after the invasion of *P. amurensis*?
- Are the seasonal and spatial patterns of selenium contamination different from those recorded earlier?
- Is selenium contamination focused in specific habitats where the element might be expected to accumulate (shallow waters vs. adjacency to marshes vs. deeper channel waters)?
- Is selenium uptake by *P. amurensis* different than in co-occurring species or experimentally transplanted species?

2. Experimental design

Four experiments were conducted to evaluate the implications of the invasion and the status of selenium contamination. To establish a reliable baseline of Se concentrations in the bivalves and evaluate seasonal variability, samples were collected near monthly from October 1995 through November 1997 at the station nearest Carquinez Strait (USGS 8.1), traditionally the most Se-contaminated reach of the Bay-Delta. Additional sites were added to resolve the spatial distribution of selenium enrichment in the bivalves. In October 1995, *P. amurensis* were collected from five locations in the tidal reaches of the Napa River and one site toward the river mouthes from Carquinez Strait (USGS 6.1). The Napa River meets the Bay at Carquinez Strait, where Se concentrations have been highest. In October it is expected that the Napa River and the Bay exchange water in both directions throughout the sampling area (D. Schoelhammer, USGS, personal communication). Twenty-four sites were sampled in October 1996 to compare contamination in San Pablo and Suisun Bays and to compare deeper water sites (four stations) to shallow sites (20 stations) adjacent to different marshes. Finally, to evaluate if transplanted bivalves yielded results typical of the native community, *P. amurensis* were collected in May 1995, October 1995 and October 1996 from three sites near those used in bivalve transplants by the San Francisco Bay Regional Monitoring Program (RMP; Fig. 1). These sites were in Grizzly Bay, Carquinez Strait (USGS 8.1) and San Pablo Bay-Pinole Point (USGS 12.5).

3. Methods

Resident clams (*P. amurensis*) were collected from the subtidal zone with a Van Veen grab and 1 or 2 mm sieves. Channel depths ranged from 8 to 20 m. The subtidal sites adjacent to marshes in Honker Bay and the Napa River (Fig. 1) were located in the shallows at an average depth of 1–3 m. Clams were also collected intertidally at low tide with a shovel, sieve and bucket. Between 60 and 120 clams of all sizes were collected at each time and each site and placed into containers of water collected at the site. The clams were kept in this ambient water in a constant temperature room at 10 °C to depurate for 48 h, as previous studies showed a residence time of material in the gut of *P. amurensis* to be approximately 24 h (Decho and Luoma, 1991). Clams from each site were separated into size classes of 1 mm difference and similar sized individuals were composited. Samples of larger numbers of individuals were necessary for smaller size classes in order to obtain enough mass for analysis. Soft tissues were dissected from the shell and tissues. Each composite was then lyophilized and homogenized. Mean concentrations characteristic of a site at a particular time were determined from analyses of three replicate composite samples each containing 20–60 individuals (each composite contained at least 250 mg dry weight (dw) soft tissue).

Selenium in the bivalves was determined by hydride atomic absorption spectrophotometry. Selenium subsamples were digested in concentrated nitric and perchloric acids at 200 °C, reconstituted in hydrochloric acid, and then stored until analysis. All glassware and field collection apparatus were acid washed, thoroughly rinsed in ultra-clean deionized water, dried in a dust-free positive pressure environment, sealed and stored in a dust free cabinet. Quality control was maintained by frequent analysis of blanks, analysis of

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National Institute of Standards and Technology standard reference materials (tissues and sediments) with each analytical run, and internal comparisons with prepared quality control standards. Analyses of National Institute of Technical Standards (NITS) reference materials (oyster tissue, San Joaquin soils) were within an acceptable range of certified values reported by NITS (data in Luoma and Linville, 1996).

Water and particulate samples were collected in June 1995 and October 1996 using methodologies described earlier (Cutter, 1989). Pre-cleaned teflon Go-Flo sampling bottles were used to obtain water 1 m below the surface. The water was filtered through pre-cleaned and pre-weighed 0.45 μm Nucleopore membrane filters into 1 l linear polyethylene bottles and acidified to pH 1.5 with HCl. Filters were carefully folded, placed in polyehtylene vials and immediately frozen. Total dissolved selenium was determined by boiling a 4 M HCl acidified sample with potassium persulfate solution for 1 h; then analyzing as a selenite sample by selective generation of hydrogen selenide, liquid nitrogen-cooled trapping, and atomic absorption detection (0.01 mol l^{-1} detection limit). The standard additions method of calibration was used to ensure accuracy and all determinations were made in triplicate. Particulate selenium determinations were made using digestion procedures described by Cutter (1985) and procedures for reducing iron concentrations described by Cutter (1989). Filters were dried at 40 °C, re-weighed, then digested using a three step nitric-perchloric acid digestion. After iron removal by passage through an anion exchange resin, the digest was analyzed as a total selenium sample.

4. Results and discussion

4.1. River discharge

River discharges could influence allochthonous inputs of selenium from the San Joaquin River. Probably more important are the inflows from the Sacramento River, which has very low selenium concentrations and dilutes enriched Se inputs to the Bay (Cutter, 1989). The Mediterranean climate of the area drives a seasonal cycle in river discharge and causes large year-to-year variability in discharge. Nearly all precipitation occurs in the watershed between approximately November and April. The early flow is trapped in dams and snowfall; the highest river flows typically occur from January through approximately June, followed by low river flows through the rest of the year (Fig. 2). Interannual differences also reflect differences in precipitation. The period of record for the present study, 1995–1997, was characterized by high peak river inflows and, especially in 1995, a prolonged period of elevated river discharge. Previous studies of selenium in San Francisco Bay occurred between 1976 and 1977 and 1986 and1990. Both were periods of prolonged drought, except for a flood in April 1986. Fig. 2 contrasts the patterns of river discharge in 1995–1997 to a typical drought year (1994) when both the magnitude and the period of high river discharges are reduced (also see hydrograph in Johns et al., 1988).

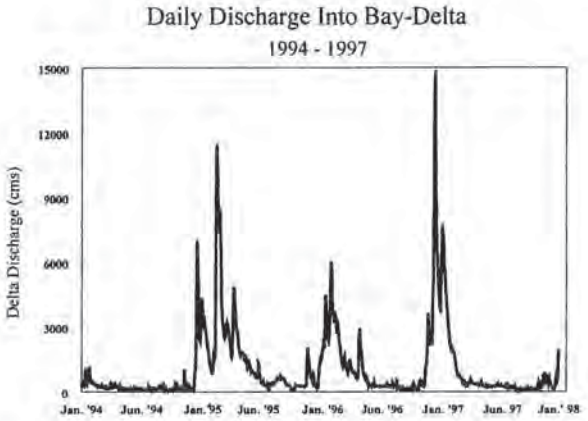


Fig. 2. Daily river discharge into San Francisco Bay, determined as net delta outflow at Chipps Island in Suisun Bay, between 1 January 1994 and 30 November 1997, as $m^3 s^{-1}$.

4.2. Selenium in the water column

Fig. 3(a) compares total dissolved selenium concentrations in estuarine transects from June 1995 to October 1996, with concentrations determined by the same methods in September 1986

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(Cutter, 1989). All values are plotted as a function of salinity. Arrows depict the location of Carquinez Strait in each transect. Selenium concentrations in the Bay in 1995–1996 exceeded those in the Sacramento River, as in previous studies (0.065 ± 0.022 μg Se per l; Cutter and San Diego-McGlone, 1990). The highest concentration in the Bay was 0.29 μg l^{-1}. Within the Bay-Delta the concentrations at most stations followed the order June 1995 < October 1996 < September 1986, but the differences among the three transects were small, and appear to fall with the range of variation defined by Cutter and San Diego-McGlone (1990). The shape of the October 1996 transect differed from that in September 1986 because of elevated selenium concentrations at the upstream-most station, perhaps indicating some San Joaquin input. Total dissolved Se concentrations were low compared with the USEPA water quality standard of 5 μg Se per l (Environmental Protection Agency, 1992).

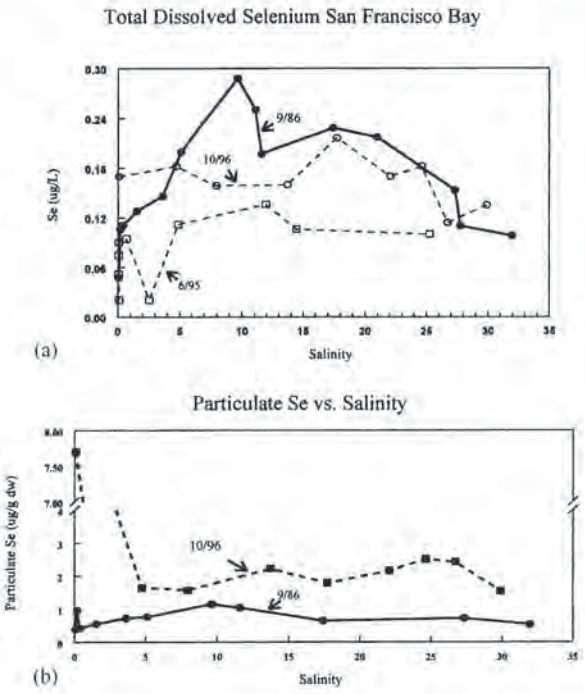


Fig. 3. (a) Dissolved Se concentrations (μg Se per l) as a function of salinity, determined in transects across the salinity gradient of North San Francisco Bay in September 1986 (Cutter, 1989), June 1995 and October 1996. (b) Concentrations of particulate Se (μg Se per g dw) as a function of salinity determined in transects across the salinity gradient of North San Francisco Bay in September 1986 (Cutter, 1989) and October 1996.

Particulate selenium is the variable most likely to ultimately determine selenium bioavailability (Luoma et al., 1992). Concentrations of selenium on suspended particulate material were determined only in October 1996, during the present study. Particulate selenium was uniformly higher in Oct 1996 than in the estuarine transect conducted in September 1986 (Cutter, 1989; Fig. 3(b)). The highest concentration was observed in the river station in October 1996 (nearly 8 μg g^{-1} dw), again indicating particulate selenium inputs from the San Joaquin River were possible (subsequent studies have not found these high values, however; Cutter et al., unpublished data).

4.3. Selenium in *P. amurensis*

4.3.1. Spatial variability

Among the stations that were sampled in May 1995, selenium concentrations in soft tissues of *P. amurensis* ranged from 3.7 ± 0.7 to 7.1 ± 0.3 μg Se per g dw (Table 1). Se concentrations were higher in *P. amurensis* from the Carquinez Strait (7.1 μg Se per g dw), than ($P < 0.01$) in the shallows of Suisun Bay (3.9 μg Se per g dw) and San Pablo Bay (3.7 μg Se per g dw). The latter two sites were not statistically different. Concentrations in October 1995 were higher than in May 1995. Se in *P. amurensis* from Carquinez Strait (15.4 μg Se per g dw) and Suisun Bay (14.5 μg Se per g dw) were not statistically different; but both were higher than Se concentrations in San Pablo Bay (11.6 μg Se per g dw; $P < 0.05$; Table 1). Concentrations were also elevated in the tidal Napa River compared with May concentrations in the North Bay.

Concentrations of Se in *P. amurensis* in October 1996 were similar to October 1995 (Table 1; Fig. 4). The range of mean Se concentrations in *P. amurensis* was 6.9–8.7 μg Se per g dw in San Pablo Bay, and 5.9–20 μg Se per g dw in Suisun Bay. The greatest enrichment was observed in the Carquinez Strait (20.0 μg Se per g dw). Higher concentrations were observed toward the rivers, at stations S1–S6, compared with other shallow water locations in Suisun Bay or San Pablo Bay

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Table 1
Selenium concentrations in μg g^{-1} dw in *P. amurensis* at 29 locations in North San Francisco Bay (Fig. 1) in May 1995, October 1995, and October 1996

Site	Se (μg g^{-1} dry)	Standard deviation (S.D.)	Sample composites
May 1995			
Grizzly Bay	3.9	0.8	5
8.1 (Carq. Straits)	3.7	0.7	3
San Pablo Bay-Pinole Pt.	7.1	0.3	3
October 1995			
6.1	14.5	1.4	3
8.1 (Carq. Straits)	15.4	1.0	3
12.5 (San Pablo)	11.6	1.1	5
Napa 1	12.5	1.0	3
Napa 2	15.3	n/a	1
Napa 3	14.1	0.5	3
Napa 4	14.0	0.9	3
Napa 5	12.7	0.7	2
Napa 6	12.6	0.8	5
October 1996			
4.1	11.0	1.0	7
6.1	16.8	1.6	5
8.1 (Carq. Straits)	20.0	1.4	4
12.5 (San Pablo)	8.7	2.1	4
S1	9.6	0.2	2
S2	9.2	0.1	2
S3	7.5	0.1	2
S4	10.0	0.0	2
S5	8.9	0.4	5
S6	10.3	0.8	2
S7	5.9	1.6	4
S8	6.1	0.3	2
S9	8.2	0.7	4
S10	6.7	0.2	3
S11	7.3	0.3	4
S12	8.3	0.3	2
S13	8.1	0.5	2
S14	8.1	0.7	3
S15	6.9	1.2	3
S16	7.5	0.3	3
S17	7.9	0.7	2

Each sample composite included approximately 20–60 individual *P. amurensis*, and >250 mg dw soft tissue. Napa River stations are numbered North-to-South ascending. Stations S1–S17 are in shallow water.

($P < 0.001$; Table 1; Fig. 4). Like dissolved and particulate concentrations in October 1996, the higher concentrations toward the rivers in *P. amurensis* could have reflected inputs from the San Joaquin River.

Thus all three samplings of bivalves indicate that Se concentrations in *P. amurensis* are enriched compared with background concentrations typical of bivalves (< 3 μg Se per g; Johns et al., 1988) and that enrichment is widespread through North San Francisco Bay. Concentrations varied nearly 4-fold among sites. The observation of the highest concentrations near Carquinez Strait is consistent with past studies (Cutter, 1989; Johns et al., 1988) and the previously identified refinery source of Se input. Dilution of contamination (i.e.

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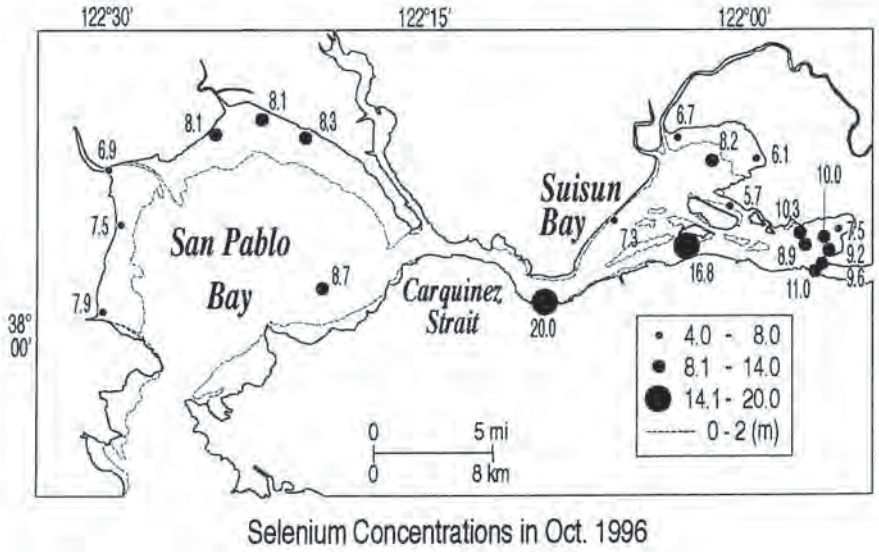


Fig. 4. Map showing distribution of mean Se concentrations in *P. amurensis* (μg Se per g dw) at 20 locations in Suisun and San Pablo Bays, in North San Francisco Bay, in October 1996. Standard deviations (S.D.) are shown in Table 1. Site codes are shown in Fig. 1.

the lowest concentrations in *P. amurensis*) near the eastward marshes in Suisun Bay and the western-most shallows of San Pablo Bay are consistent with dilution away from the refineries. Sources and mixing appeared to be more important than shallow versus deep-water habitat, despite the possibility that selenium is trapped in shallow wetlands. Some riverine input is also possible. Long residence times and complicated, tidally driven circulation patterns (Burau et al., in prep.) probably contribute to the somewhat complicated pattern of the contamination in *P. amurensis* in Suisun and San Pablo Bay during periods of low river inflow.

4.4. Temporal variability

Selenium concentrations in *P. amurensis* from Carquinez St. varied as much as three-fold seasonally between May 1995 and November 1997 (Fig. 5). The lowest concentrations were observed in May 1995 (7.1 ± 0.3 μg Se per g dw) and May 1997 (6.2 ± 0.2 μg Se per g dw). Concentrations were highest in October 1995 to February 1996 (15.4 ± 1.0 μg g^{-1}–18.9 ± 0.4 μg Se per g dw), October 1996 (20 ± 1.4 μg Se per g dw), and November 1997 (15.3 ± 3.4 μg Se per g dw). The larger standard deviations in the four samples in late 1997 are probably the result of employing fewer individual animals per composite.

The seasonal pattern of selenium in *P. amurensis* from Carquinez Strait coincided with seasonal changes in river inflows. The lowest concentrations always occurred after episodes of highest river inflows and shortest hydraulic residence

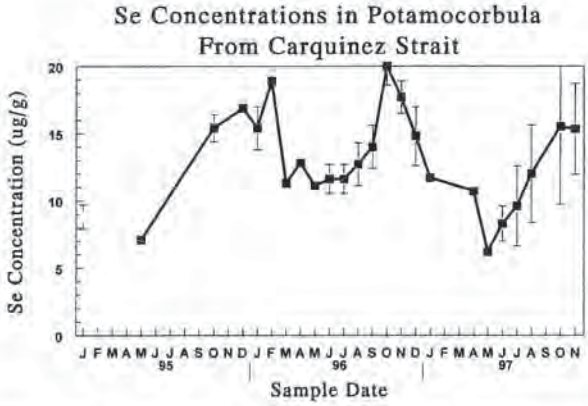


Fig. 5. Mean and S.D. of Se concentrations in *P amurensis* (μg Se per g dw) at site C8.1 as determined at near monthly intervals between May 1995 and November 1997.

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times. The greatest increase in Se occurred after prolonged periods of low flow, as hydraulic residence times increased. Increased Se bioaccumulation with increased residence times has been reported in other systems (Lemly, 1998). In contrast, Johns et al. (1988) did not observe strong seasonality in concentrations of Se in *Corbicula fluminea* in Suisun Bay, in the mid-1980s. One important difference was that that study did not include periods of river inflows as high or as prolonged as those occurring in 1995–1997.

4.5. Comparison to historic concentrations in bivalves

The selenium concentrations in *P. amurensis* in Suisun and San Pablo Bay are considerably higher than found in bivalves, in general, in uncontaminated estuaries in Northern California (1.7–3.1 μg Se per g dw, Johns et al., 1988; White et al., 1988). Data from *P. amurensis* itself is not available from uncontaminated estuaries. Concentrations in *P. amurensis* are also higher than in earlier studies from the Bay. Selenium exposures in the bivalves *Mytilus edulis* and *C. fluminea* were studied near Carquinez Strait in 1975 and 1984–1986, respectively (Risebrough, 1977; Johns et al., 1988). Risebrough et al. (1977) reported a mean concentration of 8 ± 3 μg Se per g dw in transplanted *M. edulis* from four sites near Carquinez Strait and concentrations of 10–11.4 μg Se per g dw in bivalves deployed directly in Carquinez Strait. These were some of the highest concentrations in the Bay at that time. Johns et al. (1988) sampled resident *Corbicula amurensis* at near monthly intervals from a station toward the rivers from Carquinez Strait (the most seaward population of *Corbicula* present in Suisun Bay at the time). In 67 samples they found a mean concentration of 6 ± 3 μg Se per g dw in the clams. Mean selenium concentrations in *P. amurensis* among all the samples reported above (15 ± 3 μg Se per g dw) were higher than found previously in either *M. edulis* or *C. fluminea*. The dominant bivalve in Suisun Bay changed from *C. fluminea* in 1985-86 to *P. amurensis* after the invasion of the latter species (Carlton et al., 1990; Nichols et al., 1990), so an increase in the exposure of benthic predators to Se is likely if they consumed the invasive bivalve.

4.6. Comparison to monitoring with co-occurring and transplanted bivalves

Some species possess characteristics that enhance their bioaccumulation of contaminants. High assimilation efficiencies of selenium are typical of most marine organisms (Reinfelder et al., 1997; Wang and Fisher, 1999). But some species (copepods are an example) lose selenium rapidly (~ 0.15 per day) compared with other elements (Wang and Fisher, 1998), whereas loss rates from bivalves are slow (0.01–0.03 per day; Luoma et al., 1992; Reinfelder et al., 1997). Efficient assimilation and slow loss means that bivalves have generally strong capabilities to bioaccumulate selenium in their tissues (Reinfelder et al., 1997). *P. amurensis* is an unusually voracious filter feeder, it has an unusually short gut residence time (Decho and Luoma, 1991) and it utilizes a variety of food sources. All of these traits could enhance its ability to bioaccumulate Se, even compared with other bivalves.

Direct comparisons with co-occurring species are difficult with *P. amurensis*, because it tends to replace other bivalves and consumer organisms (Nichols et al., 1990). In June 1997 we found *P. amurensis* from a Carquinez Strait mudflat had 12.9 ± 1.2 μg Se per g dw and a co-occurring population of *M. balthica* contained 3.7 ± 0.1 μg Se per g dw. But this was only one coincident sampling. A comparison of *P. amurensis* with *C. fluminea* toward the rivers in Suisun Bay found similar concentrations in both species in October 1996, but sample sizes were very small. Conclusive determination of any special bioaccumulative characteristics of *P. amurensis* await further comparisons with co-occurring species and comparative kinetic studies.

An alternative approach is to compare Se bioaccumulation in *P. amurensis* with values in transplanted bivalves used to monitor the Bay. In the RMP of the San Francisco Estuarine Institute (SFEI, 1995, 1996), bivalves are transplanted for 90–100 days then contaminant uptake is compared with concentrations observed before the

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Table 2
Comparison of selenium concentrations in transplant and resident species in North Bay in May 1995, October 1995 and October 1996

Site	Species transplant	Change in condition index ($T_F - T_o$)	Se (μg g^{-1} dry) [$T_F - T_o$]	Species: resident	Se (μg g^{-1} dry)
May 1995					
Grizzly Bay	*C. fluminea*	0.018	1.4 [−0.3]	*P. amurensis*	3.9 ± 0.8
Napa R. (Carquinez)	*C. gigas*	−0.022	6.2 [4.6]	*P. amurensis*	7.1 ± 0.3
San Pablo Bay-Pinole Pt.	*C. gigas*	0.006	5.4 [3.8]	*P. amurensis*	3.7 ± 0.7
October 1995					
Grizzly Bay	*C. fluminea*	−0.02	4.8 [0.1]	*P. amurensis*	14.5 ± 1.4
Napa R. (Carquinez)	*C. gigas*	−1.04	2.9 [−0.2]	*P. amurensis*	15.4 ± 1.0
San Pablo Bay-Pinole Pt.	*M. californianus*	−0.02	2.5 [−0.8]	*P. amurensis*	11.6 ± 1.1
October 1996					
Grizzly Bay	*C. fluminea*	−0.038	2.9 [1.3]	*P. amurensis*	8.2 ± 0.7
Napa R. (Carquinez)	*C. gigas*	−0.089	7.2 [2.9]	*P. amurensis*	20 ± 1.4
San Pablo Bay-Pinole Pt.	*M. californianus*	−0.039	2.7 [−2.4]	*P. amurensis*	8.7 ± 2.1

For transplanted species the final concentration is presented with the level of bioaccumulation of selenium over deployment period ($T_F - T_o$) displayed in brackets. The change in condition index over the period of deployment, a measure of growth (or lack of feeding), is also presented. 'Transplant' data from SFEI, 1995, 1996.

deployment. The RMP employs three different bivalves, due to differing salinities in the Bay, *C. fluminea* is used in Suisun Bay; the oyster *Crassostrea gigas* is used near Carquinez Strait; and the mussel *Mytilus californianus* is used in San Pablo Bay. Three of the sampling locations used for *P. amurensis* were near the above locations used by the RMP, and the 1995–1996 studies with *P. amurensis* were conducted at the same time as an RMP sampling.

Table 2 shows concentrations of Se in the transplants and the level of bioaccumulation, or lack thereof, during deployment in May 1995, October 1995 and October 1996. Changes in condition index over the deployment period are also shown; and these are compared with concentrations in the resident *P. amurensis* at the end of the deployment period of the transplanted species. Absolute concentrations of Se in tissues and patterns of bioaccumulation in time and space are compared. The differences in absolute concentrations were small in May 1995. But substantial differences were observed between the deployed bivalves and *P. amurensis* in both October 1995 and October 1996. In October 1995, selenium concentrations in *P. amurensis* were 11.6–15.4 μg Se per g dw among the three sites. None of the deployed species bioaccumulated Se during the deployment (concentrations were similar to the original population) and concentrations ranged from only 2.5 to 4.8 μg Se per g dw (Table 2). A similar result occurred in October 1996. In that experiment, bioaccumulation of selenium was observed in *C. gigas* but concentrations were less than half those in *P. amurensis* at a nearby site. No significant bioaccumulation occurred in *C. fluminea*, although the concentration of Se in *P. amurensis* at that site was 8.2 ± 0.7 μg Se per g dw. Thus the seasonal pattern of greatly increased bioaccumulation in October compared with May was clear in *P. amurensis* but was not observed in the deployed animals.

The approach used to study bioaccumulation may be the cause of the differences between Se

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bioaccumulation in *P. amurensis* and the transplants, *C. fluminea*, *C. gigas* or *M. californianus*. Phytoplankton blooms in Suisun Bay have essentially disappeared since the *P. amurensis* invasion, presumably due to consumption of primary production by the invasive bivalve. It is notable that condition index appeared to decline in all transplants in both October experiments (Table 2). Reduced condition index after deployment suggests that the deployed bivalves were not feeding normally in the fall. Uptake from food is the predominant route of selenium exposure (Luoma et al., 1992; Wang and Fisher, 1999). Therefore, it is possible that non-feeding deployed animals were not exposed to environmental selenium. The deployed animals gave no indication that high selenium concentrations were common in the predominant benthic species in North Bay during the season of low river inflows. Thus, the transplanted animals did not provide an accurate picture of selenium contamination in the estuary, and did not reach the level of selenium contamination found in *P. amurensis*.

4.7. Consequences of high selenium concentrations in P. amurensis

Bivalves are a critical link for passing selenium to benthivores because trophic transfer is the primary route of predator exposure (Lemly, 1985). The highest concentrations of Se in *P. amurensis* are especially significant in that they exceed values that other studies have shown reduce growth or cause reproductive damage when ingested in experiments by birds and fish (Hamilton et al., 1990; Heinz et al., 1989). Teratogenicity, effects on hatchability of eggs and reduced growth of young life stages have a threshold of occurrence above 3–10 μg Se per g dw in food in various studies (Lemly, 1998; Hamilton, 1999; Heinz et al., 1989). A high frequency of adverse effects is found when concentrations in food (prey) exceed 10–11 μg Se per g dw (Skorupa, 1998; Adams et al., 1998). The highest concentrations in *P. amurensis* exceed the latter value by two-fold.

Some of the important resource species in the North Bay/Delta eat *P. amurensis* and presumably other bivalves (sturgeon, diving ducks such as scoter and scaup, dungeness crab; Carlton et al., 1990). Earlier studies (White et al., 1988; Urquhart and Regalado, 1991) showed that these benthivores were the predators with the highest selenium concentrations. Average yearly Se concentrations in the liver of the diving duck, surf scoter, ranged from 75 to 200 ug g^{-1} dw in 1986–1990, a 7- and 14-fold increase from a reference site (Humboldt Bay). White sturgeon captured between 1986 and 1990 contained annual average concentrations ranging from about 9–30 ug Se per g dw in liver ($n = 52$); and 7–15 ug Se per g dw in flesh ($n = 99$). In 1986, the Dungeness crab had an average soft tissue concentration of 15 ug Se per g dw, which was a three fold increase from the reference site (Humboldt Bay). Predators that fed from the water column (e.g. striped bass) seemed to have lower selenium concentrations than the benthivores.

If the susceptibility of San Francisco Bay to invasion by the exotic species *P. amurensis* (Carlton et al., 1990) caused greater Se contamination in the benthos, this effect could be passed on to benthivores. Little data is available to evaluate selenium concentrations in benthivores after 1990. But the 5-year Se Verification Study extended from 1986 through 1990 (Urquhart and Regalado, 1991). *P. amurensis* was first observed in the Bay in 1986 and became well established by 1988 (Carlton et al., 1990; Nichols et al., 1990). Annual mean selenium concentrations in bivalves and two benthivores, sturgeon and scoter, were collected simultaneously in that study and in several of the years between 1986 and 1990. Bivalve selenium concentrations (not including *P. amurensis*) and benthivore concentrations were strongly correlated in that data set (Figs. 6 and 7). The highest values in benthivores were observed in 1989 and 1990. If the mean concentration of selenium in *P. amurensis* was inserted into Fig. 7 at the 1989–1990 benthivore concentration, the added point is consistent with changing selenium exposures of predators. Thus preliminary analysis indicates that the successful invasion of this new resident of Suisun Bay could have changed the exposure of at least some predators in this system.

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5. Conclusions

Invasion of San Francisco Bay by the exotic bivalve, *P. amurensis*, resulted in an increase by threefold of selenium concentrations in the predominant macrobenthic food in the estuary. Se concentrations in bivalve-consuming benthivores in the North Bay appeared to increase between the time *P. amurensis* populations were first observed (1986, Carlton et al., 1990) and when it became established as the predominant benthic species (~ 1988–1990; Urquhart and Regalado, 1991). This is of concern because Se is a strong reproductive toxin for such species, and Se concentrations in *P. amurensis* in fall 1995 and 1996 were in excess of the toxicologic threshold for adverse effects on such predators. Se-contaminated *P. amurensis* were widespread in Suisun and San Pablo Bays in 1995 and 1996. Seasonal variability is an important feature of selenium contamination in *P. amurensis*, with the highest concentrations occurring in fall during the period of longest hydraulic residence times. Transplanted bivalves were not good surrogate indicators for exposure and contamination of the resident bivalve.

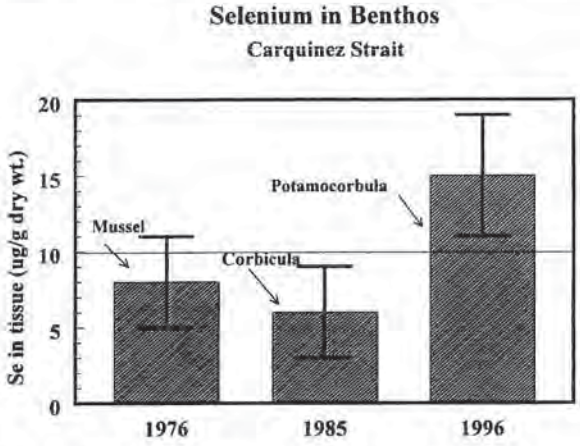


Fig. 6. Mean and S.D. of Se concentrations (μg Se per g dw) in three studies of bivalves from in or near Carquinez Strait in three different decades. 'Mussels' were studies of transplanted *M. edulis* in 1976 (Risebrough et al., 1977); 'Corbicula' represents mean of 67 samplings of the clam *C. fluminea* (Johns et al., 1988) and 'Potamocorbula' is the mean of all Carquinez samples in the present study.

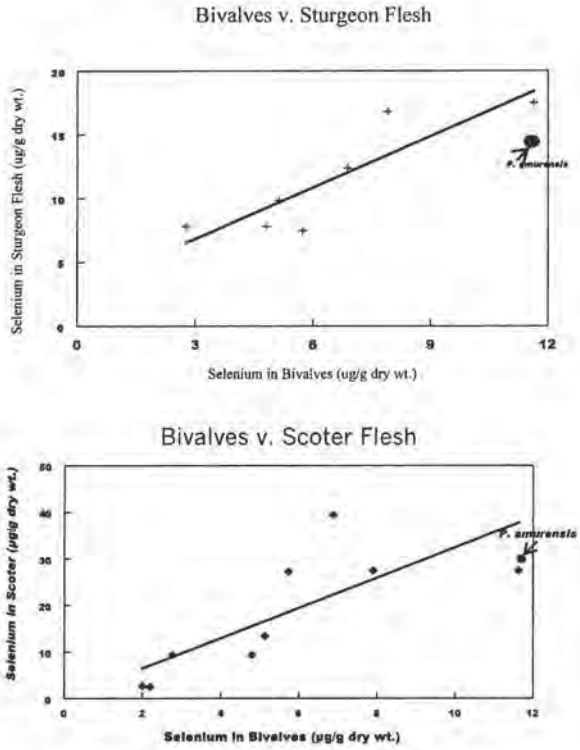


Fig. 7. Relationships between Se concentrations in resident bivalves (data from White et al., 1988; Urquhart and Regalado, 1991; Johns et al., 1988) and either sturgeon flesh or the flesh of the diving ducks (surf scoter) from North San Francisco Bay and Humboldt Bay (data from White et al., 1987, 1988, 1989; Urquhart and Regalado, 1991). Predators and prey were sampled in the same season, year and sub-bay. Mean Se concentration in *P. amurensis* at Carquinez in 1995 is superimposed on each graph to match predator data from 1989–1990, because *P. amurensis* was probably the primary food of these predators in 1989–1990.

We did not fully disprove the hypothesis that the invasive species, *P. amurensis*, is not more efficient at bioaccumulating selenium than other bivalves, although some evidence points in that direction. But this is not the only way an invasive species can affect the fate and effects of a contaminant. The efficient bioaccumulation of Se by bivalves, in general, and the efficient dietary transfer of Se from bivalves to higher trophic levels means that an invasion that shifts the structure of an estuarine community toward dominance by a bivalve-based benthic food web can enhance adverse effects of selenium in the system, by expand-

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ing the availability of a contaminated food supply. Whatever the basic mechanism, it seems clear that the invasion of the non-native bivalve *P. amurensis* has resulted in increased bioavailability of a potent environmental toxin to certain benthivores in San Francisco Bay. Changes in contaminant cycling and potential effects are yet another reason to be concerned by the threat of invasive species in our estuarine ecosystems (Cohen and Carlton, 1998; Carlton and Geller, 1993).

Acknowledgement

Selenium analyses of *P. amurensis*, and quality control of those samples, were from the laboratory of A. Horowitz and K. Ehlrick, U.S. Geological Survey.

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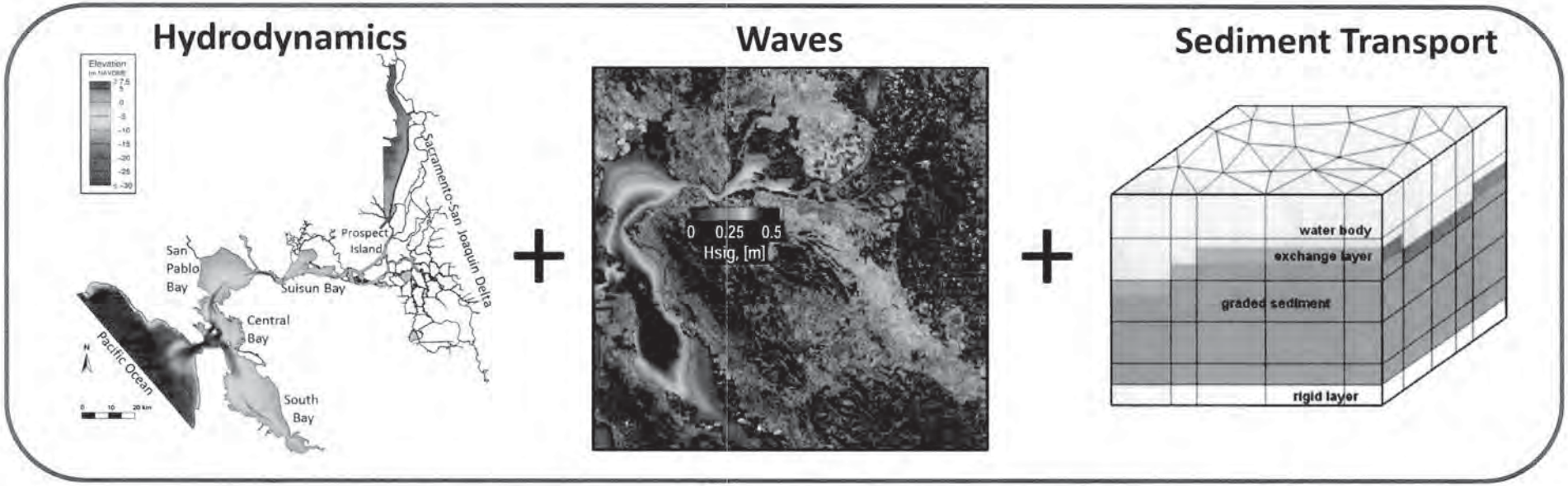
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Evaluation of the Effects of Prospect Island Restoration on Sediment Transport and Turbidity



Michael MacWilliams, Aaron Bever, Noah Hume,
Erik Loboschefsky, Stuart Siegel

February 26, 2014

Wetlands and Water Resources Joint Venture | Stillwater Sciences

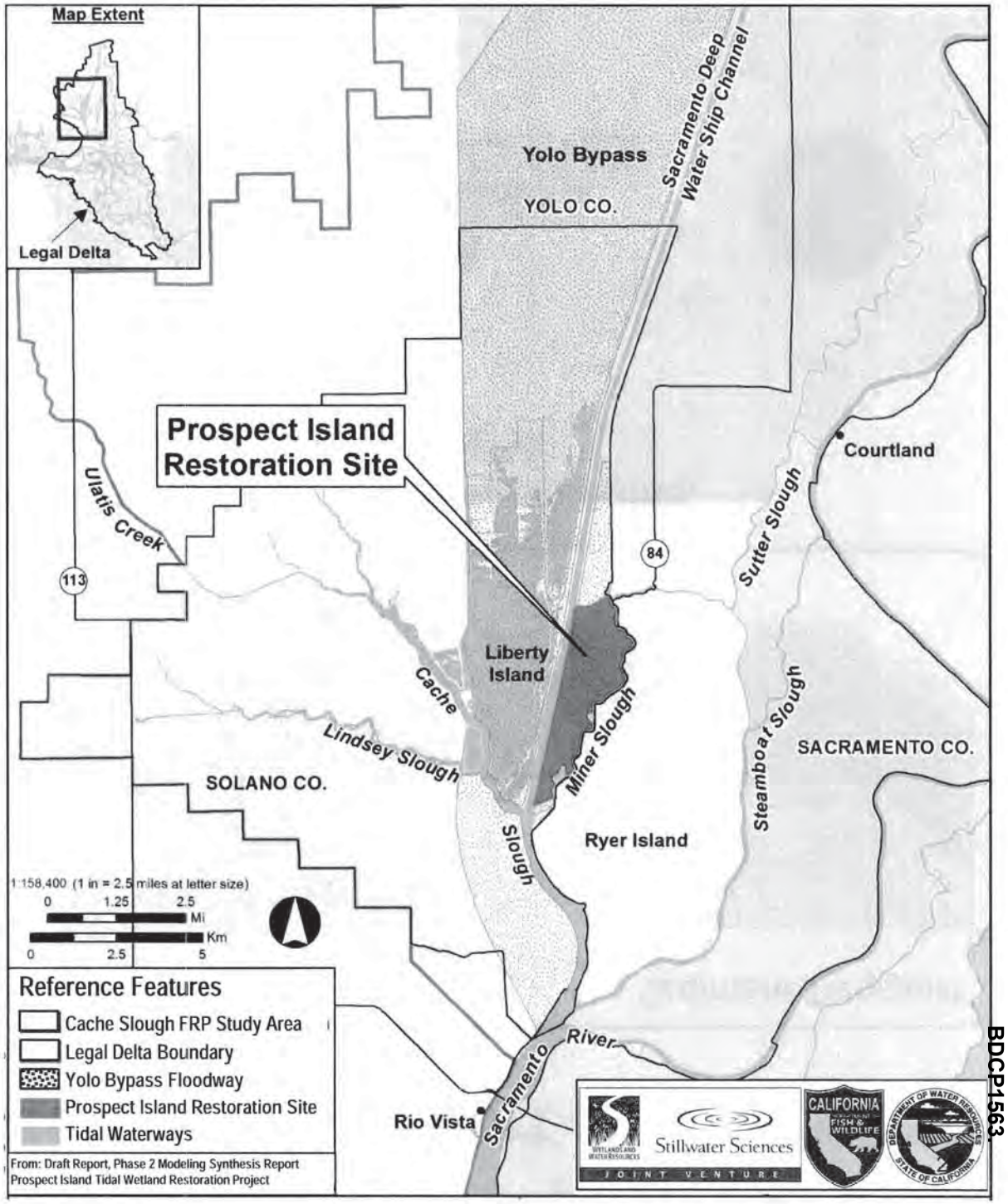
DELTA MODELING ASSOCIATES

Department of Water Resources, State of California

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Prospect Island Tidal Habitat Restoration Project

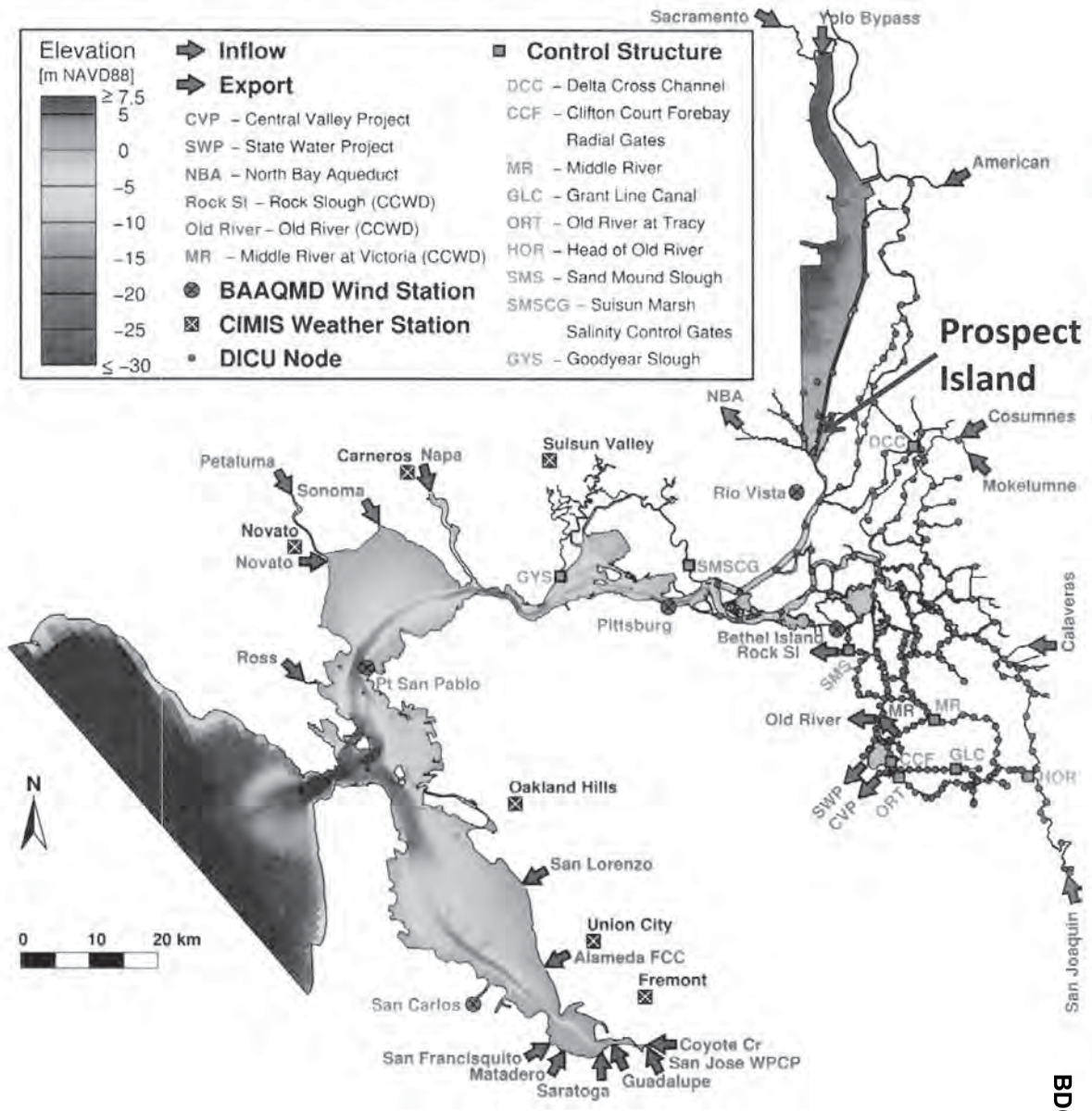
- Joint effort by California DWR and California Department of Fish & Wildlife.
- Restore up to 1,600 acres to freshwater tidal wetland.



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Ur `RIM San Francisco Bay-D `ta Model

- Applied to evaluate sediment transport near the Prospect Island Habitat Restoration Project for a suite of restoration scenarios.
- Compare how two different breach configurations affect regional turbidity and sediment deposition within Prospect Island.



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UnTRIM-SWAN-SediMorph Model Coupling



User Specified Time-step

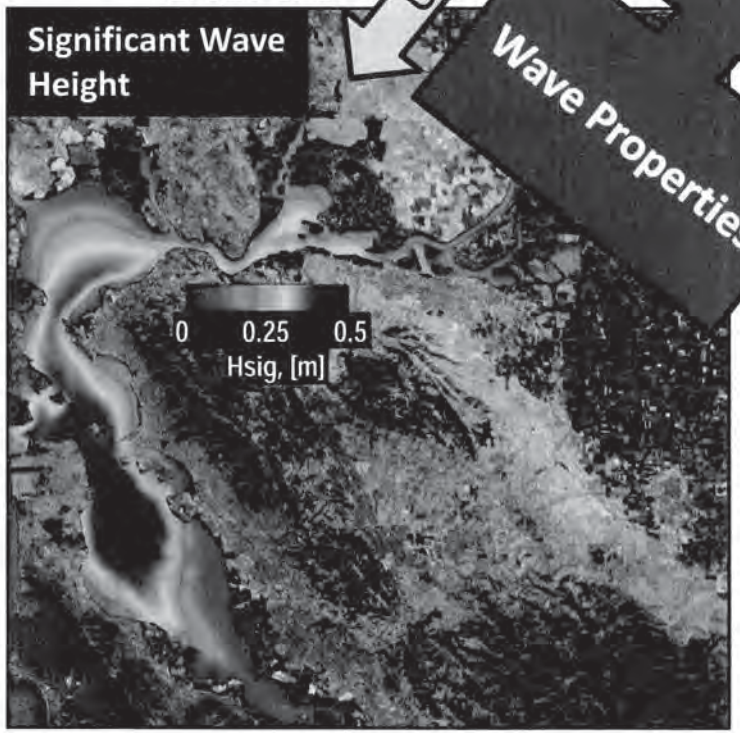
Water Depth
Depth Averaged Currents
Bottom Friction
Wind Speed/Direction

Current Speed
Suspended Sediment Concentrations
Wave Properties

Every Modeled Time-step

SWAN

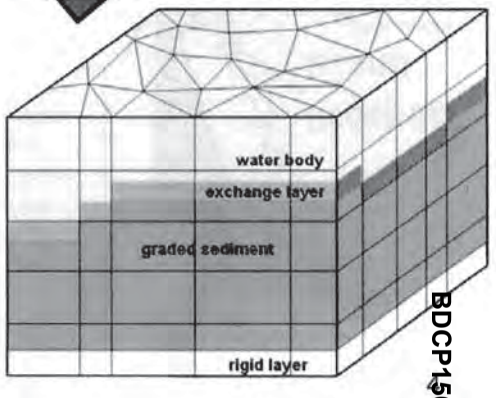
Significant Wave Height



Wave Properties

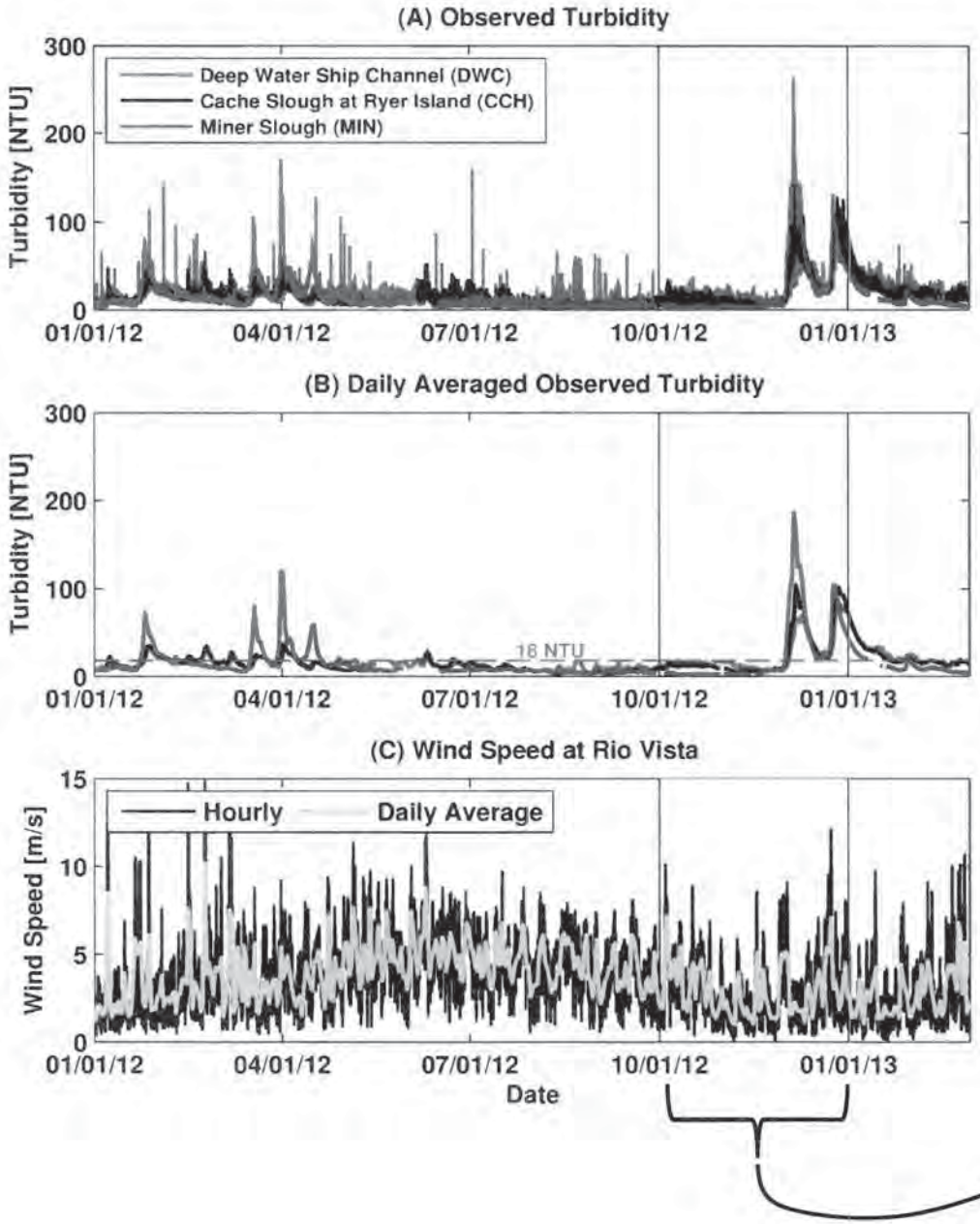
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Seabed Elevation Change

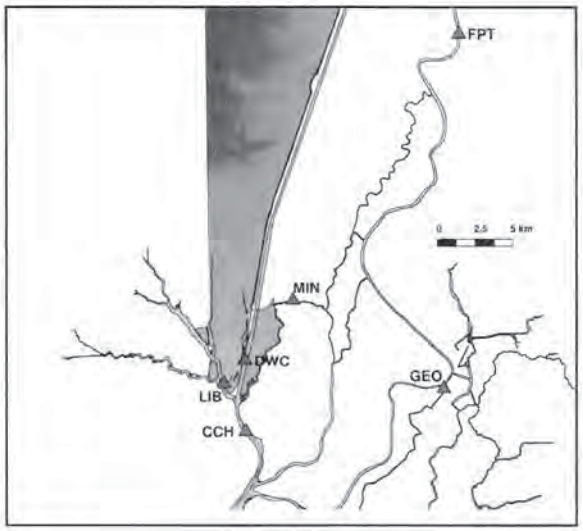
SediMorph

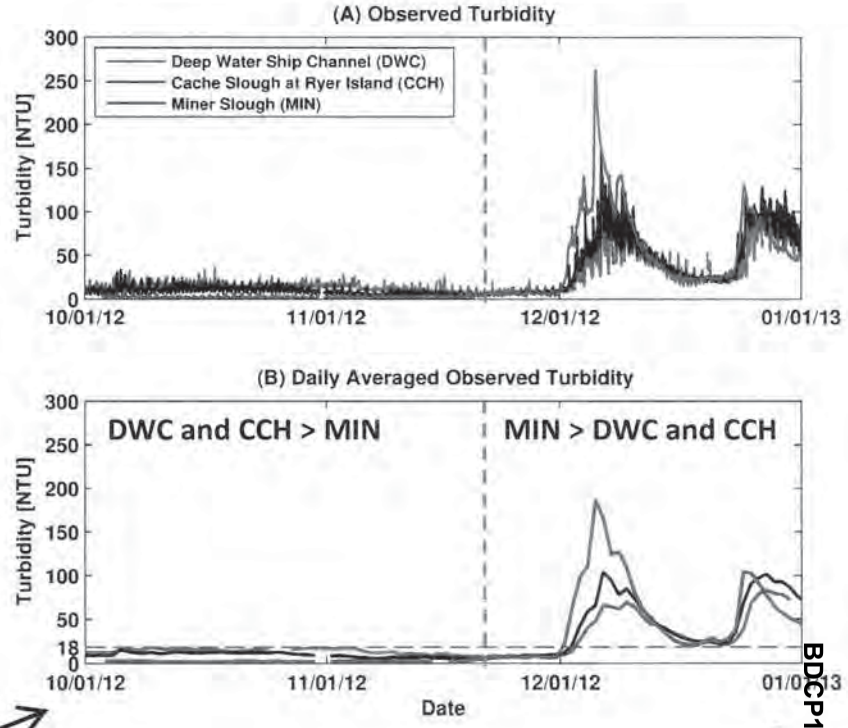


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Observed Turbidity Around Prospect Island

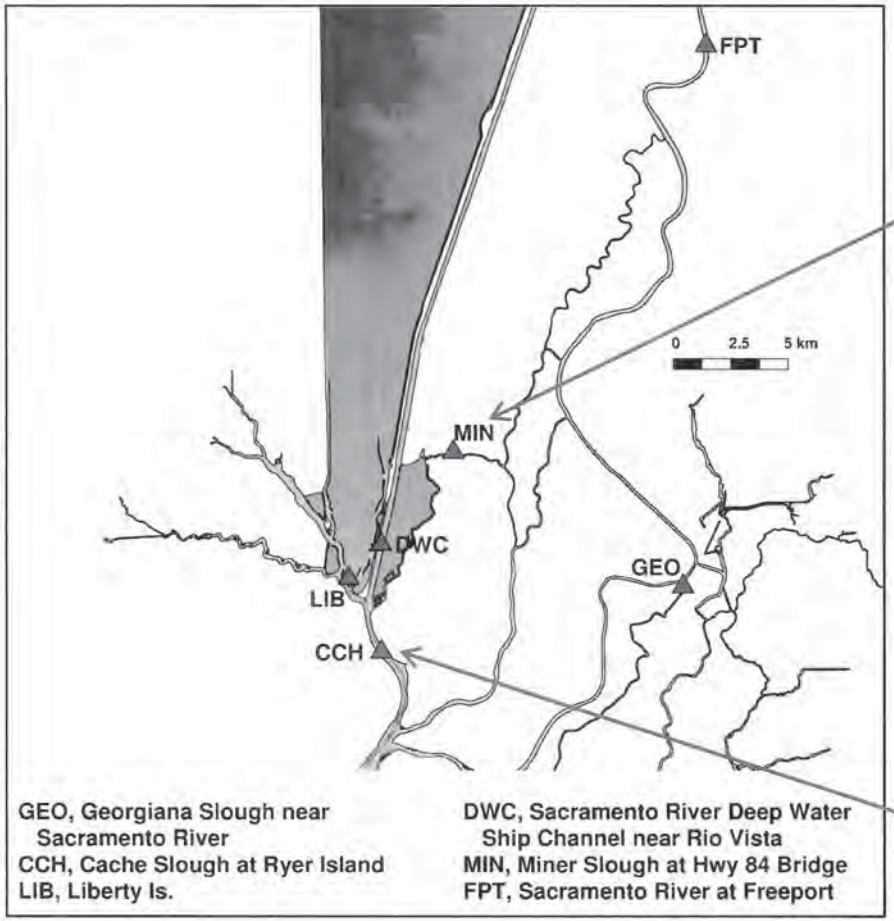


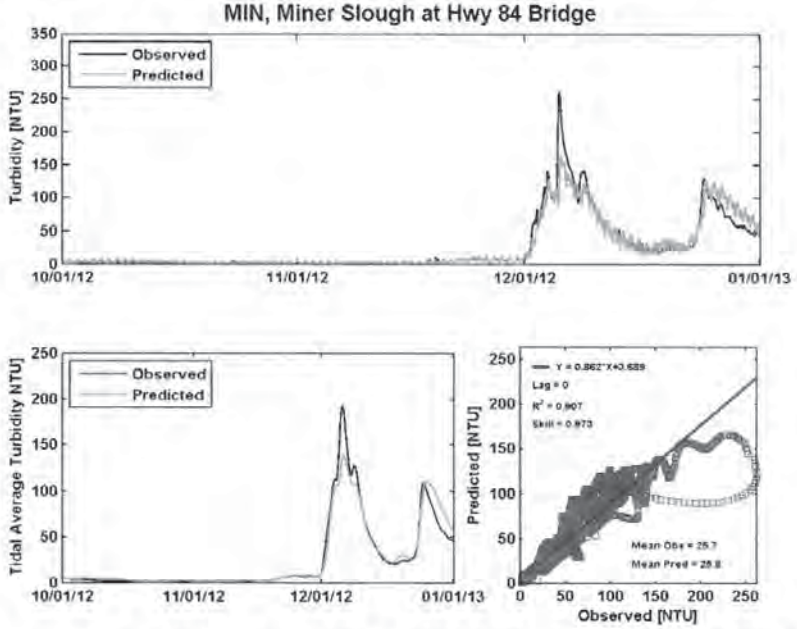


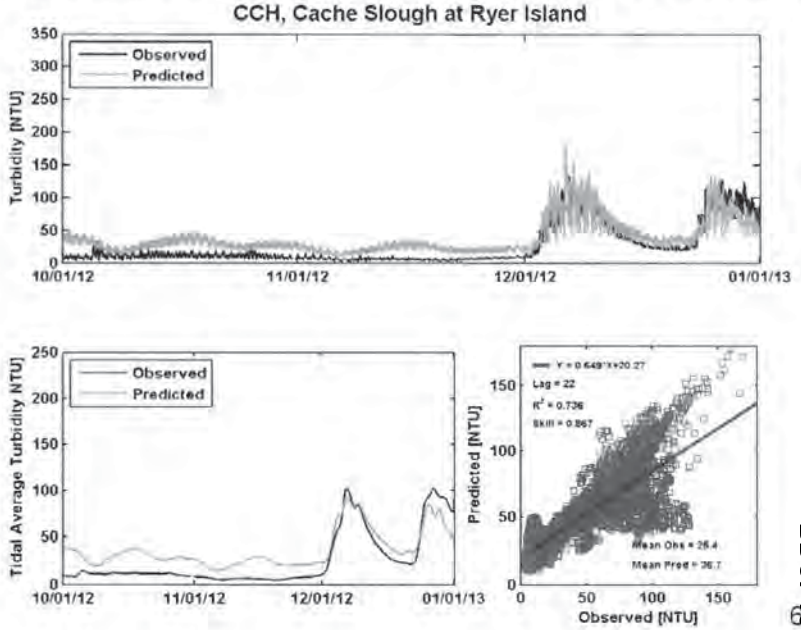


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Suspended Sediment Validation Around Prospect Island

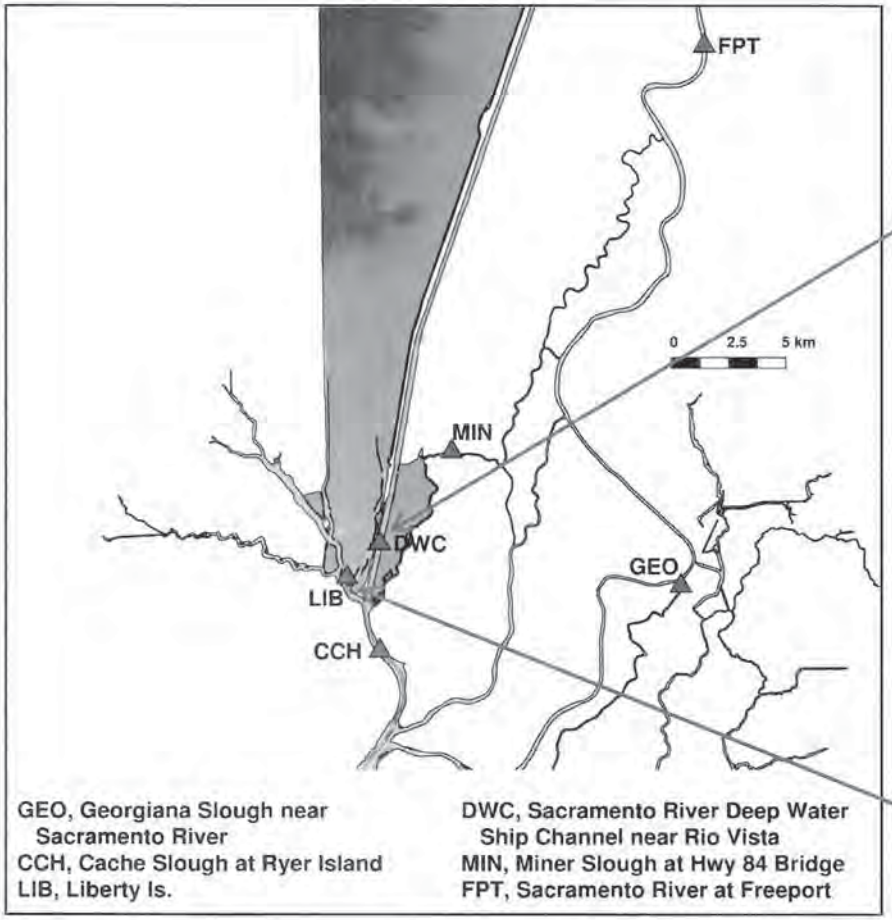


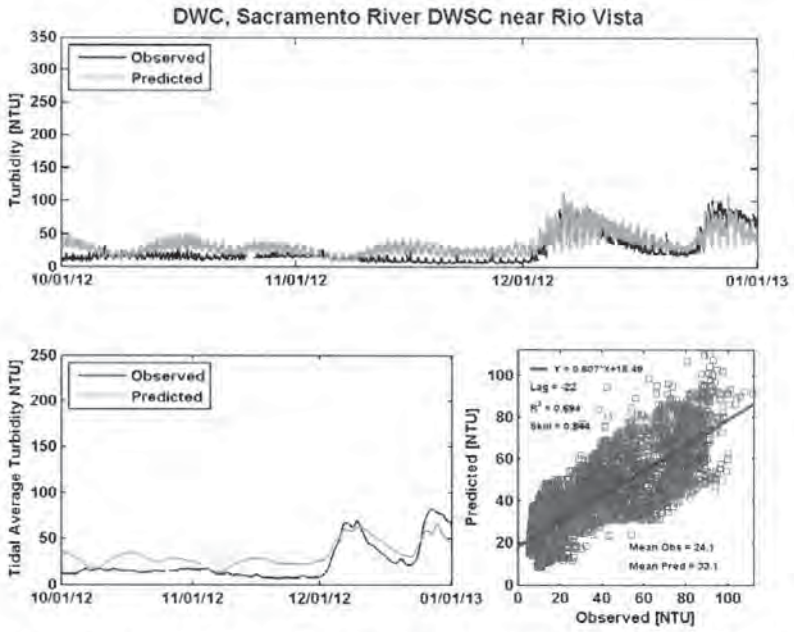


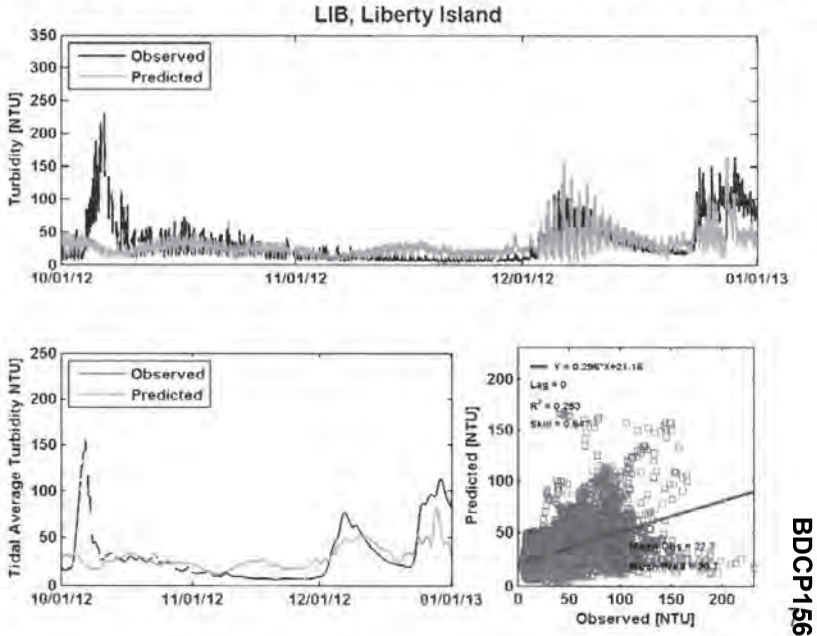


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S spended Sediment Valida ion Around Prospect Islar d

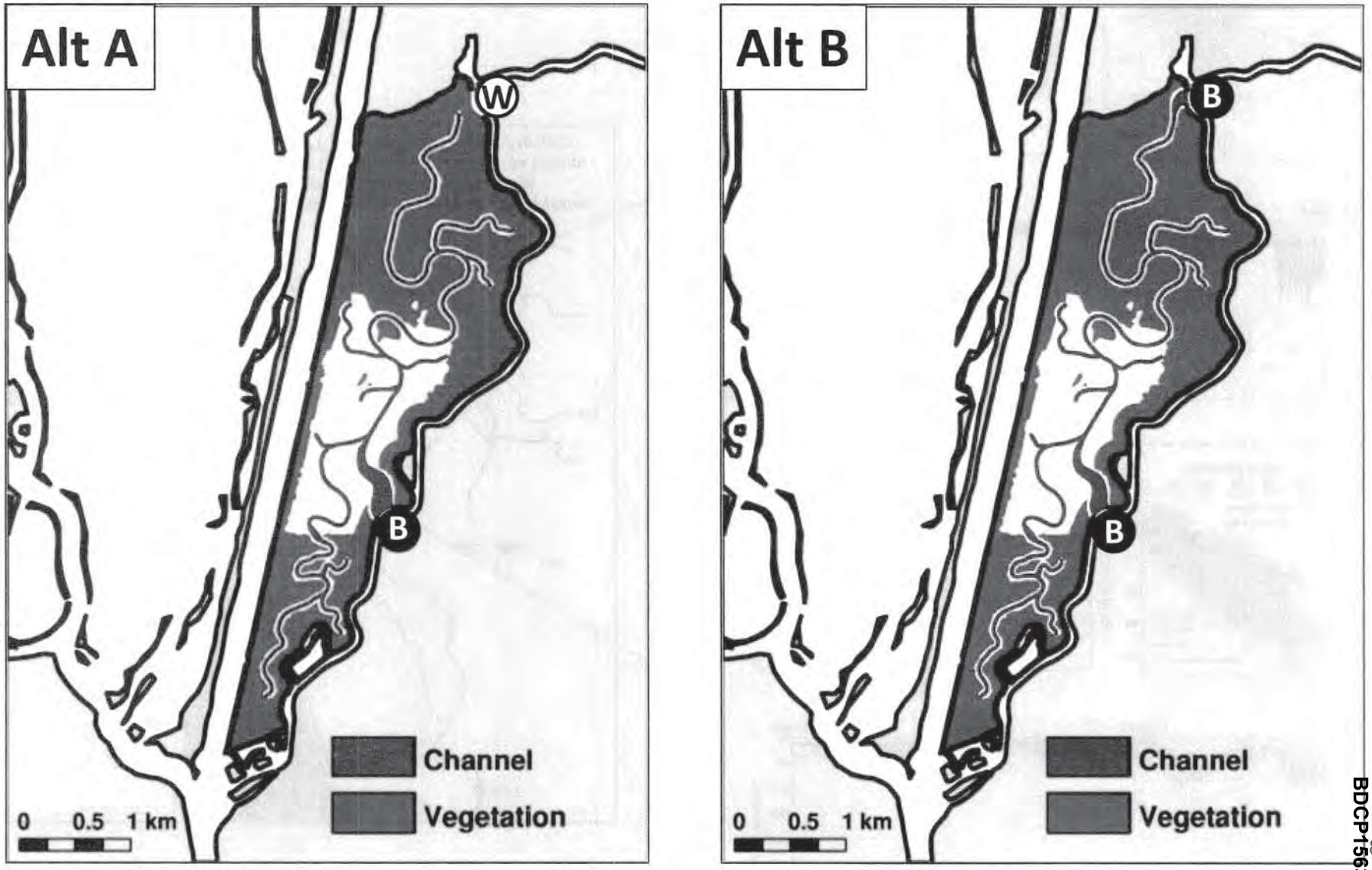






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Comparison of Two Restoration Alternatives

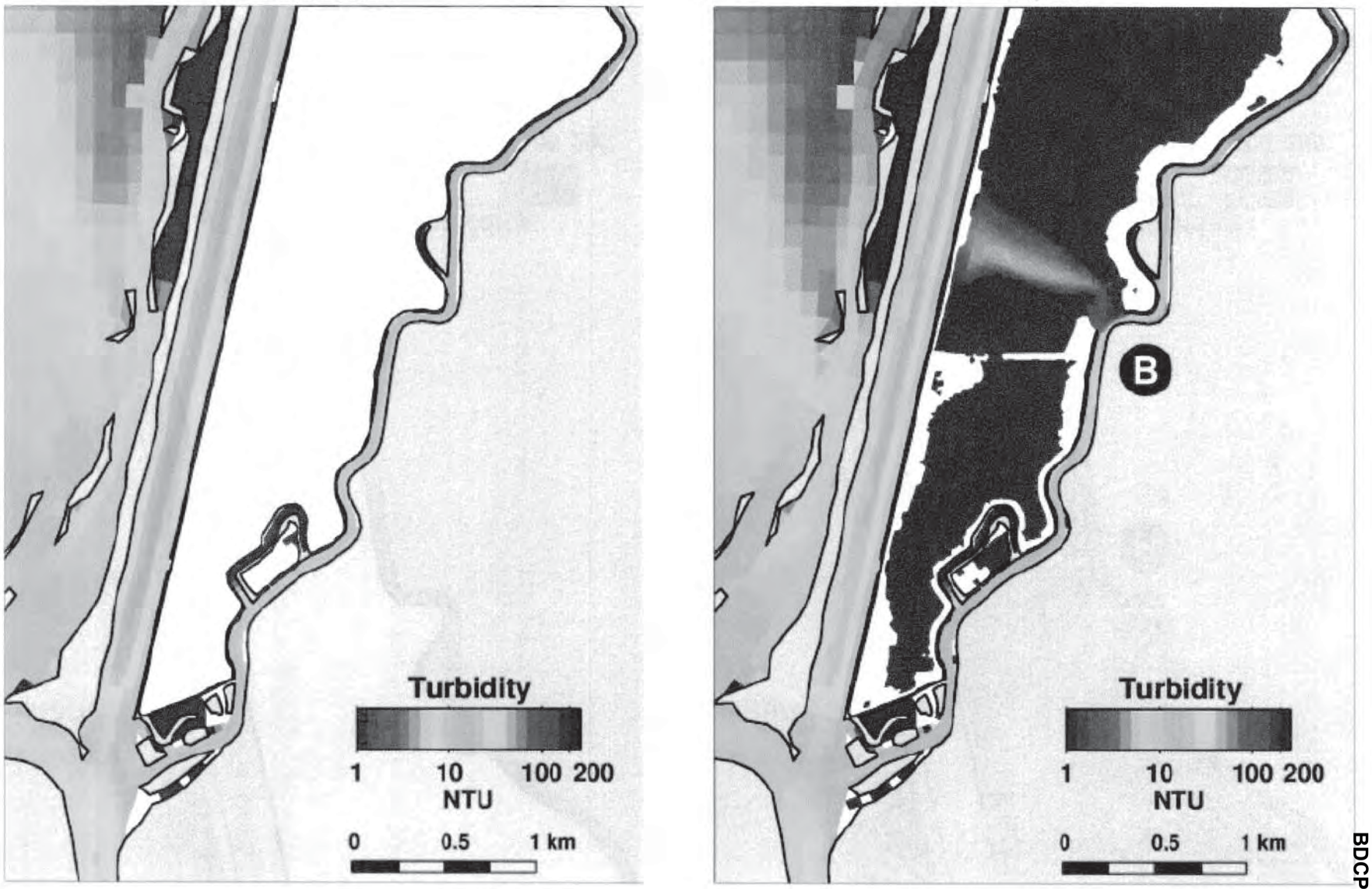


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Predicted Turbidity: Low Delta Outflow

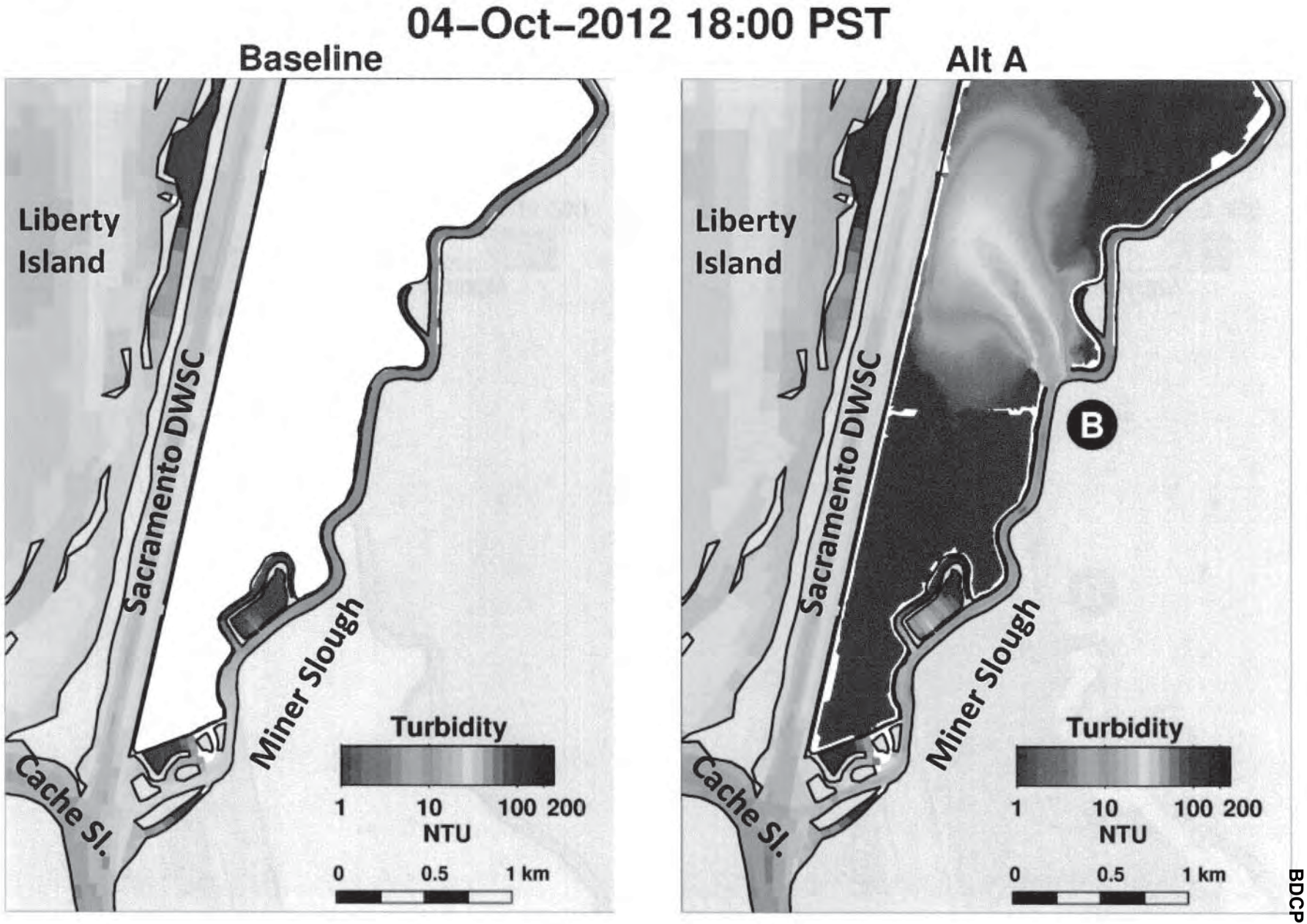
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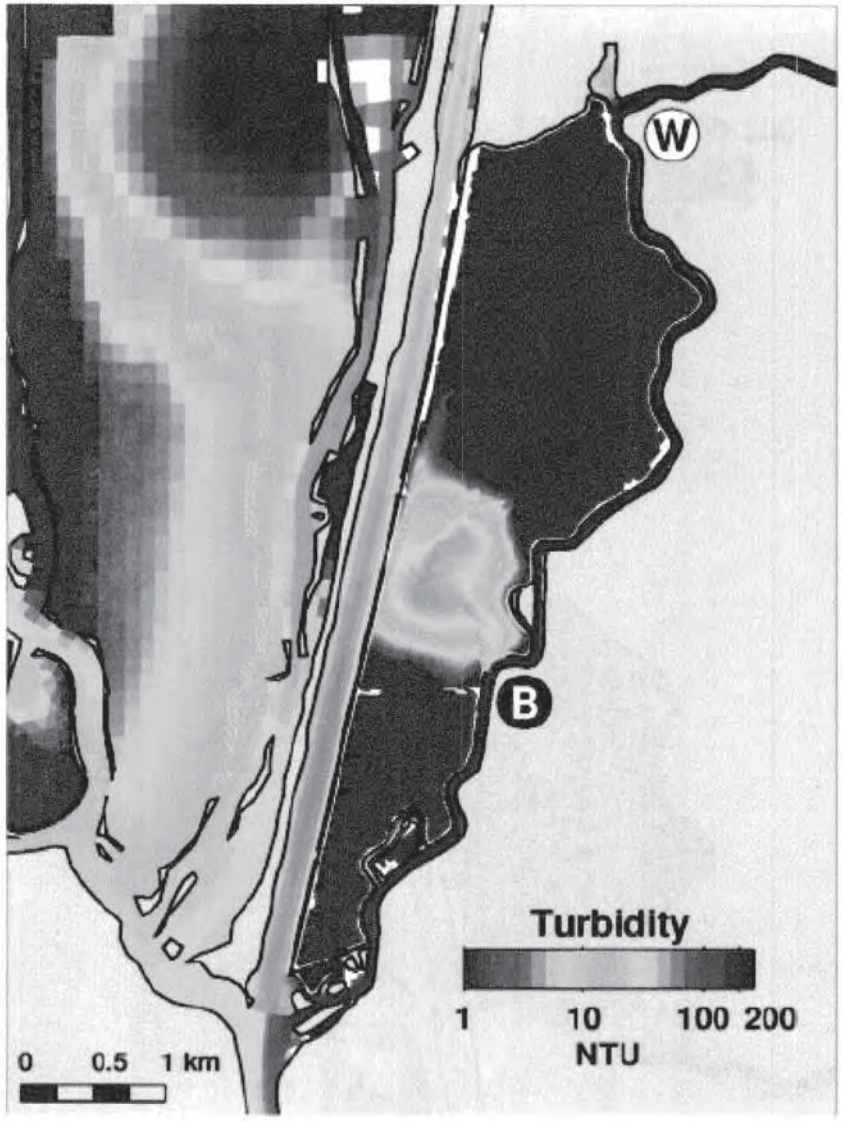
Predicted Turbidity: Low Delta Outflow

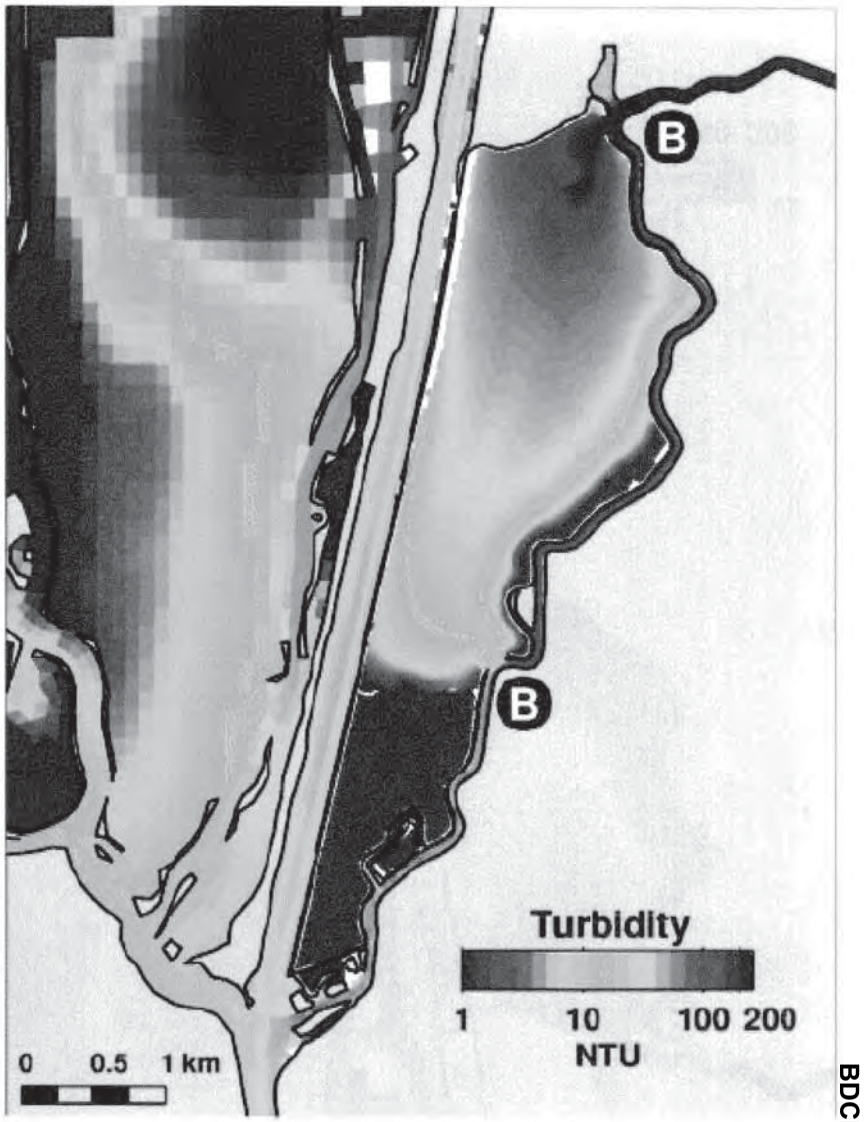


Predicted Turbidity: High Delta Outflow

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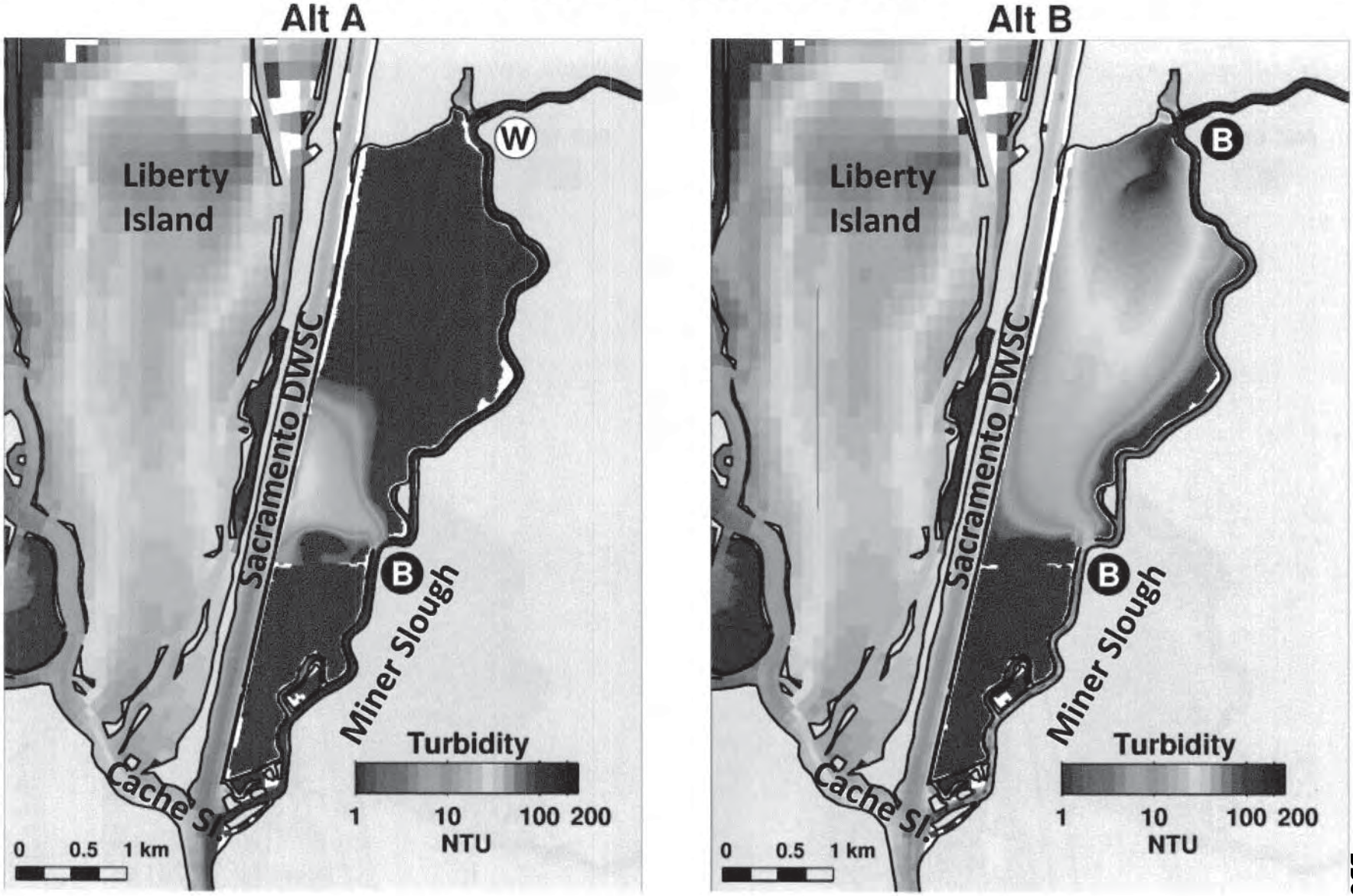




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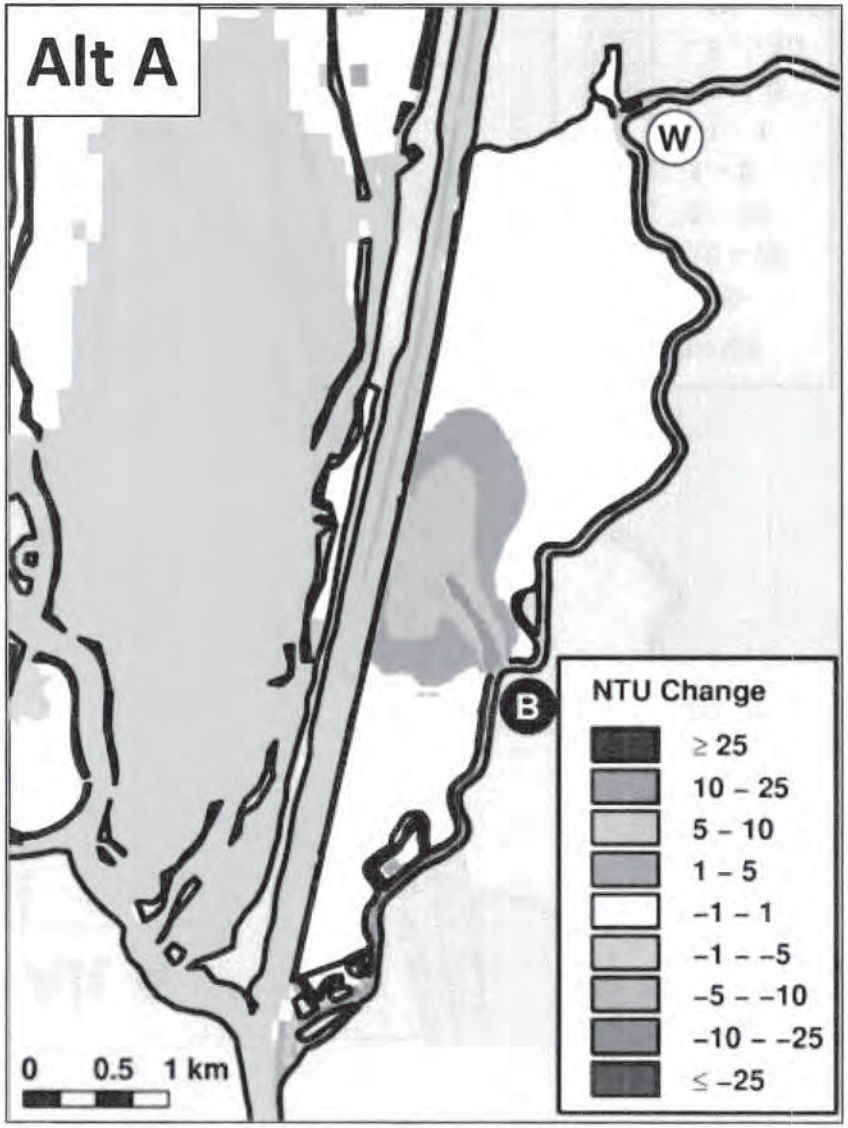
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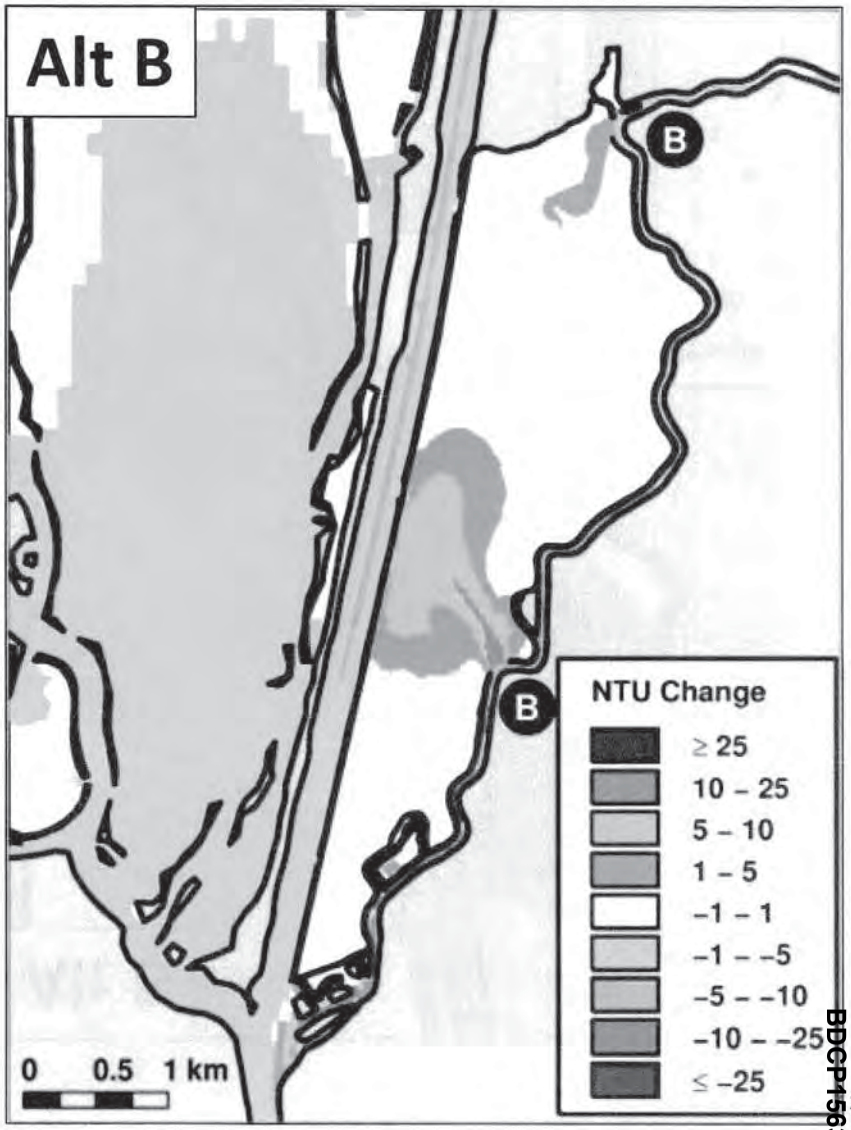
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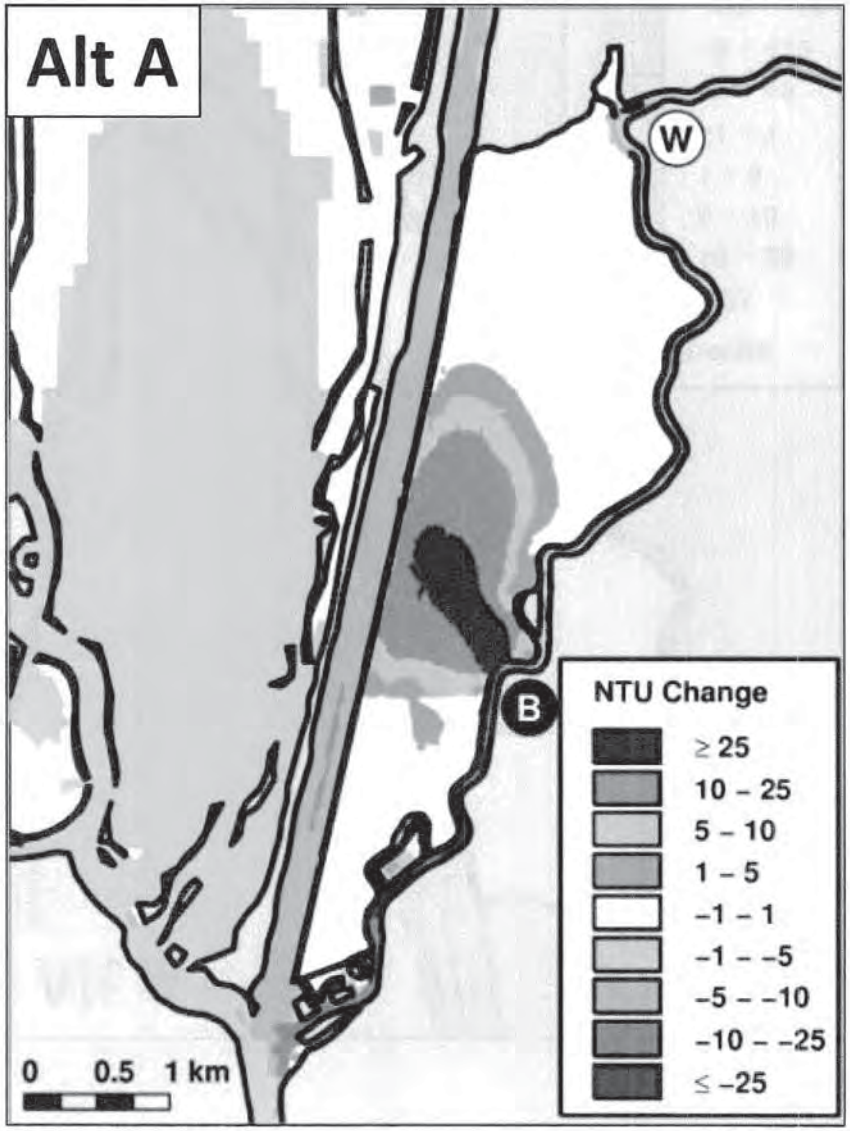
Predicted Turbidity Change Relative to Baseline
Low Delta Outflow: Monthly-Average October 2012

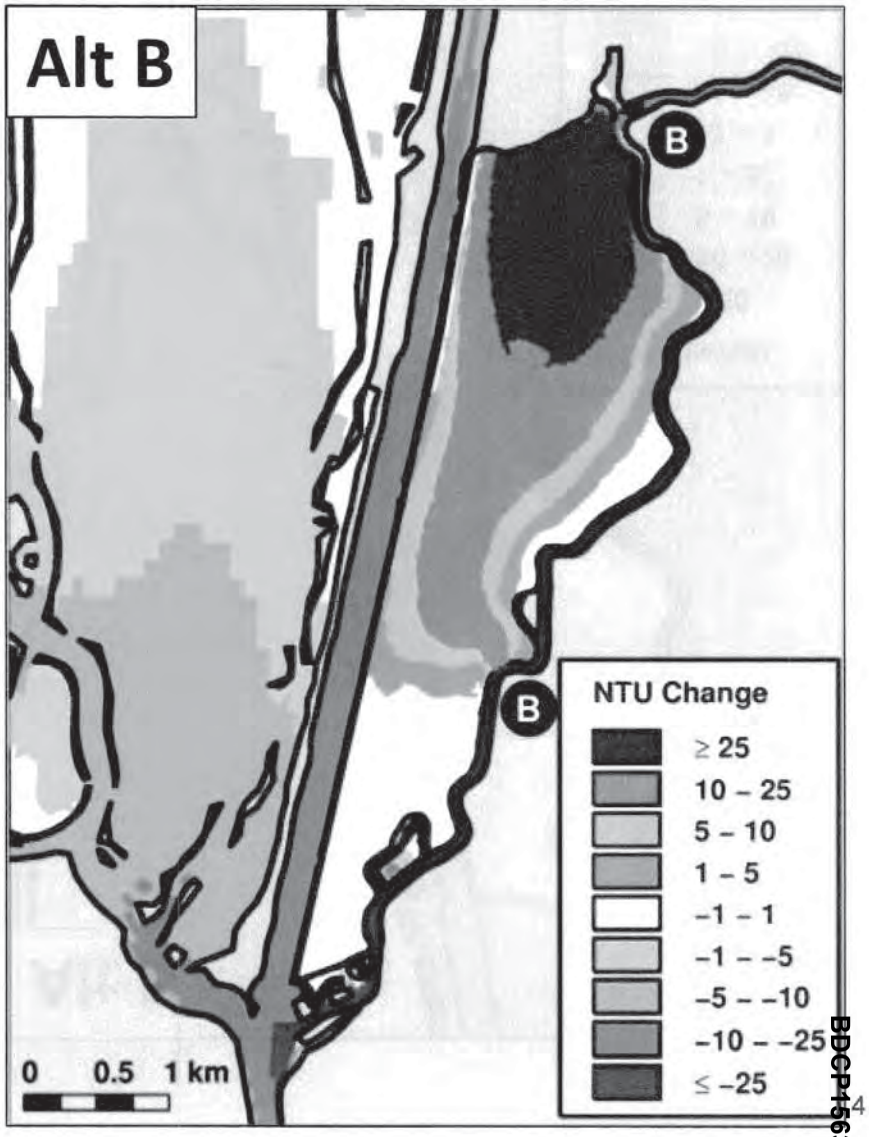




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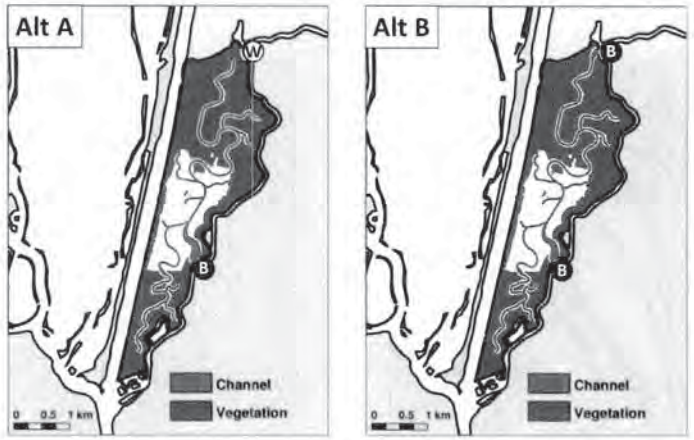
Predicted Turbidity Change Relative to Baseline
High Delta Outflow : Monthly-Average December 2012

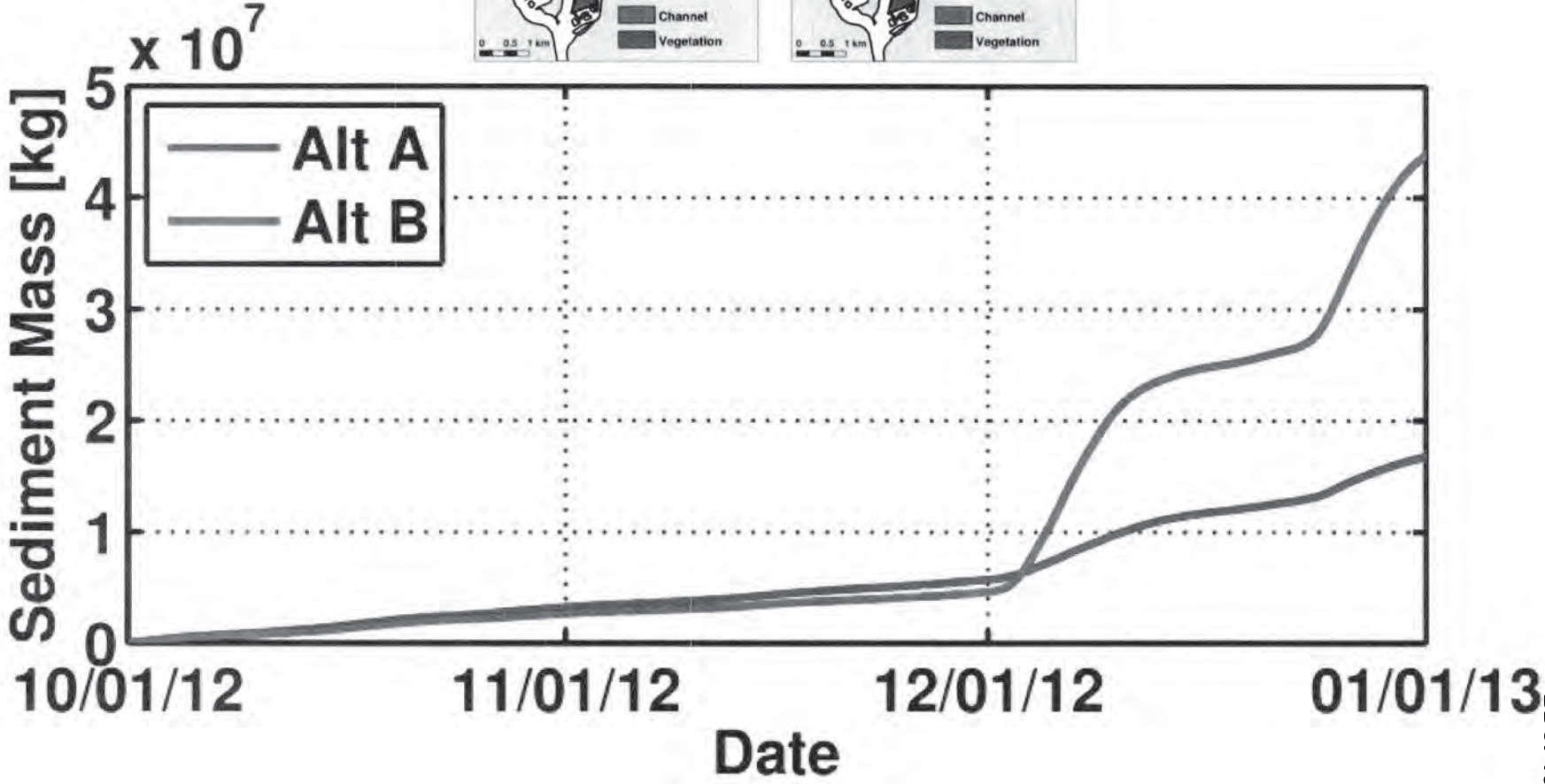




BDCP1563.4

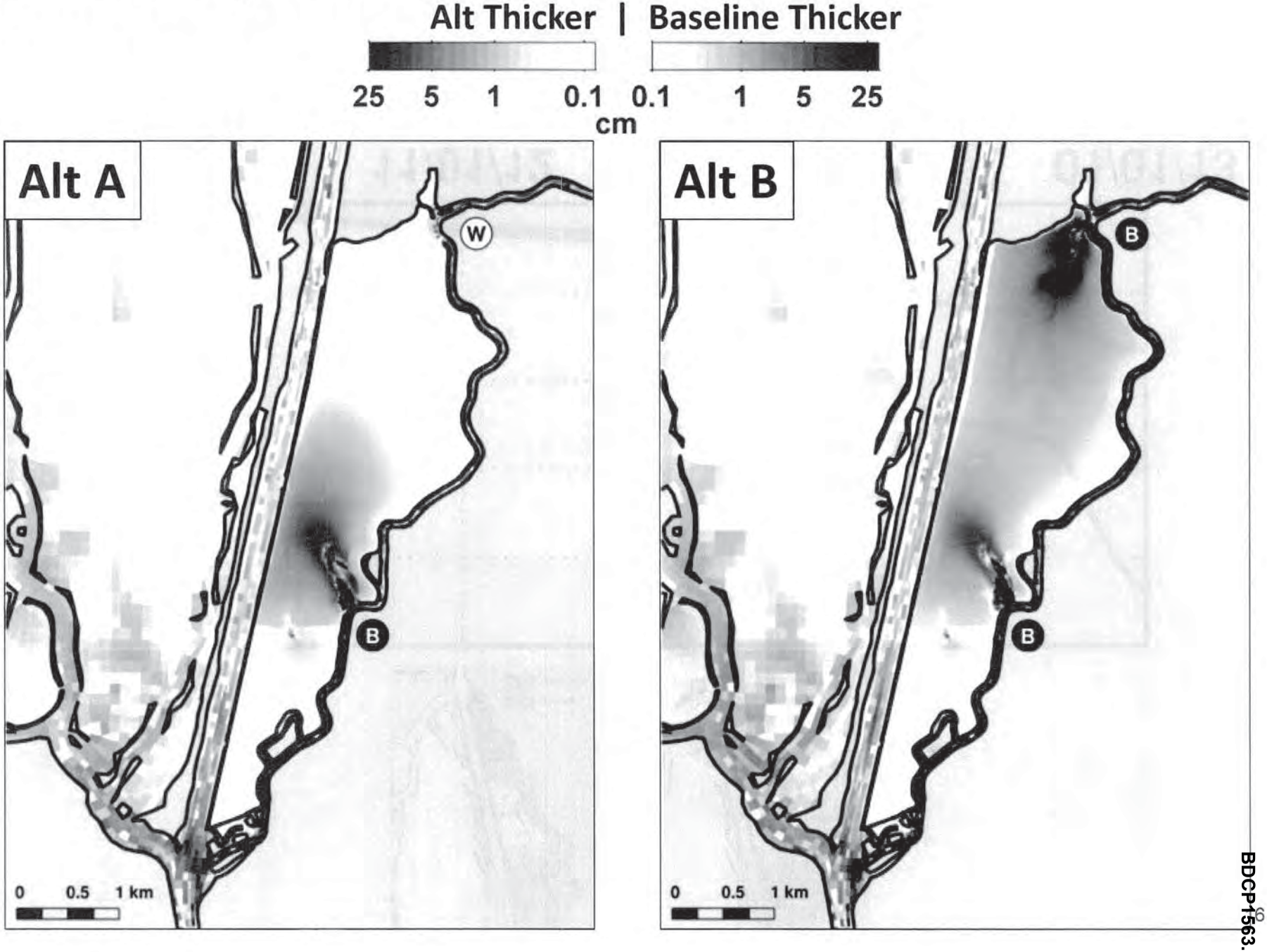
Cumulative Sediment Mass Transported Into Prospect Island





BDCP1563.

Sediment Deposition Relative to Baseline



BDCP1563.

Conclusions

- UnTRIM Bay-Delta model applied to simulate hydrodynamic, wave and sediment transport changes resulting from tidal restoration of Prospect Island.
- During low Delta outflow conditions (Oct-Nov 2012):
  - Turbidity in Miner Slough typically lower than Cache Slough Complex.
  - Higher turbidity water transported up Miner Slough into Prospect Island on flood tide.
  - Some of this sediment deposited in low energy environment inside Prospect Island.
- During high Delta outflow conditions (Dec 2012):
  - Turbidity in Miner Slough typically higher than Cache Slough Complex.
  - Some sediment from higher turbidity water in Miner Slough is deposited within Prospect Island before reaching Cache Slough.
  - North breach results in the largest effect on regional turbidity and the most sediment trapping during first flush.
- Uncertainty in model predictions needs to be taken into account when analyzing the results:
  - Largest uncertainty in assessments based on absolute turbidity values.
  - Less uncertainty in relative differences between restoration alternatives.

BDCP1563.

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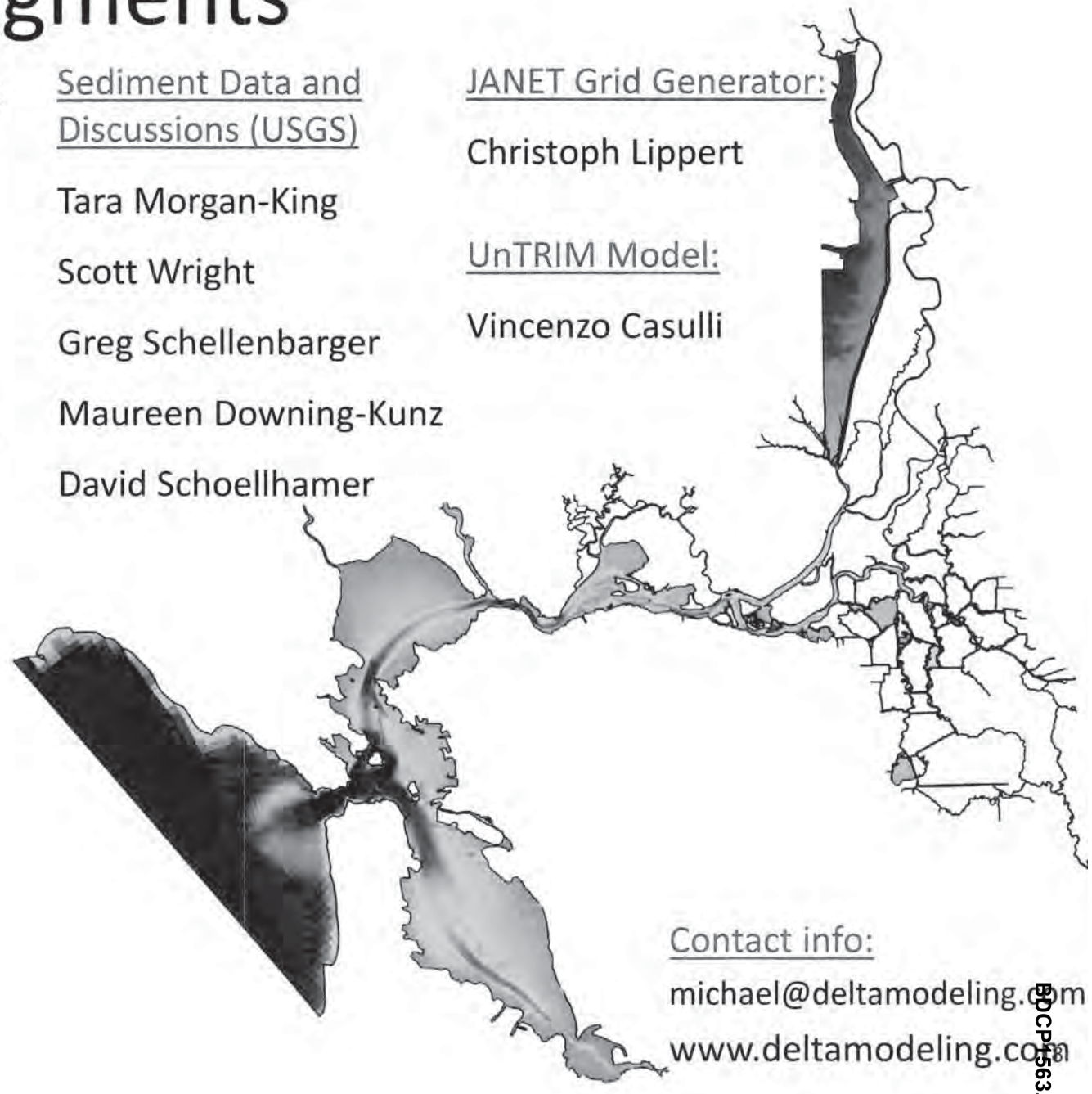
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BDCP1563.

Report on Review of Bay Delta Conservation Program Modeling

Foreword

Since December 2012, MBK Engineers and Dan Steiner (collectively "Reviewers") have assisted various parties in evaluating the operations modeling that was performed for the Bay Delta Conservation Plan (BDCP). To assist in understanding BDCP and the potential implications, stakeholders[1] requested that the Reviewers review the CalSim II modeling studies performed as part of the BDCP (hereafter "BDCP Studies" or "BDCP Model").

An initial review led the Reviewers to conclude that the BDCP Model, which serves as the basis for the environmental analysis contained in the BDCP Environmental Impact Report/Statement (EIR/S), provides very limited useful information to understand the effects of the BDCP. The BDCP Model contains erroneous assumptions, errors, and outdated tools, which result in impractical or unrealistic Central Valley Project (CVP) and State Water Project (SWP) operations. The unrealistic operations, in turn, do not accurately depict the effects of the BDCP.

The Reviewers revised the BDCP Model to depict a more accurate, consistent version of current and future benchmark hydrology so that the effects of the BDCP could be ascertained. The BDCP Model was also revised to depict more realistic CVP and SWP operations upon which to contrast the various BDCP alternatives. The Reviewers made significant efforts to coordinate with and inform the U.S. Bureau of Reclamation (Reclamation) and the California Department of Water Resources (DWR) managers and modelers, and CVP and SWP operators of the Reviewers' modifications, assumptions, and findings. Where appropriate, the Reviewers also used Reclamation and DWR's guidance and direction to refine the Reviewers' analysis.

This Report summarizes: (1) the Reviewers' independent analysis and review of the BDCP Model, publicly released for the BDCP's Draft EIR/S in December 2013, (2) the Reviewers' updates and corrections made to the BDCP Model, and (3) comparisons between the original BDCP Model and the independent Model as revised by the Reviewers.

[1] The entities who funded this report are Contra Costa Water District, East Bay Municipal Utility District, Friant Water Authority, Northern California Water Association, North Delta Water Agency, San Joaquin River Exchange Contractors Water Authority, San Joaquin Tributaries Authority, and Tehama Colusa Canal Authority.

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1 EXECUTIVE SUMMARY

Purpose of this Report

The CalSim II model is the foundational model for analysis of the BDCP, including the effects analysis in the Draft BDCP and the impacts evaluation in the Draft BDCP Environmental Impact Report/Statement (EIR/S). Results from CalSim II are used to examine how water supply and reservoir operations are modified by the BDCP. The results are also used by subsequent models to determine physical and biological effects, such as water quality, water levels, temperature, Delta flows, and fish response. Any errors and inconsistencies identified in the underlying CalSim II model are therefore present in subsequent models and adversely affect the results of later analyses based on those subsequent models.

The purpose of this Report is to examine the underlying CalSim II model used in support of the BDCP EIR/EIS and to analyze proposed operational scenarios contained in the BDCP. In undertaking the analysis for this Report, the Reviewers examined the model used in support of BDCP, the 2010 version of the CalSim II Model (BDCP Model), as well as the information contained in the Public Review Draft BDCP, released in December 2013. There are three basic reasons why the BDCP Model cannot be used to determine the effects of the BDCP: 1) the no action alternatives do not depict reasonable operations due to climate change assumptions, 2) operating criteria used in the BDCP Alternative 4 result in unrealistic operations, and 3) updates to CalSim II since the BDCP modeling was performed almost 4 years ago alter model results.

Given that it was not possible to determine how the BDCP may affect CVP and SWP operations or water system flows and conditions using the BDCP Model, independent modeling was performed to assess the potential effects of the BDCP. The first phase of this independent modeling effort was development of an updated without project baseline, which is similar to the no action alternative but with current, improved assumptions. The 2010 version of the CalSim II Model was used as the basis for the BDCP Model. The most recent version of CalSim II is the 2013 version used by DWR in its 2013 State Water Project Water Delivery Reliability Report (2013 CalSim II Model), and has undergone significant revision to not only correct errors in the 2010 model, but also to reflect regulatory changes that adversely affect the accuracy and dependability of the 2010 CalSim II Model. The BDCP was developed and analyzed using the 2010 CalSim II Model, and the changes and improvements reflected in the 2013 CalSim II Model were not used for the BDCP. For the purpose of the Reviewers' analysis and this Report, the 2013 CalSim II Model was further modified to incorporate additional updates, assumptions, and fixes. Some of these most recent Reviewer modifications have been accepted by both DWR and Reclamation, and are now incorporated into the CalSim II models that DWR and Reclamation use in conducting their own analyses. The second phase of the independent modeling effort (described in Section 4.2) incorporated the facilities and operations for the BDCP described as Alternative 4 H3 in the Draft EIR/EIS.

The manner in which the CVP and SWP are operated in the "With Project" and "Without Project" modeling scenarios significantly influences the BDCP "effects analysis". Modeling scenarios must depict how the actual system operates or how it might operate so that realistic effects can be determined. Modeling results from CalSim II are used to examine the effects of BDCP on water supply and reservoir operations, and the modeling results are also used by subsequent models to determine physical and biological effects, such as water quality, water levels, temperature, Delta flows, and fish response. If CalSim II modeling does not appropriately characterize operations in both the "With Project" and "Without Project" scenarios, the effects based on CalSim II will also not be appropriately characterized. The independent model provides a more accurate platform to assess the operations of the BDCP and isolates the effects of the BDCP from climate change. Comparing the results of the independent model to those of the BDCP model reveals significant differences in water operations and potential environmental impacts.

Key Conclusions

Assumptions, errors, and outdated tools used in the BDCP Model results in impractical or unrealistic CVP and SWP operations. Therefore, the BDCP Model provides very limited useful information to illustrate the effects of the BDCP.

Methodology used to incorporate climate change contains errors and does not incorporate reasonably foreseeable adaptation measures:

Climate change assumptions were incorrectly applied, yielding non-sensible results.

Climate change hydrology in the Upper San Joaquin River basin was incorporated incorrectly into the BDCP Model. Although inflow to Millerton Lake is expected to *decrease* under future climate scenarios, the error in the BDCP Model causes the amount of stored water in Millerton Lake to *increase* by inappropriately reducing water deliveries to the Friant Division. BDCP erroneously overestimates Millerton Lake storage, which causes an overestimation of reservoir releases and available water downstream. Because overall CVP operations and the San Joaquin River are interconnected, this error causes problems throughout the CVP system. With the coordinated operations of the CVP and SWP, this error can affect the SWP system.

Incorporation of climate change ignores reasonably foreseeable adaptation measures.

The BDCP Model uses assumed future climate conditions that obscure the effects of implementing the BDCP. The future conditions assumed in the BDCP model include changes in precipitation, temperature, and sea level rise. The result of this evaluation is that the modeled changes in water project operations and subsequent environmental impacts are caused by three different factors: (1) sea level rise; (2) climate change; and (3) implementation of the alternative that is being studied.

Including climate change, without adaptation measures, results in insufficient water needed to meet all regulatory objectives and user demands. For example, the BDCP Model results that include climate change indicate that during droughts, water in reservoirs is reduced to the minimum capacity possible. Reservoirs have not been operated like this in the past during extreme droughts and the current drought also provides evidence that adaptation measures are called for long in advanced to avoid draining the reservoirs. In this aspect, the BDCP Model simply does not reflect a real future condition. Foreseeable adaptations that the CVP and SWP could make in response to climate change include: (1) updating operational rules regarding water releases from reservoirs for flood protection; (2) during severe droughts, emergency drought declarations could call for mandatory conservation and changes in some regulatory criteria similar to what has been experienced in the current and previous droughts; and (3) if droughts become more frequent, the CVP and SWP would likely revisit the rules by which they allocate water during shortages and operate more conservatively in wetter years. The modifications to CVP and SWP operations made during the winter and spring of 2014 in response to the drought supports the likelihood of future adaptations. The BDCP Model is, however, useful in that it reveals that difficult decisions must be made in response to climate change. But, in the absence of making those decisions, the BDCP Model results themselves are not informative, particularly during drought conditions. With future conditions projected to be so dire without the BDCP, the effects of the BDCP appear positive simply because it appears that conditions cannot get any worse (i.e., storage cannot be reduced below its minimum level). However, in reality, the future condition will not be as depicted in the BDCP Model. The Reviewers recommend that Reclamation and DWR develop more realistic operating rules for the hydrologic conditions expected over the next half-century and incorporate those operating rules into any CalSim II Model that includes climate change.

The BDCP Model does not accurately reflect reasonably foreseeable conditions and changes in CVP and SWP operations due to the BDCP:

BDCP's "High Outflow Scenario" is not sufficiently defined for analysis.

The effects of many critical elements of the BDCP cannot be analyzed because those elements are not well-defined. The Reviewers recommend that the BDCP be better defined and a clear and concise operating plan be developed so that the updated CalSim II model can be used to assess effects of the BDCP.

The High Outflow Scenario (HOS) requires additional water (Delta outflow) during certain periods in the spring. The BDCP Model places most of the responsibility for meeting this new additional outflow requirement on the SWP. However, the SWP may not actually be responsible for meeting this new additional outflow requirement. This is because the Coordinated Operations Agreement ("the COA") would require a water allocation adjustment that would keep the SWP whole. Where one project (CVP or SWP) releases water to meet a regulatory requirement, the COA requires a water balancing to ensure the burden does not fall on only one of the projects. The BDCP Model is misleading because it fails to adjust project operations, as required by the COA, to "pay back" the water "debt" to the SWP due to these additional Delta outflow requirements. Unless there is a significant revision to COA, the BDCP Model overstates the impacts of increased Delta outflow on the SWP and understates the effects on the CVP.

Furthermore, after consulting with DWR and Reclamation project operators and managers, the Reviewers conclude that there is no apparent source of CVP or SWP water to satisfy both the increased Delta outflow requirements and pay back the COA "debt" to the SWP without substantially depleting upstream water storage. It appears, through recent public discussions regarding the HOS, that BDCP anticipates additional water to satisfy the increased Delta outflow requirement and to prevent the depletion of cold water pools will be acquired through water transfers from upstream water users. However, this approach is unrealistic. During most of the spring, when BDCP proposes that Delta outflow be increased, agricultural water users are not irrigating. This means that there is not sufficient transfer water available to meet the increased Delta outflow requirements and therefore, additional release of stored water from the reservoirs would be required. Releasing stored water to meet the increased Delta outflow requirements could potentially impact salmonids on the Sacramento and American River systems due to reductions in the available cold water pool.

Simulated operation of BDCP's dual conveyance, coordinating proposed North Delta diversion facilities with existing south Delta diversion facilities, is inconsistent with the project description.

The Draft BDCP and associated Draft EIR/EIS specify criteria for how much flow can be diverted by the new North Delta Diversion (NDD) facilities and specify when to preferentially use either the NDD facilities or the existing South Delta diversion (SDD) facilities. However, the BDCP Model contains an artificial constraint that prevents the NDD facilities from taking water as described in the BDCP project description. In addition to affecting diversions from the NDD, this artificial constraint contains errors that affect the No Action Alternative (NAA) operation. This error has been fixed by DWR and Reclamation in the more recent 2013 CalSim II Model; however, the error remains in the BDCP Model. Additionally, the BDCP Model does not reflect the summer operations of the SDD that are described in the Draft EIR/EIS as a feature of the BDCP project intended to prevent water quality degradation in the south Delta. The net effect of these two errors is that the BDCP Model significantly underestimates the amount of water diverted from the NDD facilities and overestimates the amount of water diverted from the SDD. The

further decrease in flows through the Delta, in comparison to what is presented in the BDCP Draft EIR/EIS, would likely result in even greater degradation in Delta water quality than reported.

The BDCP Model contains numerous coding and data issues that significantly skew the analysis and conflict with actual real-time operational objectives and constraints

Operating rules used in the BDCP Model, specifically regarding Alternative 4, result in impractical or unrealistic CVP and SWP operations. Reservoir balancing rules cause significant drawdown of upstream reservoirs during spring and summer months while targeting dead pool level in San Luis from September through December resulting in artificially low Delta exports and water shortages. CVP allocation rules are set to artificially reduce south of Delta allocations during wetter years resulting in underestimates of diversions at the NDD and the SDD. Operating rules for the Delta Cross Channel Gate do not reflect how the gates may be operated in "With Project" conditions.

Operational logic is coded into the CalSim II model to simulate how DWR and Reclamation would operate the system under circumstances for which there are no regulatory or other definitive rules. This attempt to specify (i.e., code) the logic sequence and relative weighting so that a computer can simulate "expert judgment" of the human operators is a critical element to the CalSim II model. In the BDCP version of the CalSim II model, some of the operational criteria for water supply allocations and existing facilities such as the Delta Cross Channel and San Luis Reservoir are inconsistent with real-world conditions.

The BDCP Model, as modified by the Reviewers, corrected some of the inconsistencies between the operational criteria in the BDCP Model and real-world conditions, and confirmed these changes with CVP and SWP operators. By correcting the operational criteria, the modified BDCP model (Independent Model) output is more accurate and consistent with real-world operational objectives and constraints.

Independent modeling of the BDCP revealed differences in CVP and SWP operations and water deliveries from the analysis disclosed for the Draft EIR/EIS.

The independent model provides a more accurate platform to assess the operations of the BDCP and isolates the effects of the BDCP from climate change. Comparing the results of the independent model to those of the BDCP model reveals significant differences in water operations and potential environmental impacts. The independent model "Without Project" baseline was compared to the independent model's version of Alternative 4 H3-ELT of the BDCP. The updated changes in water operations from the independent model are compared to changes in operations reported in the BDCP Draft EIR/EIS for the equivalent alternatives. The difference between the updated independent model results and those reported in the BDCP Draft EIR/EIS are presented below.

- The amount of water exported (diverted from the Delta) may be approximately 200 Thousand Acre-Feet (TAF) per year *higher* than the amount disclosed in the Draft EIR/S. This total represents:
  - approximately 40 TAF/yr more water diverted and delivered to the SWP south of Delta contractors, and
  - approximately 160 TAF/yr more water diverted and delivered to the CVP south of Delta contractors.
- The BDCP Model estimates that, under the No Action Alternative at the Early Long Term (NAA – ELT) (without the BDCP), total average annual exports for CVP and SWP combined are estimated to be 4.73 million acre-feet (MAF) and in the Independent Model Future No Action (FNA) combined exports are 5.61 MAF. The BDCP Model indicates an increase in exports of approximately 540 TAF and the Independent Model shows an increase of approximately 750 TAF in Alt 4.

- Delta outflow would decrease by approximately 200 TAF/yr compared to the quantity indicated in the Draft EIR/S.
    - This lesser amount of Delta outflow has the potential to cause more significant water quality and supply impacts for in-Delta beneficial uses and additional adverse effects on species. To determine the potential effects of the reduced amount of Delta outflow, additional modeling is needed using tools such as DSM2.
- The BDCP Model does not accurately reflect the location of the diversions that the SWP and CVP will make from the Delta.
    - When the errors in the BDCP Model are corrected, the Independent Model reveals that the NDD could divert approximately 680 TAF/yr more than what is disclosed in the BDCP Draft EIR/S.
    - Conversely, the quantity of water diverted through the existing SDD would be approximately 460 TAF/yr less than what is projected in the BDCP Draft EIR/S.
    - This difference in the location of diversions has the potential to reduce water quality in the Central and South Delta in ways that were not analyzed in the BDCP Draft EIR/S

Additional Observations and Recommendations

This review identified and remedied several modeling deficiencies that should be used by others as the BDCP and other projects move forward. However, the work done to date by the Reviewers does not capture all of the improvements necessary to depict the effects of the BDCP accurately. There are many operational uncertainties in the BDCP that require attention and must be addressed. The Reviewers offer several recommendations so that future CalSim II modeling of the BDCP will yield more meaningful results.

1. Ensure model operations of existing facilities are consistent with contemporary real world operations to the extent possible.
    a. Ensure reservoirs are not routinely drawn down to dead pool as part of 'normal' operations.
2. Given the expected changes in hydrologic conditions over the next half century, realistic operating rules for all CVP and SWP facilities, including the BDCP, must be developed.
    a. Develop a 'drought' operations plan that includes adaptations.
    b. Alter reservoir flood release operations to match the assumed shift in precipitation patterns.
    c. Perform a sensitivity analysis using a range of possible future climates.
3. BDCP operations must be defined in a clear and concise manner.
    a. Transfer water required to make an alternative feasible should be identified so the effects of that transfer can be determined.
    b. Adaptive management limits and targets must be better defined
    c. Changes to the existing COA to accommodate the BDCP must be defined.
    d. Modeled export operations spilt between the north and south intakes must be consistent with the project description.
    e. Changes in the DCC operations should be defined.
    f. Refined reservoir balancing rules

The BDCP Model must be revised prior to drawing conclusions regarding the environmental effects of the BDCP. The BDCP Model is an outdated version of the CalSim II model, which contains known errors. Only by incorporating the changes made to date by the Reviewers, incorporating the additional recommended changes above, and potential additional refinements can the effects of the BDCP be determined. Reasonable conclusions can only be drawn once these changes are made to the BDCP Model; therefore, the Reviewers recommend that Reclamation and DWR make these changes.

2 INTRODUCTION

The Public Draft BDCP has been prepared by DWR, with assistance and input from Reclamation and various entities that receive water from the SWP and CVP. The BDCP is being prepared to comply with the federal Endangered Species Act, and certain other federal and state mandates. The BDCP proposes a number of Conservation Measures that, if implemented, are believed to provide some benefit to various species covered by the BDCP in the Delta. The Conservation Measures proposed in the Public Draft BDCP include new conveyance facilities and modified operations of the SWP and CVP, as well as other Conservation Measures addressing water quality, predation, and other habitat-related measures. The BDCP has been in development for several years. DWR also has prepared a Public Draft EIR/EIS in an attempt to satisfy CEQA and NEPA. Both the Public Draft BDCP and the Public Draft EIR/EIS were released for public review and comment in December 2013. This Report analyzes the BDCP as proposed and analyzed in the documents released in December 2013.

The Public Draft EIR/EIS considered several water facility and operational configurations, ultimately identifying "Alternative 4" as the preferred alternative under CEQA. (Public Draft EIR/EIS, Section 3.1.1) In addition to identifying physical facilities, the Public Draft EIR/EIS identifies an operational scenario (Alternative 4, Operation Scenario H) as the proposed operation regime for the new and existing facilities. (Public Draft EIR/EIS, Section 3.1.1, Section 5.3.3.9.) Alternative 4, Operational Scenario H is further divided into four sub-operational scenarios, which vary depending on Fall and Spring Delta outflow requirements. Those sub-scenarios are: Alternative 4 Operational Scenario H1 (Alternative 4 H1); Alternative 4 Operational Scenario H2 (Alternative 4 H2); Alternative 4 Operational Scenario H3 (Alternative 4 H3); and Alternative 4 Operational Scenario H4 (Alternative 4 H4). (Public Draft EIR/EIS, section 5.3.3.9.)

In general the differences between the various operational sub-scenarios are as follows. Alternative 4 H1 does not include enhanced spring outflow requirements or Fall X2 requirements. Alternative 4 H2 includes enhanced spring outflow requirements but not Fall X2 requirements. Alternative 4 H3 does not include enhanced spring outflow requirements but includes Fall X2 requirements. Alternative 4 H4 includes both enhanced spring outflow requirements and Fall X2 requirements. (Public Draft EIR/EIS, section 5.3.3.9.) This Report focuses on Alternative 4 H4 and Alternative 4 H3.

The task of the Reviewers was to review the CalSim II modeling which provides the foundational analysis of the BDCP. Results from CalSim II are used to examine how water supply and reservoir operations are modified by the BDCP, and the results are also used by subsequent models to determine physical and biological effects, such as water quality, water levels, temperature, Delta flows, and fish response. Any errors and inconsistencies identified in the underlying CalSim II model are therefore present in subsequent models and adversely affect the results of later analyses based on those subsequent models.

The model used in support of BDCP is the 2010 version of the CalSim II Model (BDCP Model), as well as the information contained in the Public Review Draft BDCP, released in December 2013. Since its development in 2010, the 2010 version of the CalSim II Model has undergone significant revision to not only correct errors in the model, but also to reflect regulatory changes that adversely affect the accuracy and dependability of the 2010 CalSim II Model. The updated version of CalSim II is the model used by DWR in its 2013 State Water Project Water Delivery Reliability Report (2013 CalSim II Model). The BDCP was developed and analyzed using the 2010 CalSim II Model; the changes and improvements reflected in the 2013 CalSim II Model were not used for the BDCP.

The initial review conducted by the Reviewers led to the conclusion that the BDCP Model provides very limited useful information to illustrate the effects of the BDCP. Assumptions, errors, and outdated tools used in the BDCP Model result in impractical or unrealistic CVP and SWP operations. Because of the unrealistic operations included in the BDCP Model, the Reviewers revised the BDCP Model to depict a more accurate, consistent version of

current and future benchmark hydrology. The BDCP Model was also revised to depict more realistic CVP and SWP operations upon which to contrast the various BDCP alternatives. The Reviewers made significant efforts to coordinate with or inform Reclamation and DWR managers and modelers, and CVP and SWP operators of the Reviewers' modifications, assumptions, and findings. Where appropriate, the Reviewers also used Reclamation's and DWR's guidance and direction to refine the Reviewers' analysis. Although there are many models used to evaluate various effects of BDCP, this analysis and review focused on water operations analysis using the BDCP Model (CalSim II).

Purpose and Use of the CalSim II Model

The CalSim II model is a computer program jointly developed by DWR and Reclamation. CalSim II presents a comprehensive simulation of SWP and CVP operations, and it is used by DWR as a planning tool to predict future availability of SWP water. CalSim II is widely recognized as the most prominent water management model in California, and it is generally accepted as a useful and appropriate tool for assessing the water delivery capability of the SWP and the CVP.

Broadly speaking, the model estimates, for various times of the year, how much water will be diverted, will serve as instream flows (e.g., flow in the rivers at various locations, such as Delta outflow), and will remain in the reservoirs. Within the context of the BDCP, the CalSim II model is also used to estimate the amount of water that will be diverted from BDCP's proposed NDD facilities. Thus, for BDCP, the CalSim II model estimates how much water will be diverted at the NDD facilities, how much flow will remain in the Sacramento River below Hood (the approximate location of the NDD facilities), how much water will be diverted through the existing SDD facilities at Tracy, how much flow will leave the Delta by flowing out to the Bay, and how much water will remain in storage in the reservoirs. The location and timing of the diversion and the amount of water remaining instream are significant because they can cause impacts on species, water quality degradation, and the like.

The coding and assumptions included in the CalSim II model drive the results it yields. Data and assumptions, such as the amount of precipitation runoff at a certain measuring station over time or the demand for water by specific water users over time, are input into the model. The criteria that are used to operate the CVP and the SWP (including current regulatory requirements) are included in the model as assumptions; because of the volume of water associated with the CVP and the SWP, these operational criteria significantly influence the model's results. Additionally, operational logic is coded into the CalSim II model to simulate how DWR and Reclamation would operate the system under circumstances for which there are no regulatory or otherwise definitive rules (e.g., when to move water from upstream storage to south of Delta storage). This attempt to specify (i.e., code) the logic sequence and relative weighting that humans will use as part of their "expert judgment" is a critical element to the CalSim II model.

The model's ability to reliably predict the effects of a proposed action depends on the accuracy of its coding and its representation of operations criteria. In other words, the model's results will be only as good as its data, coding, assumptions, and judgment and knowledge of the modelers. For this reason, a detailed operating plan of existing facilities and the proposed facility is essential to create an accurate model of how a proposed action will change – i.e., affect – existing water operations. In reviewing the BDCP Model it became apparent that coding errors and operating assumptions are inconsistent with the actual purposes and objectives of the CVP and SWP, thus limiting the utility and accuracy of the results. Through collaboration and verification with CVP and SWP operators, the BDCP Model flaws were corrected in the revised BDCP Model (Independent Model) and the potential effects of the BDCP were re-analyzed.

3 REVIEW OF BDCP CALSIM II MODELING

The CalSim II model is the foundational model for analysis of the BDCP, including the effects analysis in the Draft BDCP and the impacts evaluation in the Draft EIR/EIS. Results from CalSim II are used to examine how water supply and reservoir operations are modified by the BDCP, and the results are also used by subsequent models to determine physical and biological effects, such as water quality, water levels, temperature, Delta flows, and fish response. Any errors and inconsistencies identified in the underlying CalSim II model are therefore present in subsequent models and adversely affect the results of later analyses based on those subsequent models.

The Reviewers' analysis of the BDCP Model is summarized in three categories: (3.1) assessment of climate change assumptions, implementation, and effects; (3.2) assessment of general assumptions and operations; and (3.3) assessment of the assumptions and operational criteria for inclusion of the new BDCP facilities. The issues discussed in (3.1) and (3.2) are relevant for all modeling scenarios, both baseline scenarios that do not include BDCP and with project scenarios that evaluate BDCP or the Alternatives. The issues discussed in (3.3) are specific to the inclusion of the BDCP as defined in the Draft Plan and identified as Alternative 4 in the Draft EIR/EIS.

3.1 Climate Change

Implementation of Climate Change

The analysis presented in the BDCP Documents attempts to incorporate the effects of climate change at two future climate periods: the early long term (ELT) at approximately the year 2025; and the late long term (LLT) at approximately 2060. As described in the BDCP documents[2], other analytical tools were used to determine anticipated changes to precipitation and air temperature that is expected to occur under ELT and LLT conditions. Projected precipitation and temperature was then used to estimate runoff into from the watersheds over an 82-year period of variable hydrology; these time series were then used as inputs into the BDCP Model. A second aspect of climate change, the anticipated amount of sea level rise, is incorporated into the BDCP CalSim II model by modifying flow-salinity relationships that estimate salinity within the Delta based on sea level and flows within Delta channels.

This Report does not evaluate the analytical processes by which reservoir inflows and runoff were developed, nor does it evaluate the modified flow-salinity relationships that are assumed due to sea level rise; those items could be the focus of another independent review. This Report is limited to evaluating how the modified flows were incorporated into the BDCP Model and whether the operation of the CVP and SWP water system in response to the modified flows and the modified flow-salinity relationship is reasonable for the ELT and LLT conditions. This work reviews the assumed underlying hydrology and simulated operation of the CVP/SWP, assumed regulatory requirements, and the resultant water delivery reliability.

Assessment of Climate Change Assumptions and Implementation

To assess climate change, the three Without Project (or "baseline" or "no action") modeling scenarios were reviewed: No Action Alternative (NAA)[3], No Action Alternative at the Early Long Term (NAA – ELT), and No Action Alternative at the Late Long Term (NAA –LLT). Assumptions for NAA, NAA-ELT, and NAA-LLT are provided in the Draft BDCP EIR/EIS Appendix 5A, Section B, Table B-8. The only difference between these scenarios is the climate-related changes made for the ELT and LLT conditions (Table 1).

[2] BDCP EIR/EIS Appendix 5A, Section A and BDCP HCP/NCCP Appendix 5.A.2

[3] NAA is also called the Existing Biological Conditions number 2 (EBC-2) in the Draft Plan.

Table 1. Scenarios used to evaluate climate change

	Climate Change Assumptions	
Scenario	**Hydrology**	**Sea Level Rise**
No Action Alternative (NAA)	None	None
No Action Alternative at Early Long Term (NAA-ELT)	Modified reservoir inflows and runoff for expected conditions at 2025	15 cm
No Action Alternative at Early Long Term (NAA-LLT)	Modified reservoir inflows and runoff for expected conditions at 2060	45 cm

The differences between the NAA and NAA-ELT reveal the effects of the climate change assumptions under ELT conditions; similarly, the differences between the NAA and NAA-LLT reveal the effects of the climate change assumptions under LLT conditions. Numerous comparisons between NAA, NAA-ELT, and NAA-LLT are discussed in the Technical Appendix of this report; issues that shaped our conclusions are discussed below.

Climate change implementation is incorrect, yielding non-sensible results.

Climate change hydrology in the Upper San Joaquin River basin (above Friant Dam) was incorporated incorrectly into the BDCP Model, resulting in non-sensible results. Because overall CVP operations and the San Joaquin River are interconnected, this error causes problems throughout the CVP system. With the coordinated operations of the CVP and SWP, this error can affect the SWP system.

Specifically, under climate change, inflow to Millerton Lake is expected to decrease (BDCP DEIR/S, Appendix 29B). However, when climate change was implemented into the BDCP Model, it was done incorrectly such that: (1) the inflow into Millerton Lake *was not adjusted* for climate change and is thus overestimated, and yet (2) the flood control operations and water allocation decisions for Millerton Lake *were adjusted* for climate change as if the inflow was reduced. The net effect is that storage in Millerton Lake is overestimated; in fact, the BDCP model indicates that the amount of water stored in Millerton Lake will actually be increased as a result of climate change even though the inflow to the lake is projected to be reduced (i.e., non-sensible). This error results in the overestimation of Millerton Lake storage causing an overestimation of reservoir releases for flood control purposes and available water downstream at the Mendota Pool; these unreasonably high flood releases are then diverted by CVP exchange contractors in lieu of taking CVP Delta water, which means that either CVP Delta exports are reduced or the water is backed up into San Luis Reservoir (SLR), overestimating SLR storage. Furthermore, any excess water from the Millerton Lake that is not diverted at Mendota Pool would continue downstream and ultimately increase Vernalis flow, which subsequently affects Delta exports. Ultimately, changes in exports have the potential to affect upstream reservoir releases (i.e., from Lake Shasta) as well.

This is a situation where one seemingly minor error cascades through the entire system. This error exists in all BDCP Model scenarios (baselines and project alternatives) that have climate change incorporated at either ELT or LLT conditions. In other words, all model results reported in the BDCP and associated Draft EIR/S contain this error, with the only exception of the Existing Biological Conditions baselines numbers 1 and 2 (EBC1 and EBC2), which are evaluated in the BDCP.

Effects of climate change create unrealistic operations.

Review of the BDCP Model output for the Without Project condition with climate change assumptions for the ELT or LLT (NAA-ELT and NAA-LLT, respectively) reveal that the model is operated beyond its usable range. The purpose of CalSim II is to simulate how the CVP and SWP systems would be operated in order to meet regulatory requirements and water delivery objectives based on a certain amount of precipitation and runoff. When the precipitation patterns and resultant runoff were changed in the BDCP Model for climate change, the logic

regarding how the system is operated to meet the regulatory and water delivery objectives was not changed. The net effect is that neither the regulatory criteria nor the delivery objectives are met.

With rising temperatures and shifting precipitation patterns with less snow, temperature criteria on the Sacramento River will become increasingly more difficult to meet. For instance, the BDCP Model includes an assumption that equilibrium temperatures in the Sacramento River between Shasta and Gerber will increase on an average annual basis by 1.6°F by 2025 (ELT) by 3.3°F by 2060 (LLT). NMFS 2009 Biological Opinion specifies temperature targets of 56°F in the Sacramento River between Balls Ferry and Bend Bridge for the protection of salmon. Because of lower storage conditions in Shasta Lake and the magnitude of temperature increase in the assumptions is so large, the BDCP Model shows that the probability of exceeding the mortality threshold in the Sacramento River at Bend Bridge in August and September increases from approximately 80% in the No Action Alternative to 90% to 95% by 2025 (under ELT conditions) and to 95% to 100% by 2060 (under LLT conditions). This significant difference shows the overwhelming influence that the climate change assumptions have on the BDCP Model results.

Reservoir Storage: Under the climate change scenarios, reservoir storage (particularly in the CVP system) is operated very aggressively so that the reservoirs are drawn down to an extremely low level (termed "dead pool") in approximately 1 of every 10 years, even without the BDCP. At dead pool level, little or no water can be released from the reservoir – not for fish, not for drinking water, not for agriculture. For example, since Folsom Reservoir became operational in 1955, the storage has never been drawn down to reach dead pool (which is approximately 100,000 acre-feet); the lowest storage level on record was 147,000 acre-feet at the end of September 1977. However, the BDCP Model predicts that, under climate change, the reservoir will be about 100,000 acre-feet or about 30% lower than its historical low in 10% of years. Some municipalities, such as the city of Folsom, are entirely dependent on reservoir releases for drinking water. Reaching dead pool would cut municipal deliveries below the level required to maintain public health and safety. In reality, and to avoid such dire circumstances, the CVP and SWP would likely request that regulatory agencies modify standards to conserve storage and would likely mandate conservation (or rationing) by water users. Similar steps were taken in early in 2014 to reduce water diversions and reservoir releases for fishery needs and Delta requirements. Emergency measures such as these are not simulated in the model, so the BDCP Model does not reflect reasonable future operations with climate change.

With the predicted changes in precipitation and temperature implemented in the BDCP Model, there is simply not enough water available to meet all regulatory objectives and water user demands. Yet the BDCP Model continues its normal routine and thus fails to meet its objectives. In this aspect, the BDCP Model simply does not simulate reality. For instance, if the ELT and LLT conditions actually occur, the CVP and SWP would likely adapt to protect water supplies and the environment. Examples of reactions to climate change would likely include: (1) updating operational rules regarding water releases for flood protection; (2) during severe droughts, emergency drought declarations could call for mandatory conservation and changes in some regulatory criteria similar to what has been experienced in the current and previous droughts ; and (3) if droughts become more frequent, the CVP and SWP would likely revisit the rules by which they allocate water during shortages and operate more conservatively in wetter years. The likelihood of an appropriate operational response to climate change is supported by the many modifications to CVP and SWP operations made during the winter and spring of 2014 to respond to the current drought. The BDCP Model is, however, useful in that it reveals that difficult decisions must be made.

Conclusions Regarding Climate Change Assumptions and Implementation

Water Code section 85320, subdivision (b)(2)(C) requires consideration of, among other things, the "potential effects of climate change, possible sea level rise up to 55 inches, and possible changes in total precipitation and runoff patterns on the conveyance alternatives and habitat restoration activities considered in the environmental

impact report". In examining the possible effects of climate change, it is not appropriate to assume that current project operations will remain static and not respond to climate change. The BDCP's simplistic approach of assuming a linear operation of the CVP and SWP produces results that are not useful for dealing with the complex problem of climate change because it does not reflect the way in which the CVP and the SWP would actually operate whether or not the BDCP is implemented. The Reviewers recommend a sensitivity analysis be conducted to develop a better understanding of the range of possible responses to climate change by the CVP and SWP, and the regulatory structures that dictate certain project operations.

Including climate change, without adaptation measures, results in insufficient water needed to meet all regulatory objectives and user demands. For example, the BDCP Model results that include climate change indicate that during droughts, water in reservoirs is reduced to the minimum capacity possible. Reservoirs have not been operated like this in the past during extreme droughts and the current drought also provides evidence that adaptation measures are called for long in advanced to avoid draining the reservoirs. In this aspect, the BDCP Model simply does not reflect a real future condition. Foreseeable adaptations that the CVP and SWP could make in response to climate change include: (1) updating operational rules regarding water releases for flood protection; (2) during severe droughts, emergency drought declarations could call for mandatory conservation; and (3) if droughts become more frequent, the CVP and SWP would likely revisit the rules by which they allocate water during shortages and operate more conservatively in wetter years. The modifications to CVP and SWP operations made during the winter and spring of 2014 in response to the drought supports the likelihood of future adaptations. The BDCP Model is, however, useful in that it reveals that difficult decisions must be made in response to climate change. But, in the absence of making those decisions, the BDCP Model results themselves are not informative, particularly during drought conditions. With future conditions projected to be so dire without the BDCP, the effects of the BDCP appear positive simply because it appears that conditions cannot get any worse (i.e., storage cannot be reduced below its minimum level). However, in reality, the future condition will not be as depicted in the BDCP Model. The Reviewers recommend that Reclamation and DWR develop more realistic operating rules for the hydrologic conditions expected over the next half-century and incorporate those operating rules into the any CalSim II Model that includes climate change.

3.2 General Assumptions and Operations

BDCP CalSim II Assumptions

The assumptions for these runs are defined in the December 2013 Draft BDCP[4] and associated Draft EIR/S.

Each of the no action alternatives assumes the same regulatory requirements, generally representing the existing regulatory environment at the time of study formulation (February 2009), including Stanislaus ROP the National Marine Fisheries Services (NMFS) Biological Opinion (BO) (June 2009) Actions III.1.2 and III.1.3, Trinity Preferred EIS Alternative, NMFS 2004 Winter-run BO, NMFS BO (June 2009) Action I.2.1, SWRCB WR90-5, CVPIA (b)(2) flows, NMFS BO (June 2009) Action I.2.2, ARFM NMFS BO (June 2009) Action II.1, no SJRRP flow modeled, Vernalis SWRCB D1641 Vernalis flow and WQ and NMFS BO (June 2009) Action IV.2.1, Delta D1641 and NMFS Delta Actions including Fall X2 Fish & Wildlife Service (FWS) BO (December 2008) Action 4, Export restrictions including NMFS BO (June 2009) Action IV.11.2v Phase II, OMR FWS BO (December 2008) Actions 1-3 and NMFS BO (June 2009) Action IV.2.3v.

The modeling protocols for the recent USFWS BO (2008) and NMFS BO (2009) have been cited as being cooperatively developed by Reclamation, NMFS, U.S. Fish and Wildlife Service (USF&WS), California Department of Fish and Wildlife (CDF&W), and DWR.

[4] BDCP EIR/EIS Appendix 5A

Each of the BDCP no action alternatives (NAA, NAA-ELT, and NAA-LLT) uses the same New Melones Reservoir and other San Joaquin River operations. At the time of these studies' formulation, the NMFS BO (June 2009) had been recently released. Also, the San Joaquin River Agreement (SJRA), including the Vernalis Adaptive Management Program (VAMP) and its incorporation into D1641 for Vernalis flow requirements were either still in force or being discussed for extension. As a component of study assumptions, the protocols of the SJRA and an implementation of the NMFS BO for San Joaquin River operations (including New Melones Reservoir operations) are included in the studies. These protocols, in particular the inclusion of VAMP which has now expired, are not appropriate as an assumption within either the No Action or Alternative Scenarios within a full disclosure of BDCP impacts. Although appropriate within the identification of actions, programs and protocols present at the time of the NOI/NOP, they are not representative of current or reasonably foreseeable operations. Also, the BDCP Model assumes no San Joaquin River Restoration Program releases in the future operation of the Friant Division of the CVP. While assuming no difference in the current and future operation of the Friant Division avoids another difference in existing and projected future hydrology of the San Joaquin River, the assumption does not recognize the existence of the San Joaquin River Restoration Program. Results of CVP and SWP operations, in particular as affected by export constraints dependent on San Joaquin River flows and their effect on OMR, E/I and I/E diversion constraints, would be different with a different set of assumptions for San Joaquin River operations, in a manner similar to the cascading effect described above in connection with climate change.

Finally, the habitat restoration requirements in the 2008 FWS BO and the 2009 NMFS BO are not included in the NAA baselines. Although the restoration is required to be completed either with or without completion of the BDCP, the restoration was only analyzed as part of the with project scenarios.

Conclusions Regarding General Assumptions and Operations

The benchmark study upon which the BDCP Model was built contains inaccuracies that affect the analysis.

CalSim II is continuously being improved and refined. As the regulatory environment changes and operational and modeling staff work together to improve the model's capability to simulate actual operations, the model is continually updated. The BDCP Model relied upon a version of CalSim II that dates back to 2009, immediately after the new biological opinions (BiOps) from the NMFS and the United States Fish and Wildlife Service (USFWS) significantly altered the operational criteria of the CVP and SWP. In the last 4 to 5 years, DWR, Reclamation, and outside modeling experts have worked together to improve the model. Changes include better (more realistic) implementation of the new BiOps and numerous fixes to the code. Since CalSim II is undergoing continual improvements, there will always be "vintage" issues in that by the time a project report is released, the model is likely slightly out of date. However, in this case - with the major operational changes that have occurred in the new regulatory environment – many issues have been identified and fixed in the last 4 to 5 years that have a significant effect on model results. CalSim II modeling for the DWR 2013 Delivery Reliability Report contains numerous modeling updates and fixes that significantly alter results of the BDCP Model. A key modeling revision in the 2013 DWR modeling was fixing an error regarding artificial minimum instream flow requirements in the Sacramento River at Hood. An "artificial" minimum instream flow requirement had been specified; the requirement is artificial in that it does not represent a regulatory requirement, but rather is a modeling technique to force upstream releases to satisfy Delta needs.

3.3 Assumptions and Operational Criteria for inclusion of proposed BDCP facilities

To evaluate the assumptions and operations of the proposed BDCP facilities, the Reviewers analyzed the output from the BDCP Model and examined the internal workings of the models. This approach allows for evaluation of not only the possible effects of the BDCP, also but whether the assumptions and operational criteria are implemented appropriately to reflect the project description and reasonably foreseeable actions.

Assessment of Assumptions and Operations in coordination with new BDCP facilities

BDCP's Alternative 4 has four possible sets of operational criteria, termed the Decision Tree, that differ based on the "X2" standards[5] that they contemplate:

- Low Outflow Scenario (LOS), otherwise known as operational scenario H1, assumes existing spring X2 standard and the removal of the existing Fall X2 standard;
- High Outflow Scenario (HOS), otherwise known as H4, contemplates the existing Fall X2 standard and providing additional outflow during the spring;
- Evaluated Starting Operations (ESO), otherwise known as H3, assumes continuation of the existing X2 spring and fall standards;
- Enhanced spring outflow only (not evaluated in the December 2013 Draft BDCP), scenario H2, assumes additional spring outflow and no Fall X2 standards.

While it is not entirely clear how the Decision Tree would work in practice, the general concept is that prior to operation of the new facility, implementing authorities would select the appropriate Scenario (from amongst the four choices) based on their evaluation of targeted research and studies to be conducted during planning and construction of the facility.

For this analysis, the Reviewers analyzed the HOS (or H4) scenario because the BDCP[6] indicates that the initial permit will include HOS operations that may be later modified at the conclusion of the targeted research studies. The HOS includes the existing Fall X2 requirements but adds additional outflow requirements in the spring. The model code was reviewed and discussed with DWR and Reclamation, who acknowledged that although the SWP was bearing the majority of the responsibility for meeting the additional spring outflow in the modeling, the responsibility would need to be shared with the CVP[7]. In subsequent discussions, DWR and Reclamation have suggested that the additional water may be purchased from other water users. However, the actual source of water for the additional outflow has not been defined. While not how the projects would actually be operated, since the BDCP Model assumes that the SWP bears the majority of the responsibility for meeting the additional outflow, the Reviewers' analysis of the BDCP Model results for HOS is limited to the evaluation of how the SWP reservoir releases on the Feather River translate into changes in Delta outflow and exports.

Our remaining analysis examines the ESO (or H3) scenario (labeled Alt 4-ELT or Alt 4-LLT in this section) because it employs the same X2 standards as are implemented in NAA-ELT and NAA-LLT. This allowed the Reviewers to focus the analysis on the effects of the BDCP operations independent of the possible change in the X2 standard.

The differences between the without project scenario (NAA-ELT) and the corresponding with project scenario (Alt4 H3-ELT) should reveal the effects of the project under ELT conditions. However, as discussed above, implementation of climate change assumptions and the occurrence of unrealistic operations likely obfuscates the effects of the BDCP. Although the modeling approach may provide a relative comparison between equal foundational operations, the Reviewers are hesitant to place any confidence in the computed differences shown between the NAA-ELT and Alt4-ELT Scenarios. Numerous comparisons between NAA-ELT and Alt4 H3-ELT are discussed in the technical appendix of this report; issues that shaped our conclusions are discussed below.

[5] X2 is a salinity standard that requires outflows sufficient to attain a certain level of salinity at designated locations in the Delta at certain times of year.
[6] Draft BDCP, Chapter 3, Section 3.4.1.4.4
[7] August 7, 2013 meeting with DWR, Reclamation, and CH2M HILL

Assumptions for the "High Outflow Scenario" are unrealistic.

The HOS is one branch of the BDCP Decision Tree, also identified as Alternative 4, operational scenario H4 in the DEIR/EIS. The HOS requires additional water (Delta outflow) during certain periods in the spring, in excess of the current regulatory requirements. The BDCP Model assumes that if the required additional Delta outflow cannot be met by reducing exports, this increased Delta outflow will be met by releases made by the SWP's Oroville Reservoir. The assumptions regarding how much water to release from Oroville to attempt to meet the proposed regulations and how much and when to refill Oroville are unrealistic.

According to the Draft EIR/EIS[8], the HOS will reduce SWP south of Delta water deliveries for municipal and industrial (M&I) water users 7% below the level that they would receive without the BDCP (on average). During dry and critical years, SWP south of Delta water deliveries for M&I and agricultural water users will drop 17% below the level that they would receive without the BDCP. In other words, according to the BDCP Model results SWP Contractors would get less water than they would otherwise get without BDCP.

CVP and SWP obligations for providing flow to satisfy Delta outflow requirements is described in the Coordinated Operations Agreement (COA). Because the CVP and SWP share responsibility for meeting required Delta outflow based on specific sharing in the agreement, it is not reasonable to conclude that CVP water supplies would increase an average of 70 TAF while SWP water supplies decrease on average of 100 TAF under the HOS. The manner in which this alternative is modeled is inconsistent with existing agreements and operating criteria. If the increases in outflow were met based on COA, there would likely be reductions in Shasta and Folsom storage that would likely cause adverse environmental impacts, which have not been modeled or analyzed in the BDCP EIR/S.

Furthermore, there is no apparent source of water to satisfy the increased outflow requirements and pay back the COA debt. It appears, through recent public discussions regarding the HOS that BDCP anticipates additional water to satisfy the increased Delta outflow requirement and to prevent the depletion of cold water pools will be acquired through water transfers from upstream water sources. However, this approach is unrealistic. During most of the spring, when BDCP proposes that Delta outflow be increased, agricultural water users are not irrigating. This means that there is not sufficient transfer water available to meet the increased Delta outflow requirements without releasing stored water from the reservoirs.

San Luis Reservoir operational assumptions produce results that are inconsistent with real world operations.

San Luis Reservoir (SLR) is an off-stream reservoir located south of the Delta and jointly owned and operated by CVP and SWP. The reservoir is used to store water that is exported from the Delta when available and used to deliver water to CVP and SWP Contractors when water demands exceed the amount of water that can be pumped from the Delta. The decision of when to move water that is stored in upstream reservoirs, such as Shasta, Folsom, or Oroville, through the Delta for export to fill SLR is based on the experience and expert judgment of the CVP and SWP operators.

CalSim II attempts to simulate the expert judgment of the operators by imposing artificial operating criteria; the criteria are artificial in the sense that they are not imposed by regulatory or operational constraints but rather imposed as a tool to simulate expert judgment. One such artificial operating criteria is the SLR target storage level: CalSim II attempts to balance upstream Sacramento Basin CVP and SWP reservoirs with storage in SLR by setting artificial target storage levels in SLR, such that the CVP and SWP will release water from upstream reservoirs to meet target levels in SLR. The artificial target storage will be met as long as there is ability to convey

[8] Draft EIR/EIS, Appendix 5A-C, Table C-13-20-2

water (under all regulatory and physical capacity limits) and as long as water is available in upstream reservoirs. SLR target storage criteria are also sometimes described in section 4.2 as the "San Luis rule-curve".

In the BDCP Model, CVP and SWP reservoir operating criteria for Alternative 4 H3 ELT differ from the corresponding without project scenario (e.g. NAA-ELT). The difference in criteria and result is primarily driven by changes to the artificial constraint used to determine when to fill SLR: the SLR target storage. In Alternative 4 H3 ELT, SLR target storage is set very high in the spring and early summer months, and then reduced in August and set to SLR dead pool from September through December. This change in SLR target storage relative to the no action alternative causes upstream reservoirs to be drawn down from June through August and then recuperate storage by cutting releases in September. This change to the artificial operating criteria SLR target storage causes changes in upstream cold water pool management and affects several resource areas.

In addition to changes in upstream storage conditions, changes in SLR target storage cause SLR storage to drop below a water supply concern level (300,000 acre-feet) in almost 6 out of every 10 years under ELT conditions and more than 7 out of every 10 years under LLT conditions for Alternative 4 H3. When storage in SLR drops below this 300,000 acre-foot level, algal blooms in the reservoir often cause water quality concerns for drinking water at Santa Clara Valley Water District. The change in SLR target storage also causes SLR levels to continue to drop and reach dead pool level for the SWP in 4 out of every 10 years and also dead pool level for the CVP in 1 out of every 10 years under the ELT conditions.

Reaching dead pool level in SLR creates shortages to water users south of the Delta. Although some delivery shortages are due to California Aqueduct capacity constraints, the largest annual delivery shortages are a result of inappropriately low SLR target storage. Average annual Table A shortages due to artificially low SLR storage levels increased from 3 TAF in the NAA-ELT scenario to 35 TAF in the Alt4-ELT scenario. Such shortages occurred in 2% of simulated years in the NAA-ELT scenario and 23% of years in the Alt4-ELT scenario. In addition to the inability to satisfy Table A allocations, low storage levels cause loss of SWP Contractors' Article 56 water stored in SLR. Average annual Article 56 shortages were 43 TAF in the Alt4-ELT scenario because of low San Luis storage and 5 TAF in the NAA-ELT scenario. Low San Luis storage causes Article 56 shortages in 27% of simulated years in the Alt4-ELT scenario as compared to 5% of simulated years in the NAA-ELT. Another consequence of low storage levels in SLR is a shift in water supply benefits from Article 21 to Table A.

In summary, the operational assumptions for SLR are unrealistic in Alternative 4 because they create problems in upstream storage reservoirs and create shortages for south of Delta water users that would not occur in the real world. In reaching this conclusion, the Reviewers met with operators from CVP and SWP to review the BDCP Model results and discussed real-time operations. The operators provided guidance in selection of superior assumptions, which results in more realistic operations in the independent model (see Section 4).

Delta Cross Channel operational assumptions overestimate October outflow

When south Delta exports are low due to regulatory limits, and upstream reservoirs are making releases to meet the instream flow objectives at Rio Vista, operators have the ability to close the Delta Cross Channel (DCC) in order to reduce the required reservoir releases (by closing the DCC a greater portion of water released from the reservoirs stays in the Sacramento River to meet the Rio Vista requirements). As long as the Delta salinity standards are met, operators have indicated that they would indeed close the DCC in this manner (as was done in October and November 2013). In the BDCP Model, the DCC is not closed in this manner. The net result is that the BDCP Model overestimates outflow under such circumstances typically occurring in October.

The overestimated outflow leads to incorrect conclusions regarding the effects of BDCP. For instance, an actual increase in fall outflow could be beneficial for the endangered fish species delta smelt (USFWS, 2008). Therefore, by overestimating outflow in October, the BDCP studies likely overestimate the benefit to delta smelt (Mount

et al, 2013). Similarly, an actual increase in fall outflow would reduce salinity in the western Delta, which could be beneficial for in-Delta diverters; therefore, overestimating outflow in October artificially reduces salinity, incorrectly reducing the net impacts on in-Delta diverters.

Conclusions Regarding Assumptions and Operations in coordination with new BDCP facilities

BDCP's "High Outflow Scenario" is not sufficiently defined for analysis.

The HOS requires additional water (Delta outflow) during certain periods in the spring. The BDCP Model places most of the responsibility for meeting this new additional outflow requirement on the SWP. However, the SWP may not actually be responsible for meeting this new additional outflow requirement. This is because the COA, as it is currently being implemented, would require a water allocation adjustment that would keep the SWP whole. Where one project (CVP or SWP) releases water to meet a regulatory requirement, the COA requires a water balancing to ensure the burden does not fall inappropriately among the projects. The BDCP Model is misleading because it fails to adjust project operations, as required by the COA, to "pay back" the water "debt" to the SWP due to these additional Delta outflow requirements. Unless there is a significant revision to COA, the BDCP Model overstates the impacts of increased Delta outflow on the SWP and understates the effects on the CVP.

Furthermore, after consulting with DWR and Reclamation project operators and managers, the Reviewers conclude that there is no apparent source of CVP or SWP water to satisfy both the increased Delta outflow requirements and pay back the COA "debt" to the SWP without substantially depleting upstream water storage. It appears, through recent public discussions regarding the HOS, that BDCP anticipates additional water to satisfy the increased Delta outflow requirement and to prevent the depletion of cold water pools will be acquired through water transfers from upstream water users. However, this approach is unrealistic because during most of the spring, when BDCP proposes that Delta outflow be increased, agricultural water users are not typically irrigating. This means that there is not sufficient transfer water available to meet the increased Delta outflow requirements without releasing stored water from the reservoirs. Releasing stored water to meet the increased Delta outflow requirements could potentially impact salmonids on the Sacramento and American River systems.

Simulated operation of BDCP's dual conveyance, coordinating proposed North Delta diversion facilities with existing south Delta diversion facilities, is inconsistent with the project description.

The Draft BDCP and associated Draft EIR/EIS specify criteria for how much flow can be diverted by the new NDD facilities and specify when to preferentially use either the NDD facilities or the existing SDD facilities. However, the BDCP Model contains an artificial constraint that prevents the NDD facilities from taking water as described in the BDCP project description. In addition to affecting diversions from the NDD, this artificial constraint contains errors that affect the NAA operation. This error has been fixed by DWR and Reclamation in more recent versions of the model; however, the error remains in the BDCP Model. Additionally, the BDCP Model does not reflect the Summer operations of the SDD that are described in the Draft EIR/EIS as a feature of the BDCP project intended to prevent water quality degradation in the south Delta. The net effect of these two errors is that the BDCP Model significantly underestimates the amount of water diverted from the NDD facilities and overestimates the amount of water diverted from the SDD.

BDCP Model contains numerous coding and data issues that skew the analysis and conflict with actual real-time operational objectives and constraints

Operational logic is coded into the CalSim II model to simulate how DWR and Reclamation would operate the system under circumstances for which there are no regulatory or other definitive rules. This attempt to specify (i.e., code) the logic sequence and relative weighting so that a computer can simulate "expert judgment" of the

human operators is a critical element to the CalSim II model. In the BDCP Model, some of the operational criteria for water supply allocations and existing facilities such as the Delta Cross Channel and SLR are inconsistent with real-world conditions.

4 INDEPENDENT MODELING

The Independent Modeling effort originally stemmed from reviews of BDCP Model during which the Reviewers discovered that the BDCP Model did not provide adequate information to determine the effects of the BDCP. There are three basic reasons why the Reviewers cannot assess how the BDCP will affect water operations: 1) NAAs do not depict reasonable operations under the described climate change assumptions, 2) operating criteria used in the BDCP Alternative 4 result in unrealistic operations, and 3) updates to CalSim II since the BDCP modeling was performed almost 4 years ago will likely alter model results to a sufficient degree that conclusions based on the BDCP modeling will likely be different than those disclosed in the Draft EIR/EIS. Given that it is not possible to determine how BDCP may affect CVP and SWP operations or water system flows and conditions with the BDCP model, Independent Modeling was performed to assess potential effects due to the BDCP.

To revise the models, the Reviewers consulted with operators at DWR and Reclamation to improve the representation of operational assumptions. Additionally, the Reviewers consulted with modelers at DWR and Reclamation to share findings, to strategize on the proper way to incorporate the guidance received from the operators, and to present revised models to DWR and Reclamation for their review. This collaborative and iterative process differed considerably from a standard consulting contract where the work product is not shared beyond the client-consultant until a final version is complete. To the contrary, consultations with agency experts were conducted early and repeatedly to ensure the revisions would reflect reasonable operations and to provide an independent review.

The first phase of this Independent Modeling effort (described in Section 4.1) was development of an updated without project baseline (similar to the NAA but with current, improved assumptions). The Independent Modeling does not incorporate climate change because the climate change hydrological assumptions developed by BDCP cause unrealistic operation of the system absent commensurate changes to operating criteria.

After the baseline was complete and reviewed, the second phase of this effort (described in Section 4.2) incorporated the facilities and operations for the BDCP described as Alternative 4 H3 in the Draft EIR/EIS, and otherwise known as the Evaluated Starting Operations (ESO) scenarios in the BDCP. During this phase, the issues that were identified during the Reviewers' initial review were corrected (see Section 3.3) along with corrections made to resolve additional issues that were revealed as improvements were incorporated. Finally, results of the Independent Modeling and potential effects of the BDCP on water supply and instream flows are discussed in Section 4.3.

4.1 Improvements to CalSim II Assumptions

For this effort, the most up to date modeling tools were provided by DWR and Reclamation and further improvements were added to the CalSim II assumptions in coordination with DWR and Reclamation staff. Many of the improvements have since been incorporated into DWR and Reclamation's model and others are under review.

Revisions incorporated by DWR and Reclamation for the 2013 baseline

DWR and Reclamation provided CalSim II models used for the 2013 SWP Delivery Reliability Report (DRR) for use in this Independent Modeling effort. The 2013 SWP DRR, Technical Addendum, and associated models are now available on DWR's website[9]. Assumptions used for this Independent Modeling effort are consistent with the 2013 SWP DRR and are listed in Table 4 of the Technical Addendum.

[9] http://baydeltaoffice.water.ca.gov/swpreliability/

CalSim II is continuously being improved to better represent CVP and SWP operations and fix known problems. The Technical Addendum to the 2013 SWP DRR contains a list of updates and fixes that have occurred since the last SWP DRR was released in 2011. Among these changes and fixes are key items that directly affect operation of facilities proposed in the BDCP Alternative 4; these items are listed on pages 4-6 of the 2013 SWP DRR Technical Addendum.

A key component of this package of modeling revisions was fixing an error regarding artificial minimum instream flow requirements in the Sacramento River at Hood. An "artificial" minimum instream flow requirement had been specified; the requirement is artificial in that it does not represent a regulatory requirement, but rather is a modeling technique.

Additional Revisions to CalSim II Assumptions

As part of the Independent Modeling effort, a number of changes were made to the 2013 SWP DRR version of CalSim II to better represent the existing facilities, regulatory requirements, and water user demands. These revisions are described in the Technical Appendix and summarized here:

- San Joaquin River Restoration Program (SJRRP) was not incorporated. This modification was made to be consistent with the BDCP assumptions, but also allows the identification of the separate effect of the BDCP void of the combined effect with SJRRP flows. Although inclusion of the SJRRP is necessary in the documentation of BDCP, the Independent Modeling did not include it.
- VAMP operations were not incorporated because the VAMP program has expired and is no longer being implemented.
- Tuolumne River basin was updated.
- Folsom Reservoir operations for flood control were updated.
- Additional water demands on the Feather River were incorporated to represent existing agricultural diversions used for rice decomposition.
- Diversions by East Bay Municipal Utility District (EBMUD) from the Sacramento River at Freeport were modified to better represent the EBMUD CVP water service contract.
- Minimum flow requirements for Wilkins Slough and Red Bluff were corrected for September 1933.
- CVP M&I demands are updated to reflect current assumptions used by Reclamation.
- Modifications were made to more accurately reflect refilling of New Bullards Bar Reservoir in coordination with transfers made under the Yuba Accord.
- Los Vaqueros Reservoir capacity was updated to reflect a recent expansion of the reservoir that was completed in 2012.

4.2 Improvements to BDCP Operations

After the baseline was completed and reviewed (as summarized above in Section 4.1), the facilities and operations associated with BDCP Alternative 4 H3 in the Draft EIR/EIS, otherwise known as the Evaluated Starting Operations (ESO) scenarios in the Draft Plan, were incorporated into the model. During this phase, the issues that were identified during the Reviewers' initial review (see Section 3.3) were corrected along with correcting additional issues that were revealed as improvements were incorporated. These revisions are described in the Technical Appendix and summarized here:

- San Luis Reservoir operation
- Delta Cross Channel gate operation in October
- Delivery allocation adjustment for CVP SOD contractors

- Folsom/Shasta balance
- North Delta Diversion bypass criteria
- Wilkins Slough minimum flow requirement

In the Independent Modeling, San Luis rule-curve logic was refined for both SWP and CVP operations. San Luis rule-curve is used to maintain an appropriate balance between San Luis Reservoir (SLR) storage and North of Delta reservoirs. The key considerations in formulating rule-curve are 1) ensuring that sufficient water is available in SLR to meet contract allocations when exports alone are insufficient due to various operational constraints and 2) minimize SLR carryover storage to low point criteria (both CVP and SWP) and Article 56 carryover (only SWP). The basic premise is to maintain SLR storage no higher than necessary to satisfy south of Delta obligations to avoid excessive drawdown of upstream storage.

In the BDCP NAA and the Independent Modeling FNA, the model has a priority to release excess stored water that will likely be released for flood control purposes from Shasta and Folsom storage for export at Jones Pumping Plant to storage in SLR in the late summer and early fall months. The purpose was to get a head start on filling SLR for the coming water year if there is a high likelihood of Shasta or Folsom spilling. This was an assumed CVP/SWP adaptation to the export reductions in the winter and spring months due to the salmon and smelt biological opinions. However, with the NDD facility in Alt 4, winter and spring export restrictions impact CVP exports much less and there is no longer a reason to impose this risk on upstream storage. As such, the weights, or prioritizations, of storage in Shasta and Folsom were raised so that excess water would not be released specifically to increase CVP San Luis storage Reservoir above rule-curve. This was changed in Alt 4 and not the FNA to better reflect how the system may operate under these different conditions.

The BDCP Alt 4 results in significantly more October surplus Delta outflow as compared to the baseline. The cause of this Delta surplus at a time when the Delta is frequently in balance is a combination of proposed through-Delta export constraints Old and Middle River (OMR) flow criteria and no through-Delta exports during the San Joaquin River October pulse period), Rio Vista flow requirements, and DCC gate operations. In DWR's BDCP studies, it was assumed that the DCC gates would be open for the entire month of October thereby requiring much higher Sacramento River flows at Hood in order to meet the Rio Vista flow requirement than if the DCC gates were closed. Whereas in the Independent Modeling of the BDCP it was assumed that the DCC gates were closed for a number of days during the month such that the 7,000 cfs NDD bypass criteria would be sufficient to meet the weekly average Rio Vista flow requirements. The intent was to minimize surplus Delta outflow while meeting Delta salinity standards and maintaining enough bypass flow to use the NDD facility for SDD. This is an approximation of what is likely to occur in real-time operations under similar circumstances. Further gate closures may be possible as salinity standards allow if operators decide to preserve upstream storage at the expense of NDD diversions. This type of operation would require additional model refinements.

CVP SOD Ag service and M&I allocations are limited by both system wide water supply (storage plus inflow forecasts) and Delta export constraints; whereas similar CVP NOD allocations are dependent solely on water supply. This frequently results in SOD water service contractors receiving a lower contract year allocation than NOD water service contractors, especially under the Biological Opinion export restrictions. However, with the NDD facility operations as proposed under Alt 4 H3, the CVP can largely bypass these Delta export restrictions and the export capacity constraint on CVP SOD allocations was determined to be overly conservative. Therefore, the export capacity component of CVP SOD allocations was removed in the BDCP Alternative and both SOD and NOD CVP allocations are equal and based only on water supply.

For the Independent Modeling, CVP operations were refined in the BDCP Alternative to provide maximum water supply benefits to CVP contractors while protecting Trinity, Shasta, and Folsom carryover storage in the drier years. As a whole, this was accomplished with refinements to allocation logic and San Luis rule-curve. However, in the initial study runs, an imbalance between Folsom and Shasta was created; while there was a total positive

impact to upstream storage in dry years, there was a negative impact to Folsom storage. This was resolved by inserting Folsom protections in the Shasta-Folsom balancing logic. With these protections, the positive carryover impacts were distributed to Trinity, Shasta, and Folsom.

The daily disaggregation method for implementing NDD bypass criteria as implemented in DWR's BDCP model was left mostly intact for the Independent Modeling. However, to properly fit the bypass criteria implementation within the latest CalSim operations formulation certain modifications were made. Modifications are as follows:

1. No NDD operations occur in cycles 6 through 9 so that Delta operations and constraints can be fully assessed without NDD interference.
2. Cycles 10 and 11 (Daily 1 and Daily 2 respectively) were added to determine NDD operations given various operational constraints including the NDD bypass criteria.
3. From July to October, bypass criteria are based on monthly average operations (no daily disaggregation). Given the controlled reservoir releases at this time and the constant bypass criteria (5,000 cfs from July to September and 7,000 cfs in October), this was determined to be a reasonable assumption. This also simplified coordination of DCC gate operations with NDD in October which will be discussed later.
4. When warranted by conditions in cycle Daily 1 (cycle 10), the bypass criteria in May and June were allowed to be modeled on a monthly average basis in cycle Daily 2 (cycle 11). This allowed a reduction in the number of cycles necessary to determine the fully allowed diversion under the bypass criteria when the Delta was in balance and additional upstream releases were made to support diversions from the North Delta.

Currently in CalSim II, relaxation of the Wilkins Slough minimum flow requirement is tied to CVP NOD Ag Service Contractor allocations. This does not reflect actual operations criteria where relaxation of the flow requirement is dependent solely on storage conditions at Shasta. From the comparative analysis perspective of our CalSim planning studies, this introduces a potential problem: changes in CVP NOD Ag Service allocations can result in unrealistic changes in required flow at Wilkins Slough, and such changes in Wilkins Slough required flow can result in unrealistic impacts to Shasta storage. To bypass this problem, we assumed that the required flow at Wilkins Slough in the alternative was equal to the baseline.

4.3 Independent Modeling output and analysis of BDCP Effects

Analysis for this effort was focused on BDCP Alt 4 with existing spring and Fall X2 requirements, which corresponds to "Alternative 4 H3" in the Decisions Tree. This modeling is performed without climate change, and includes refined operating criteria for the NDD, CVP and SWP reservoirs, DCC gate closures, and water supply allocations. This modeling includes all Project features that are included in Alt 4 in the BDCP Model. The key Project features incorporated into BDCP are displayed in Figure 1 and summarized as:

- North Delta Diversion capacity of 9,000 cfs
- NDD bypass flow requirements
- 25,000 acres of additional tidal habitat
- Notched Fremont Weir to allow more flow into Yolo Bypass
- Additional positive Old and Middle River flow requirements
- Removal of the San Joaquin River I/E ratio (NMFS 2009)
- Changed location for Emmaton water quality standard in SWRCB D-1641
- Additional Sacramento River flow requirement at Rio Vista



Figure 1. Map of Delta with location of key BDCP facilities and regulatory changes
Annual maximum and minimum storage in San Luis for the (a) CVP and (b) SWP under ELT conditions for the no action alternative (NAA_ELT) and BDCP Alternative 4 H3 (Alt4_ELT).

For the purpose of describing results of the Independent Modeling, the revised baseline scenario without climate change, originally termed No Action Alternative (NAA) in the BDCP Draft EIR/EIS, is referred to as the Future No Action (FNA) in this discussion. Additionally, in the Independent Modeling, Alternative 4 operational scenario H3 without climate change is simply referred to as "Alt 4". The results for the Independent Modeling are illustrated in the Technical Attachment. Key results are presented below.

The change in conditions between FNA and Alt 4 is indicative of the effects of the BDCP on water supply and Delta flows. An effect of the BDCP is an anticipated increase in Delta export and corresponding decrease in Delta Outflow. Table 2 illustrates the estimated change in Delta Outflow by year type, amounting to an average annual 0.76 MAF. Table 3 illustrates the corresponding change in exports by year type, and also illustrates the estimated change in geographical source of export water. With the BDCP it is anticipated that exports from the South Delta (via through Delta conveyance) will decrease by 2.53 MAF. Exports derived from the North Delta (via the tunnels) will amount to 3.28 MAF.

Table 2. Change in Delta outflow due to the BDCP (Alt 4 minus FNA) (Million Acre-Feet)
Reduction in the quantity of water that leaves the Delta by flowing west into San Francisco Bay by water year type.

Water Year Type	FNA Delta Outflow	Change in Delta Outflow
Wet	28.6	-1.2
Above Normal	17.1	-1.0
Below Normal	9.9	-0.68
Dry	7.3	-0.39
Critical	5.1	-0.13
Average	15.6	**-0.76**

Table 3. Change in quantity of water exported due to the BDCP (Alt 4 minus FNA) (Million Acre-Feet)
Reduction in the quantity of water exported from the existing South Delta export facilities and corresponding increase in the quantity exported from the proposed facilities in the North Delta, by water year type.

Water year Type	FNA Total Delta Export	Change in South Delta Exports (through Delta)	Change in North Delta Exports (through tunnels)	Change in Total Exports
Wet	6.0	-3.8	5.0	1.2
Above Normal	5.2	-2.9	4.4	1.5
Below Normal	5.1	-2.4	3.2	0.8
Dry	4.2	-1.8	1.8	0.07
Critical	2.8	-0.7	0.7	0.02
Average	**4.9**	**-2.53**	**3.28**	**0.75**

Table 4. Change in quantity of CVP water exported by SWP facilities (Alt 4 minus FNA) (Thousand Acre-Feet)
Quantity of water exported at Banks Pumping Plant for later use by CVP contractors is increased in all water year types except the driest years (critical designation).

Water Year Type	FNA CVP water exported by SWP	Change in CVP water exported by SWP
Wet	58	229
Above Normal	44	208
Below Normal	66	117
Dry	86	7
Critical	38	-9
Average	60	**123**

The Independent Modeling shows that implementation of the BDCP could shift a portion of the SWP exports from summer to winter and spring because the proposed NDD facilities can export water at times when the existing SDD facilities are constrained due to fishery concerns. As a result of this shift in timing, capacity is available at the SWP facilities during the summer months. The BDCP Model assumes that CVP could utilize the SWP facilities (Table 4) at any time when the CVP facilities are fully utilized; this sharing of diversion facilities is termed "joint point of diversion" or JPOD. Additional criteria to meet specific water quality and water level objectives are defined in response plans required by the State Water Board's water right decision D-1641. BDCP Model assumes that these additional criteria are met; the Independent Modeling continues this assumption without making any judgment as to whether the criteria would be met. An evaluation of this would require additional hydrodynamic modeling.

The Independent Modeling shows higher average annual CVP carryover (end of September) storage than the NAA by about 28 TAF. During dryer years when upstream storage is lower there is an increase in carryover and during wetter years when storage is higher there are storage decreases (Table 5). Upstream SWP storage, Table 6, behaves in a similar manner as CVP storage, there are decreases in wetter years and increased in dryer years.

CVP San Luis Reservoir fills in about 40% of years in Alt 4 compared to about 20% in the FNA. CVP San Luis reaches dead pool in about 25% of years in both the FNA and Alt 4. SWP San Luis Reservoir fills in about 43% of years in Alt 4 compared to about 18% in the FNA. SWP San Luis reaches dead pool in about 25% of years in Alt 4 and about 30% of years in the FNA.

Table 5. Change in CVP upstream carryover storage (Alt 4 minus FNA) (Thousand Acre-Feet)
CVP carryover (end of September) storage decreases in wetter years when FNA storage is highest and increases in dryer years when FNA storage is lowest

Water Year Type	FNA CVP Upstream Storage	Change in CVP Upstream Storage
Wet	5578	-8
Above Normal	5200	-150
Below Normal	4717	-1
Dry	4049	66
Critical	2285	258
Average	4558	**28**

Table 6. Change in SWP upstream carryover storage (Alt 4 minus FNA) (Thousand Acre-Feet)
SWP carryover (end of September) storage decreases in wetter years when FNA storage is highest and increases in dryer years when FNA storage is lowest

Water Year Type	FNA SWP Upstream Storage	Change in SWP Upstream Storage
Wet	2407	33
Above Normal	1934	-150
Below Normal	1517	14
Dry	1194	157
Critical	968	127
Average	1709	**44**

5 COMPARING INDEPENDENT MODELING AND BDCP MODEL

The Independent Modeling effort originally stemmed from reviews of DWR's BDCP Model where the Reviewers through their independent analysis found that BDCP Model does not provide adequate information to determine how BDCP may affect the system. Based on the premise that the Independent Modeling portrays a more accurate characterization of how the CVP/SWP system may operate under Alt 4, this comparison is meant to demonstrate the differences between results of a more accurate and realistic analysis and the BDCP Model. Differences in results between these modeling efforts are believed to provide insight regarding how effects that BDCP will have on the actual CVP/SWP system differ from modeling used to support the Draft EIR/S.

Although thorough comparisons of modeling were performed, only key differences are illustrated for the purpose of this comparison.

Conclusions regarding BDCP effects

Based on the Independent Modeling, the amount of water exported (diverted from the Delta) may be approximately 200 thousand acre-feet (TAF) per year higher than the amount disclosed in the Draft EIR/S. This total represents

- approximately 40 TAF/yr more water diverted and delivered to the SWP south of Delta contractors, and
- approximately 160 TAF/yr more water diverted and delivered to the CVP south of Delta contractors.

The BDCP Model estimates that, under the NAA ELT (without the BDCP), total average annual exports for CVP and SWP combined are estimated to be 4.73 million acre feet (MAF) and in the Independent Modeling FNA combined exports are 5.61 MAF. The BDCP Model indicates an increase in exports of approximately 540 TAF and the Independent Modeling shows an increase of approximately 750 TAF in Alt 4.

The Independent Modeling suggests that Delta outflow would decrease by approximately 200 TAF/yr compared to the amount indicated in the Draft EIR/S.

- This lesser amount of Delta outflow has the potential to cause greater water quality and supply impacts for in-Delta beneficial uses and additional adverse effects on species. To determine the potential effects of the reduced amount of outflow, additional modeling is needed using tools such as DSM2.

The BDCP Model does not accurately reflect the location of the diversions that the SWP and CVP will make from the Delta.

- When the errors in the model are corrected, it reveals that the North Delta intakes could divert approximately 680 TAF/yr more than what was disclosed in the BDCP Draft EIR/S, and
- the amount of water diverted at the existing South Delta facilities would be approximately 460 TAF/yr less than what is projected in the BDCP Draft EIR/S.

Hydrologic modeling of BDCP alternatives using CalSim II has not been refined enough to understand how BDCP may affect CVP and SWP operations and changes in Delta flow dynamics. Better defined operating criteria for project alternatives is needed along with adequate modeling rules to analyze how BDCP may affect water operations. Without a clear understanding of how BDCP may change operations, affects analysis based on this modeling may not produce reliable results and should be revised as improved modeling is developed.

6 GLOSSARY

acre-foot The volume of water (about 325,900 gallons) that would cover an area of 1 acre to a depth of 1 foot. This is enough water to meet the annual needs of one to two households.

agricultural water supplier As defined by the California Water Code, a public or private supplier that provides water to 2,000 or more irrigated acres per year for agricultural purposes or serves 2,000 or more acres of agricultural land. This can be a water district that directly supplies water to farmers or a contractor that sells water to the water district.

annual Delta exports The total amount of water transferred ("exported") to areas south of the Delta through the Harvey O. Banks Pumping Plant (SWP) and the C. W. "Bill" Jones Pumping Plant (CVP) in 1 year.

appropriative water rights Rights allowing a user to divert surface water for beneficial use. The user must first have obtained a permit from the State Water Resources Control Board, unless the appropriative water right predates 1914.

Article 21 water Water that a contractor can receive in addition to its allocated Table A water. This water is only available if several conditions are met: (1) excess water is flowing through the Delta; (2) the contractor can use the surplus water or store it in the contractor's own system; and (3) delivering this water will not interfere with Table A allocations, other SWP deliveries, or SWP operations.

biological opinion A determination by the U.S. Fish and Wildlife Service or National Marine Fisheries Service on whether a proposed federal action is likely to jeopardize the continued existence of a threatened or endangered species or result in the destruction or adverse modification of designated "critical habitat." If jeopardy is determined, certain actions are required to be taken to protect the species of concern.

CalSim-II A computer model, jointly developed by DWR and the U.S. Bureau of Reclamation, that simulates existing and future operations of the SWP and CVP. The hydrology used by this model was developed by adjusting the historical flow record (1922–2003) to account for the influence of changes in land uses and regulation of upstream flows.

Central Valley Project (CVP) Operated by the U.S. Bureau of Reclamation, the CVP is a water storage and delivery system consisting of 20 dams and reservoirs (including Shasta, Folsom, and New Melones Reservoirs), 11 power plants, and 500 miles of major canals. CVP facilities reach some 400 miles from Redding to Bakersfield and deliver about 7 million acre-feet of water for agricultural, urban, and wildlife use.

cubic feet per second (cfs) A measure of the rate at which a river of stream is flowing. The flow is 1 cfs if a cubic foot (about 7.48 gallons) of water passes a specific point in 1 second. A flow of 1 cubic foot per second for a day is approximately 2 acre-feet.

Delta exports Water transferred ("exported") to areas south of the Delta through the Harvey O. Banks Pumping Plant (SWP) and the C. W. "Bill" Jones Pumping Plant (CVP).

Delta inflow The combined total of water flowing into the Delta from the Sacramento River, San Joaquin River, and other rivers and waterways.

exceedence plot For the SWP, a curve showing SWP delivery probability (especially for Table A water)—specifically, the likelihood that SWP Contractors will receive a certain volume of water under current or future conditions.

incidental take permit A permit issued by the U.S. Fish and Wildlife Service or National Marine Fisheries Service, under Section 10 of the federal Endangered Species Act, to private nonfederal entities undertaking otherwise lawful projects that might result in the "take" of an endangered or threatened species. In California, an additional permit is required and take may be authorized under Section 2081 of the California Fish and Game Code through issuance of either an incidental take permit or a consistency determination. The California Department of Fish and Wildlife is authorized to accept a federal biological opinion as the take authorization for a State-listed species when a species is listed under both the federal and California Endangered Species Acts.

riparian water rights Water rights that apply to lands traversed by or adjacent to a natural watercourse. No permit is required to use this water, which must be used on riparian land and cannot be stored for later use. Riparian rights attach only to the "natural" flow in the water course and do not apply to abandoned flows or stored water releases.

State Water Project (SWP) Operated by DWR, a water storage and delivery system of 33 storage facilities, about 700 miles of open canals and pipelines, four pumping-generating plants, five hydroelectric power plants, and 20 pumping plants that extends for more than 600 miles in California. Its main purpose is to store and distribute water to 29 urban and agricultural water suppliers in Northern California, the San Francisco Bay Area, the San Joaquin Valley, the Central Coast, and Southern California. The SWP provides supplemental water to 25 million Californians (almost two-thirds of California's population) and about 750,000 acres of irrigated farmland. Water deliveries have ranged from 1.4 million acre-feet in a dry year to more than 4.0 million acre-feet in a wet year.

SWP Contractors Twenty-nine entities that receive water for agricultural or municipal and industrial uses through the SWP. Each contractor has executed a long-term water supply contract with DWR. Also sometimes referred to as "State Water Contractors."

Table A water (Table A amounts) The maximum amount of SWP water that the State agreed to make available to an SWP Contractor for delivery during the year. Table A amounts determine the maximum water a contractor may request each year from DWR. The State and SWP Contractors also use Table A amounts to serve as a basis for allocation of some SWP costs among the contractors.

urban water supplier As defined by the California Water Code, a public or private supplier that provides water for municipal use directly or indirectly to more than 3,000 customers or supplies more than 3,000 acre-feet of water in a year. This can be a water district that provides the water to local residents for use at home or work, or a contractor that distributes or sells water to that water district.

Water Rights Decision 1641 (D-1641) A regulatory decision issued by the State Water Resources Control Board in 1999 (updated in 2000) to implement the 1995 Water Quality Control Plan for the San Francisco Bay/Sacramento–San Joaquin Delta. D-1641 assigned primary responsibility for meeting many of the Delta's water quality objectives to the SWP and CVP, thus placing certain limits on SWP and CVP operations.

water year In reports on surface water supply, the period extending from October 1 through September 30 of the following calendar year. The water year refers to the September year. For example, October 1, 2010, through September 30, 2011 is the 2011 water year.

Review of Bay Delta Conservation Program Modeling

by MBK Engineers and Daniel B. Steiner, Consulting Engineer

Technical Appendix

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1 INTRODUCTION

Since December 2012, MBK Engineers and Dan Steiner (collectively "Reviewers") have assisted various parties in evaluating the operations modeling that was performed for the Bay Delta Conservation Plan (BDCP). To assist in understanding BDCP and the potential implications, stakeholders[1] requested that the Reviewers review the CalSim II modeling studies performed as part of the BDCP (hereafter "BDCP Studies" or "BDCP Model").

An initial review led the Reviewers to conclude that the BDCP Model, which serves as the basis for the environmental analysis contained in the BDCP Environmental Impact Report/Statement (EIR/S), provides very limited useful information to understand the effects of the BDCP. The BDCP Model contains erroneous assumptions, errors, and outdated tools, which result in impractical or unrealistic Central Valley Project (CVP) and State Water Project (SWP) operations. The unrealistic operations, in turn, do not accurately depict the effects of the BDCP.

The Reviewers revised the BDCP Model to depict a more accurate, consistent version of current and future benchmark hydrology so that the effects of the BDCP could be ascertained. The BDCP Model was also revised to depict more realistic CVP and SWP operations upon which to contrast the various BDCP alternatives. The Reviewers made significant efforts to coordinate with and inform the U.S. Bureau of Reclamation (Reclamation) and the California Department of Water Resources (DWR) managers and modelers, and CVP and SWP operators of the Reviewers' modifications, assumptions, and findings. Where appropriate, the Reviewers also used Reclamation and DWR's guidance and direction to refine the Reviewers' analysis.

This technical appendix summarizes: (1) the independent review of the CalSim II modeling publicly released for the BDCP's Draft Environmental Impact Report/Statement (EIRS), (2) the corrections and revisions made to the assumptions in the CalSim II model, and (3) comparisons between the BDCP and independent modeling results. The detailed information in this appendix is summarized in our main report.

[1] The entities who funded this report are Contra Costa Water District, East Bay Municipal Utility District, Friant Water Authority, Northern California Water Association, North Delta Water Agency, San Joaquin River Exchange Contractors Water Authority, San Joaquin Tributaries Authority, and Tehama Colusa Canal Authority.

2 REVIEW OF BDCP CALSIM II MODELING

2.1 Climate Change

Implementation of Climate Change

The analysis presented in the BDCP Documents attempts to incorporate the effects of climate change at two future climate periods: the early long term (ELT) at approximately the year 2025; and the late long term (LLT) at approximately 2060. As described in the BDCP documents[2], other analytical tools were used to determine anticipated changes to precipitation and air temperature that is expected to occur under ELT and LLT conditions. Projected precipitation and temperature was then used to determine how much water is expected to flow into the upstream reservoirs and downstream accretions/depletions over an 82-year period of variable hydrology; these time series were then used as inputs into the CalSim II operations model. A second aspect of climate change, the anticipated amount of sea level rise, is incorporated into the CalSim II model by modifying a subroutine that determines salinity within the Delta based on flows within Delta channels. The effects of sea level rise will manifest as a need for additional outflow when water quality is controlling operations to prevent seawater intrusion.

This report does not review the analytical processes by which reservoir inflows and runoff were developed, nor does it evaluate the modified flow-salinity relationships that are assumed due to sea level rise; those items could be the focus of another independent review. This review is limited to evaluating how the modified flows were incorporated into CalSim II and whether the operation of the CVP and SWP water system in response to the modified flows and the modified flow-salinity relationship is reasonable for the ELT and LLT conditions. This work reviews the assumed underlying hydrology and simulated operation of the CVP/SWP, assumed regulatory requirements, and the resultant water delivery reliability.

CalSim II Assumptions

To assess climate change, the three without Project (or "baseline" or "no action") modeling scenarios were reviewed: No Action Alternative (NAA)[3], No Action Alternative at the Early Long Term (NAA – ELT), and No Action Alternative at the Late Long Term (NAA –LLT). Assumptions for NAA, NAA-ELT, and NAA-LLT are provided in the Draft EIR[4]. The only difference between these scenarios is the climate-related changes made for the ELT and LLT conditions (Table 1).

Table 1. Scenarios used to evaluate climate change

	Climate Change Assumptions	
Scenario	**Hydrology**	**Sea Level Rise**
No Action Alternative (NAA)	None	None
No Action Alternative at Early Long Term (NAA-ELT)	Modified reservoir inflows and runoff for expected conditions at 2025	15 cm
No Action Alternative at Early Long Term (NAA-LLT)	Modified reservoir inflows and runoff for expected conditions at 2060	45 cm

[2] BDCP EIR/EIS Appendix 5A, Section A and BDCP HCP/NCCP Appendix 5.A.2
[3] NAA is also called the Existing Biological Conditions number 2 (EBC-2) in the Draft Plan.
[4] BDCP EIR/EIS Appendix 5A, Section B, Table B-8

The differences between the NAA and NAA-ELT reveal the effects of the climate change assumptions under ELT conditions; similarly, the differences between the NAA and NAA-LLT reveal the effects of the climate change assumptions under LLT conditions.

Regulatory requirements

Each of the no action alternatives assumes the same regulatory requirements, generally representing the existing regulatory environment at the time of study formulation (February 2009), including Stanislaus ROP NMFS BO (June 2009) Actions III.1.2 and III.1.3, Trinity Preferred EIS Alternative, NMFS 2004 Winter-run BO, NMFS BO (June 2009) Action I.2.1, SWRCB WR90-5, CVPIA (b)(2) flows, NMFS BO (June 2009) Action I.2.2, ARFM NMFS BO (June 2009) Action II.1, no SJRRP flow modeled, Vernalis SWRCB D1641 Vernalis flow and WQ and NMFS BO (June 2009) Action IV.2.1, Delta D1641 and NMFS Delta Actions including Fall X2 FWS BO (December 2008) Action 4, Export restrictions including NMFS BO (June 2009) Action IV.11.2v Phase II, OMR FWS BO (December 2008) Actions 1-3 and NMFS BO (June 2009) Action IV.2.3v.

The modeling protocols for the recent USFWS BO (2008) and NMFS BO (2009) have been cited as being cooperatively developed by Reclamation, NMFS, U.S. Fish and Wildlife Service (USF&WS), California Department of Fish and Wildlife (CDF&W), and DWR.

Each of the BDCP no action alternatives (NAA, NAA-ELT, and NAA-LLT) uses the same New Melones Reservoir and other San Joaquin River operations. At the time of these studies' formulation, the National Marine Fisheries Services (NMFS) Biological Opinion (BO) (June 2009) had been recently released. Also, the San Joaquin River Agreement (SJRA, including the Vernalis Adaptive Management Program [VAMP]) and its incorporation into D1641 for Vernalis flow requirements were either still in force or being discussed for extension. As a component of study assumptions, the protocols of the SJRA and an implementation of the NMFS BO for San Joaquin River operations (including New Melones Reservoir operations) is included in the studies. These protocols, in particular the inclusion of VAMP which has now expired, is not appropriate as an assumption within either the No Action or Alternative Scenarios. Although appropriate within the identification of actions, programs and protocols present at the time of the NOI/NOP, they are not representative of current or reasonably foreseeable operations. Also, modeling of the future operation of the Friant Division of the CVP assumes no San Joaquin River Restoration Program releases. While assuming no difference in the current and future operation of the Friant Division avoids another difference in existing and projected future hydrology of the San Joaquin River, the assumption does not recognize the existence of the San Joaquin River Restoration Program. Results of CVP and SWP operations, in particular as affected by export constraints dependent on San Joaquin River flows and their effect on OMR, E/I and I/E diversion constraints, would be different with a different set of assumptions for San Joaquin River operations.

Finally, the habitat restoration requirements in the 2008 FWS BO and the 2009 NMFS BO are not included in the No Action Alternative baselines. Although the restoration is required to be completed either with or without completion of the BDCP, the restoration was only analyzed as part of the with project scenarios.

Model Results

Inflow and Reservoir Storage in the Sacramento River Basin

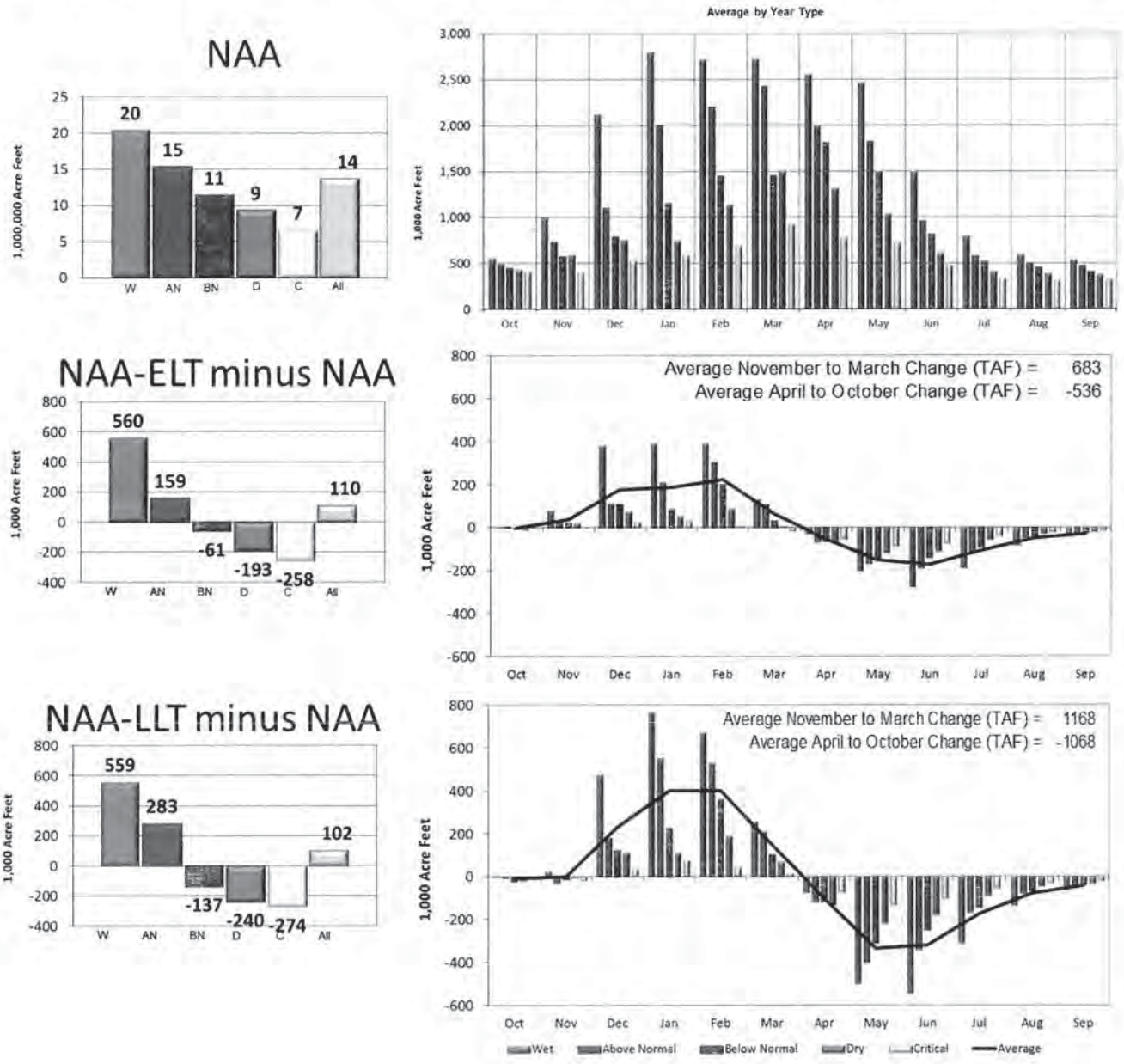
The significance of changed hydrology between the three without project baselines is illustrated in Figure 1 below. The figure illustrates the projected combined inflow of Trinity, Shasta, Oroville, and Folsom Reservoirs under the three NAA baselines. Numerous modeling projections for climate change have been developed, and in this BDCP group of Scenarios Trinity, Shasta, and Oroville inflow are projected to increase overall, but with a

significant shift from spring runoff to winter runoff and increases in wetter years with decreases in dryer years. Folsom Reservoir inflow is projected to remain about the same at the time of the NAA-ELT Scenario but decreases by the time of the NAA-LLT Scenario. The spring to winter shift in runoff is also projected for Folsom Reservoir inflow.

If climate change resulted in such drastic inflow changes, there is argument that certain underlying operating criteria such as instream flow requirements and flood control diagrams would require change in recognition of the changed hydrology. Regarding current environmental flow requirements carried into the NAA Scenarios, we question an assumed operation that continues to attempt to meet temperature targets when flow releases are unlikely to meet the target and thus a sustainable operation plan is not possible. For example, the CVP and SWP are unlikely to draw reservoirs to dead pool as often as the models depict. The NAA-ELT and NAA-LLT model Scenarios show project reservoirs going to dead pool in 10% of years; such operation would result in cutting upstream urban area deliveries below what is needed for public health and safety in 10% of years and would lead to water temperature conditions that would likely not achieve the assumed objectives. Again in short, the Scenarios that include climate change do not provide a reasonable underlying CVP/SWP operation with a changed hydrology from which to impose a Project upon to understand how BDCP Alternatives will affect the water system and water users.

In our opinion, the CalSim II depicted operations that incorporate climate change are not reasonably foreseeable and do not represent a likely future operation of the CVP/SWP. Although an argument is typically made that these study baselines will be used in a comparison analysis with Project Alternatives tiering from these baselines, we believe that the depicted operations do not represent credible CVP/SWP operations and we have no confidence in the results and they are inappropriate as the foundation of a Project Alternative. As such, although the modeling approach may provide a relative comparison between equal foundational operations, we are apprehensive to place much confidence in the computed differences shown between the NAA and Project Alternative Scenarios.

Figure 1. Projected Inflow to Trinity, Shasta, Oroville, and Folsom Reservoirs – NAA, NAA-ELT and NAA-LLT



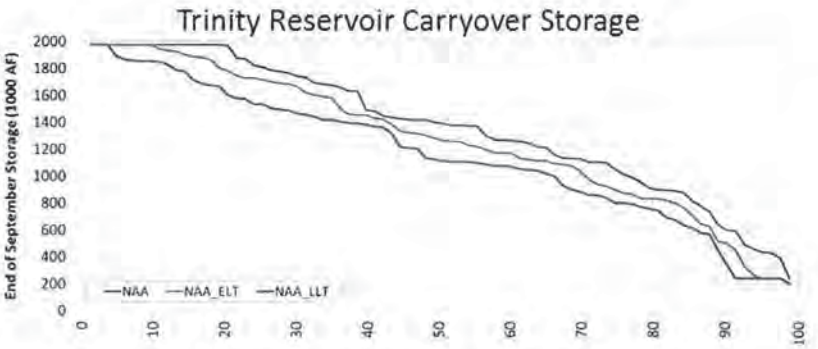
Carryover Storage in the Sacramento River Basin

For upstream CVP and SWP reservoirs the assumed shift of inflows due to climate change (Figure 1) along with a continuing need to satisfy exports demands significantly affects carryover storage. The CVP and SWP simply cannot satisfy water demands and regulatory criteria imposed on them in the NAA-ELT and NAA-LLT modeling scenarios.

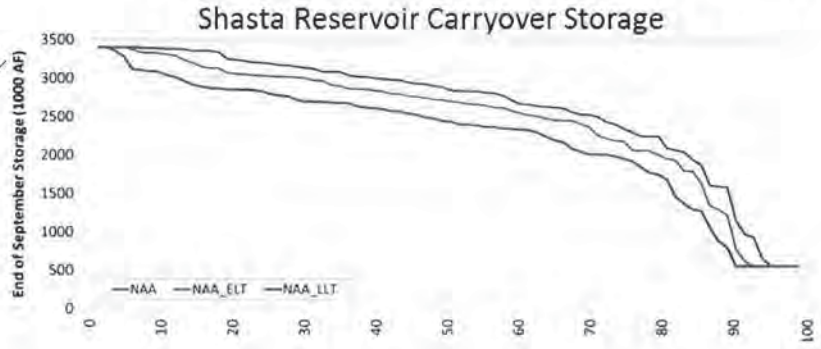
Figure 2 illustrates the typical change in carryover storage as shown for Trinity, Shasta, Oroville, and Folsom Reservoirs. The relatively high frequency (approximately 10% of time) of minimum storage occurring at CVP reservoirs illustrates our questioning of credible operations in the studies.

Figure 2. Projected Shasta Reservoir Carryover Storage, NAA, NAA-ELT and NAA-LLT

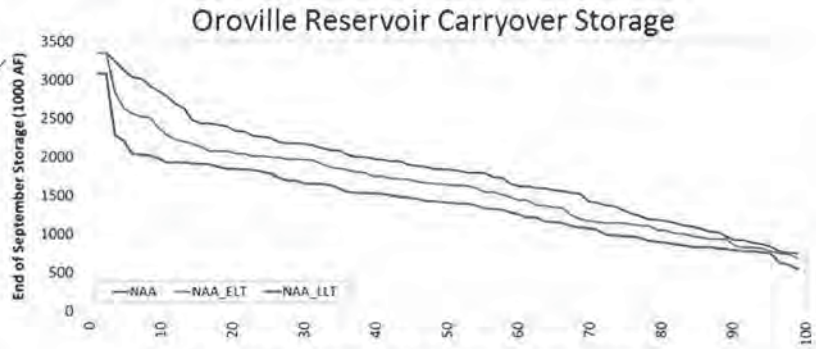
	Year Type	NAA_ELT minus NAA	NAA_LLT minus NAA
Trinity	W	-62	-187
	AN	-79	-198
	BN	-102	-170
	D	-138	-271
	C	-126	-216
	All	-97	-209



	Year Type	NAA_ELT minus NAA	NAA_LLT minus NAA
Shasta	W	-117	-331
	AN	-199	-452
	BN	-152	-340
	D	-154	-463
	C	-192	-377
	All	-154	-386



	Year Type	NAA_ELT minus NAA	NAA_LLT minus NAA
Oroville	W	-296	-588
	AN	-225	-460
	BN	-229	-513
	D	-180	-296
	C	-54	-159
	All	-213	-430



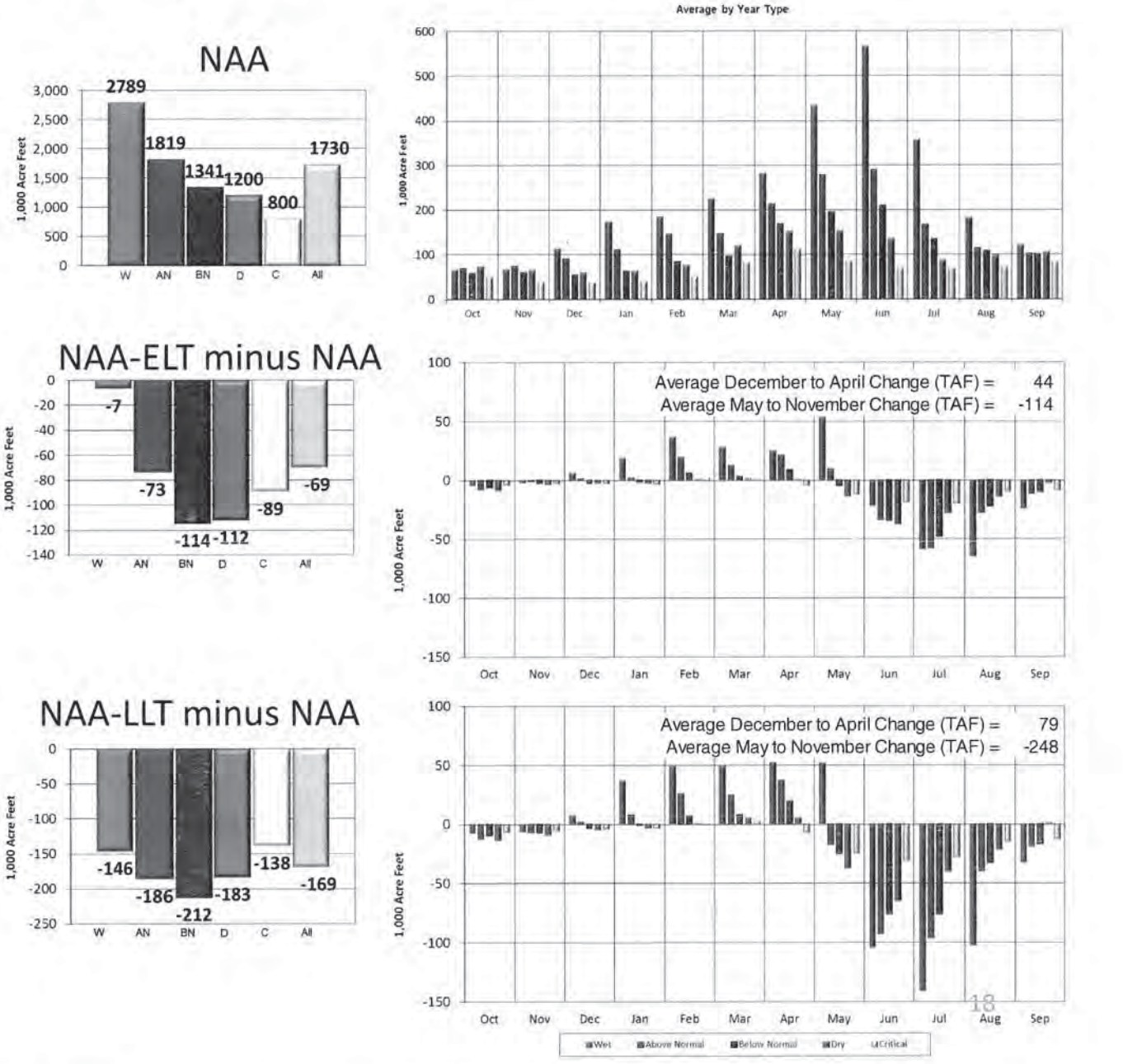
	Year Type	NAA_ELT minus NAA	NAA_LLT minus NAA
Folsom	W	-42	-115
	AN	-54	-128
	BN	-58	-136
	D	-43	-112
	C	-43	-68
	All	-47	-113



Inflow and Carryover Storage in the San Joaquin River Basin

San Joaquin Valley reservoirs are depicted with an overall decrease in annual runoff with some shifting of runoff from spring to winter, but mostly just decreases in spring runoff due to a decline in snowmelt runoff during late spring[5]. Figure 3 illustrates the assumed effects of climate change upon inflow to Millerton Lake.

Figure 3. Projected Inflow to Millerton Lake –NAA, NAA-ELT and NAA-LLT



The hydrology differences imposed in the NAA Scenarios of the Friant Division are described above, and its appropriateness may be subject to additional debate and Alternative assumptions. However, our review found that implementation of Millerton Reservoir inflow as affected by climate change was improperly performed.

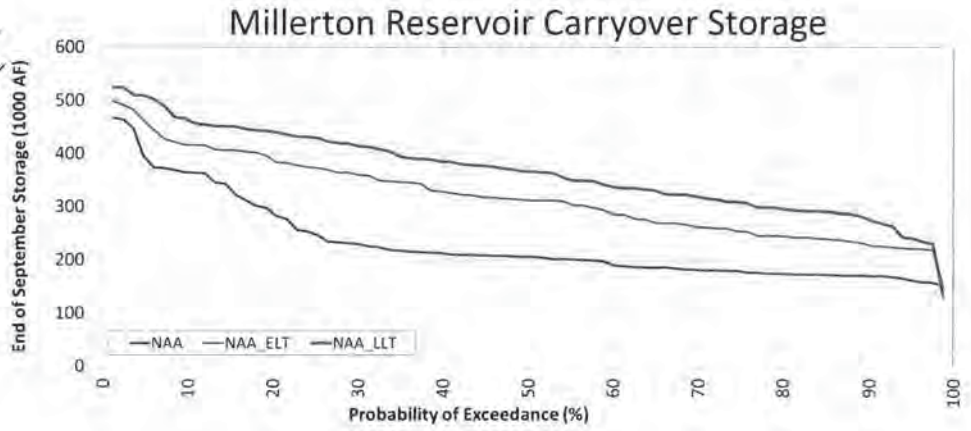
[5] BDCP Appendix 5A.2

Inflow to Millerton Reservoir in this version of CalSim is input in three separate time series for purposes of depicting the hydrology of potential upper basin reservoirs. Climate change hydrology was inconsistently incorporated at Millerton Reservoir and misapplied to the water supply and flood control operations. The result is an unrealistic operation for river releases and canal diversions. Figure 3 illustrates the projected ELT and LLT changes in Millerton Reservoir inflow incorporated in these studies. On face value of the input data, regardless of Friant Dam river release assumptions the effect of climate change at Millerton Lake will affect water deliveries.

Evidence of the inconsistent inflow problem is shown in the result for the comparison of carryover storage of Millerton Reservoir under the NAA, NAA-ELT, and NAA-LLT Scenarios (Figure 4). Carryover storage is higher in the ELT and LLT Scenarios due to climate change effects to inflow incorporated in reservoir operations but not in the computation of water supply deliveries. Thus, water deliveries are suppressed and the reservoir ends the year with greater storage.

Figure 4. Millerton Reservoir Carryover Storage, NAA, NAA-ELT and NAA-LLT Scenarios

	Year Type	NAA_ELT minus NAA	NAA_LLT minus NAA
Millerton	W	56	103
	AN	82	137
	BN	99	161
	D	87	131
	C	131	166
	All	87	136



CVP Water Service Contractor's water allocations are based on available CVP supplies, Figure 5 contains exceedance probability plots of deliveries and allocation percentages to these contractors. Table 2 contains average annual allocation to these CVP Water Service Contractors. Water supplies to these contractors decrease in the ELT and LLT relative to NAA Conditions.

Table 2. CVP Water Service Contractor Allocation Summary

	NAA	NAA-ELT	NAA-LLT
North of Delta Agricultural Service Contractors	61%	53%	46%
South of Delta Agricultural Service Contractors	48%	44%	39%
North of Delta M&I Contractors	85%	81%	77%
South of Delta M&I Contractors	79%	77%	74%

CVP Sacramento River Settlement, San Joaquin River Exchange, and Refuge deliveries are based on Shasta Criteria and are 100% in most years and 75% in "Shasta critical" years[6]. Figure 6 contains exceedance probability charts for annual water deliveries to CVP contractors whose allocations are based on Shasta Criteria. In the NAA-ELT and NAA-LLT modeling scenarios, the Sacramento River Settlement and Refuge deliveries are reduced due to water shortages that occur more often under the climate change assumptions.

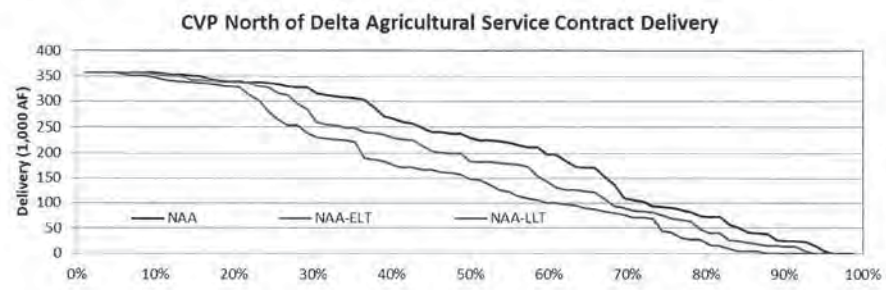
SWP Water Supply

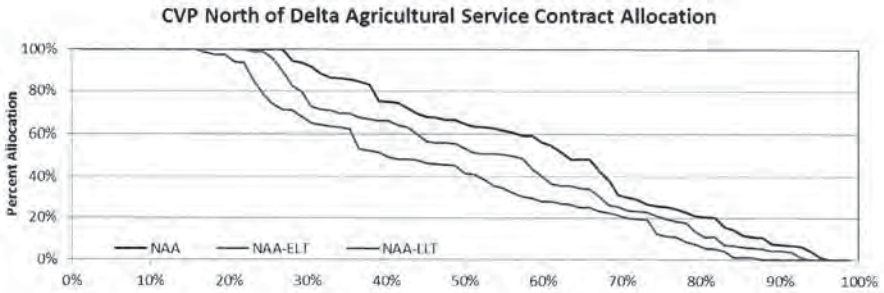
Corresponding with the CVP operation is the projected operation of the SWP under No Action Conditions. These illustrations are shown to provide a comparison to SWP storage and exports, particularly during drought. A comparison of SWP exports to CVP SOD deliveries shows that each project exports about the same amount of water during drought.

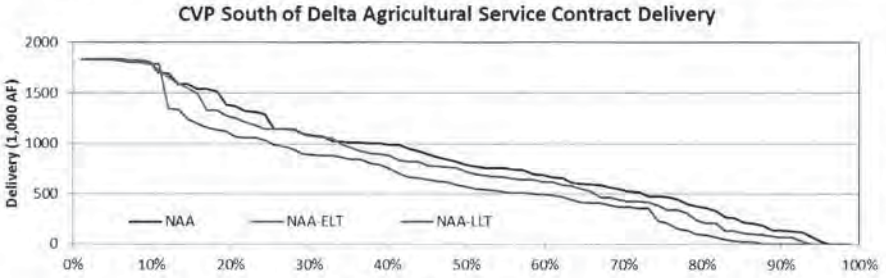
Average annual SWP Table A water supply allocations are 62% for NAA, 61% for NAA-ELT, and 57% for NAA-LLT. Figure 7 contains an exceedance probability plot summary of SWP deliveries. SWP North of Delta deliveries to the Feather River Service Area in both the ELT and LLT are less than NAA during about 10% of the time.

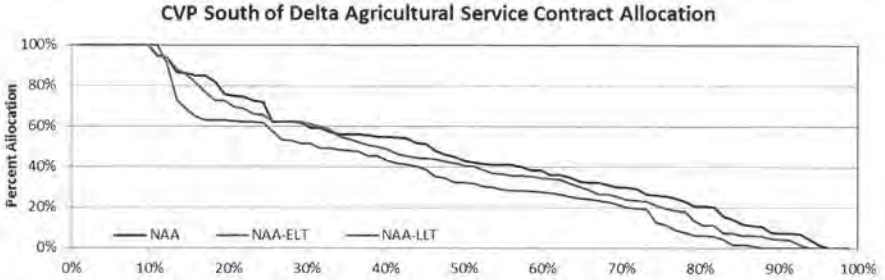
[6] A "Shasta critical" year is determined when the forecasted full natural inflow into Shasta Lake is equal to or less than 3.2 million acre-feet.

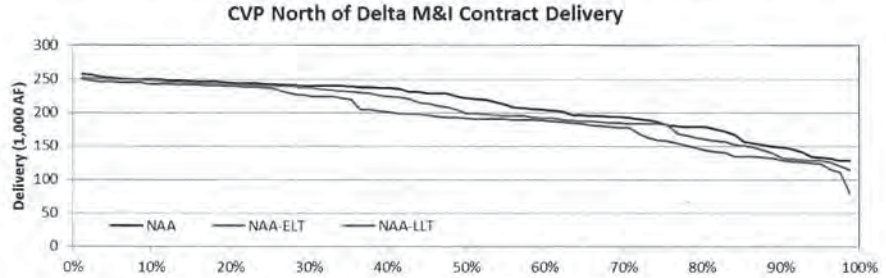
Figure 5. CVP Water Service Contractor Delivery Summary

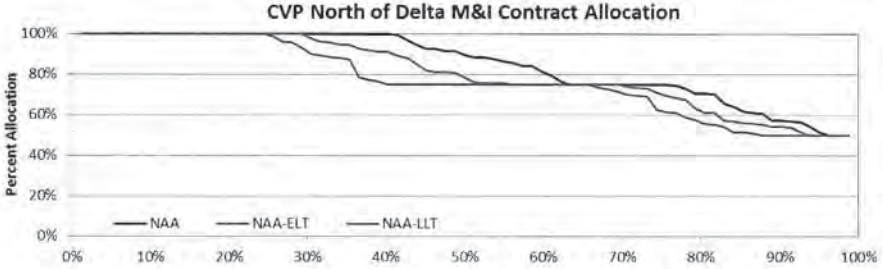


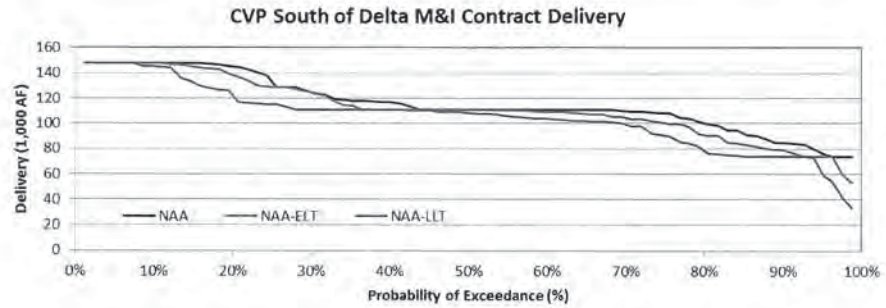


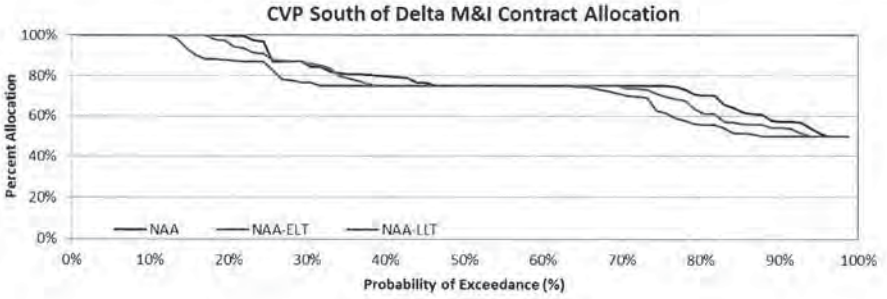






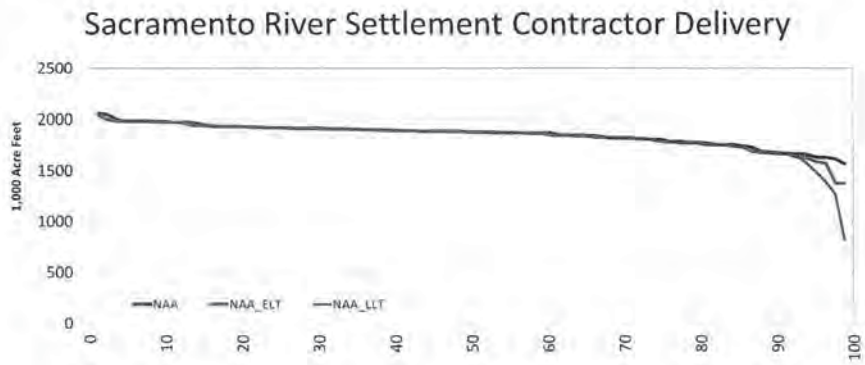


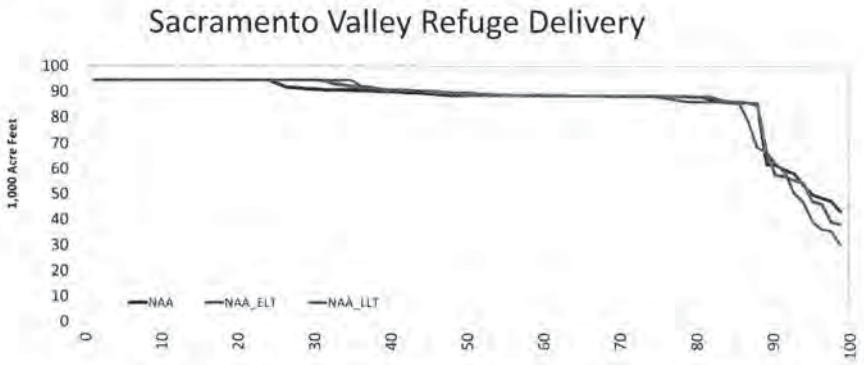


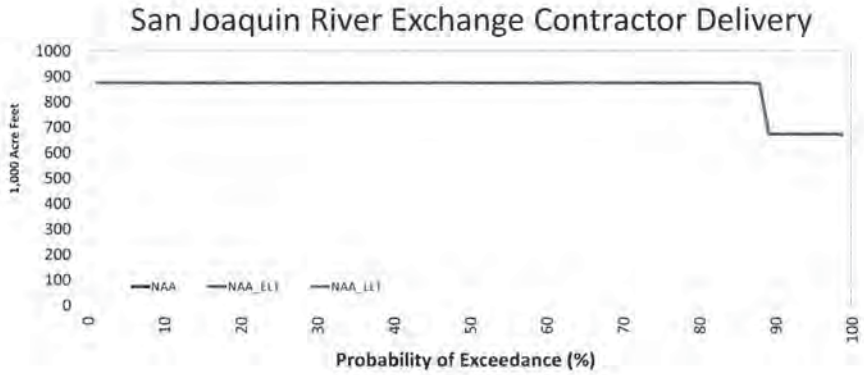


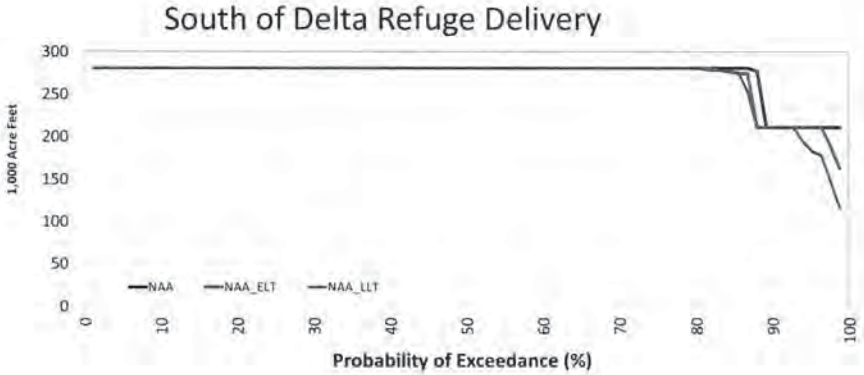
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Figure 6. CVP Contractor Delivery Summary for Contractors with Shasta Criteria Allocations



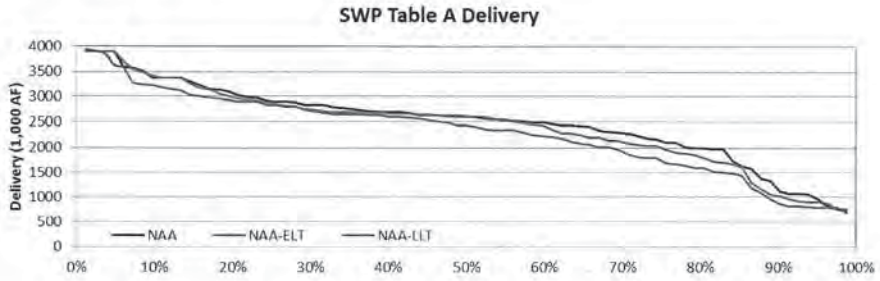


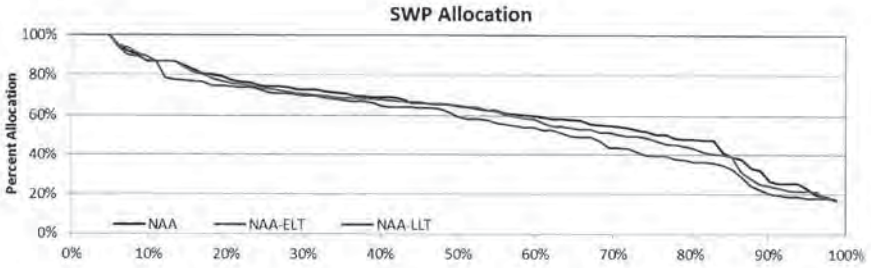


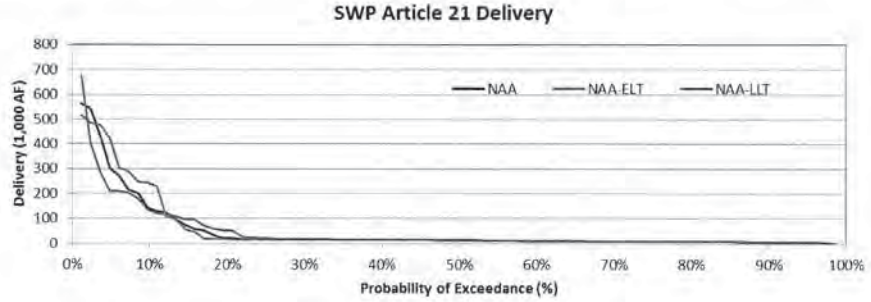


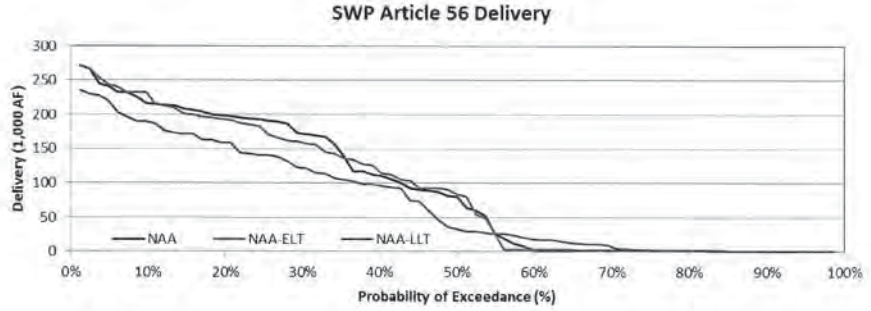
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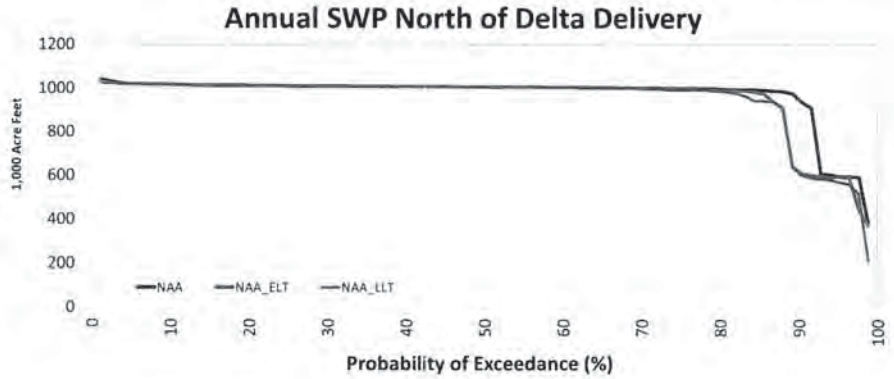
Figure 7. SWP Delta Delivery Summary











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CVP/SWP Exports

Exports of the CVP and SWP have been projected to change due to a combination of climate change effects on water availability (primary effect), flow requirements for salinity control (sea level rise), additional in-basin water demands, and to a small extent greater export potential (DMC-CA intertie). Figure 8 illustrates the simulation of CVP exports and combined CVP/SWP exports under NAA, NAA-ELT, and NAA-LLT Scenarios. Under NAA average annual CVP exports are about 2.24 MAF (2.18 at Jones PP) and are about 100 TAF less in the NAA-ELT Scenario and 230 TAF less in the NAA-LLT. Annual average SWP exports are about 2.61 MAF in the NAA and are 68 TAF less in the NAA-ELT and 212 TAF less in the NAA-LLT. Annual average combined CVP/SWP exports are about 4.9 MAF in the NAA modeling (Figure 9) and about 170 TAF and 460 TAF less in the NAA-ELT and NAA-LLT respectively.

Figure 8. CVP Exports at Jones PP, NAA, NAA-ELT and NAA-LLT

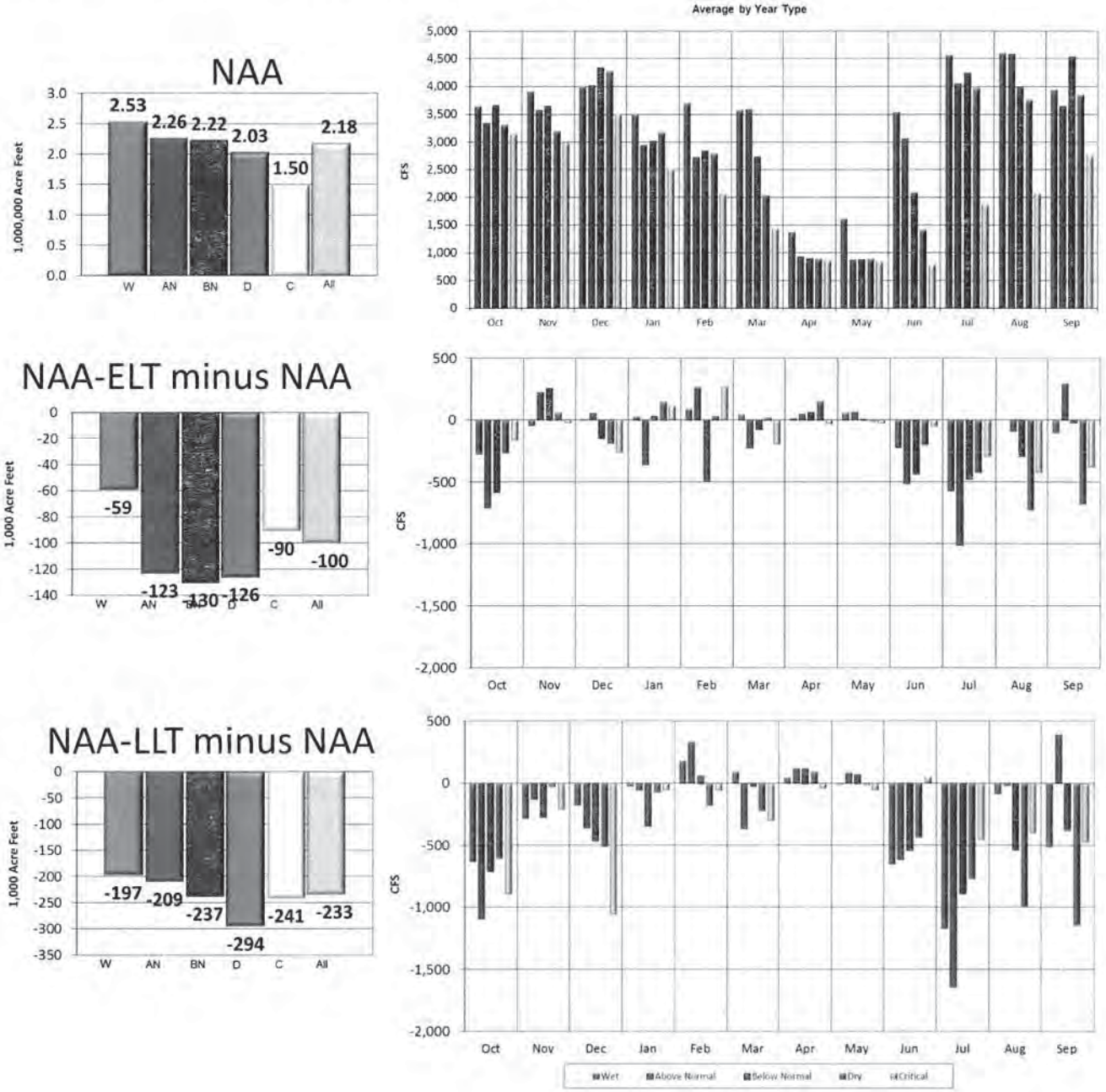
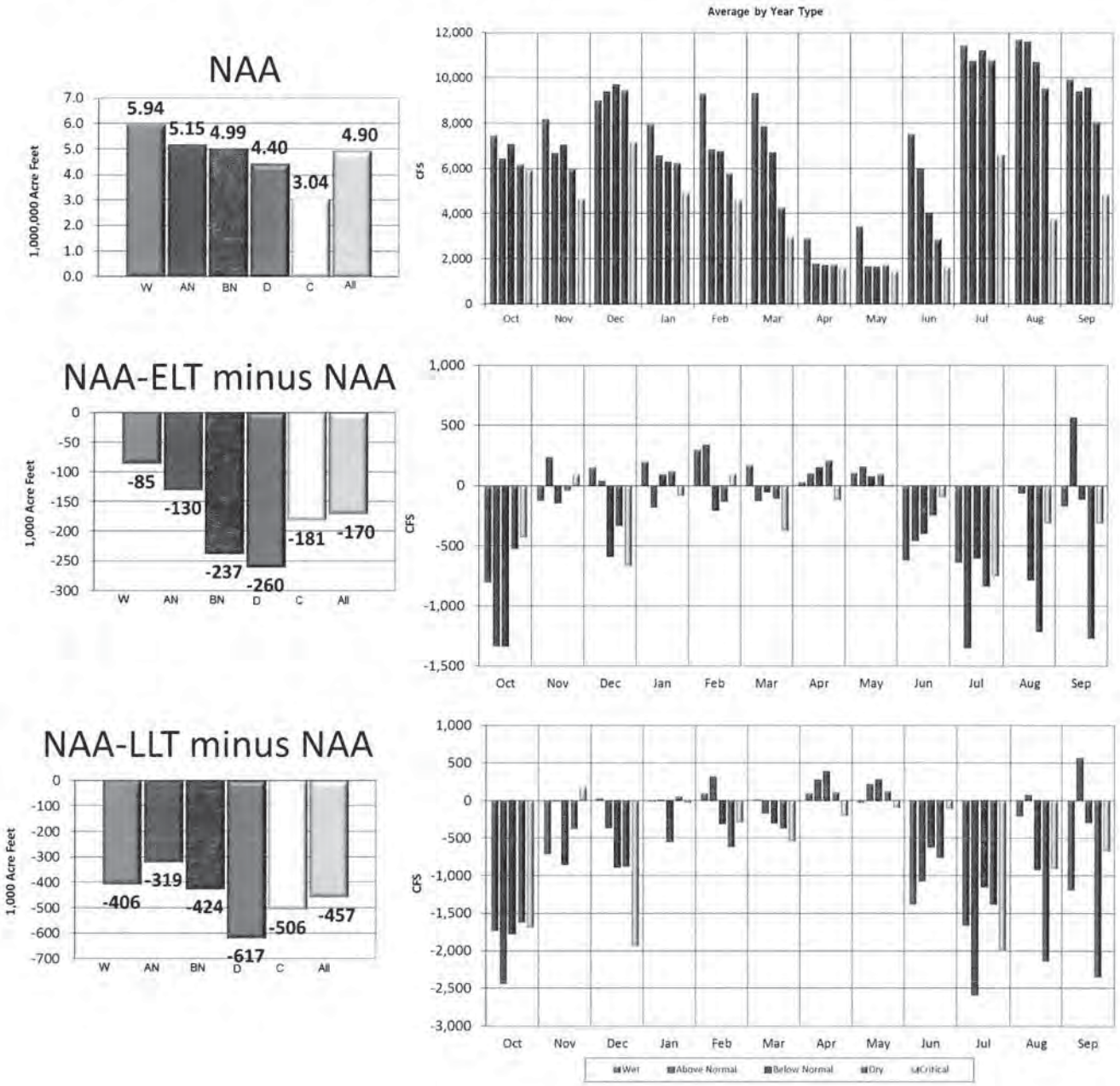


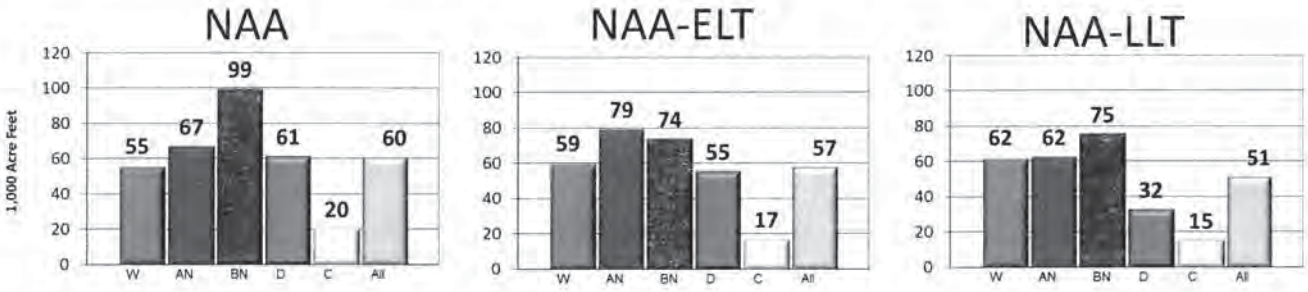
Figure 9. Total CVP/SWP Exports, NAA, NAA-ELT and NAA-LLT



Joint Point of Diversion

The NAA Alternatives do not make use of Joint Point of Diversion (JPOD), however CVP water is pumped at Banks to satisfy the Cross Valley Canal (CVC) contracts. **Figure** 10 shows annual Banks wheeling for CVC for the NAA, NAA-ELT and NAA-LLT.

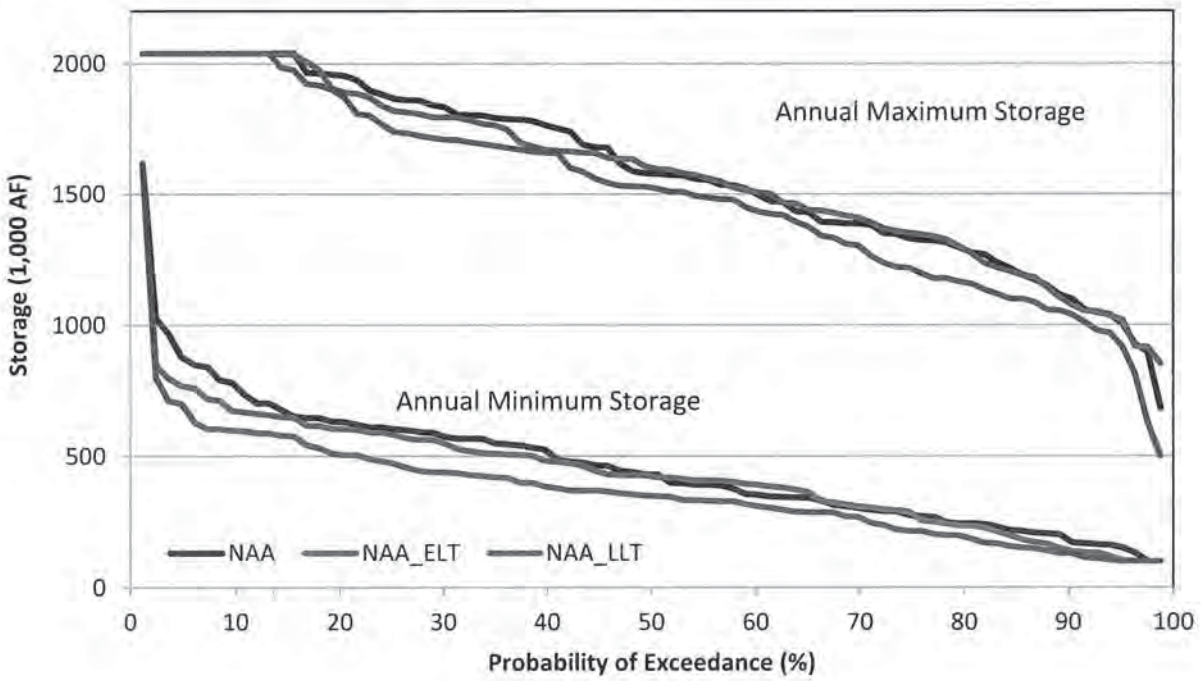
Figure 10. Cross Valley Canal Wheeling at Banks



San Luis Reservoir Operations

Modeling protocols will use San Luis Reservoir to store water when available and provide supply as exports are constrained by hydrology or regulatory constraints. Figure 11 illustrates the projected operation of San Luis Reservoir under the NAA, NAA-ELT, and NAA-LLT Scenarios. The annual maximum storage shows that the ability to fill San Luis Reservoir is somewhat similar for NAA and NAA-ELT but with less ability to fill in the NAA-LLT. The frequency of a low annual low point of San Luis Reservoir is exacerbated in the NAA-LLT Scenario. In all the Scenarios, San Luis Reservoir is heavily exercised. As currently projected, San Luis Reservoir will only fill as the result of very favorable hydrologic conditions including the availability of spill water from Friant or the Kings River system that offsets DMC water demands at the Mendota Pool.

Figure 11. San Luis Reservoir Storage – NAA, NAA-ELT and NAA-LLT



Sacramento River Temperature

CalSim II results, along with meteorological data, are used in temperature models that simulate reservoir temperature and river temperature. The BDCP modeling provided by DWR for review included the Sacramento

River temperature model and results for the No Action and Alternatives. Each BDCP Alternative used temperature target criteria for the upper Sacramento River as is used for the Existing Conditions modeling scenario. Equilibrium temperatures, a calculated model input that approximately depicts the effective air temperature for interaction with water temperature in the model, between Shasta and Gerber are increased by an annual average of 1.6°F for the ELT Scenarios and by 3.3°F for LLT Scenarios. Figure 12 contains monthly exceedance probability charts of temperature at Bend Bridge in the Sacramento River for April through October for the Existing Conditions and NAA-ELT Scenarios. There is about a 1 degree increase in average monthly temperature for the April through October period. Figure 13 contains similar information as Figure 12, but compares modeling results for the NAA-LLT and Existing Conditions Scenarios, there is often a 2°F increase in the NAA-LLT relative to Existing Conditions.

The increase in equilibrium temperatures combined with decreases in storage would lead to water temperature conditions that would likely not achieve the assumed objectives. Figure 12 and Figure 13 illustrate an increase in the probability that a water temperature target of 56°F would be exceeded at Bend Bridge under both the NAA-ELT and NAA-LLT Scenarios. The probability of exceedance increases approximately 5% to 20% depending on the month for the NAA-ELT Scenario and approximately 10% to 40% for the NAA-LLT Scenario.

Figure 12. Temperature Exceedance Sacramento River at Bend Bridge Existing, No Action Alternative, ELT

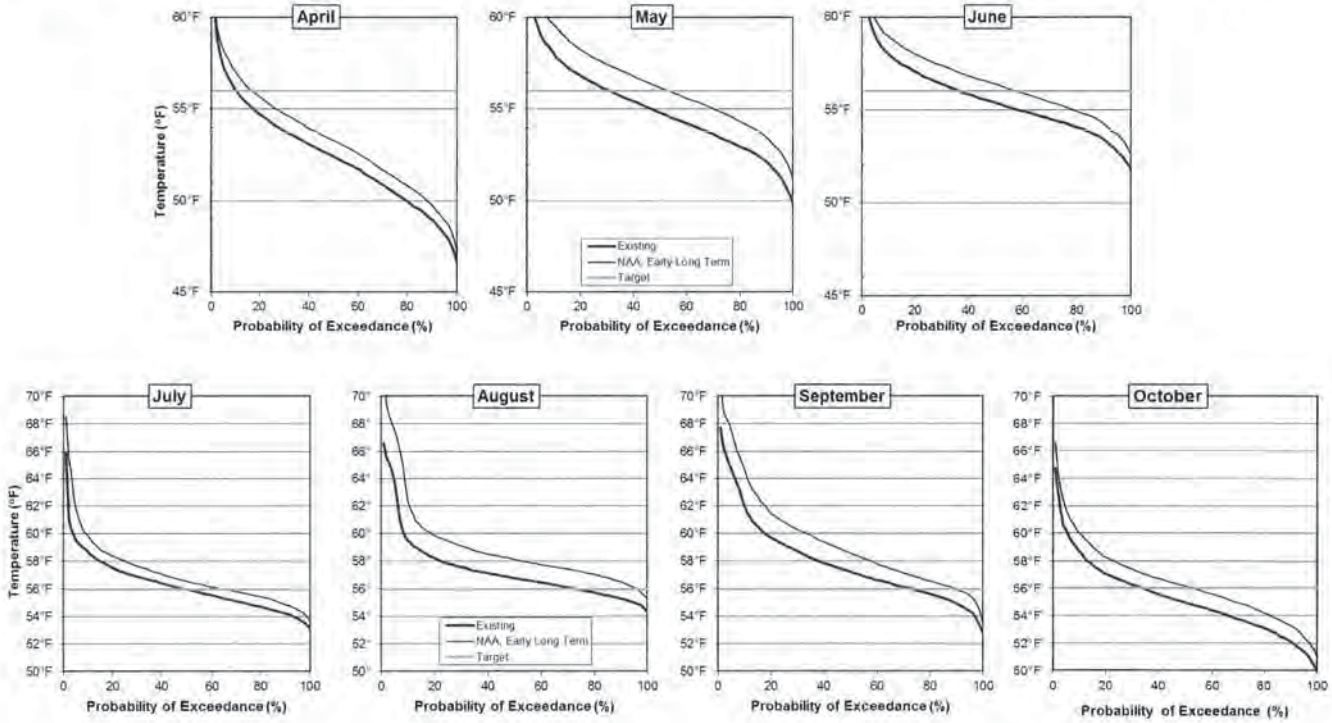
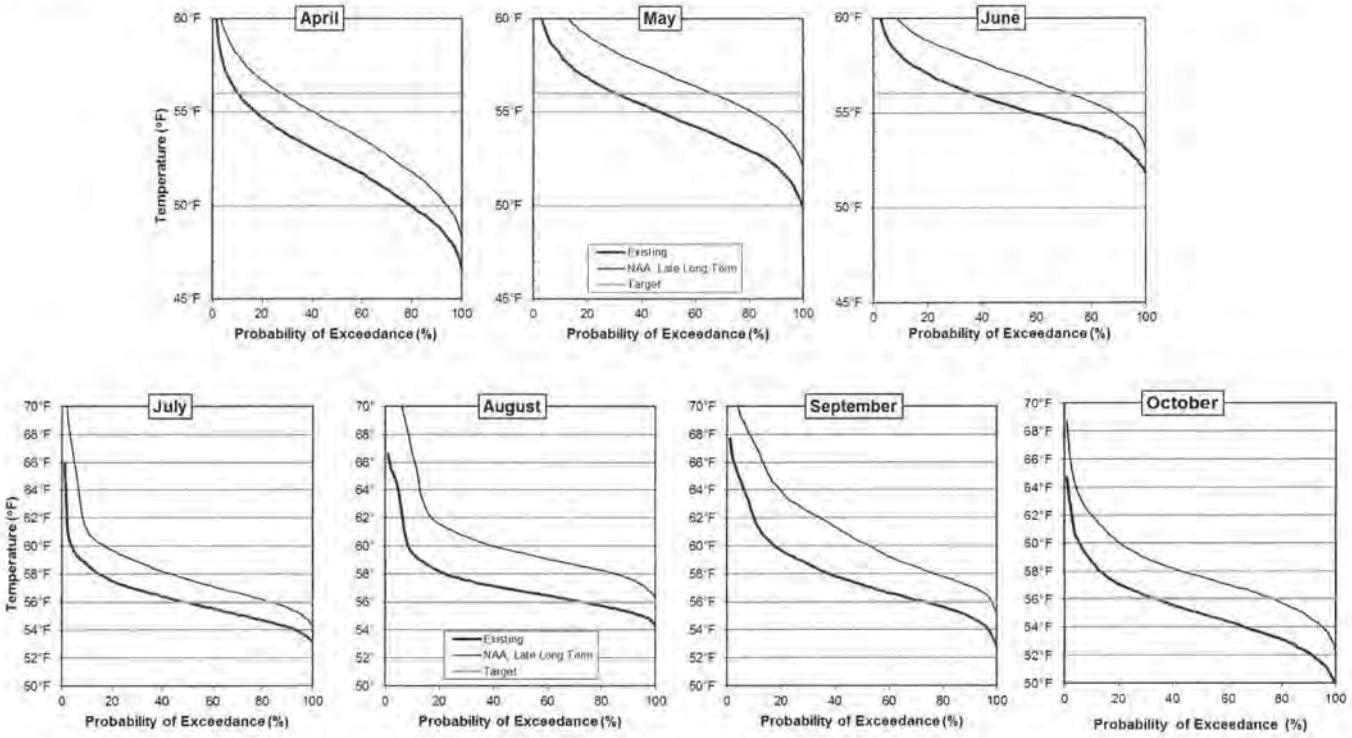


Figure 13. Temperature Exceedance Sacramento River at Bend Bridge Existing, No Action Alternative, LLT



Conclusions regarding Climate Change Assumptions and Implementation

In examining the possible effects of climate change, it is not appropriate to assume that current project operations will remain static and not respond to climate change. The BDCP's simplistic approach of assuming a linear operation of the CVP and SWP produces results that are not useful for dealing with the complex problem of climate change because it does not reflect the way in which the CVP and the SWP would actually operate whether or not the BDCP is implemented. Reviewers recommend a sensitivity analysis be conducted to develop a better understanding of the range of possible responses to climate change by the CVP and SWP, and the regulatory structures that dictate certain project operations.

Including climate change, without adaptation measures, results in insufficient water needed to meet all regulatory objectives and user demands. For example, the BDCP Model results that include climate change indicate that during droughts, water in reservoirs is reduced to the minimum capacity possible. Reservoirs have not been operated like this in the past during extreme droughts and the current drought also provides evidence that adaptation measures are called for long in advanced to avoid draining the reservoirs. In this aspect, the BDCP Model simply does not reflect a real future condition. Foreseeable adaptations that the CVP and SWP could make in response to climate change include: (1) updating operational rules regarding water releases for flood protection; (2) during severe droughts, emergency drought declarations could call for mandatory conservation; and (3) if droughts become more frequent, the CVP and SWP would likely revisit the rules by which they allocate water during shortages and operate more conservatively in wetter years. The modifications to CVP and SWP operations made during the winter and spring of 2014 in response to the drought supports the likelihood of future adaptations. The BDCP Model is, however, useful in that it reveals that difficult decisions must be made in response to climate change. But, in the absence of making those decisions, the BDCP Model results themselves are not informative, particularly during drought conditions. With future conditions projected to be so dire without the BDCP, the effects of the BDCP appear positive simply because it appears that conditions cannot get any worse (i.e., storage cannot be reduced below its minimum level). However, in reality, the future condition will

not be as depicted in the BDCP Model. The Reviewers recommend that Reclamation and DWR develop more realistic operating rules for the hydrologic conditions expected over the next half-century and incorporate those operating rules into the any CalSim II Model that includes climate change.

2.2 BDCP Operation

The next step of our analysis centered on reviewing BDCP modeling of the with project scenarios as described in the December 2013 Draft BDCP and described as Alternative 4 in the Draft EISR.

Description of the BDCP Project

At the time of review, this Alternative was coined Alt 4 and represented a dual conveyance facility. The two DWR analyses reviewed were identified as:

- Alt 4 (dual conveyance) – ELT
  The same system demands and facilities as described in the NAA-ELT with the following primary changes: three proposed North Delta Diversion (NDD) intakes of 3,000 cfs each; NDD bypass flow requirements; additional positive OMR flow requirements and elimination of the San Joaquin River I/E ratio and the export restrictions during VAMP; modification to the Freemont Weir to allow additional seasonal inundation and fish passage; modified Delta outflow requirements in the spring and/or fall (defined in the Decision Tree discussed below); movement of the Emmaton salinity standard; redefinition of the EI ratio; and removal of current permit limitations for the south Delta export facilities. Set within the ELT environment.
- Alt 4 (dual conveyance) – LLT
  The same as the previous Scenario except established in the LLT environment.

The BDCP contemplates a dual conveyance system that would move water through the Delta's interior or around the Delta through an isolated conveyance facility. The BDCP CalSim II files contained a set of studies evaluating the projected operation of a specific version of such a facility. The Alternative was imposed on two baselines: the NAA-ELT scenario and the NAA-LLT scenario.

The changes (benefits or impacts) of the operation due to Alt 4 are highly dependent upon the assumed operation of not only the BDCP facilities and the changed regulatory requirements associated with those facilities, but also by the assumed integrated operation of the CVP and SWP facilities. The modeling of the NAA Scenarios introduced a significant change in operating protocols suggested primarily for reaction to climate change. We consider the extent of the reaction not necessarily representing a likely outcome, and thus have little confidence that the NAA baselines are a "best" (or even valid) representation of a baseline from which to compare an action Alternative. However, a comparison review of the Alternative to the NAA baselines illuminates operational issues in the BDCP modeling and provides insight as to where benefits or impacts may occur as additional studies are provided.

Since the effects of climate changes are more severe in the LLT than in the ELT, this review focuses on the ELT modeling because the results are less skewed by the climate change assumptions and problems.

BDCP's Alternative 4 has four possible sets of operational criteria, termed the Decision Tree, that differ based on the "X2" standards[7] that they contemplate:

- Low Outflow Scenario (LOS), otherwise known as operational scenario H1, assumes existing spring X2 standard and the removal of the existing fall X2 standard;

[7] X2 is a salinity standard that requires outflows sufficient to attain a certain level of salinity at designated locations in the Delta at certain times of year.

- High Outflow Scenario (HOS), otherwise known as H4, contemplates the existing fall X2 standard and providing additional outflow during the spring;
- Evaluated Starting Operations (ESO), otherwise known as H3, assumes continuation of the existing X2 spring and fall standards;
- Enhanced spring outflow only (not evaluated in the December 2013 Draft BDCP), scenario H2, assumes additional spring outflow and no fall X2 standards.

While it is not entirely clear how the Decision Tree would work in practice, the general concept is that the prior to operation of the new facility, implementing authorities would select the appropriate Scenario (from amongst the four choices) based on their evaluation of targeted research and studies to be conducted during planning and construction of the facility.

For our analysis, we reviewed the HOS (or H4) scenario because the BDCP[8] indicates that the initial permit will include HOS operations that may be later modified at the conclusion of the targeted research studies. The HOS includes the existing fall X2 requirements but adds additional outflow requirements in the spring. We reviewed the model code and discussed the operations with DWR and Reclamation, who acknowledged that although the SWP was bearing the majority of the responsibility for meeting the additional spring outflow in the modeling, the responsibility would need to be shared with the CVP[9]. In subsequent discussions, DWR and Reclamation have suggested that the additional water may be purchased from other water users. However, the actual source of water for the additional outflow has not been defined. Since the BDCP modeling assumes that SWP bears the majority of the responsibility for meeting the additional outflow, yet this is not how the project will be operated in reality, our review of the BDCP modeling results for HOS is limited to the evaluation of how the SWP reservoir releases on the Feather River translate into changes in Delta outflow and exports.

Our remaining analysis examines the ESO (or H3) scenario (labeled Alt 4-ELT or Alt 4-LLT in this section) because it employs the same X2 standards as are implemented in the No Action Alternatives NAA-ELT and NAA-LLT. This allows us to focus our analysis on the effects of the BDCP operations independent of the possible change in the X2 standard.

High Outflow Scenario (HOS or H4) Results

In Alt 4-ELT H4 Feather River flows during wetter years are increased more than 3,000 cfs in April and May and then decreased in most year types during July and August, while September flow is only decreased in wetter years. Figure 14 shows average monthly change in Feather River flow by water year type. Accompanying the changes in Feather River flow are changes in Oroville Reservoir storage levels, Figure 15 contains average monthly changes in Oroville storage. Alt4-ELT H4 end of June storage in Oroville during wetter years is about 480 TAF lower than the NAA-ELT while critical year storage is about 400 TAF higher. Counter to the reduction in Oroville storage, CVP average upstream carryover storage increases about 80 TAF and critical year increases by 380 TAF. Figure 16 contains average monthly changes in Delta outflow, increases in Feather River spring time flows are generally not used to increase Delta outflow, but are allowed to support increases in Delta exports.

Figure 17 displays changes in average monthly Delta exports, there are increases when diverting higher upstream spring releases in wetter years, while there are decreases during summer months in most years. Figure 18

[8] Draft BDCP, Chapter 3, Section 3.4.1.4.4
[9] August 7, 2013 meeting with DWR, Reclamation, and CH2M HILL

contains an average annual summary of project deliveries, total CVP deliveries increase by about 70 TAF while SWP deliveries decrease by about 100 TAF. Dryer year SWP deliveries decrease by 250 to 400 TAF, while wet year deliveries increase by 200 TAF. Total CVP deliveries increase in wetter years by exporting increased releases from Oroville.

The overall effect of the HOS appears to be increases in Oroville releases that support both CVP and SWP exports in wetter years, with modest increases in Delta outflow. There is also a decrease in SWP reliability through large delivery reductions in dryer years accompanied by Oroville storage increases. In addition to increases in dry and critical year storage in Oroville, total CVP dry and critical year carryover increases by 100 TAF and 380 TAF respectively with negligible reductions in wetter years types.

CVP and SWP obligation for providing flow to satisfy Delta outflow requirements is described in the Coordinated Operations Agreement (COA). Because the CVP and SWP share responsibility for meeting required Delta outflow based on specific sharing agreement, it doesn't seem reasonable that CVP water supplies would increase while SWP water supplies decrease under this Alternative. The manner in which this alternative is modeled is inconsistent with existing agreements and operating criteria. If the increases in outflow were met based on COA, there would likely be reductions in Shasta and Folsom storage that may cause adverse environmental impacts.

Figure 14. Changes in Feather River Flow, Alt 4 H4 ELT minus NAA-ELT

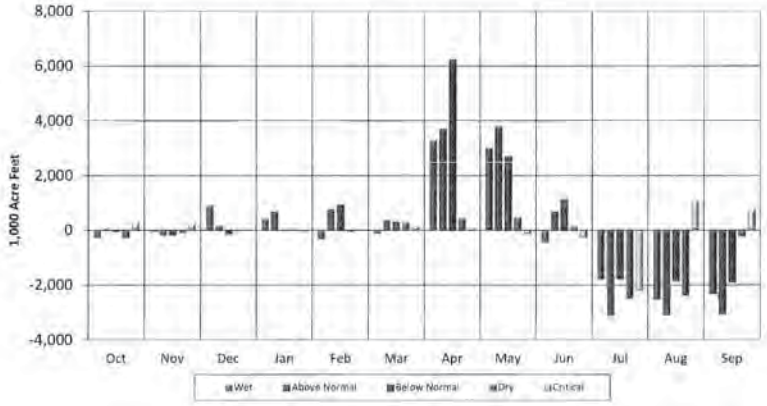


Figure 15. Changes in Oroville Storage, Alt 4 H4 ELT minus NAA-ELT

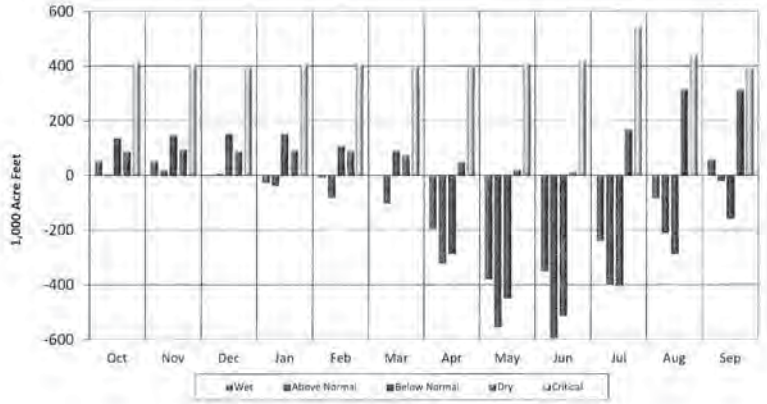


Figure 16. Changes in Delta Outflow, Alt 4 H4 ELT minus NAA-ELT

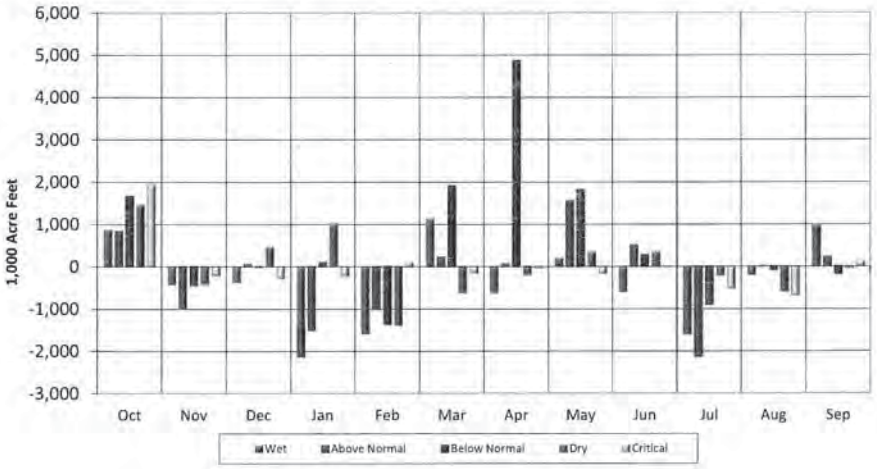


Figure 17. Changes in Delta Export, Alt 4 H4 ELT minus NAA-ELT

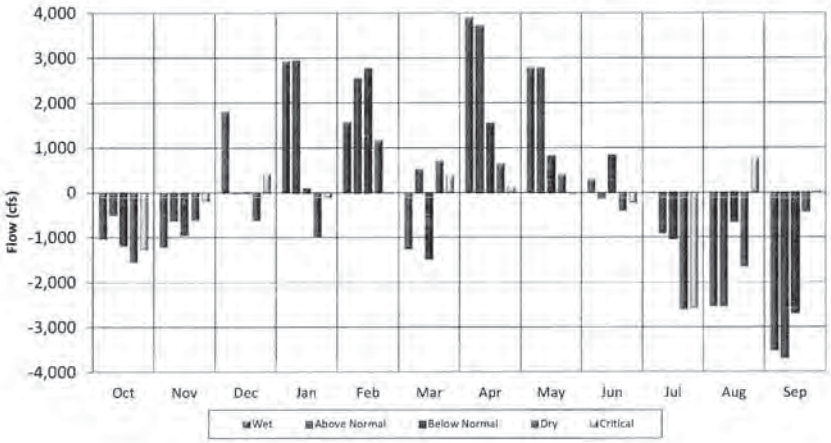
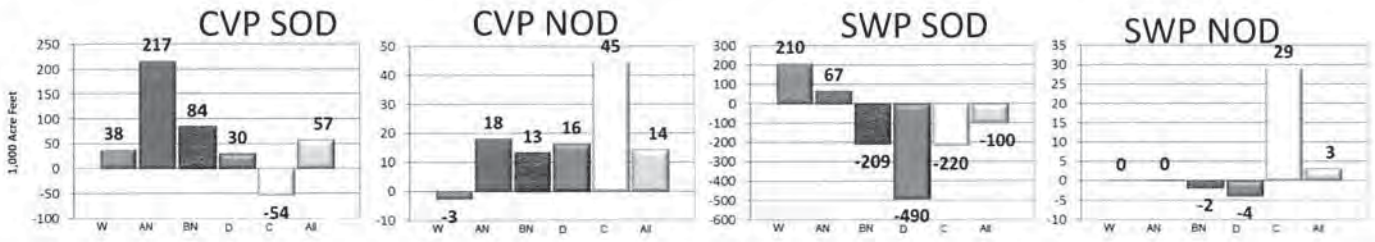


Figure 18. Changes in CVP and SWP Deliveries, Alt 4 H4 ELT minus NAA-ELT

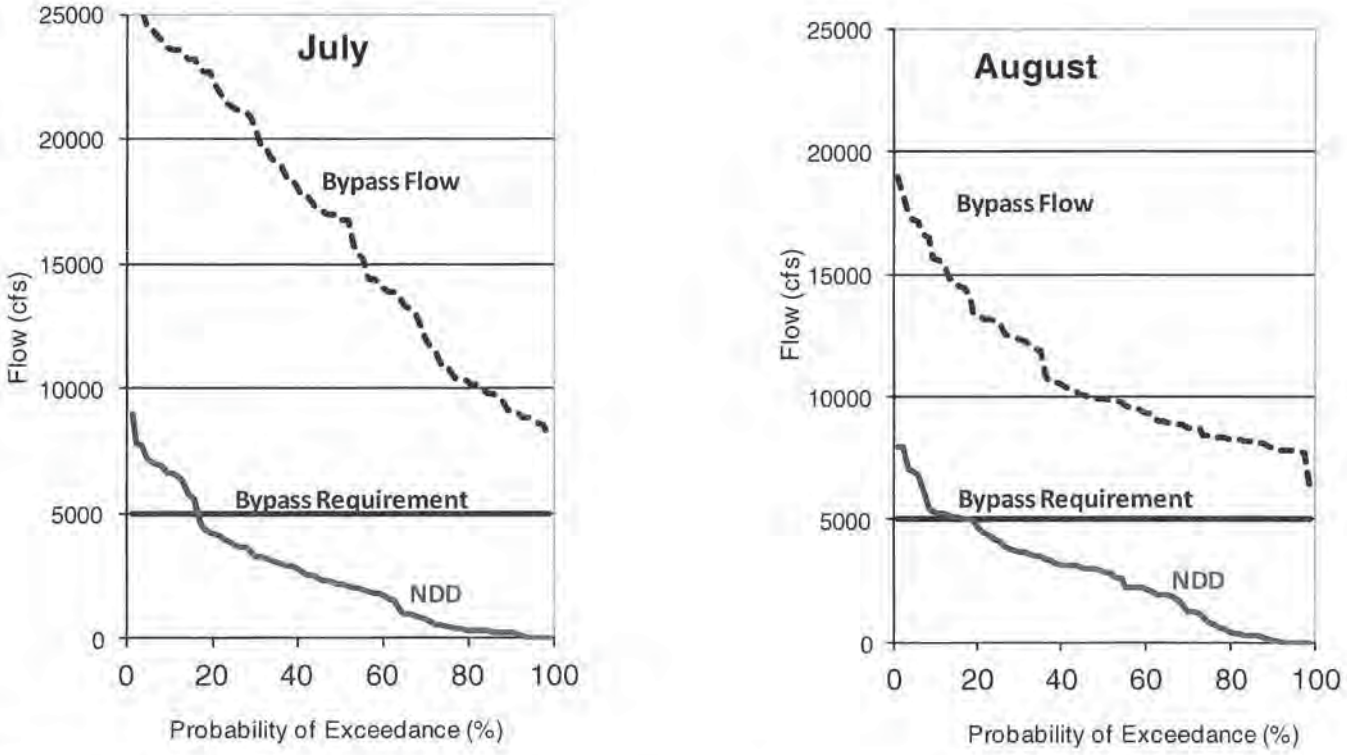


Evaluated Starting Operations (ESO or H3) Results

North Delta Diversion Intakes

Sacramento River flow below the North Delta Diversion (NDD) must be maintained above the specified bypass flow requirement, therefore the NDD rates are limited to the Sacramento River flow above the bypass requirement. Due to an error in CalSim II that specifies an unintended additional bypass requirement, modeling performed for the BDCP EIRS often bypasses more Sacramento River flow than is specified in the BDCP project description. This error has been fixed in the most recent public releases of CalSim II, but BDCP modeling has not been updated to reflect these fixes. Figure 19 contains exceedance probability plots showing the Sacramento River required bypass, Sacramento River bypass flow, NDD, and excess Sacramento River flow to the Delta as modeling for BDCP. As can be seen in Figure 19, the bypass flow is always above the bypass requirement in July and August. The BDCP version of CalSim sets a requirement for Sacramento River inflow to the Delta needed to satisfy all Delta flow, quality, and export requirements, this requirement should be removed when modeling the NDD.

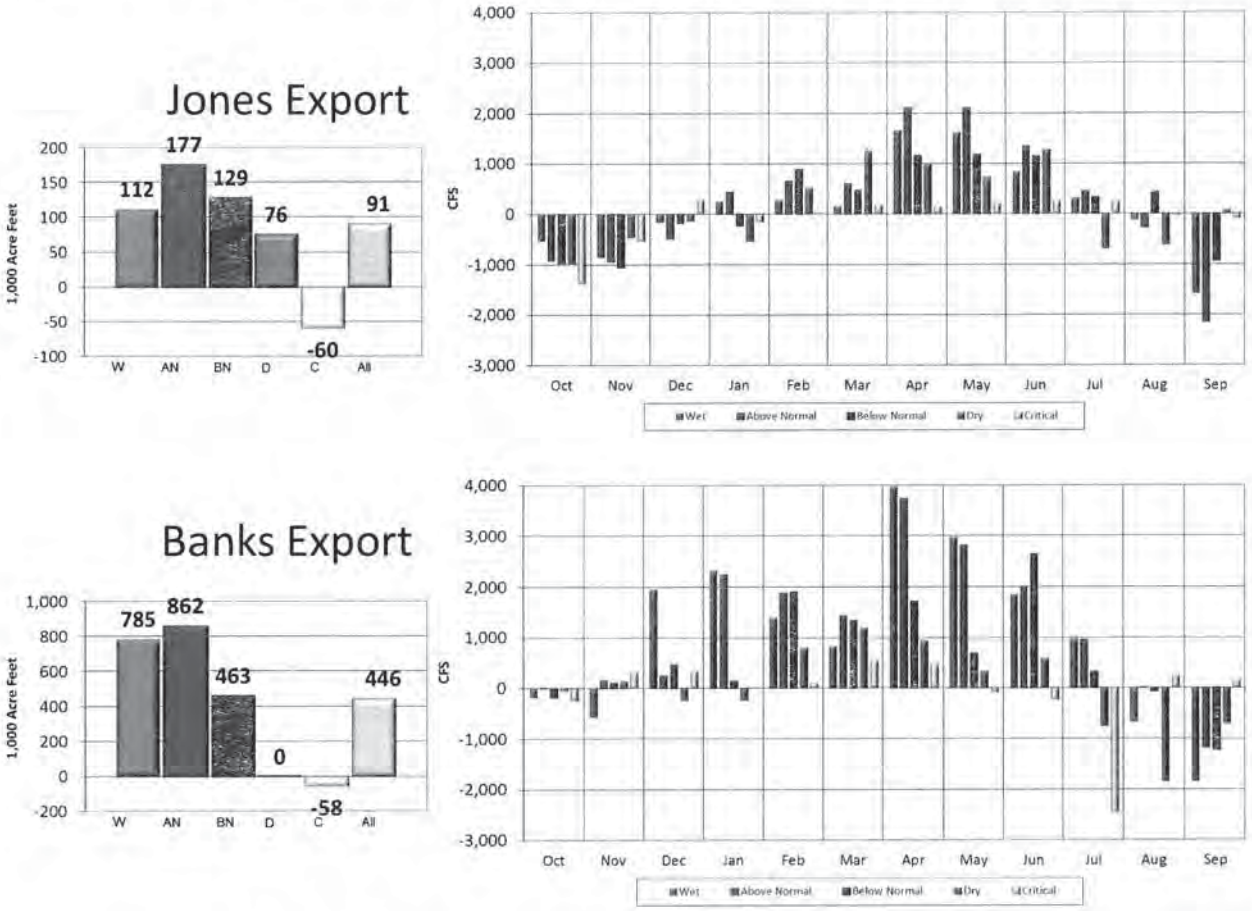
Figure 19. NDD, Bypass Requirement, Bypass Flow, and Excess Sacramento R. flow for Alt 4-ELT



CVP/SWP Exports

Overall the Alt 4 will increase exports compared to the NAA-ELT, with the majority of the increased exports realized by the SWP. Figure 20 illustrates a comparison between the NAA-ELT and Alt 4-ELT of CVP and SWP exports. On average, total combined exports under Alt 4–ELT are projected to increase by 537 TAF from 4.73 MAF to 5.26 MAF compared to the NAA-ELT.

Figure 20. Change in CVP (Jones) and SWP (Banks) Exports (Alt 4-ELT minus NAA-ELT)



With the addition of the North Delta Diversion facility, the water exported dramatically shifts from South Delta diversions to North Delta diversions. Figure 21 illustrates the change in routing of South of Delta exports under Alt 4 compared to the NAA-ELT. On average, export through the South Delta facility are projected to decrease by 2.1 MAF and the North Delta diversions will export 2.6 MAF which includes the 2.1 MAF shifted from the South Delta facility plus the additional 537 TAF of increased exports.

Figure 21. Change in Conveyance Source of Exports (Alt 4-ELT minus NAA-ELT)

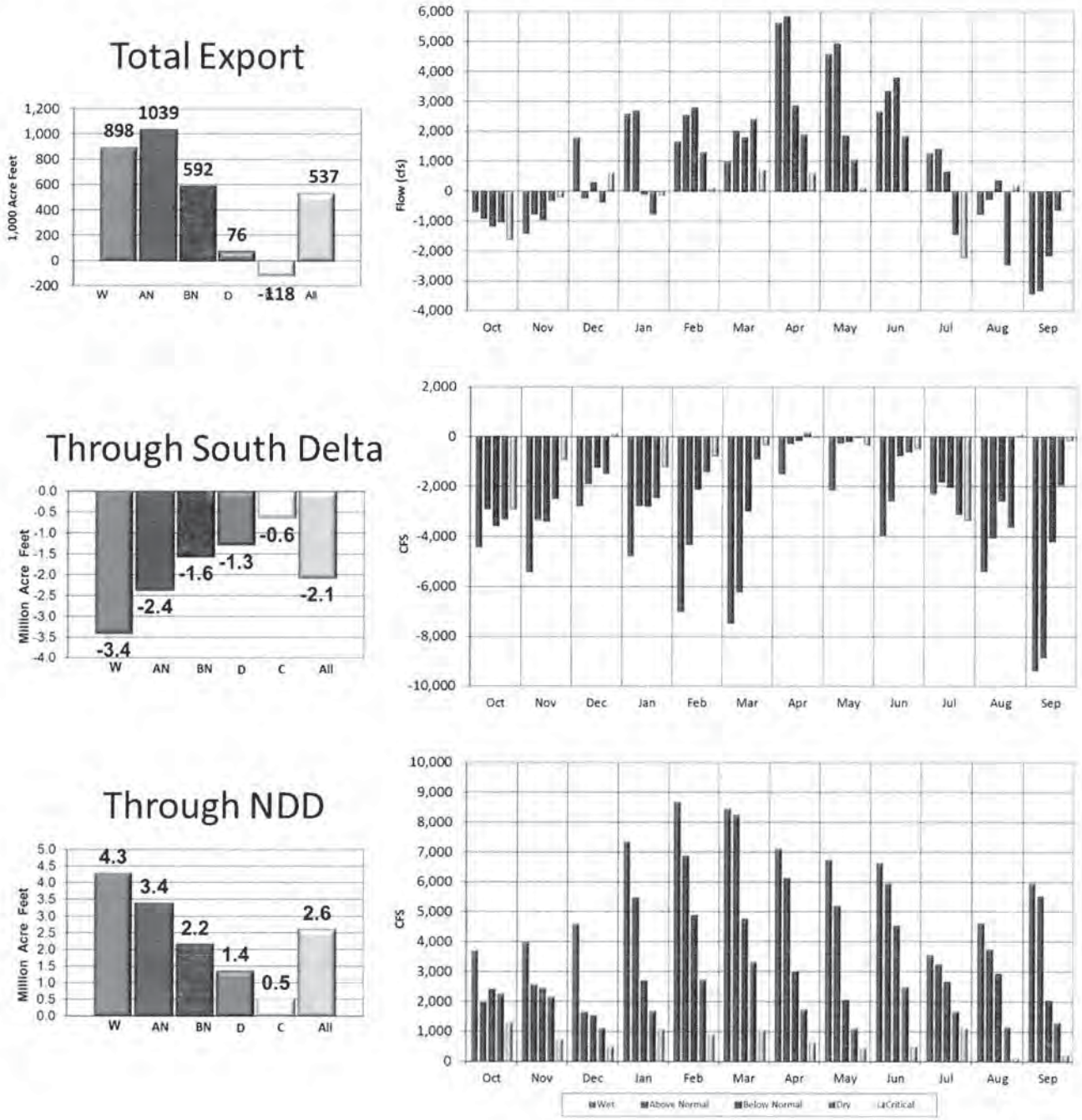
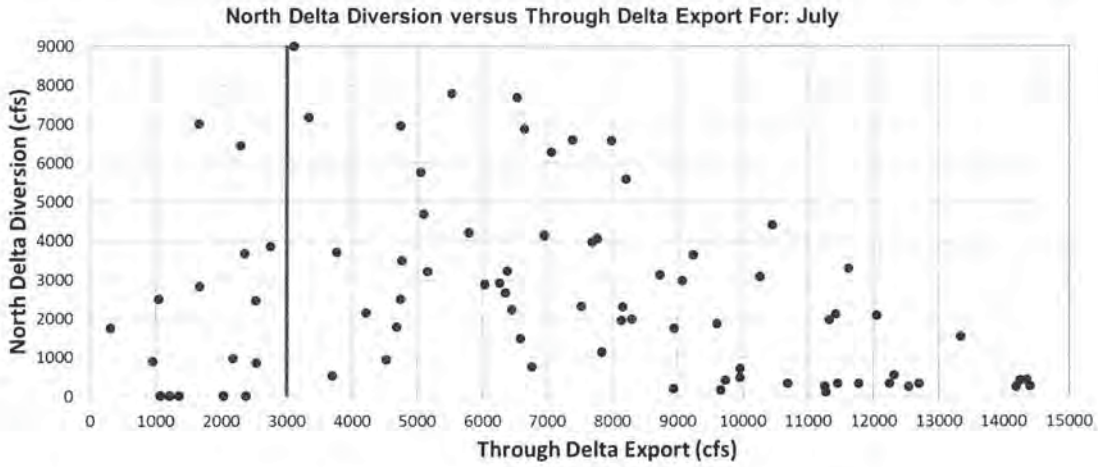
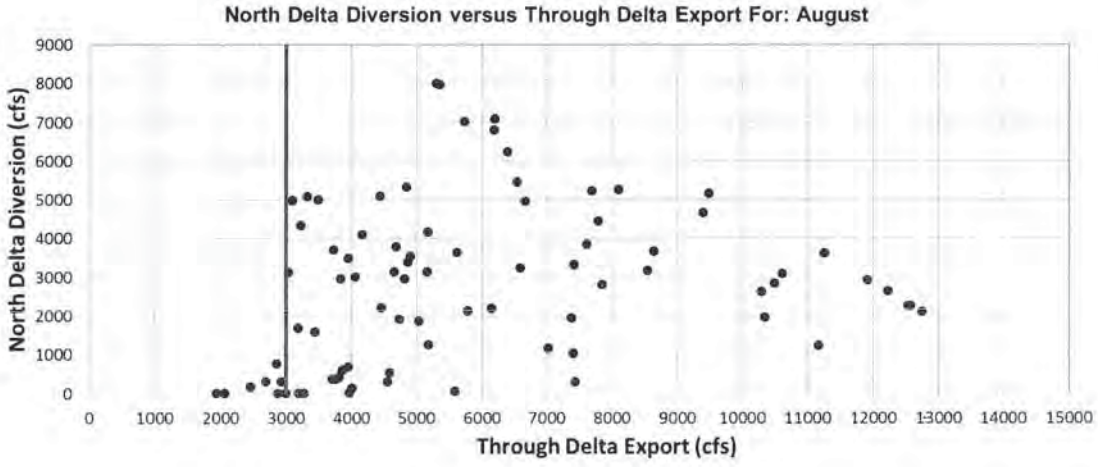
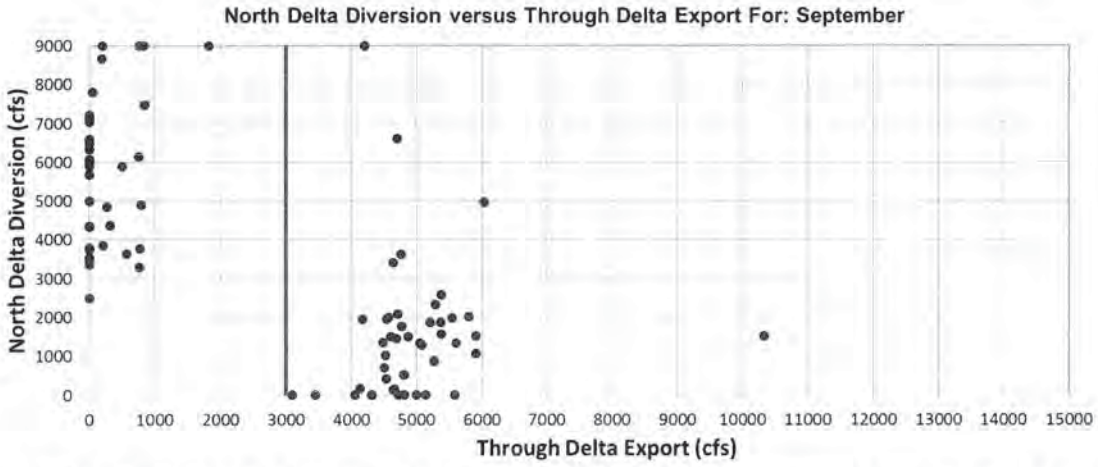


Figure 22 contains figures for July, August, and September for Alt 4-ELT that plot NDD against SDD. In the months of July to September SDD are occasionally very high, exceeding 14,000 cfs in July, with minimal NDD. This occurs due to outdated model code that imposes an instream flow requirement in Sacramento River flow below Hood in excess of the bypass criteria prescribed in the BDCP. There are numerous occurrences when bypass flows prescribed in the BDCP are exceeded and SDD are higher than expected. On the other hand, there are also many times when NDD are above minimum pumping levels and SDD are below the BDCP prescribed 3,000 cfs threshold indicated by the green line in Figure 22. For unknown reasons, the model code requiring SDD to be greater than 3,000 cfs before NDDs occur from July through September is deactivated in the BDCP modeling of this Alternative.

Figure 22. Alt 4-ELT North Delta Diversion Versus South Delta Diversion for July, August, and September

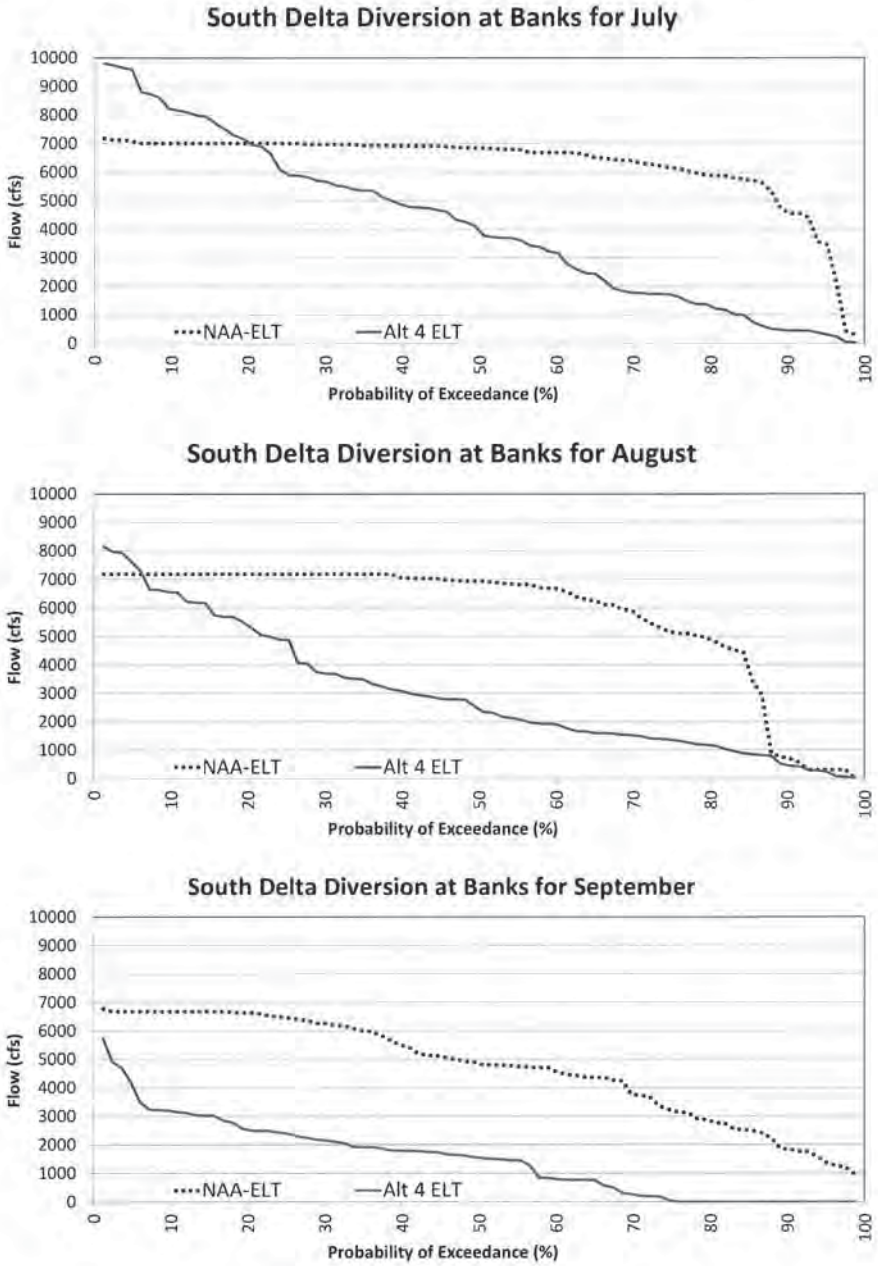






South Delta Diversion at Banks is not limited to existing permit capacity of 6,680 cfs and pumping may reach full capacity of 10,300 cfs in July, August, and September. Figure 23 contains exceedance probability charts of South Delta Diversion at Banks for July, August, and September. The chart for July shows SDD at Banks exceeding existing permit capacity 20% of years, in August this occurs in about 7% of years. There are South Delta diversions at Banks 25% of the time in September while diversions from the Sacramento River may range from 2,500 cfs to 7,500 cfs.

Figure 23. South Delta Diversion at Banks



Generally exports increase during winter and spring months due to the ability to avoid fishery concerns by diverting at the North Delta rather than South Delta.

Delta Outflow

Figure 24 illustrates a comparison of Delta outflow between the NAA-ELT and Alt 4-ELT. Decreases in Delta outflow are the result of the CVP and SWP ability to increase Delta exports in Alt 4-ELT. The apparent increase in Delta outflow in October is partially due to additional export restrictions though Old and Middle River flow requirements. However, the increase in October Delta outflow is also due to an unrealistic operation of the Delta Cross Channel. The additional export restrictions cause the flow standards imposed at Rio Vista to be the controlling point in CVP and SWP operations; the water quality standards are all being met and do not require

flows above the amount needed to satisfy the Rio Vista standard. Meeting the Rio Vista flow standards without closing the Delta Cross Channel gate results in releasing more water from upstream reservoirs than would otherwise be necessary. This occurs because a certain amount of the water released to meet the Rio Vista flow standards would flow into the Central Delta at location of the Delta Cross Channel gate. This water would not make it to Rio Vista and therefore would not be counted towards meeting the Rio Vista flow standards. However, due to the BDCP model's assumed restrictions on exports at this time, this water could not be pumped from the South Delta facilities and thus ends up as "extra" Delta outflow. By closing the Delta Cross Channel gate, the operators would assure that all of the water released to meet the Rio Vista flow standards would be counted towards those standards. The BDCP model's assumptions that the Delta Cross Channel gate would not be closed are not practical or a sensible operation as the operators confirmed they would close the gate during these conditions to avoid the unnecessary loss of water supplies (as was done in October and November 2013). The assumption in the BDCP model to maintain the gate in the open position causes it to overstate the amount of Delta outflow.

Figure 24. Delta Outflow Change (Alt 4-ELT minus NAA-ELT)



CVP/SWP Reservoir Carryover Storage

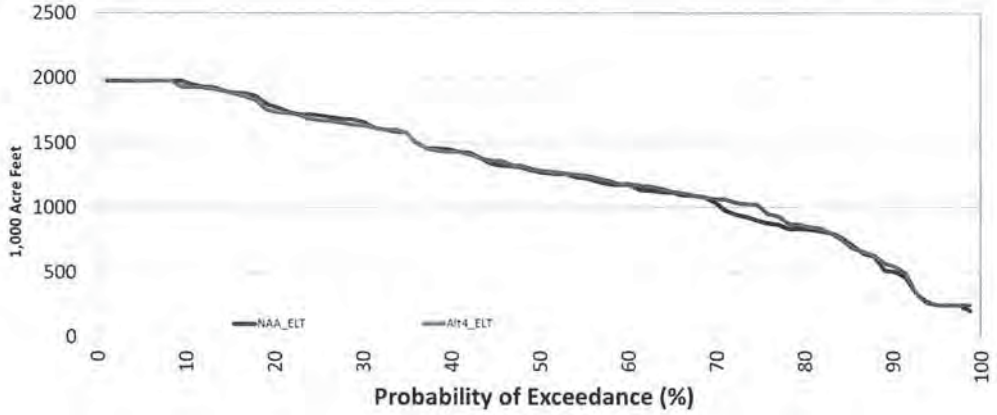
CVP/SWP reservoir operating criteria in the Alt4-ELT scenario differs from the NAA-ELT scenario. This difference is primarily driven by changes in both CVP and SWP San Luis Reservoir target storage. CalSim II balances upstream Sacramento Basin CVP and SWP reservoirs with storage in San Luis Reservoir by setting target storage levels in San Luis Reservoir. CalSim II will release water from upstream reservoirs to meet target levels in San Luis Reservoir and the target storage will be met as long as there is capacity to convey water and water is available in upstream reservoirs. In Alt 4 the San Luis Reservoir target storage is set very high in the spring and early summer months, and then reduced in August and set to San Luis Reservoir dead pool from September through December. This change in San Luis target storage relative to the NAA causes upstream reservoirs to be drawn down from June through August and then recuperate storage relative to the NAA by cutting releases in September; Alt 4 upstream storage then remains close to the NAA during fall months. These operational criteria cause changes in upstream cold water pool management and affect several resource areas. Figure 25, Figure 26, Figure 27, and Figure 28 contain exceedance charts for carryover storage and average monthly changes in storage by Sacramento Valley Water Year Type for North of Delta CVP and SWP reservoirs.

San Luis Reservoir Operations

In addition to changes in upstream storage conditions, changes in San Luis Reservoir target storage cause San Luis Reservoir storage to reach dead pool in many years with subsequent SOD delivery shortages. Although some

delivery shortages are due to California Aqueduct capacity constraints, the largest annual delivery shortages are a result of inappropriately low target storage levels. Average annual Table A shortages due to artificially low San Luis reservoir storage levels increased from 3 TAF in the NAA-ELT scenario to 35 TAF in the Alt4-ELT scenario. (Shortages due only to a lack of South of Delta conveyance capacity were not included in these averages.) Such shortages occurred in 2% of simulated years in the NAA-ELT scenario and 23% of years in the Alt4-ELT scenario. In addition to the inability to satisfy Table A allocations, low storage levels cause loss of SWP contractors' Article 56 water stored in San Luis Reservoir. Average annual Article 56 shortages were 43 TAF in the Alt4-ELT scenario because of low San Luis storage and 5 TAF in the NAA-ELT scenario. Low San Luis storage causes Article 56 shortages in 27% of simulated years in the Alt4-ELT scenario as compared to 5% of simulated years in the NAA-ELT. Another consequence of low storage levels in San Luis Reservoir is a shift in water supply benefits from Article 21 to Table A. As seen in Figure 29 and Figure 30 San Luis Reservoir storage fills more regularly in the Alt 4-ELT scenario, but is exercised to a lower point more often.

Figure 25. Trinity Reservoir Carryover Storage and Average Monthly Changes (Alt 4-ELT minus NAA-ELT) in Storage by Water Year Type



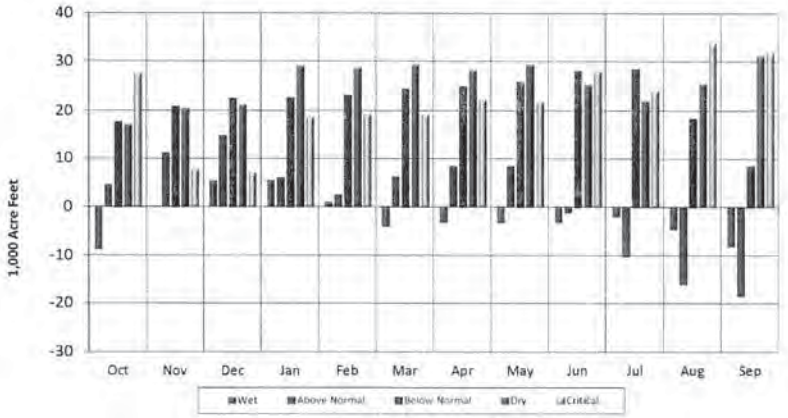
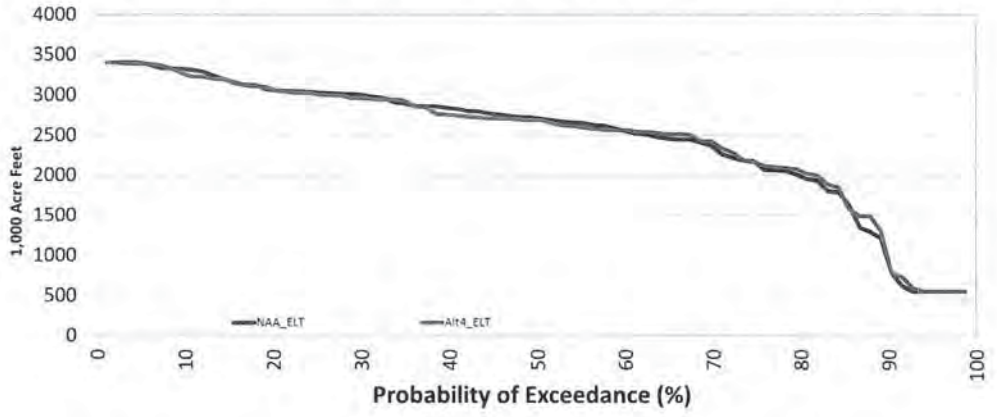
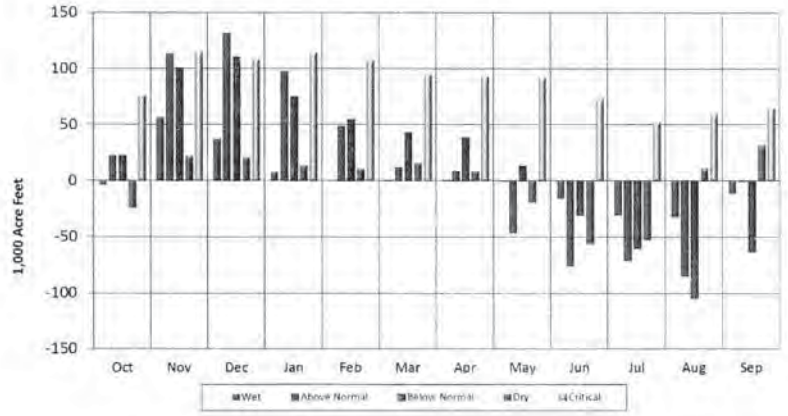


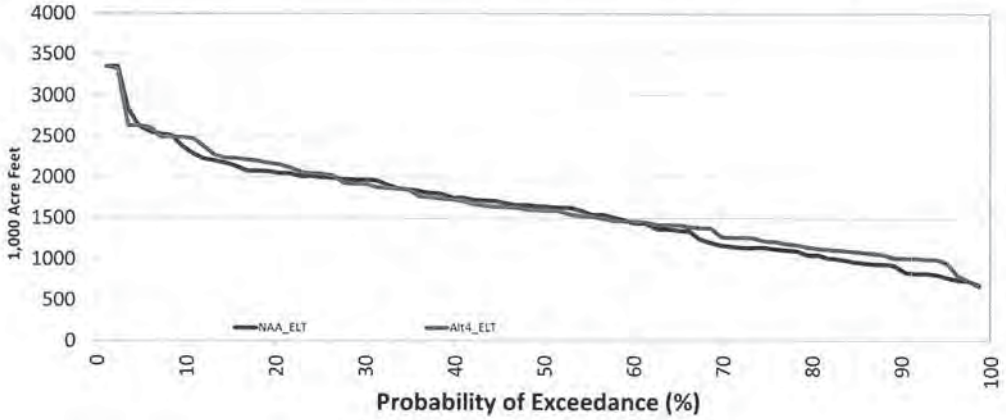
Figure 26. Shasta Reservoir Carryover Storage and Average Monthly Changes (Alt 4-ELT minus NAA-ELT) in Storage by Water Year Type





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Figure 27. Oroville Reservoir Carryover Storage and Average Monthly Changes (Alt 4-ELT minus NAA-ELT) in Storage by Water Year Type



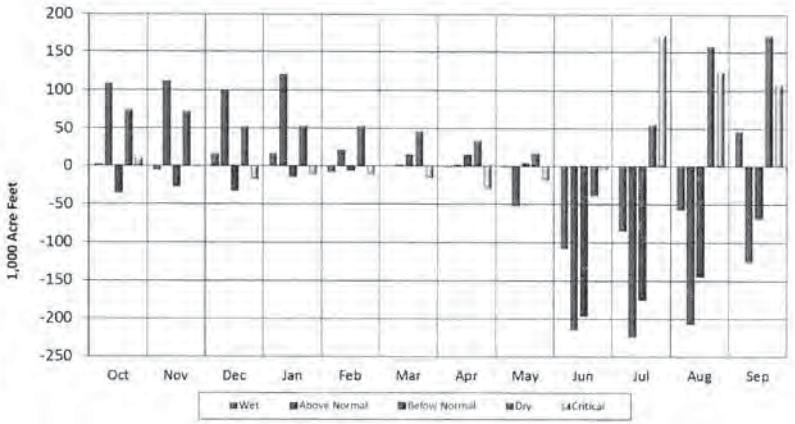
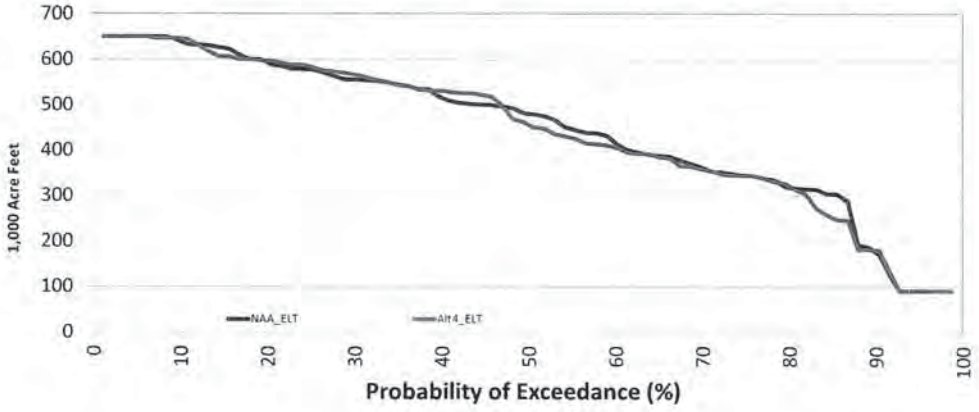
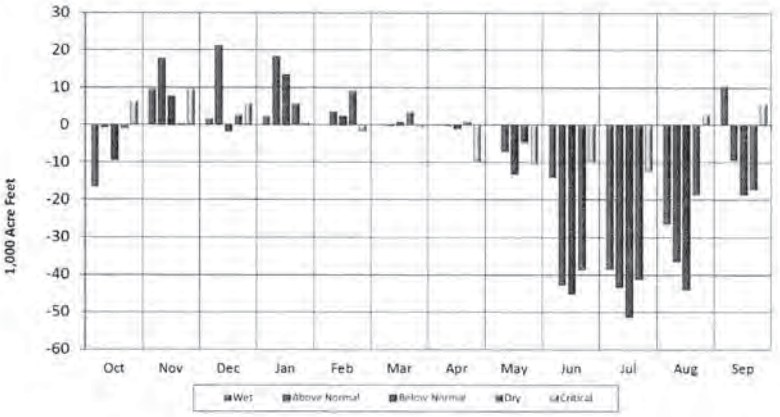


Figure 28. Folsom Reservoir Carryover Storage and Average Monthly Changes (Alt 4-ELT minus NAA-ELT) in Storage by Water Year Type





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Figure 29. Federal Share of San Luis Reservoir (Alt 4-ELT and NAA-ELT)

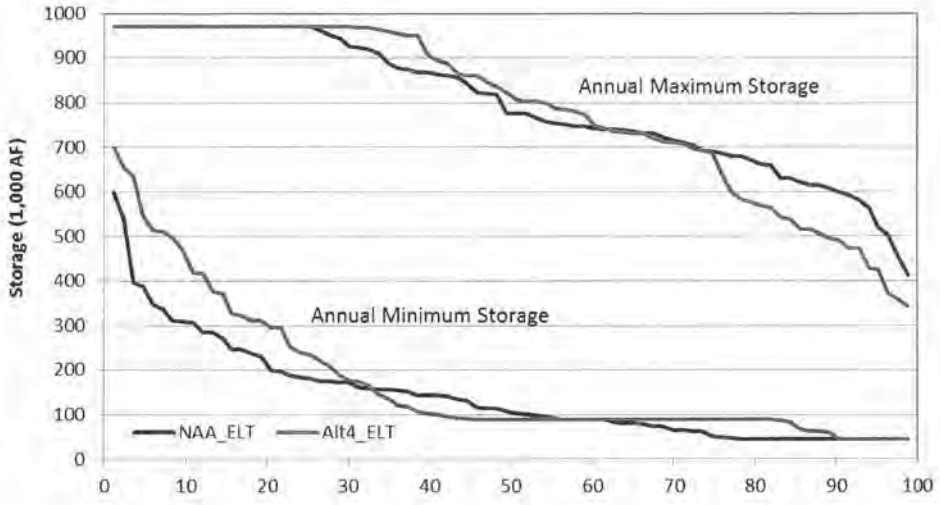
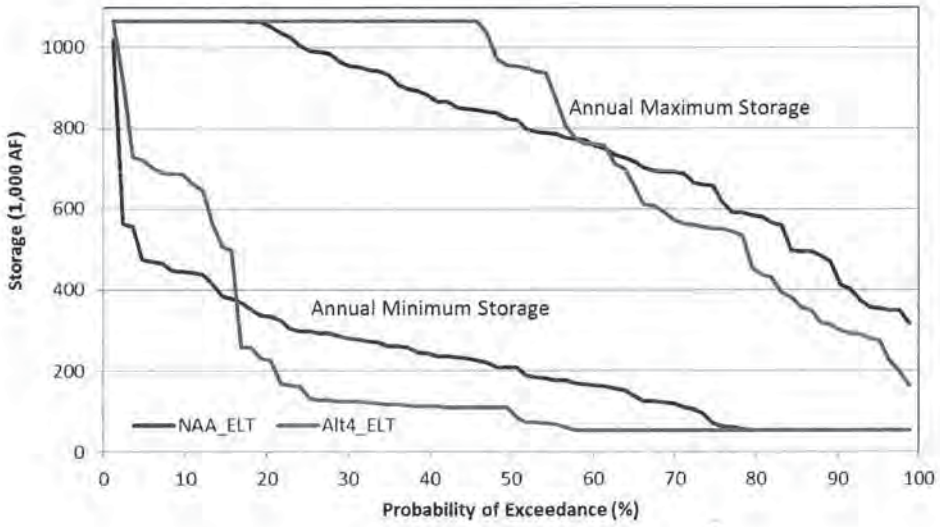


Figure 30. State Share of San Luis Reservoir (Alt 4-ELT and NAA-ELT)



CVP Water Supply

The changes in water supply to CVP customers, based on customer type and water year type is shown in Table 3. Alt 4-ELT shows an average increase of approximately 109,000 AF of delivery accruing to CVP customers with CVP SOD agricultural contractors receiving most of the benefit. Changes in Sacramento River Settlement contract deliveries are not an anticipated benefit of the BDCP, increases in these deliveries in Alt 4-ELT relative to the NAA-ELT are due to the shortages in the NAA-ELT from climate change that are reduced in Alt 4-ELT. Although the BDCP modeling demonstrates minor benefits to NOD CVP service contractors, this increase is not an anticipated benefit of the BDCP.

Consistent with modeling for the NAA-ELT Scenario, San Joaquin River Exchange Contractors receive full deliveries in accordance with contract provisions. Figure 31 compares CVP Service Contract delivery of Alt 4-ELT to the NAA-ELT Scenario. Increases in delivery generally occur in below and above normal years.

Table 3. CVP Delivery Summary (Alt 4-ELT and NAA-ELT)

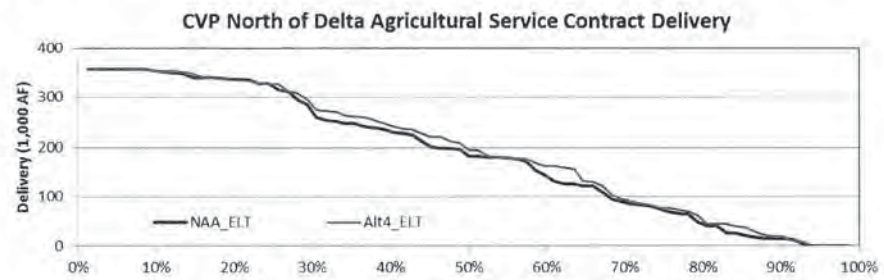
NAA-ELT (1,000 AF)

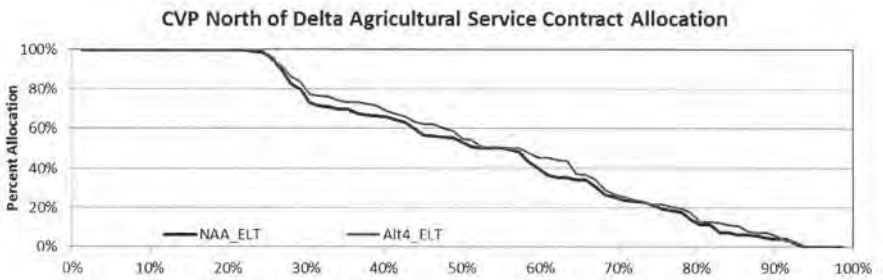
	AG NOD	AG SOD	Exchange	M&I NOD	M&I SOD	Refuge NOD	Refuge SOD	Sac. Setlmnt	CVP NOD Total	CVP SOD Total
All Years	**187**	**796**	**852**	**201**	**112**	**86**	**271**	**1846**	**2321**	**2215**
W	309	1364	875	236	134	90	281	1856	2491	2837
AN	246	908	802	214	110	83	257	1716	2258	2246
BN	146	596	875	198	108	92	281	1899	2335	2044
D	95	440	864	175	100	90	277	1890	2250	1864
C	29	152	741	140	79	64	223	1674	1908	1376

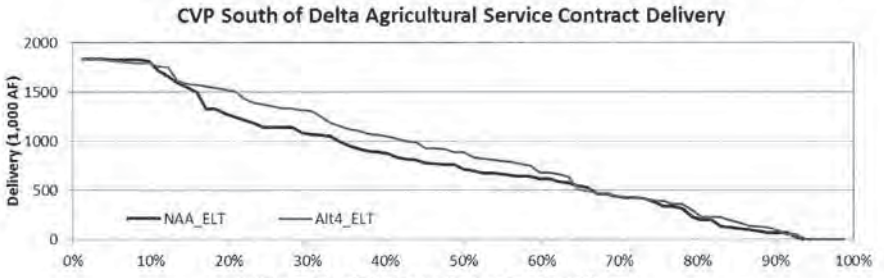
Difference: Alt4-ELT minus NAA-ELT (1,000 AF)

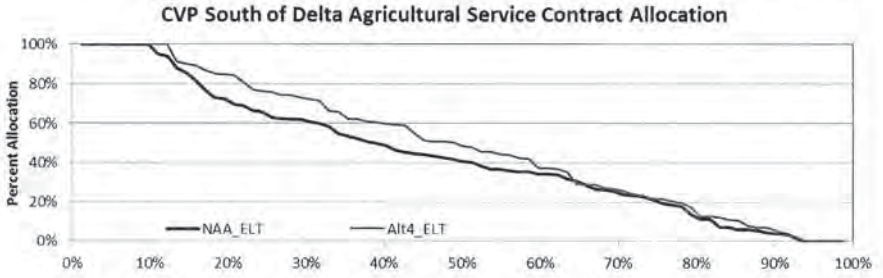
	AG NOD	AG SOD	Exchange	M&I NOD	M&I SOD	Refuge NOD	Refuge SOD	Sac. Setlmnt	CVP NOD Total	CVP SOD Total
All Years	8	90	0	4	4	1	0	3	15	94
W	1	68	0	1	3	2	1	-2	1	72
AN	14	199	0	3	12	1	0	-1	17	211
BN	17	153	0	5	4	0	0	0	22	158
D	10	48	0	5	2	1	-1	-1	15	49
C	3	6	0	5	2	-1	2	26	33	12

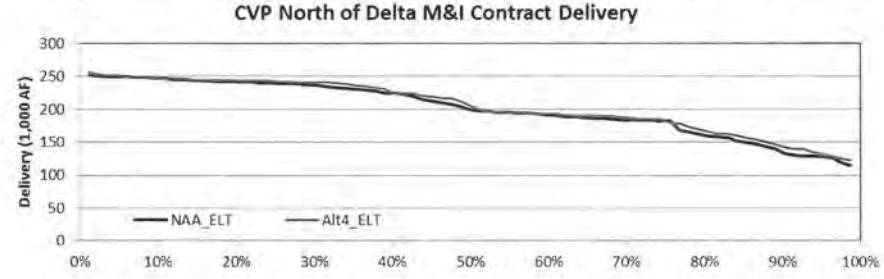
Figure 31. CVP Service Contract Deliveries (Alt 4-ELT and NAA-ELT)

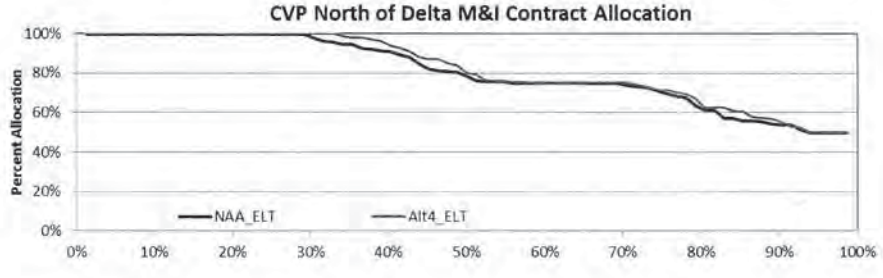


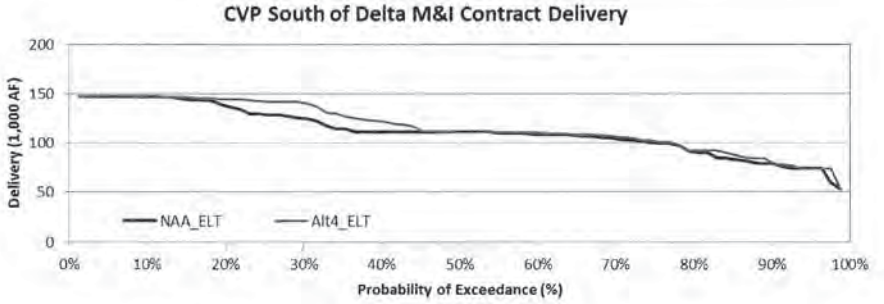


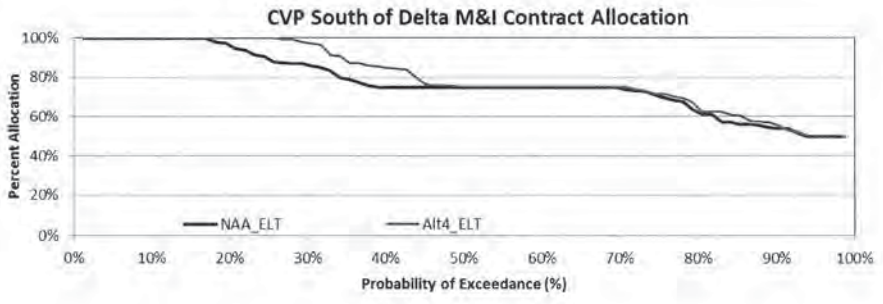












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SWP Water Supply

Similar in nature, but larger in magnitude are changes in SWP deliveries. Figure 32 and Table 4 illustrate the benefits of Alt 4-ELT in comparison to the NAA-ELT Scenario. These studies show an increase in average annual SWP SOD deliveries of approximately 408,000 AF, but a reduction in critical year deliveries of approximately 177,000 AF. There is an overall reduction in Article 56 deliveries. Typically in modeling and in actual SWP operations, increases in Table A correspond with increases in Article 56. The reason that Article 56 deliveries decrease overall is that insufficient quantities of water are carried over in San Luis and Article 56 contractors are subsequently shorted. SWP delivery increase is slightly less than increases in Banks export because there is increased wheeling for the Cross Valley Canal contractors with BDCP.

Table 4. SWP Delivery Summary (Alt 4-ELT and NAA-ELT)

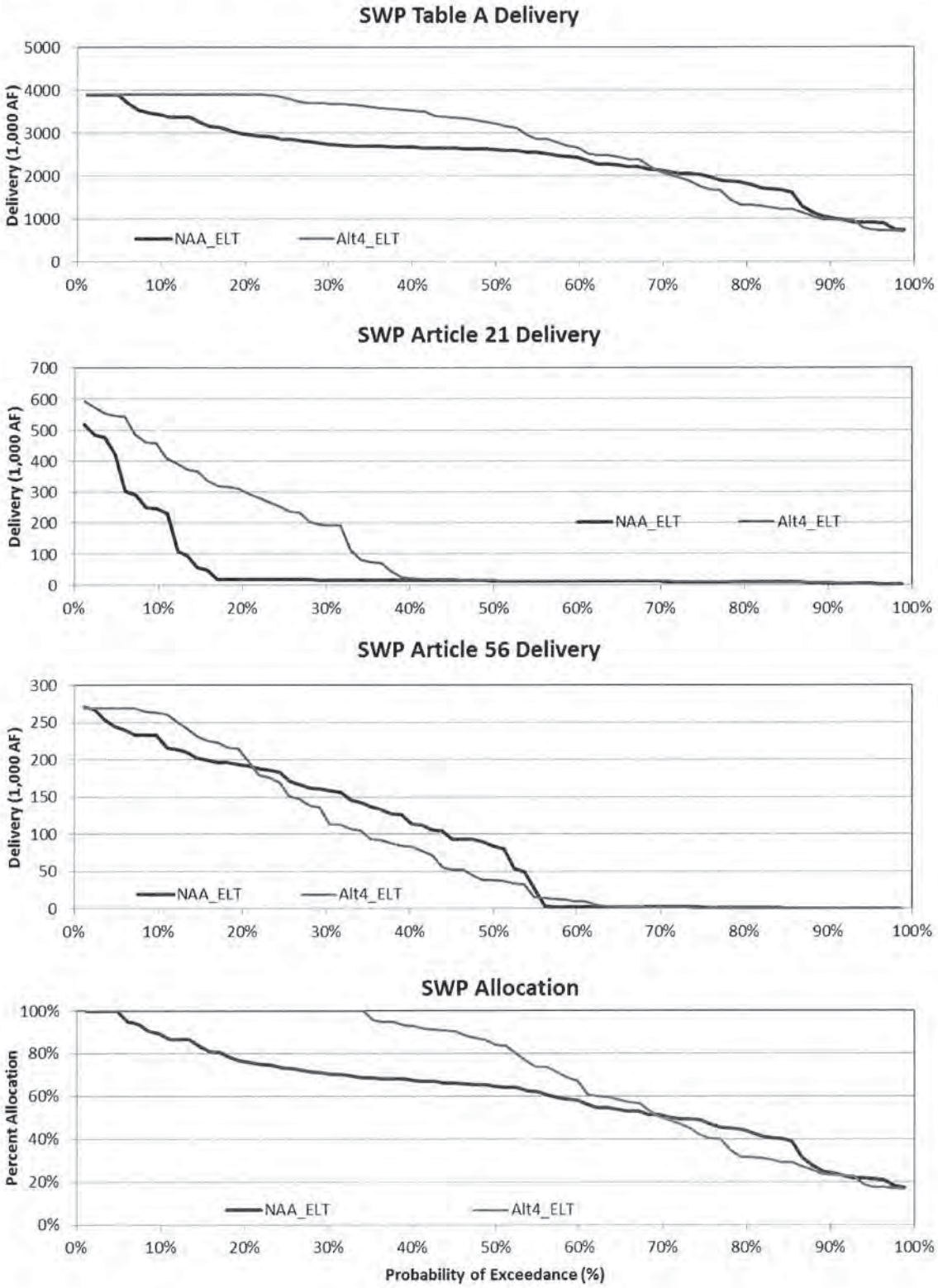
NAA-ELT (1,000 AF)

	Table A	Art. 21	Art. 56	Total
All Years	**2425**	**52**	**90**	**2567**
W	3112	79	112	3303
AN	2467	34	57	2559
BN	2515	48	109	2673
D	2033	43	88	2165
C	1172	28	47	1246

Difference: Alt4-ELT minus NAA ELT (1,000 AF)

	Table A	Art. 21	Art. 56	Total
All Years	339	75	-6	408
W	587	159	5	751
AN	728	99	-24	803
BN	525	44	2	571
D	-120	19	-10	-111
C	-146	-19	-12	-177

Figure 32. SWP Contract Deliveries (Alt 4-ELT and NAA-ELT)



Freemont Weir Modifications and Yolo Bypass Inundation

A component of the BDCP Alternative 4 is a modification to the Freemont Weir to allow water to flow into the Yolo Bypass when the Sacramento River is at lower flow than is currently needed. Currently, the Sacramento River does not flow over the Freemont Weir until flow reaches about 56,000 cfs. With the proposed modification Sacramento River flow may enter the Yolo Bypass at much lower flow levels. Figure 33 and Figure 34 contains charts that compare Freemont Weir flow into the Yolo Bypass to Sacramento River flow at the weir, Figure 33 show this relationship for the NAA-ELT and Figure 34 shows this same relationship for Alt 4-ELT.

Although CalSim II is a monthly time-step model, it contains an algorithm that estimates daily flow. Therefore, average monthly flows displayed in Figure 33 shows Sacramento River entering the Yolo Bypass at flow levels less than 56,000 cfs, when this occurs water is flowing over the Freemont Weir for a portion of the month. There is a 100 cfs minimum flow diversion from the Sacramento River diversion to the Yolo Bypass from September through June in Alt 4-ELT.

Figure 35 and Figure 36 contains average monthly flow from the Sacramento River over the Freemont Weir to the Yolo Bypass for the NAA-ELT (Figure 35), average monthly difference between Alt 4-ELT and NAA-ELT (Figure 36), and the annual average difference between Alt 4-ELT and NAA-ELT (Figure 37). In the NAA-ELT scenario flow over the Freemont Weir generally occurs in wet years, this flow is extended to all year types and all months except July and August in Alt 4-ELT. The average annual increase in flow is about 430 TAF.

Figure 33. Fremont Weir vs. Sacramento River NAA-ELT

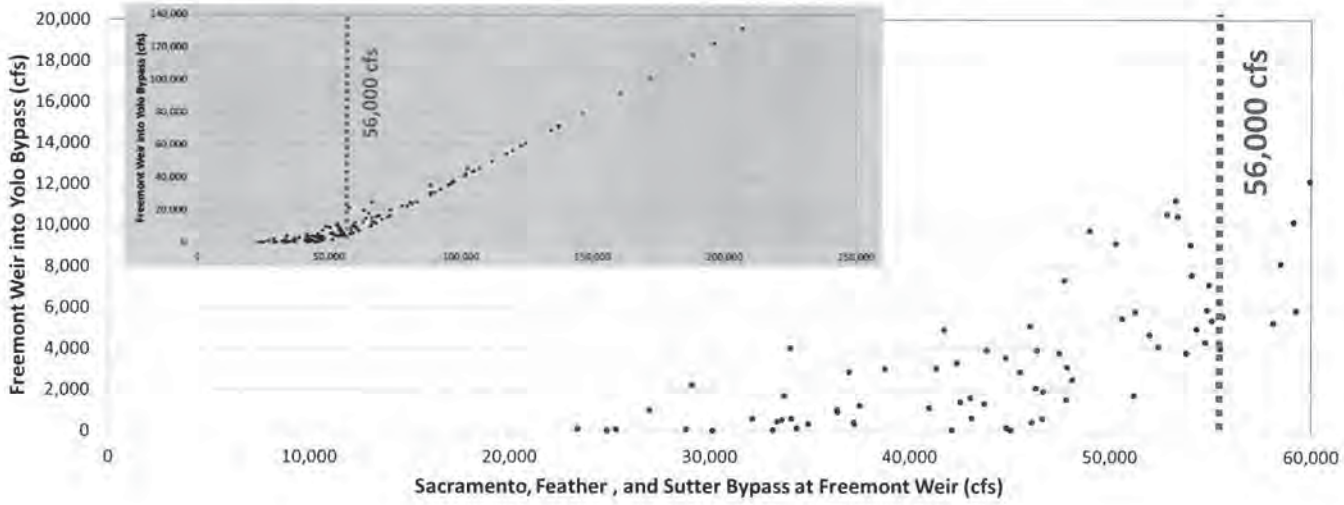


Figure 34. Fremont Weir vs. Sacramento River Alt 4-ELT

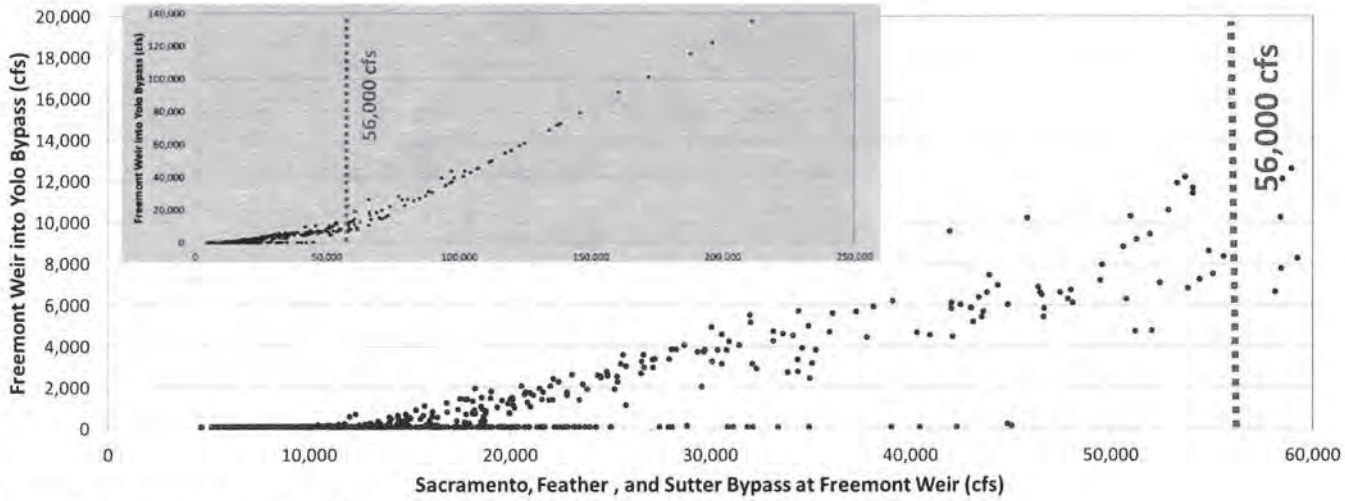


Figure 35. Average Fremont Weir Flow to Bypass by Water Year Type NAA-ELT

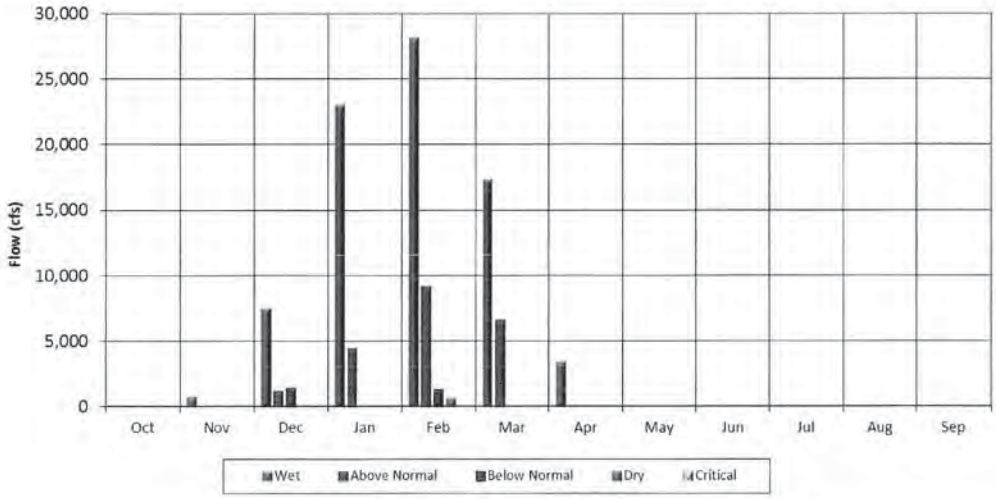


Figure 36. Average Fremont Weir Flow to Bypass by Water Year Alt 4 ELT minus NAA-ELT

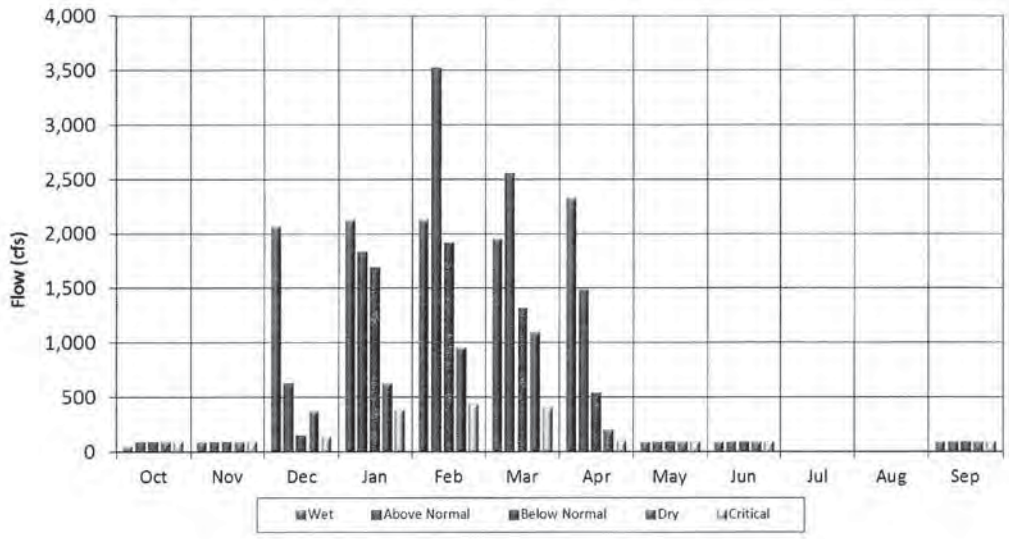
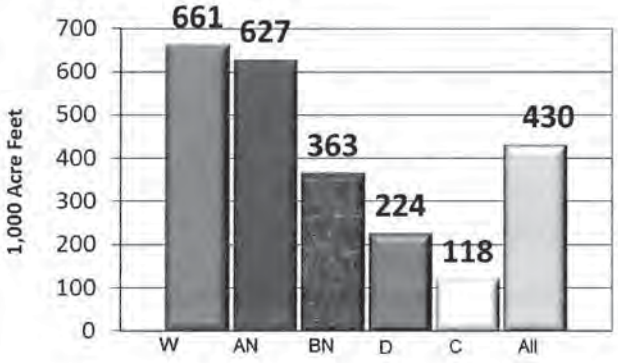


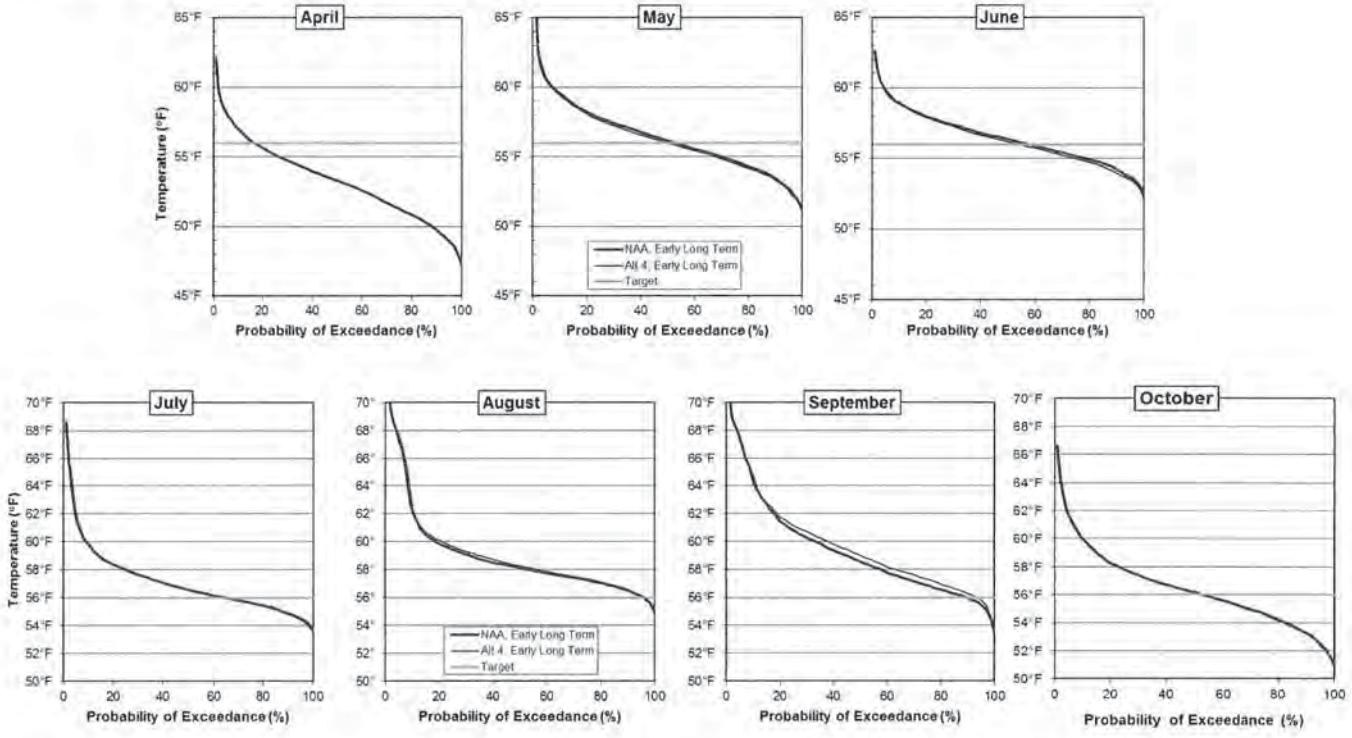
Figure 37. Annual Change in Fremont Weir Flow to Bypass Alt 4-ELT minus NAA-ELT



Sacramento River Temperature

Figure 38 contains exceedance probability plots of Sacramento River temperature at Bend Bridge for the NAA-ELT and Alt 4-ELT. For the months of April through July modeling shows few changes in upper Sacramento River water temperature. The Alt 4-ELT scenario shows temperature increases in August relative to the NAA-ELT. In about 75% of years modeling shows about 0.5°F increase in Alt 4-ELT relative to the NAA-ELT. The temperature models will meet inputted target temperatures until Shasta Lake cold water is depleted, this typically occurs in September. This is the likely reason temperature increases in modeling tend to occur in September.

Figure 38. Sacramento River Temperature at Bend Bridge NAA-ELT and Alt 4-ELT



Conclusions regarding CalSim II modeling of BDCP Alternative 4

BDCP's "High Outflow Scenario" is not sufficiently defined for analysis.

The High Outflow Scenario (HOS) requires additional water (Delta outflow) during certain periods in the spring. The BDCP Model places most of the responsibility for meeting this new additional outflow requirement on the SWP. However, the SWP may not actually be responsible for meeting this new additional outflow requirement. This is because the COA, as it is currently being implemented, would require a water allocation adjustment that would keep the SWP whole. Where one project (CVP or SWP) releases water to meet a regulatory requirement, the COA requires a water balancing to ensure the burden does not fall inappropriately among the projects. The BDCP Model is misleading because it fails to adjust project operations, as required by the COA, to "pay back" the water "debt" to the SWP due to these additional Delta outflow requirements. Unless there is a significant revision to COA, the BDCP Model overstates the impacts of increased Delta outflow on the SWP and understates the effects on the CVP.

Furthermore, after consulting with DWR and Reclamation project operators and managers, the Reviewers conclude that there is no apparent source of CVP or SWP water to satisfy both the increased Delta outflow requirements and pay back the COA "debt" to the SWP without substantially depleting upstream water storage. It appears, through recent public discussions regarding the HOS, that BDCP anticipates additional water to satisfy the increased Delta outflow requirement and to prevent the depletion of cold water pools will be acquired through water transfers from upstream water users. However, this approach is unrealistic because during most of the spring, when BDCP proposes that Delta outflow be increased, agricultural water users are not typically irrigating. This means that there is not sufficient transfer water available to meet the increased Delta outflow requirements without releasing stored water from the reservoirs. Releasing stored water to meet the increased Delta outflow requirements could potentially impact salmonids on the Sacramento and American River systems

Simulated operation of BDCP's dual conveyance, coordinating proposed North Delta diversion facilities with existing south Delta diversion facilities, is inconsistent with the project description.

The Draft BDCP and associated Draft EIR/EIS specify criteria for how much flow can be diverted by the new North Delta Diversion (NDD) facilities and specify when to preferentially use either the NDD facilities or the existing South Delta Diversion (SDD) facilities. However, the BDCP Model contains an artificial constraint that prevents the NDD facilities from taking water as described in the BDCP project description. In addition to affecting diversions from the NDD, this artificial constraint contains errors that affect the NAA operation. This error has been fixed by DWR and Reclamation in more recent versions of the model; however, the error remains in the BDCP Model. Additionally, the BDCP Model does not reflect the Summer operations of the SDD that are described in the Draft EIR/EIS as a feature of the BDCP project intended to prevent water quality degradation in the south Delta. The net effect of these two errors is that the BDCP Model significantly underestimates the amount of water diverted from the NDD facilities and overestimates the amount of water diverted from the SDD.

BDCP modeling contains numerous coding and data issues that skew the analysis and conflict with actual real-time operational objectives and constraints

logic is coded into the CalSim II model to simulate how DWR and Reclamation would operate the system under circumstances for which there are no regulatory or other definitive rules. This attempt to specify (i.e., code) the logic sequence and relative weighting so that a computer can simulate "expert judgment" of the human operators is a critical element to the CalSim II model. In the BDCP Model, some of the operational criteria for water supply allocations and existing facilities such as the Delta Cross Channel and San Luis Reservoir are inconsistent with real-world conditions.

3 INDEPENDENT MODELING

The Independent Modeling effort originally stemmed from reviews of BDCP Model during which the Reviewers discovered that the BDCP Model did not provide adequate information to determine the effects of the BDCP. There are three basic reasons why the Reviewers cannot assess how the BDCP will affect water operations: 1) NAAs do not depict reasonable operations under the described climate change assumptions, 2) operating criteria used in the BDCP Alternative 4 result in unrealistic operations, and 3) updates to CalSim II since the BDCP modeling was performed almost 4 years ago will likely alter model results to a sufficient degree that conclusions based on the BDCP modeling will likely be different than those disclosed in the Draft EIR/EIS. Given that it is not possible to determine how BDCP may affect CVP and SWP operations or water system flows and conditions with the BDCP model, Independent Modeling was performed to assess potential effects due to the BDCP.

To revise the models, the Reviewers consulted with operators at DWR and Reclamation to improve the representation of operational assumptions. Additionally, the Reviewers consulted with modelers at DWR and Reclamation to share findings, to strategize on the proper way to incorporate the guidance received from the operators, and to present revised models to DWR and Reclamation for their review. This collaborative and iterative process differed considerably from a standard consulting contract where the work product is not shared beyond the client-consultant until a final version is complete. To the contrary, consultations with agency experts were conducted early and repeatedly to ensure the revisions would reflect reasonable operations and to provide an independent review.

The first phase of this Independent Modeling effort was development of an updated without project baseline (similar to the NAA but with current, improved assumptions). The Independent Modeling does not incorporate climate change because the climate change hydrological assumptions developed by BDCP cause unrealistic operation of the system absent commensurate changes to operating criteria.

After the baseline was complete and reviewed, the second phase of this effort incorporated the facilities and operations for the BDCP described as Alternative 4 H3 in the Draft EIR/EIS, and otherwise known as the Evaluated Starting Operations (ESO) scenarios in the BDCP. During this phase, the issues that were identified during the Reviewers' initial review were corrected along with corrections made to resolve additional issues that were revealed as improvements were incorporated. Finally, results of the Independent Modeling and potential effects of the BDCP on water supply and instream flows are discussed.

3.1 Changes to CalSim II Assumptions

Revisions approved by DWR and Reclamation for the 2013 baseline

DWR and Reclamation provided CalSim II models used for the 2013 SWP Delivery Reliability Report (DRR) for use in this independent modeling effort. Changes to these models were made for this effort and provided to DWR and Reclamation, many of these changes have since been incorporated into DWR and Reclamation's model and others are under review.

The CalSim II model used for the 2013 SWP DRR is located on DWR's web site at: http://baydeltaoffice.water.ca.gov/modeling/hydrology/CalSim/Downloads/CalSimDownloads/CalSim-IIStudies/SWPReliability2013/index.cfm. Documentation for this model is described in the report titled: "*Draft Technical Addendum to the State Water Project Delivery Reliability Report 2013*", also located on DWR's web site at: http://baydeltaoffice.water.ca.gov/swpreliability/. Key modeling assumptions used for this effort are consistent with the 2013 SWP DRR and are listed in Table 4 of the Technical Addendum.

CalSim II is continuously being worked on and improved to better represent CVP and SWP operations and fix known problems. The Technical Addendum to the 2013 SWP DRR contains a description of updates and fixes that have occurred since modeling was performed for the BDCP Draft EIRS. Among these changes and fixes are key items that directly affect operation of facilities proposed in BDCP Alternative 4, these items are described on page 4 of 2013 SWP DRR Technical Addendum. Key among these fixes is the correction of the Sacramento River flow requirement for Delta inflow that causes NDD bypass to exceed requirements.

A key component of this independent modeling effort is the development of an acceptable CalSim II Future No-Action (FNA) model scenario. The purpose for developing the FNA Scenario is to produce an operational scenario that is realistic enough to understand how changes proposed in the BDCP will affect operations. The process of developing the FNA involved research and development of CalSim II model updates and several meetings with Reclamation and DWR modeling and operations staff. In addition to changes in the FNA Scenario, CalSim II was updated to better reflect operation of the NDD, CVP and SWP reservoir balancing, DCC gate operations, and CVP/SWP water supply allocations.

Additional Revisions to CalSim II Assumptions

The following changes were made to the 2013 SWP DRR version of CalSim II for this effort:

- San Joaquin River Basin
    - Turned off San Joaquin River Restoration Program (SJRRP) The SJRRP will cause a change to San Joaquin River inflow to the Delta not associated with the BDCP. To avoid adding complications to the identification of BDCP export benefits the SJRRP was not incorporated into the analysis.
    - Tuolumne: updated time-series, lookup tables, and wresl code
    - Turned off SJRA (VAMP) releases
- Updated Folsom flood diagram
- Rice decomposition demand diversions from Feather River
- Dynamic EBMUD diversion at Freeport
- SEP1933 correction to daily disaggregated minimum flow requirements at Wilkins Slough and Red Bluff
- CVP M&I demands are updated to reflect assumptions used by Reclamation
- Yuba Accord Transfer
- Los Vaqueros Reservoir capacity

<u>San Joaquin River Basin</u>

BDCP modeling depicted San Joaquin River Basin operations generally consistent with the actions, programs and protocols in place at the time of NOI/NOP issuance. Some of those conditions are now not representative of current development or operations. With the exception of the assumption for the SJRRP, the independent modeling has revised San Joaquin River Basin operations to reflect more contemporary LOD assumptions. In future level analyses the independent modeling similarly assumes no SJRRP, but only for analysis simplicity concerning BDCP export benefits. Additional analyses may be useful in understanding effects of collectively implementing the BDCP and SJRRP.

The San Joaquin River Basin (SJR) is depicted for current conditions, primarily affected by the operations of the Stanislaus, Tuolumne, Merced, and upper San Joaquin River tributaries. The upper San Joaquin River is currently modeled in a "pre-" SJRRP condition, consistent with the 2005 CalSim version. The FNA Scenario also models the upper San Joaquin River without the SJRRP. The SJR depicts near-term operations including SWRCB D-1641 flow and water quality requirements at Vernalis met when hydrologically possible with New Melones operations. The Vernalis flow objective is set by SWRCB D-1641 February-June base flow requirements. There are no pulse flow requirements during April and May, and there is no acquired flow such as VAMP or Merced water. D1641 Vernalis water quality requirements are set at 950/650 EC to provide an operational buffer for the requirement. New

Melones is operated to provide RPA Appendix 2E flows as fishery releases and maintains the DO objective in the Stanislaus River through a flow surrogate. Stanislaus River water right holders (OID/SSJID) are provided deliveries up to land use requirements as occasionally limited due to operation agreement (formula). CVP Stanislaus River contractors are provided allocations up to 155 TAF per year in accordance with proposed 3-level plan based on the New Melones Index (NMI). For modeling purposes during the worst drought sequence periods, CVP Stanislaus River contractors and OID/SSJID diversions are additionally cut to maintain New Melones Reservoir storage no lower than 80 TAF. Merced River is operated for Federal Energy Regulatory Commission (FERC) and Davis-Grunsky requirements, and provides October flows as a condition of Merced ID's water rights. The Tuolumne River is operated to its current FERC requirements and current water use needs and has been updated to recent conditions.

Folsom Lake Flood Control Diagram

During wetter years, inflow to Folsom Lake is sufficient to keep the reservoir full while satisfying all demands downstream. When this condition occurs in actual operations, operators increase releases during summer months to maintain higher instream flows and prevent large releases in the fall to evacuate Folsom to satisfy flood control storage requirements. To prevent the model from keeping the reservoir full going into the fall months and then making large releases to comply with flood control storage requirements, the maximum allowable storage during summer months is ramped from full storage in June to flood control levels in the fall. Although this is a common modeling tool, Folsom storage level for the end of September was set too low in the SWP DRR model causing unnecessary releases and resulting in Folsom storage being lower than desired. An adjustment was made to achieve a more realistic summer drawdown for Folsom.

Feather River Rice Decomposition Demand

Demand for rice straw decomposition (decomp) water from Thermalito Afterbay was added to the model and updated to reflect historical diversion from Thermalito in the October through January period. There are approximately 110,000 acres of rice in the Feather River Service Area irrigated primarily with water diverted from Thermalito Afterbay. Although decomp water demand for the Sacramento River has been included in CalSim II since about 2006, this demand has been absent for the Feather River. Inclusion of decomp demand in the version of CalSim II used for this effort results in an increase in Feather River diversion in fall months of about 160,000 AF.

Dynamic EBMUD Diversion at Freeport

Previously the EBMUD operation was pre-determined and input to CalSim II as a time-series. The below criteria was implemented in CalSim II model code to achieve a dynamic representation of EBMUD diversion from the Sacramento River at Freeport.

The EBMUD water service contract is unique. EBMUD's total system storage must be forecast to be below 500 TAF on October 1 for CVP water to be available under the EBMUD contract. In years when this occurs, we assume EBMUD will take the minimum of 65 TAF of CVP water or their CVP allocation (133 TAF * CVP M&I allocations) in the first and second years of any multi-year period when CVP water is available under their contract. In the third year, EBMUD would be limited to 35 TAF of CVP water (assuming diversion of 65 TAF in years one and two) because their contract limits cumulative CVP water over three consecutive years to 165 TAF. The 65, 65, 35 TAF annual diversion pattern then repeats if water is available for four or more consecutive years under the EBMUD contract.

Wilkins Slough Minimum Flow Requirement

Wilkins Slough minimum flow requirements, C129_MIF, includes an adjustment for daily operations based on work with the Sacramento River Daily Operations Model (SRDOM). The flow adjustment for daily flows for September 1933 in the state variable input file appeared unreasonable in the previous model. The flow

adjustment in this month was approximately 1,860 cfs and was requiring release of approximately 100 TAF out of Shasta. Review of the entire time-series of daily adjustments showed the adjustment in this month was an order of magnitude greater than in any other September in the simulation period. The year 1933 is a critically dry year, and the third of four consecutive Shasta Critical years. Historical precipitation records from the consumptive use models for the Sacramento Valley, which serves as the basis of much of the CalSim hydrology, were reviewed to ensure there was no unusual precipitation in this month that may create variations in daily flows. It was determined that this daily adjustment is in error. The daily adjustment for this time-step was set to 10 cfs, the value for August 1933.

CVP M&I Demands

Reclamation M&I contractor demands upstream from the Delta have not been adequately represented in CalSim II until Reclamation updated the model in 2012. A more accurate representation of CVP M&I demands, developed in 2012, was incorporated into the model for this effort.

Yuba Accord Water Transfer

In CalSim, Yuba Accord Water Transfers are limited to releases from New Bullards Bar Reservoir. The release is picked up at Banks Pumping Plant or stored in Oroville and Shasta for later release. The additional release from New Bullards Bar is represented in CalSim through an inflow arc. The subsequent refill of New Bullards Bar is represented in CalSim through a diversion arc. In CalSim II, refill is assumed to always occur in the winter following the transfer. However, in the SWP DRR model, there were a few years in which no transfers took place but refill still occurred in the following winter. This was fixed in the updated baseline by capping refill to the previous summer's total transfer.

Los Vaqueros Reservoir

Expansion of Los Vaqueros Reservoir was completed in 2012. Storage capacity was increased from 103 TAF to 160 TAF. In DWR's BDCP studies, Los Vaqueros capacity was set to 103 TAF. The independent modeling increases Los Vaqueros capacity to 160 TAF.

3.2 Changes to BDCP Operations

San Luis Reservoir Rule-Curve Logic Change

In the independent modeling, San Luis rule-curve logic was refined for both SWP and CVP operations. San Luis rule-curve is used to maintain an appropriate balance between San Luis Reservoir storage and North of Delta reservoirs. The key considerations in formulating rule-curve are as follows:

- Ensure that sufficient water is available in San Luis Reservoir to meet contract allocations when exports alone are insufficient due to various operational constraints.
- Minimize San Luis Reservoir carryover storage to low point criteria (both CVP and SWP) and Article 56 carryover (only SWP). The basic premise is to maintain Reservoir San Luis storage no higher than necessary to satisfy south of Delta obligations to avoid excessive drawdown of upstream storage.

In DWR's BDCP studies, there were significant shortages in Table A and Article 56 deliveries because of an improper balance between upstream and San Luis Reservoir storage. The updated SWP rule-curve logic reduces these shortages but does not eliminate them. Also, the updated CVP rule-curve logic allows for higher CVP allocations without increasing risk of shorting SOD contractors.

Upstream Storage Release to Fill San Luis Reservoir Above Needed Supply

In the BDCP NAA and the independent modeling FNA, the model has a priority to release excess stored water that will likely be released for flood control purposes from Shasta and Folsom storage for export at Jones Pumping Plant to storage in San Luis Reservoir in the late summer and early fall months. The purpose was to get a head start on filling San Luis Reservoir for the coming water year if there is a high likelihood of Shasta or Folsom spilling. This was an assumed CVP/SWP adaptation to the export reductions in the winter and spring months due to the salmon and smelt biological opinions. However, with the NDD facility in Alt 4, winter and spring export restrictions impact CVP exports much less and there is no longer a reason to impose this risk on upstream storage. As such, the weights, or prioritizations, of storage in Shasta and Folsom were raised so that excess water would not be released specifically to increase CVP San Luis storage Reservoir above rule-curve. This was changed in Alt 4 and not the FNA to better reflect how the system may operate under these different conditions.

Delivery allocation adjustment for CVP SOD Ag service and M&I contractors

CVP SOD Ag service and M&I allocations are limited by both systemwide water supply (storage plus inflow forecasts) and Delta export constraints; whereas similar CVP NOD allocations are dependent solely on water supply. This frequently results in SOD water service contractors receiving a lower contract year allocation than NOD water service contractors, especially under the Biological Opinion export restrictions. However, with the NDD facility operations as proposed under Alt 4 H3, the CVP can largely bypass these Delta export restrictions, and the export capacity constraint on CVP SOD allocations was determine to be overly conservative. Therefore, the export capacity component of CVP SOD allocations was removed in the BDCP Alternative and both SOD and NOD CVP allocations are equal and based only on water supply.

Folsom/Shasta Balance

CVP operations were refined in the BDCP Alternative to provide maximum water supply benefits to CVP contractors while protecting Trinity, Shasta, and Folsom carryover storage in the drier years. As a whole, this was accomplished with refinements to allocation logic and San Luis rule-curve. However, in initial study runs, an imbalance between Folsom and Shasta was created; while there was a total positive impact to upstream storage in dry years, there was a negative impact to Folsom storage. This was resolved by inserting Folsom protections in the Shasta-Folsom balancing logic. With these protections, the positive carryover impacts were distributed to Trinity, Shasta, and Folsom.

North Delta Diversion Bypass Criteria

The daily disaggregation method for implementing NDD bypass criteria as implemented in DWR's BDCP model was left mostly intact for the updated BDCP studies. However, there were modifications to properly fit the bypass criteria implementation within the latest CalSim operations formulation. Modifications are as follows:

1. No NDD operations occur in cycles 6 through 9 so that Delta operations and constraints can be fully assessed without NDD interference.
2. Cycles 10 and 11 (Daily 1 and Daily 2 respectively) were added to determine NDD operations given various operational constraints including the NDD bypass criteria.
3. From July to October, bypass criteria are based on monthly average operations (no daily disaggregation). Given the controlled reservoir releases at this time and the constant bypass criteria (5,000 cfs from July to September and 7,000 cfs in October), this was determined to be a reasonable assumption. This also simplified coordination of DCC gate operations with NDD in October which will be discussed later.
4. When warranted by conditions in cycle Daily 1 (cycle 10), the bypass criteria in May and June were allowed to be modeled on a monthly average basis in cycle Daily 2 (cycle 11). This allowed a reduction in the number of cycles necessary to determine the fully allowed diversion under the bypass criteria when

the Delta was in balance and additional upstream releases were made to support diversions from the North Delta.

Delta Cross Channel Gate Reoperation in October

The BDCP Alt 4 results in significantly more October surplus Delta outflow as compared to the baseline. The cause of this Delta surplus at a time when the Delta is frequently in balance is a combination of proposed through-Delta export constraints (OMR flow criteria and no through-Delta exports during the San Joaquin River October pulse period), Rio Vista flow requirements, and DCC gate operations. In DWR's BDCP studies, it was assumed that the DCC gates would be open for the entire month of October thereby requiring much higher Sacramento River flows at Hood in order to meet the Rio Vista flow requirement than if the DCC gates were closed. Whereas in the independent BDCP modeling it was assumed that the DCC gates were closed for a number of days during the month such that the 7,000 cfs NDD bypass criteria would be sufficient to meet the weekly average Rio Vista flow requirements. The intent was to minimize surplus Delta outflow while meeting Delta salinity standards and maintaining enough bypass flow to use the NDD facility for SOD exports. This is an approximation of what is likely to occur in real-time operations under similar circumstances. Further gate closures may be possible as salinity standards allow if operators decide to preserve upstream storage at the expense of NDD diversions. This type of operation would require additional model refinements.

Wilkins Slough minimum flow requirement

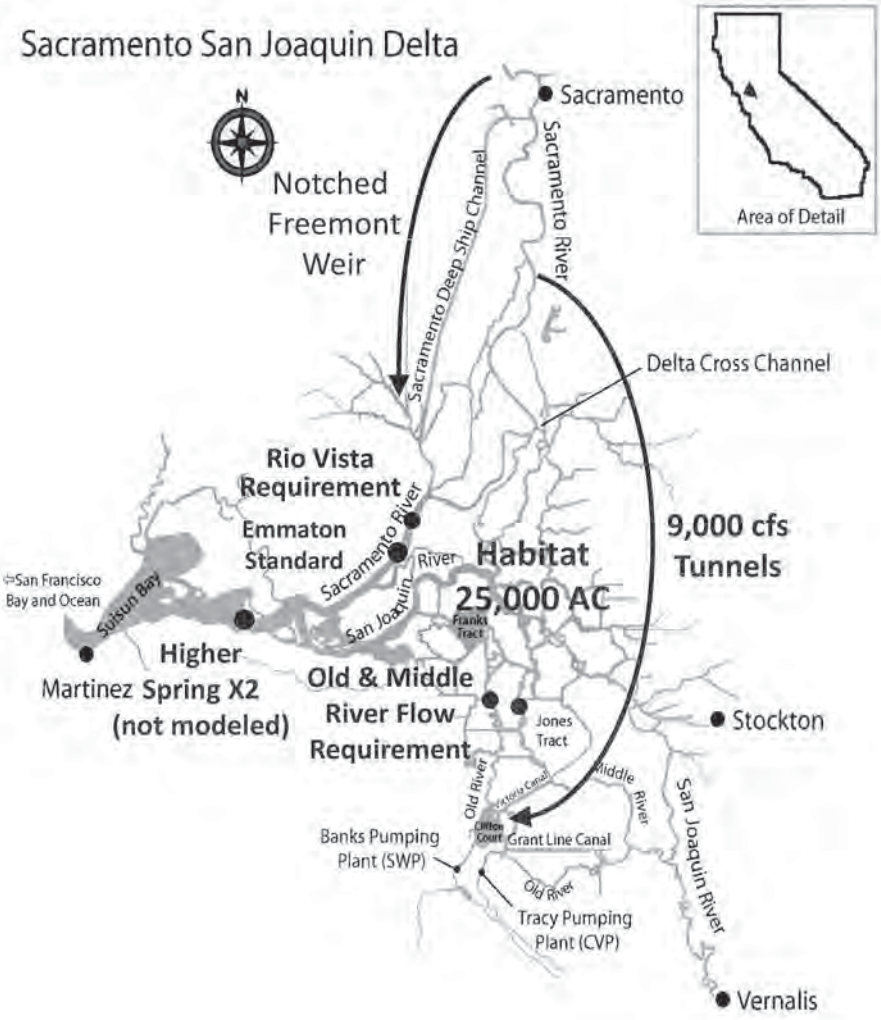
Currently in CalSim II, relaxation of the Wilkins Slough minimum flow requirement is tied to CVP NOD Ag Service Contractor allocations. This does not reflect actual operations criteria where relaxation of the flow requirement is dependent solely on storage conditions at Shasta. From the comparative analysis perspective of our CalSim planning studies, this introduces a potential problem: changes in CVP NOD Ag Service allocations can result in unrealistic changes in required flow at Wilkins Slough, and such changes in Wilkins Slough required flow can result in unrealistic impacts to Shasta storage. To bypass this problem, we assumed that the required flow at Wilkins Slough in the alternative was equal to the baseline.

3.3 Alternative 4 Modeling results

Analysis for this effort was focused on BDCP Alt 4 with existing spring and fall X2 requirements, which corresponds to "Alternative 4 H3" in the Decisions Tree. This modeling is performed without climate change, and includes refined operating criteria for the NDD, CVP and SWP reservoirs, DCC gate closures, and water supply allocations. This modeling includes all Project features that are included in Alt 4 in the BDCP modeling. The Project features are displayed in Figure 39 and summarized as:

- NDD capacity of 9,000 cfs
- Bypass flow requirements for operation of the NDD
- Additional positive OMR flow requirements
- No San Joaquin River I/E ratio
- Changed location for Emmaton water quality standard in SWRCB D-1641
- Additional Sacramento River flow requirement at Rio Vista
- 25,000 acres of additional tidal habitat
- Notched Fremont Weir

Figure 39. Alt 4 Features

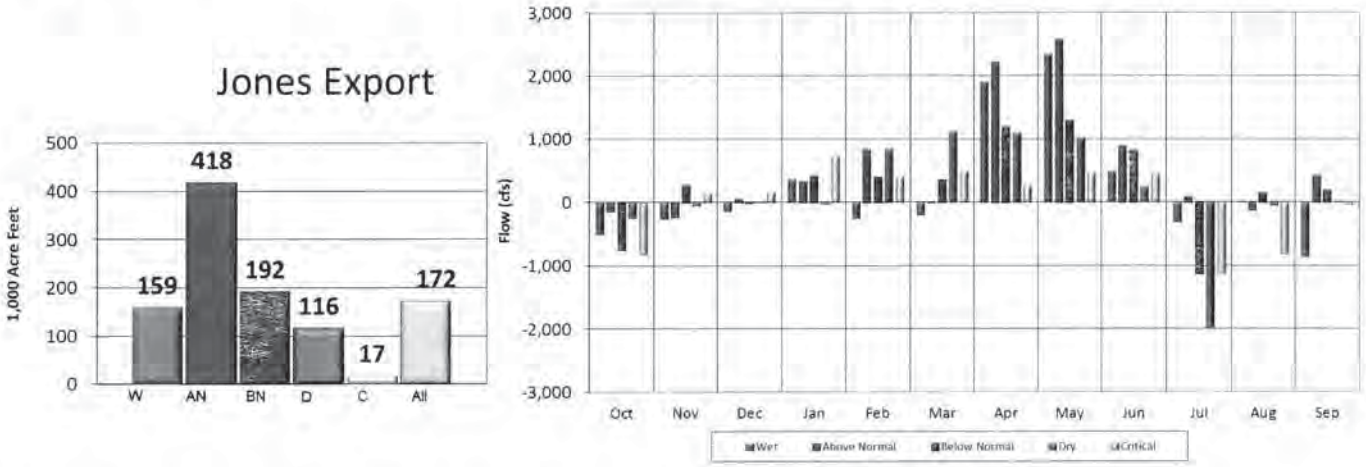


For the purpose of describing results of the independent modeling, the revised Future No Action model scenario is labeled "FNA" and the revised BDCP Alt 4 scenario is labeled "Alt 4".

CVP/SWP Delta Exports

Average annual exports at Jones pumping plant are about 170 TAF higher in the Alt 4 Scenario compared to the FNA scenario, as seen in Figure 40. Increases generally occur from January through June when Old & Middle River (OMR) criteria limit use of Jones PP in the FNA Scenario. Decreases occur in July in drier year types because the increased ability to convey water in spring months reduces the need to convey water stored in upstream reservoirs in July. Reductions in Jones export in October are partially a function of increases in OMR flow requirements.

Figure 40. Change in Delta Exports at Jones Alt 4 minus FNA



Similar to export at Jones, Banks exports are generally higher from January through June because use of NDD allows pumping that is not possible in the FNA Scenario, as seen in Figure 41. Banks exports are increased during summer months of wetter year types. This is due to earlier wheeling for CVP Cross Valley Canal contractors (without NDD Banks capacity isn't typically available until Fall in wet years) and wheeling of CVP water through Joint Point of Diversion (JPOD). CVP export at Banks is displayed in **Figure 42**. In wetter years, upstream CVP reservoirs hold more water than can be exported at Jones pumping plant, this water is typically spilled in the FNA scenario. CVP water stored in upstream reservoirs can be released in July, August, and September to support south of Delta beneficial use of water through use of JPOD in Alt 4.

Figure 41. Change in Delta Exports at Banks Alt 4 minus FNA

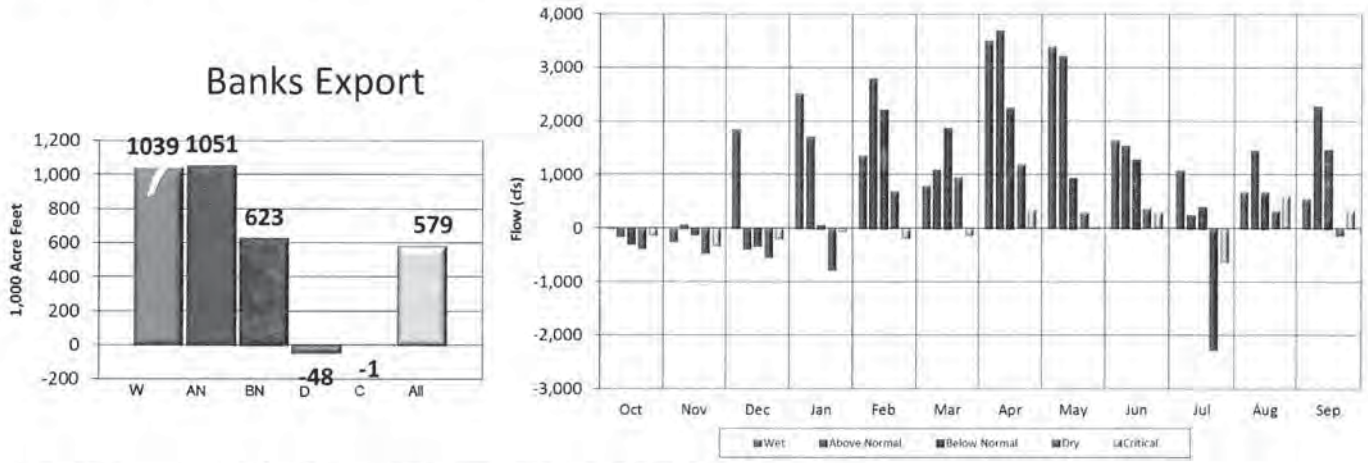
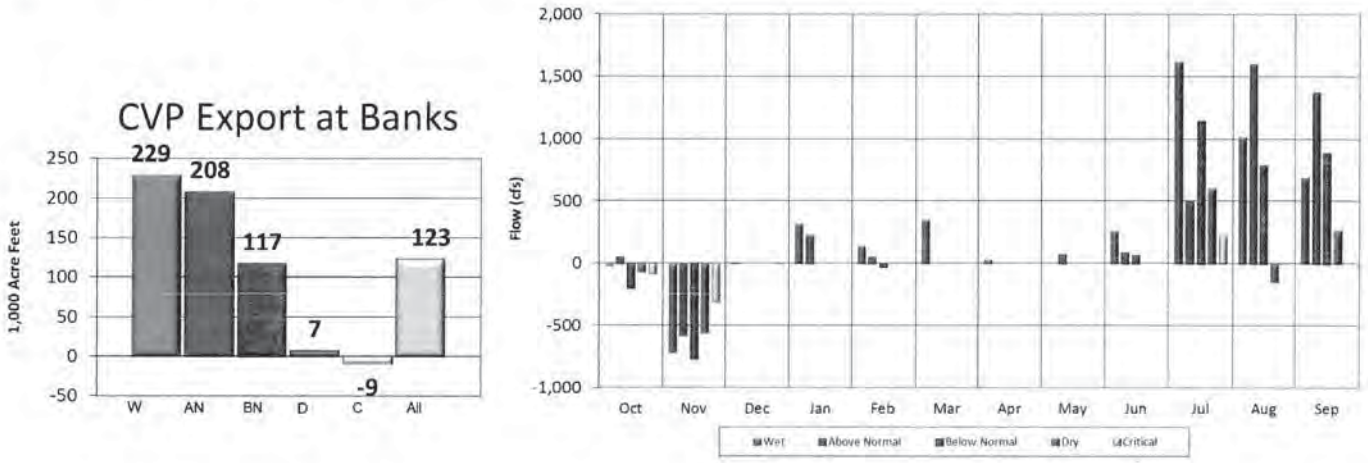


Figure 42. Change in CVP Delta Exports at Banks Alt 4 minus FNA



Changes in total, South Delta, and North Delta exports are displayed in Figure 43. Average annual increase in total Delta exports is about 750 TAF, the increases primarily occur in wetter year types with lesser increases in dryer years. South Delta export decreases about 2.53 MAF in Alt 4 relative to the FNA. Export through the NDD is 3.28 MAF in Alt 4, about 58% of total exports are diverted from the North Delta.

Figure 43. Change in Conveyance Source of Exports (Alt 4 minus FNA)

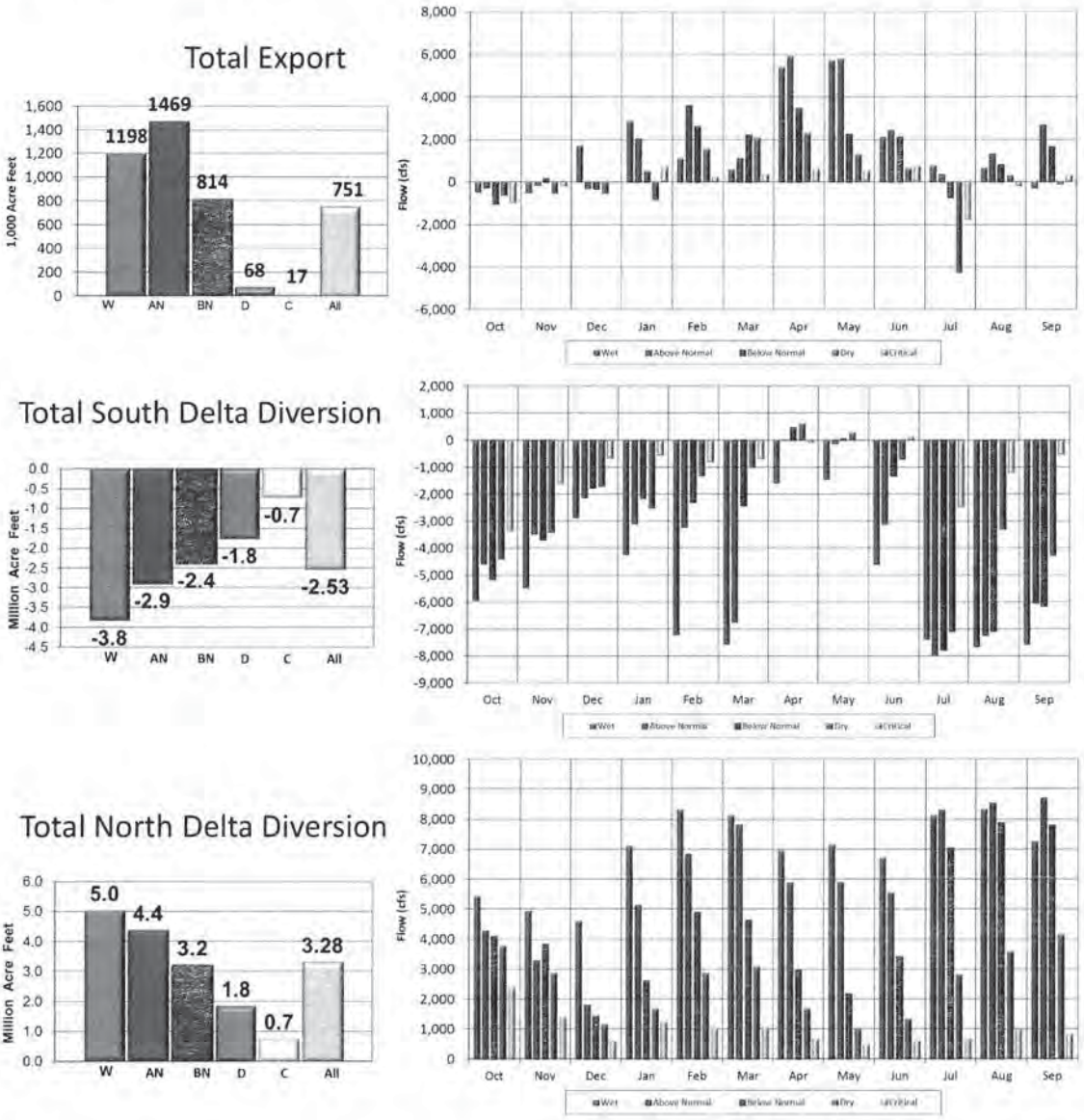
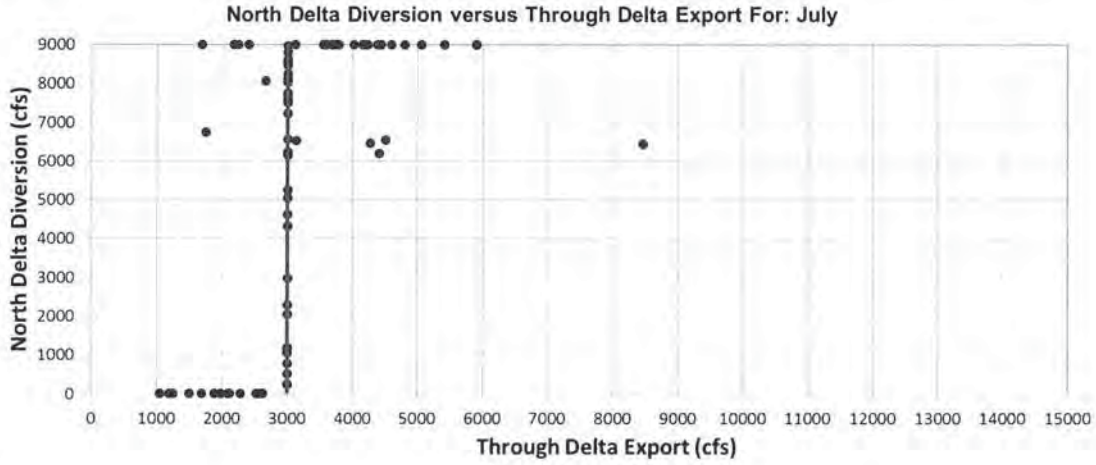
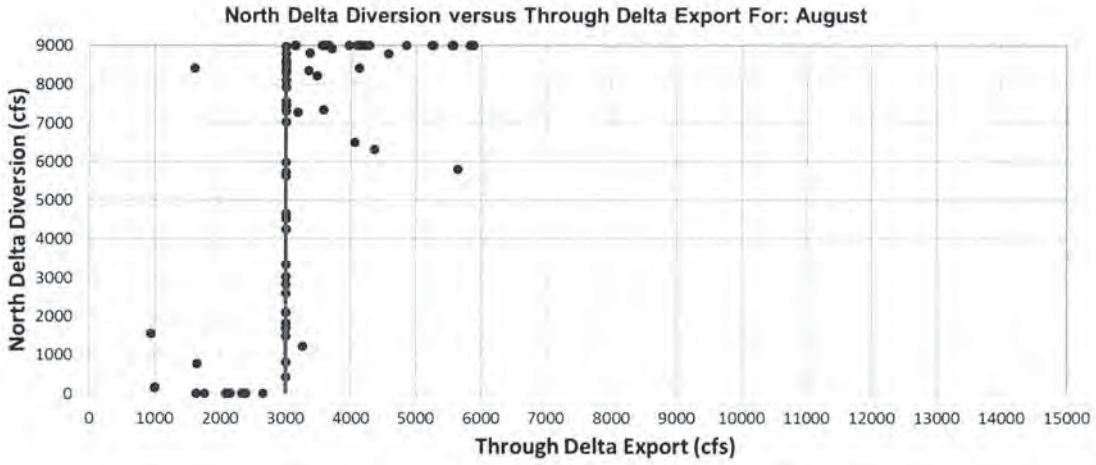
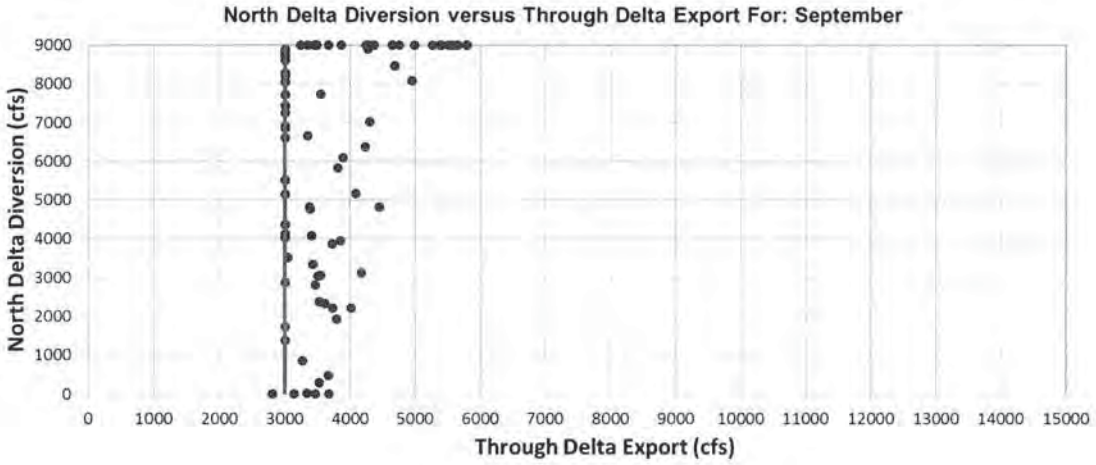


Figure 44 contains modeling results from Alt 4 for July, August, and September that plot NDD against SDD (Through Delta Export). There are many occasions when SDD are 3,000 cfs, which is due to criteria specifying that SDD during this time period need to be at least 3,000 cfs prior to diverting at the NDD facility. Although there are about six occurrences in July and three in August where the model did not satisfy this criterion, this issue has not yet been addressed for this modeling effort.

Figure 44. Alt 4 North Delta Diversion Versus South Delta Diversion for July, August, and September



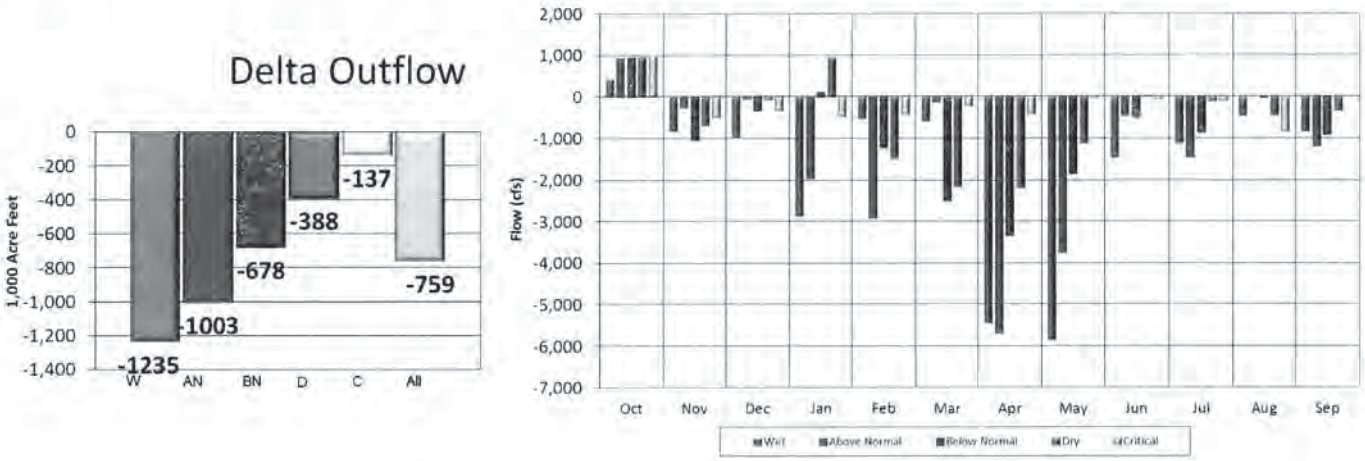




Delta Outflow

Figure 45 contains annual and monthly average changes in Delta outflow by water year type, average annual Delta outflow decreases about 760 TAF in the Alt 4 Scenario relative to the FNA Scenario. The decrease is primarily due to increases in Delta exports, which are about 750 TAF on average. Larger decreases generally occur in January through May when exports are constrained in the FNA Scenario and in the Alt 4 Scenario the NDD can be used to export water. Delta outflow increases in October due to the combination of additional OMR flow requirements that restrict exports and Sacramento River flow requirements at Rio Vista. The additional surplus Delta outflow in Alt 4 was minimized through coordination of the Delta Cross Channel Gate operations with the Rio Vista flow requirements and North Delta Diversion bypass requirements.

Figure 45. Changes in Delta Outflow (Alt 4 minus FNA)



Carryover Storage

Figure 46, Figure 47, Figure 48, and Figure 49 contain exceedance charts for carryover storage and average monthly changes in storage by Sacramento Valley Water Year Type for CVP and SWP upstream reservoirs. CVP/SWP reservoirs tend to be higher in the Alt 4 Scenario relative to the FNA on an average basis. Generally, CVP/SWP reservoirs are higher in storage in dryer year types and can be lower in wetter year types.

Ability to convey stored water from upstream CVP/SWP reservoirs to south of Delta water users is increased in Alt 4 relative to the FNA. Therefore, when upstream reservoirs are at higher storage levels more water is released to satisfy south of Delta water demands. This is the primary reason Shasta, Oroville, and Folsom tend to be lower during summer months of wetter years.

Currently, and in the FNA Scenario, the CVP and SWP ability to export natural flow, or unstored water, is constrained due to SWRCB D-1641 and requirements in the salmon and smelt biological opinions. With the greater ability to export unstored water during winter and spring months in the Alt 4 Scenario, compared to FNA, there is generally a reduced reliance on stored water to satisfy south of Delta demands. The increased ability to export unstored water allows the CVP and SWP to maintain higher storage levels in upstream reservoirs during dryer year types while still maintaining south of Delta deliveries. Carryover storage in the Alt 4 Scenario tends to be higher than the FNA Scenario at lower storage levels, and Alt 4 storage is lower in wetter years when storage levels are higher. In the wettest of years there is enough water in the system that both scenarios have similar carryover storage conditions.

Figure 46. Trinity Reservoir Carryover Storage and Average Monthly Changes in Storage by Water Year Type

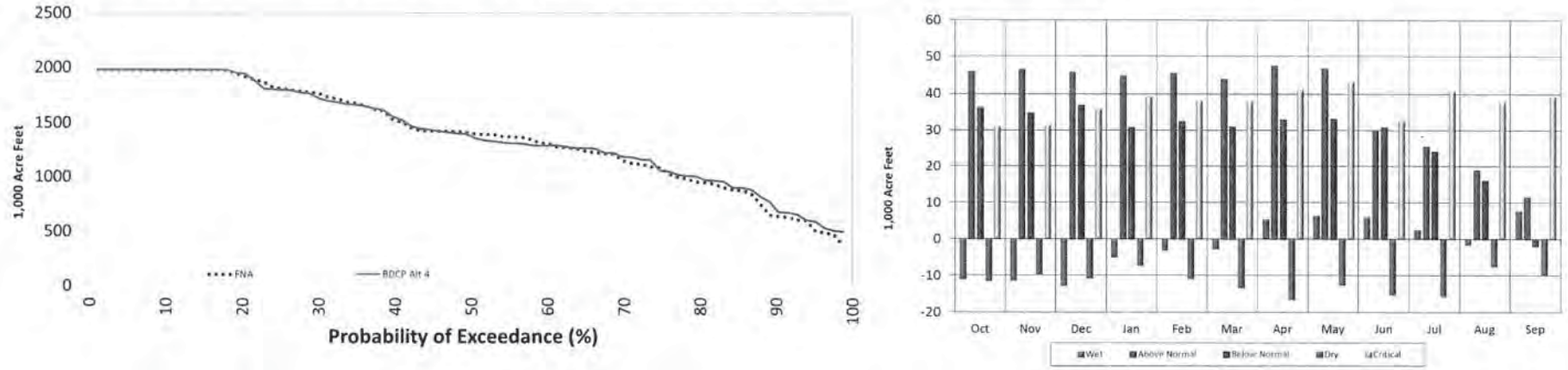
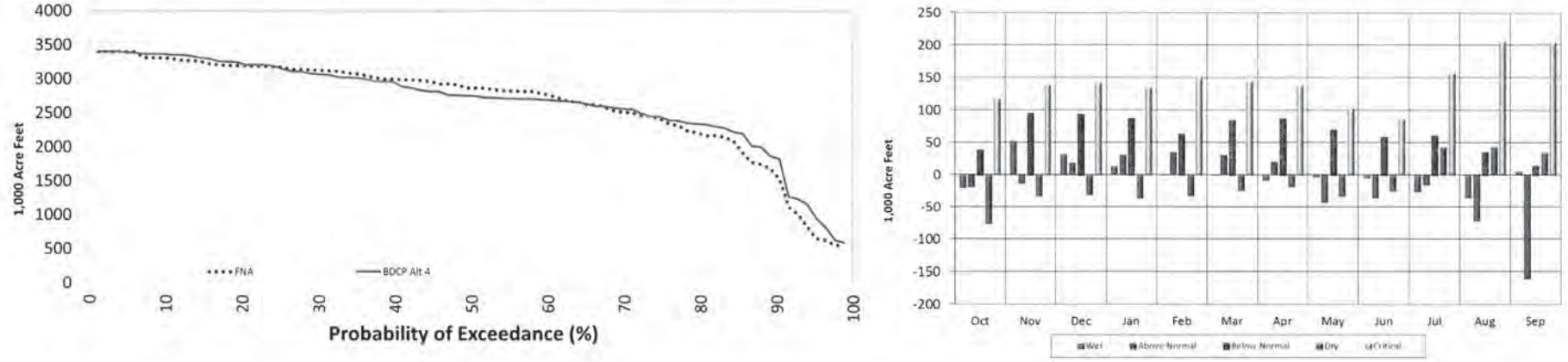


Figure 47. Shasta Reservoir Carryover Storage and Average Monthly Changes in Storage by Water Year Type



BDCP1563.

Figure 48. Oroville Reservoir Carryover Storage and Average Monthly Changes in Storage by Water Year Type

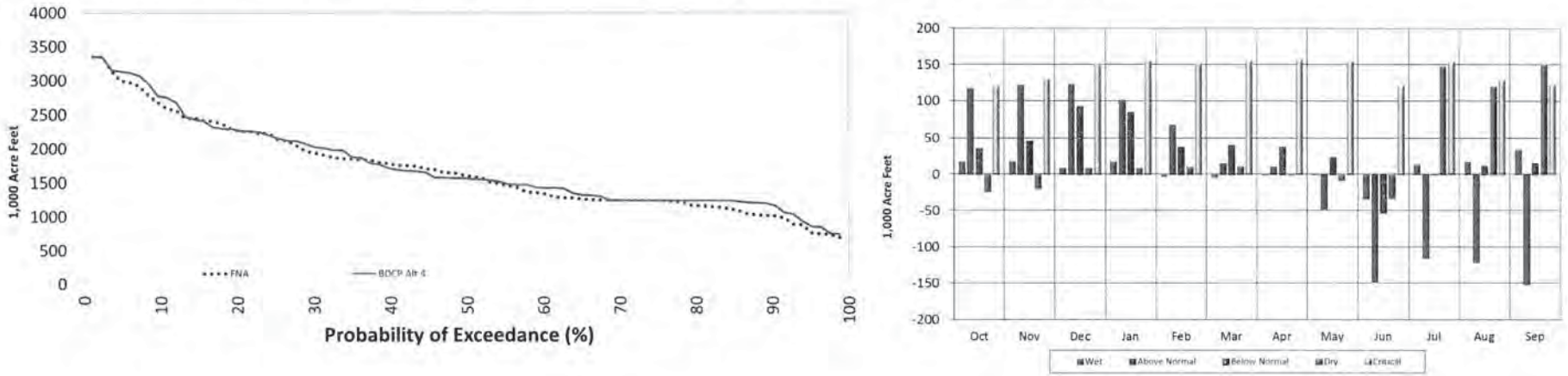
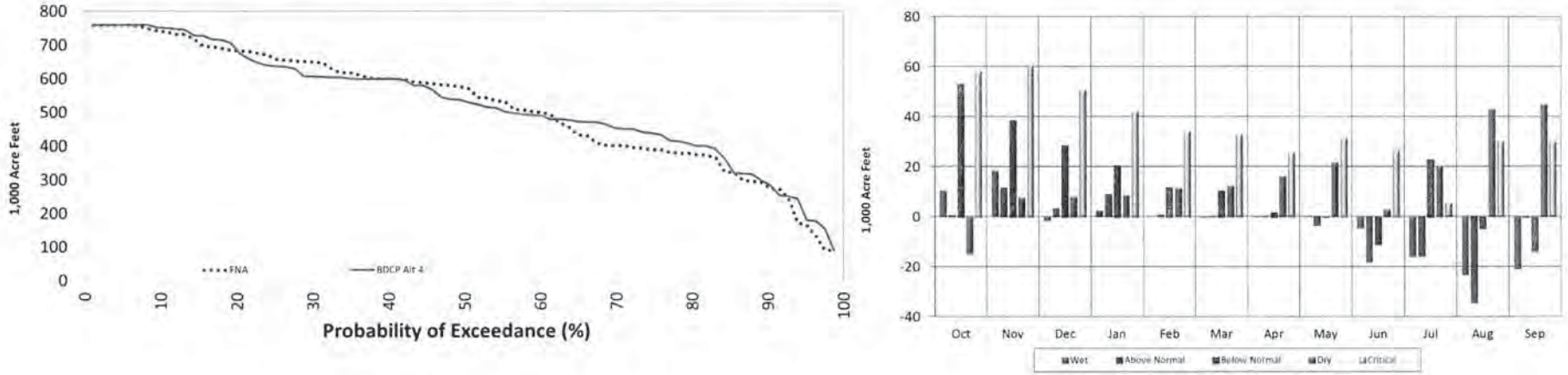


Figure 49. Folsom Reservoir Carryover Storage and Average Monthly Changes in Storage by Water Year Type



BDCP1563.

San Luis Reservoir Operations

As seen in Figure 50 and Figure 51 below, both CVP and SWP portions of San Luis Reservoir storage fills more regularly in the Alt 4 Scenario. As described earlier in this document, low point in both CVP and SWP San Luis Reservoir is managed to satisfy water supply obligations the model makes during the spring of each year. This is a complex balance involving available upstream storage, available conveyance capacity, delivery allocations, and south of Delta demand patterns. Considering this myriad of variables, there are times when low point in San Luis Reservoir is higher in the Alt 4 Scenario than the FNA Scenario and times when the opposite is true.

Figure 50. SWP San Luis

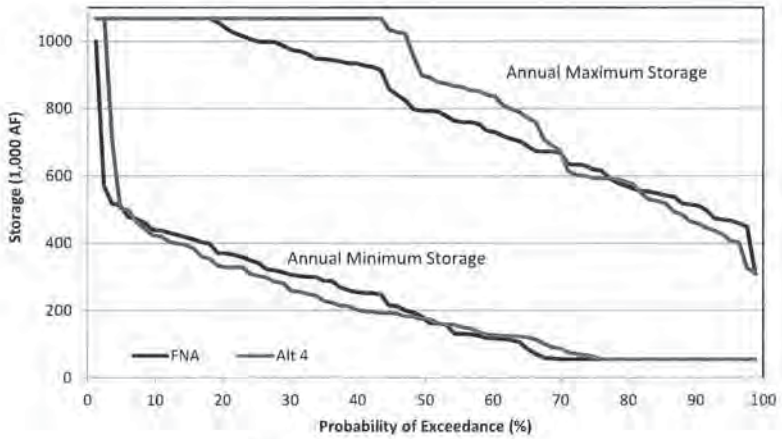
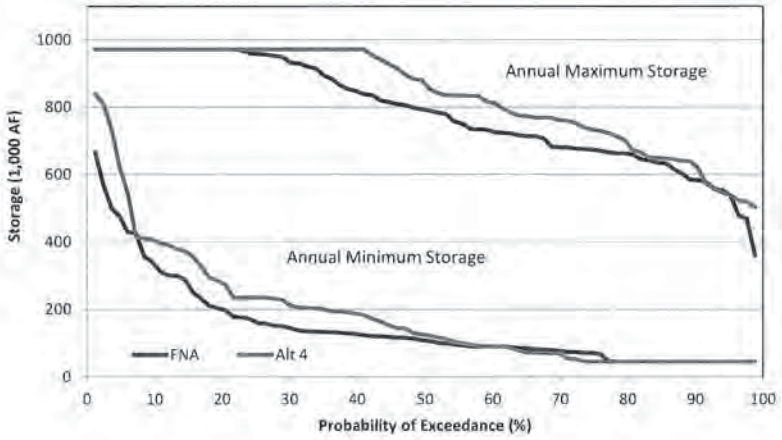


Figure 51. CVP San Luis



CVP Water Supply

As can be seen in Table 5, the independent modeling analysis shows an average increase of approximately 262 TAF of delivery accruing to CVP customers in the Alt 4 Scenario relative to the FNA Scenario, mostly occurring to CVP SOD agricultural customers. Delivery increases are greater in wetter year types with lower increases in dryer years. Figure 52 contains exceedance probability plots for CVP water service contractor deliveries and allocations. Changes in Sacramento River Settlement and San Joaquin River Exchange Contractor deliveries do not occur in the modeling analysis and are not an anticipated benefit of the BDCP. Although modeling demonstrates minor changes to NOD CVP service contractors, this increase is not an anticipated benefit of the BDCP.

Table 5. CVP Delivery Summary

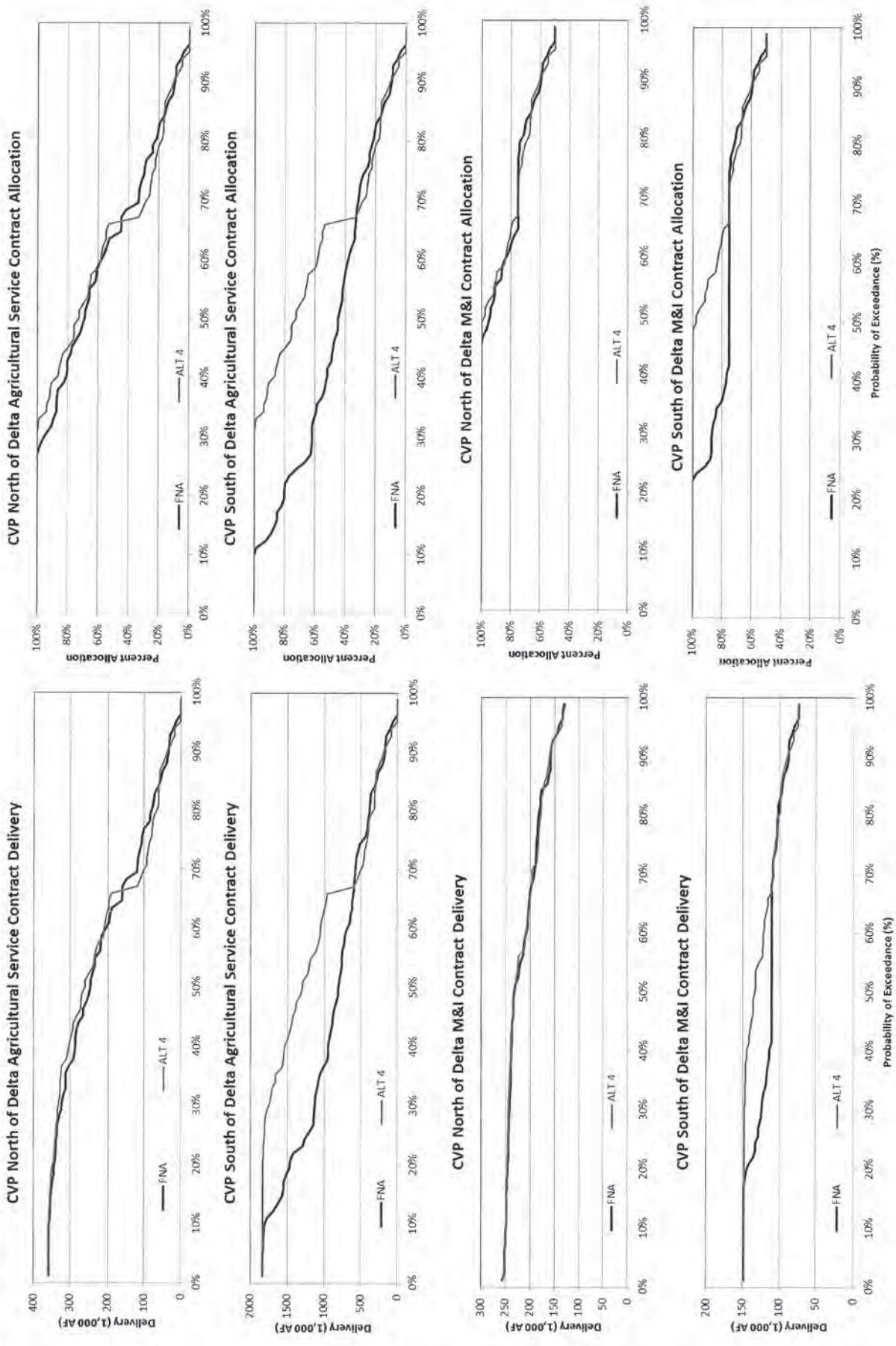
Average Annual CVP deliveries by Water Year Type FNA (1,000 AF)

	AG NOD	AG SOD	Exchange	M&I NOD	M&I SOD	Refuge NOD	Refuge SOD	Sac. Setlmnt	CVP NOD Total	CVP SOD Total
All Years	**220**	**882**	**852**	**214**	**116**	**87**	**273**	**1860**	**2380**	**2306**
W	327	1408	875	241	135	90	280	1856	2515	2881
AN	284	999	802	221	113	83	258	1716	2304	2341
BN	206	725	875	217	111	90	281	1900	2413	2176
D	138	569	864	195	106	88	277	1896	2317	2000
C	43	202	741	157	87	71	234	1754	2025	1447

Difference: Alt 4 minus FNA (1,000 AF)

	AG NOD	AG SOD	Exchange	M&I NOD	M&I SOD	Refuge NOD	Refuge SOD	Sac. Setlmnt	CVP NOD Total	CVP SOD Total
All Years	2	251	0	0	9	0	0	0	2	260
W	0	305	0	0	10	0	1	0	0	316
AN	10	492	0	1	14	1	0	-2	10	504
BN	12	354	0	5	16	0	-2	1	19	366
D	-10	67	0	-4	4	1	0	-1	-15	72
C	2	27	0	2	2	1	0	-1	4	29

Figure 52. CVP Water Supply Delivery and Allocation



SWP Water Supply

The independent analysis shows an increase in average annual SWP SOD deliveries of approximately 450 TAF, but a reduction in critical year deliveries of approximately 116 TAF. Annual average Article 21 deliveries increase by about 100 TAF and Article 56 increases by about 18 TAF. Figure 53 contains exceedance probability plots for SWP SOD deliveries for the FNA and Alt 4 Scenarios, each of these plots show increases in higher delivery years. Although Table A deliveries increase in 65% of years, there are decreases in 35% of the dryer years (see Table 6).

Table 6. SWP Delivery Summary

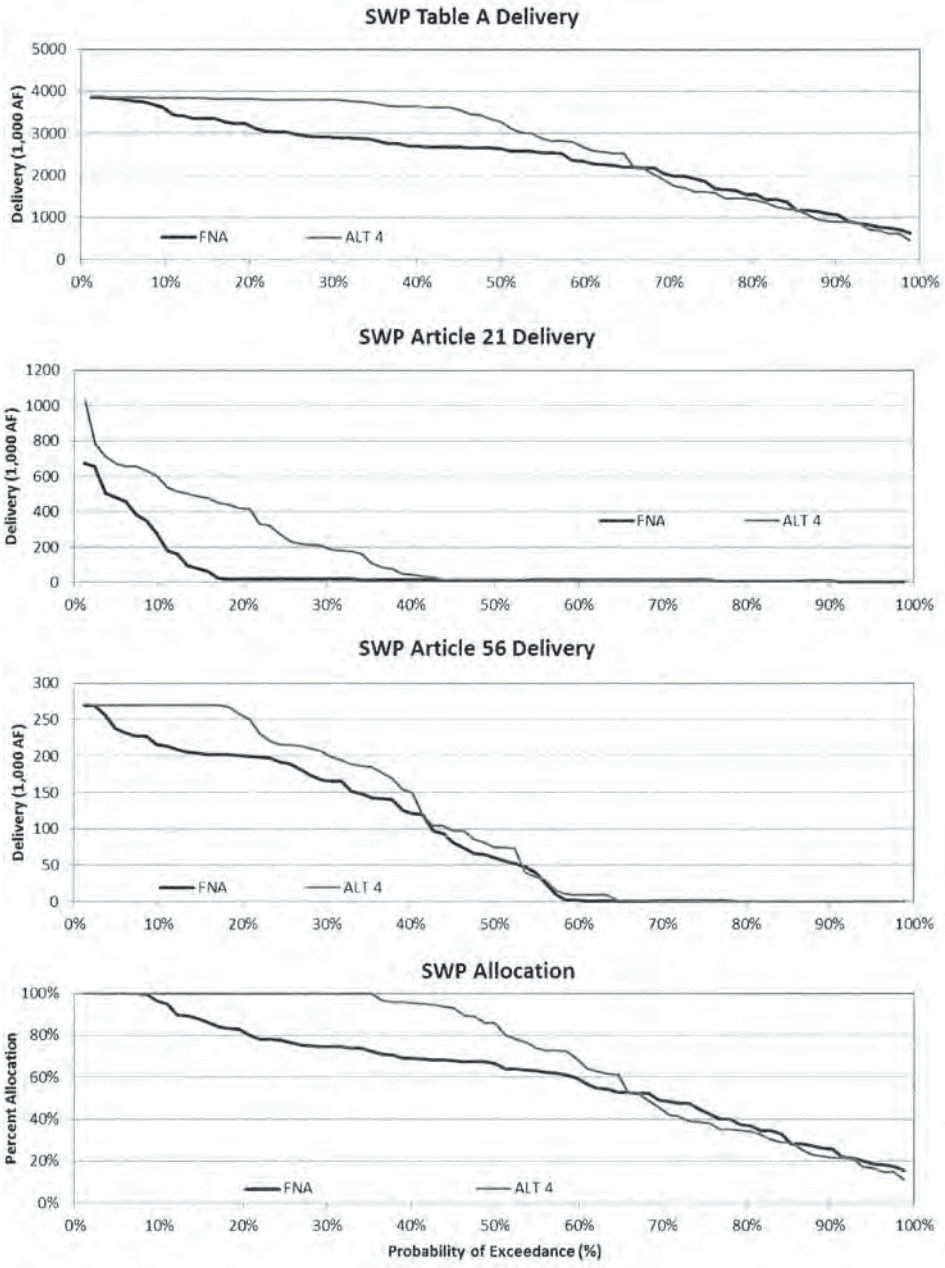
FNA

	Table A	Art. 21	Art. 56	Total
All Years	**2426**	**64**	**90**	**2580**
W	3221	98	121	3440
AN	2628	86	81	2794
BN	2527	82	95	2703
D	1809	14	70	1893
C	1105	17	48	1170

Difference Alt4 minus FNA

	Table A	Art. 21	Art. 56	Total
All Years	328	102	18	448
W	525	220	14	759
AN	636	98	-1	733
BN	565	50	31	647
D	-63	41	27	6
C	-124	-8	16	-116

Figure 53. SWP Delivery for Alt 4 and FNA



4 COMPARING INDEPENDENT MODELING AND BDCP MODELING

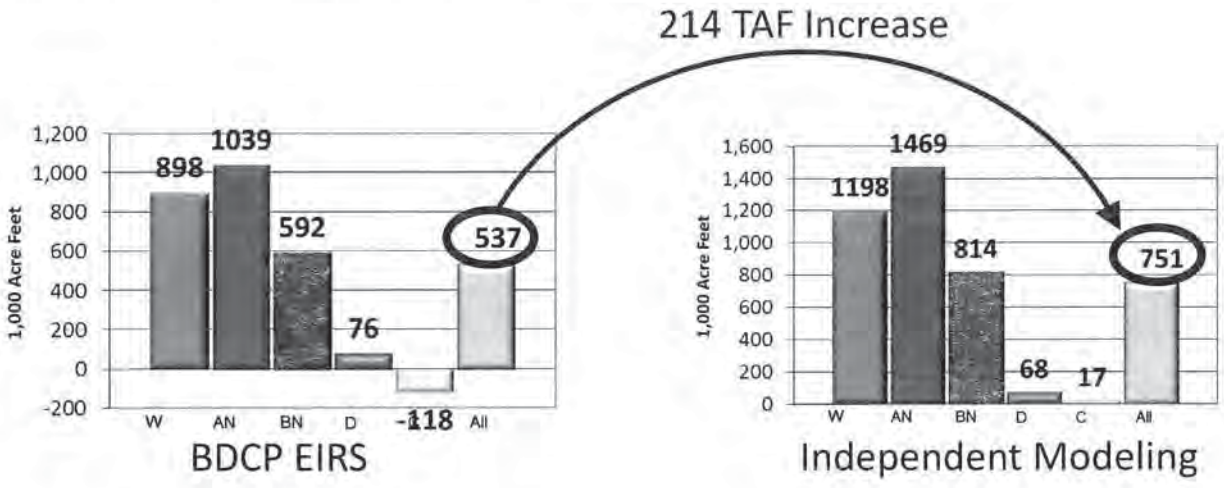
The independent modeling effort originally stemmed from reviews of DWR's BDCP modeling where we found that BDCP modeling does not provide adequate information to determine how BDCP may affect the system. Based on the premise that the independent modeling portrays a more accurate characterization of how the CVP/SWP system may operate under Alt 4, this comparison is meant to demonstrate the differences between results of a more accurate analysis and BDCP modeling. Differences in results between these modeling efforts are believed to provide insight regarding how effects that BDCP will have on the actual CVP/SWP system differ from modeling used to support the Draft EIRS.

Although thorough comparisons of modeling were performed, only key differences are illustrated for the purpose of this comparison.

Delta Exports

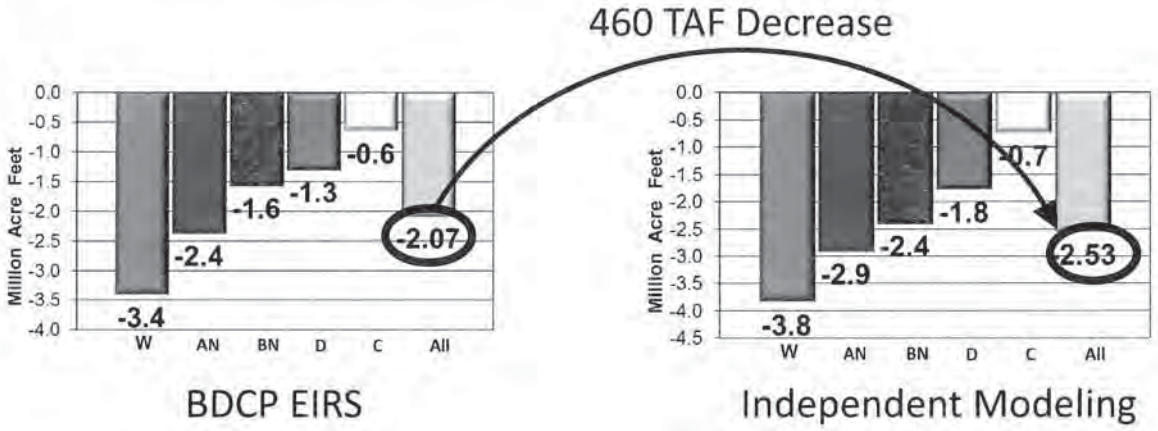
Figure 54 displays changes in the Delta exports for the BDCP modeling (Alt 4-ELT minus NAA-ELT) and for the independent modeling (Alt 4 minus FNA). Independent modeling analysis shows about 200 TAF greater increases in exports than the BDCP modeling. A large component of this difference is due to fixes of known modeling issues, as described in the 2013 SWP DRR. This difference is also attributable to more realistic reservoir operations, more efficient DCC gate operations, changes in water supply allocation logic, and more efficient operation of the NDD.

Figure 54. Result Difference: Delta Exports



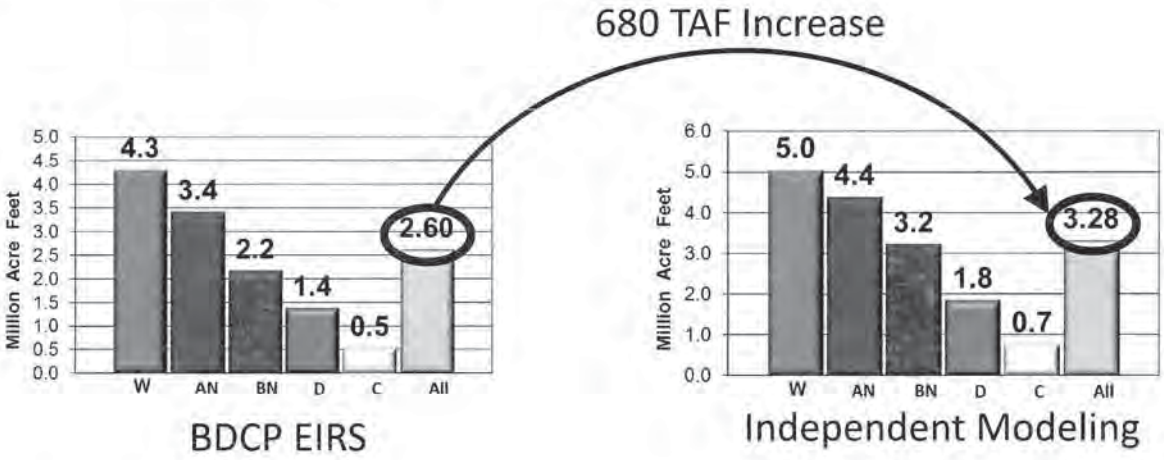
Average annual SDD are decreased by about 460 TAF in the independent analysis compared to the BDCP modeling. A large component of this difference is due to fixes of known modeling issues, as described in the 2013 SWP DRR. These fixes prevent "artificial" bypass criteria from limiting use of the NDD beyond what is intended in the BDCP project description. This difference is also attributable to more efficient DCC gate operations and more efficient operation of the NDD. Figure 55 demonstrates the difference between the BDCP and independent analysis, where SDD decrease by 2.07 MAF in the BDCP analysis and by 2.53 MAF in the independent analysis.

Figure 55. Result Difference: South Delta Diversion



Use of the NDD is 680 TAF greater in the independent analysis relative to the BDCP analysis. A large component of this difference is due to fixes of known modeling issues, as described in the 2013 SWP DRR. These fixes prevent "artificial" bypass criteria from limiting use of the NDD beyond what is described in the BDCP project description. Figure 56 compares average annual NDD in the BDCP to the independent analysis.

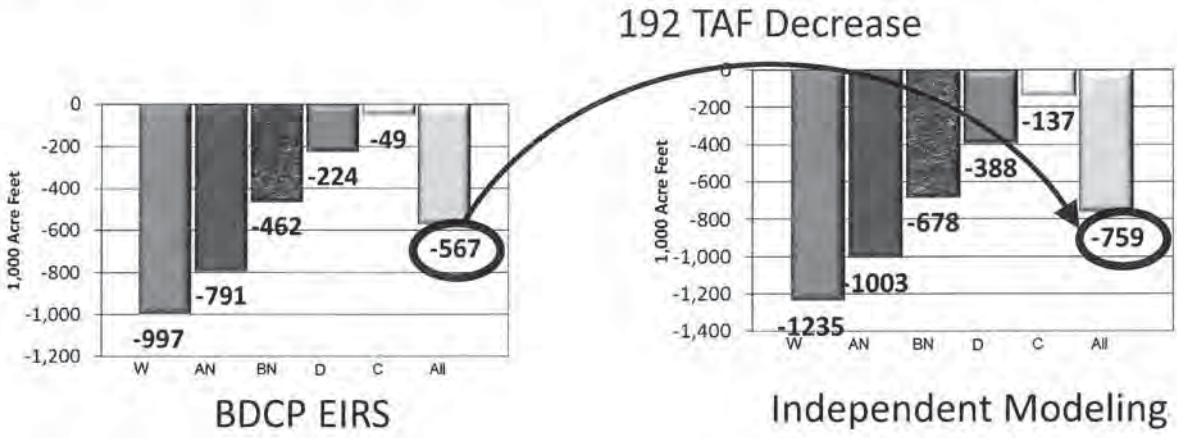
Figure 56. Result Difference: North Delta Diversion



Delta Outflow

Total Delta exports in the independent analysis are about 200 TAF greater than the BDCP modeling analysis with a corresponding decrease in Delta outflow in the independent analysis of about 200 TAF. Figure 57 compares average annual changes in Delta outflow between the independent analysis and BDCP modeling, BDCP modeling shows a decrease of about 567 TAF and the independent analysis shows a decrease of about 759 TAF.

Figure 57. Result Difference: Net Delta Outflow



Reservoir Storage

Reservoir operating rules for Alt4 in the BDCP EIRS modeling are changed relative to the NAA. In the BDCP EIRS modeling of Alt 4 rules are set to releases more water from upstream reservoirs to San Luis Reservoir from late winter through July, reduce releases in August, and then minimize releases to drive San Luis Reservoir to dead pool from September through December. This operation is inconsistent with actual operations and causes reductions in upstream storage from May through August. Figure 58 and Figure 59 contain exceedance probability plots of carryover storage and average monthly changes in storage by water year type for Shasta and Folsom for the BDCP and independent modeling. Although carryover storage for Alt 4 and the NAA is similar in the BDCP EIRS modeling, there is drawdown from June through August that may cause impacts to cold water pool management. In the independent modeling upstream reservoirs are drawn down more in years when storage is available while dryer year storage is maintained at higher levels, this is illustrated in the carryover plots for Shasta and Folsom in Figure 58 and Figure 59.

Figure 58. Result Difference: Shasta Storage

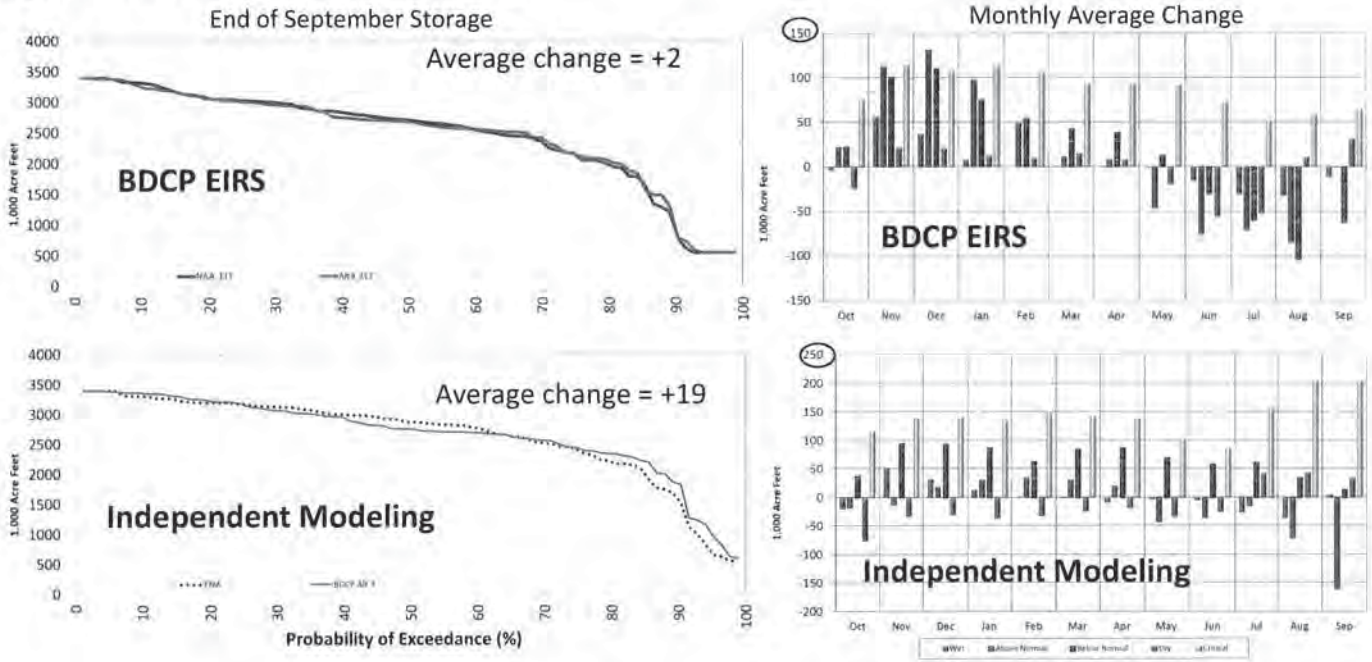
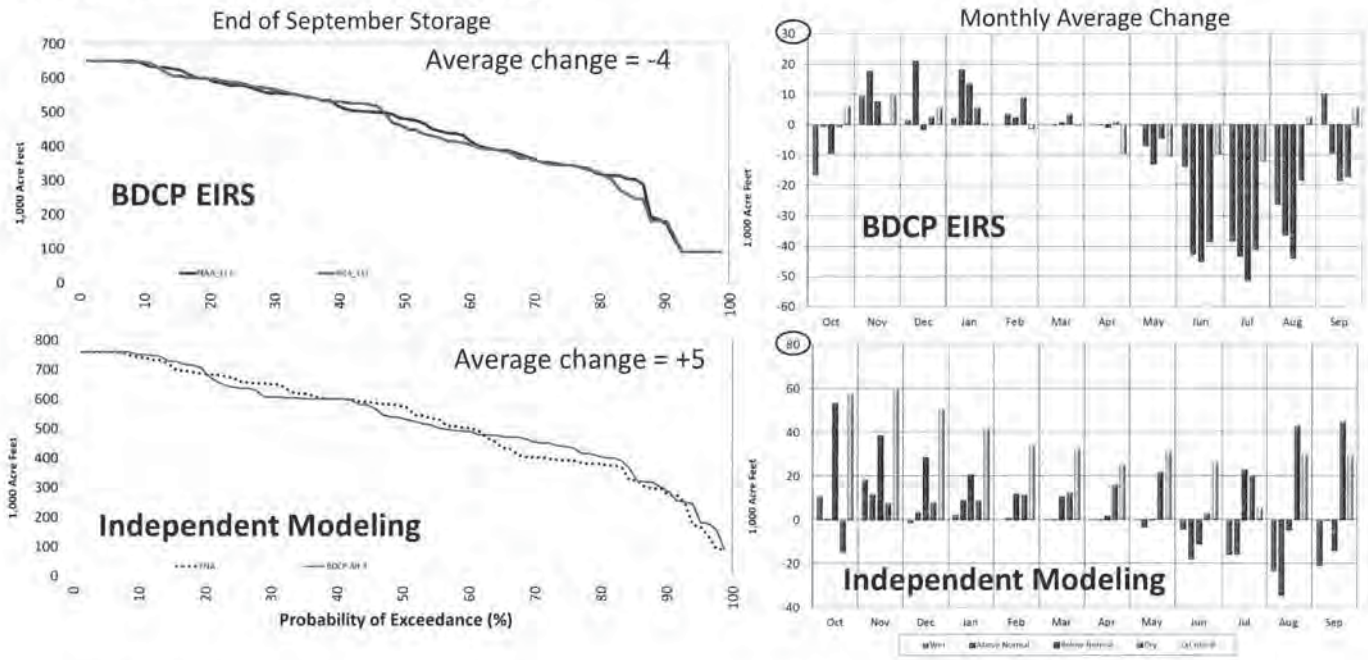


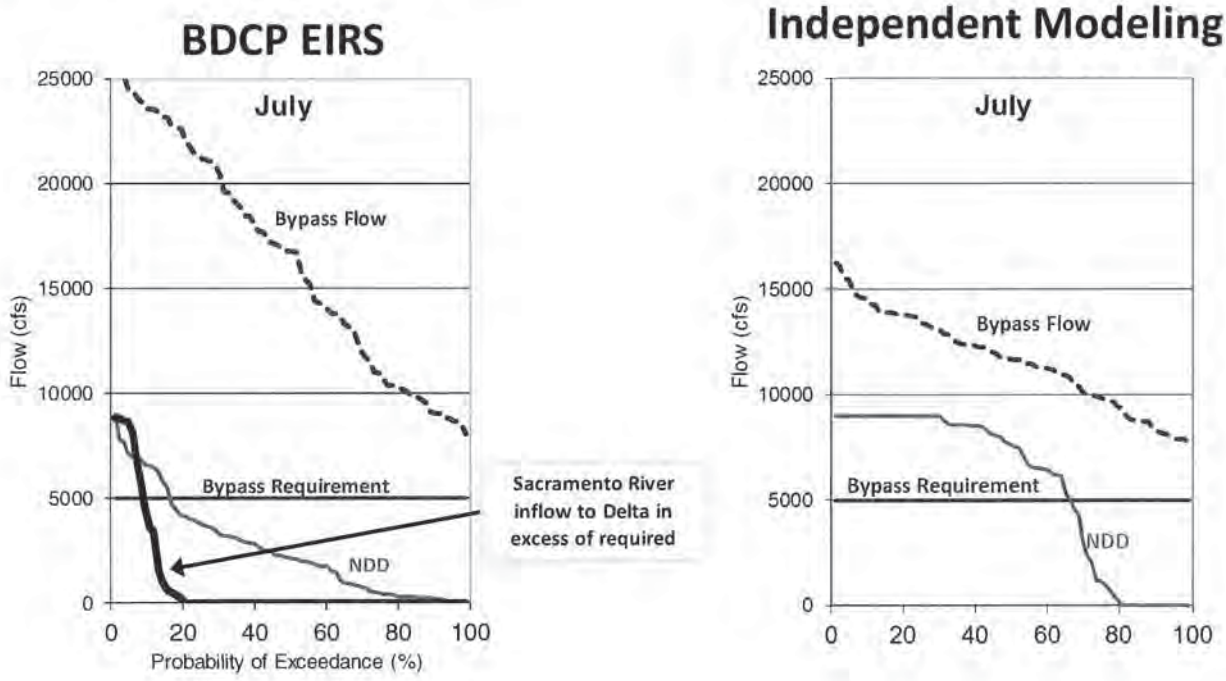
Figure 59. Result Difference: Folsom Storage



North Delta Diversions

Independent modeling shows greater NDD during July and other months because the BDCP EIRS modeling includes artificially high Sacramento River bypass flow requirements. Figure 60 contains exceedance probability plots of Sacramento River required bypass, Sacramento River bypass flow, NDD, and excess Sacramento River flow to the Delta. As can be seen in Figure 60, bypass flow is always above the bypass requirement. The BDCP version of CalSim sets a requirement for Sacramento River inflow to the Delta that the independent modeling does not need in order to satisfy Delta requirements, therefore the NDD is higher in the independent modeling.

Figure 60. NDD, and Sacramento River Flow



Delta flows below the NDD facility

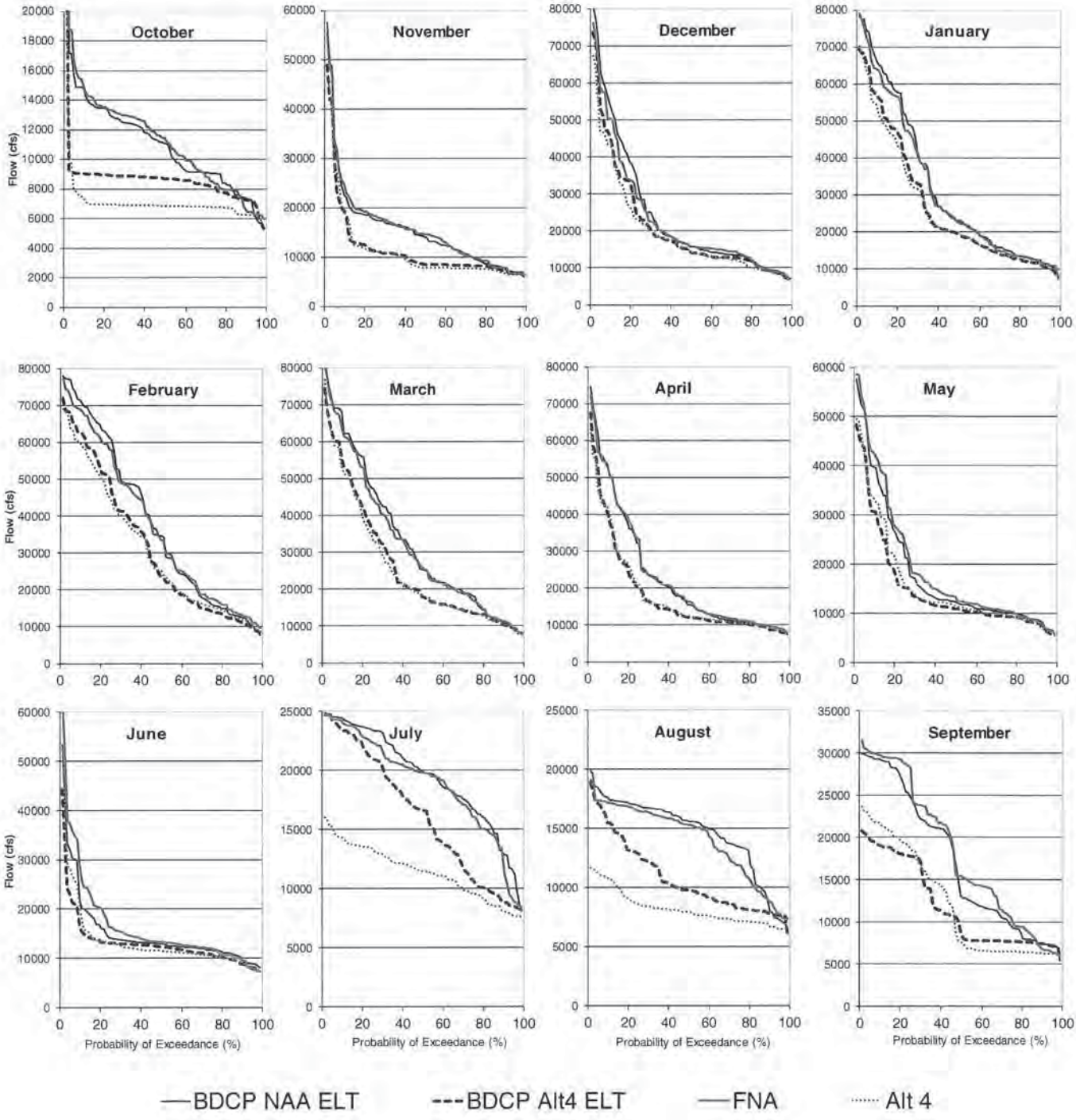
Figure 61 contains monthly exceedance probability plots for Sacramento River below the NDD for the following scenarios: 1) BDCP NAA-ELT, 2) BDCP Alt 4-ELT, 3) independent modeling FNA, and 4) independent modeling Alt 4. The most significant differences in flow changes occur in October, July, August, and September. Changes in Sacramento River flow entering the Delta are a key indicator of changes in interior Delta flows, water levels, and water quality.

For the month of October the independent modeling shows flow below the NDD to be about 2,000 cfs lower than the BDCP modeling. The difference in this month is largely due to reoperation (closure) of the cross channel gate to lessen the amount of Sacramento River flow at Hood necessary to maintain Rio Vista flow requirements downstream of the cross channel gates.

The most substantial difference between the BDCP and independent modeling occurs in July and August. The differences in these two months are primarily attributable to model fixes that have occurred since the BDCP modeling was performed. In the independent modeling, July flows are reduced on average about 7,500 cfs while BDCP shows a reduction of about 3,300 cfs. In the independent modeling August flows are reduced on average about 5,900 cfs while BDCP shows a reduction of about 3,900 cfs.

In the independent modeling September flows are reduced by about 6,100 cfs while BDCP modeling shows a reduction of about 5,300 cfs. The independent modeling shows Sacramento River flow entering the Delta to be about 7,000 cfs 50% of the time, BDCP modeling show Sacramento River flow is about 8,000 cfs 50% of the time.

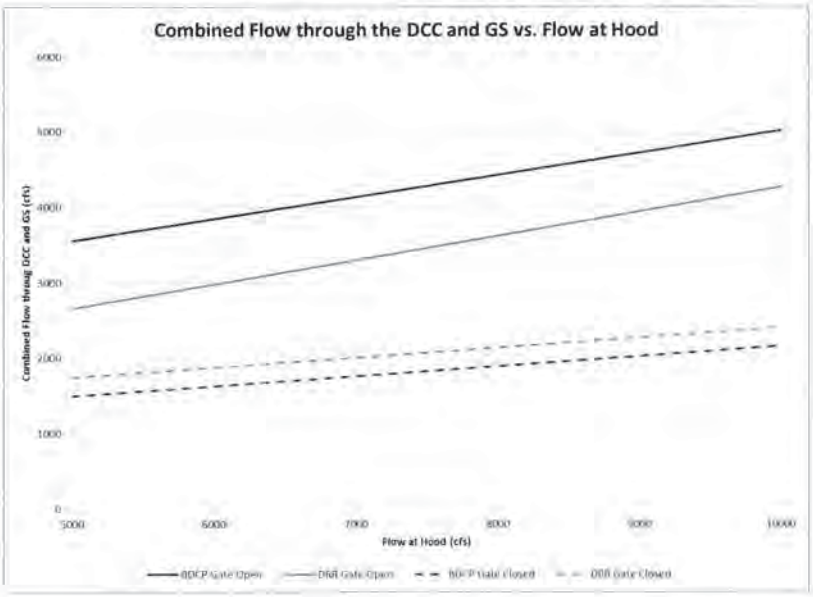
Figure 61. Sacramento River below Hood



Sacramento River water entering the Central Delta

In CalSim, flow through the DCC gate and Georgianna Slough from the Sacramento River into the Central Delta is assumed to be linearly dependent on flow at Hood. There are two linear relationships; one is used when the DCC gates are closed, and the other is used when the DCC gates are open. The 2013 SWP Delivery Reliability Report CalSim II modeling, and therefore our independent modeling, used different linear flow relationships than BDCP. The BDCP and 2013 DRR (and independent) flow relationships for both the open and closed gate conditions are compared in Figure 62. When Sacramento River flow at Hood is in the range from 5,000 cfs to 10,000 cfs the balance between Hood flow, required flow at Rio Vista, and DCC gate operation can affect upstream reservoir operations, SOD exports, and Delta outflow. As shown in Figure 62, given the same flow at Hood and DCC gates closed, the independent analysis will show slightly higher flow into the Central Delta (12% to 17% difference for the Hood flows in the 5,000 cfs to 10,000 cfs range). With DCC gates open the same flow at Hood, the independent analysis will show lower flow into the Central Delta (-15% to -25% difference for the Hood 5,000 cfs to 10,000 cfs range). Figure 63 and Figure 64 show the differences through the DCC and combined flow through the DCC and Georgiana Slough.

Figure 62. Flow through Delta Cross Channel and Georgiana Slough versus Sacramento River Flow at Hood



In addition to the differences in flow equations for portion of Sacramento River entering the interior Delta through the DCC and Georgiana Slough, the DCC gate operations were modified for the month of October. In the independent modeling, the DCC gate is operated to balance the amount of Sacramento River flow needed to meet flow standards at Rio Vista on the Sacramento River and flow needed to meet western Delta water quality. This changed operation often results in DCC gate closures for about 15 days during the month of October. The reduction in flow through the DCC during October can be seen in Figure 64.

Figure 63. Cross Channel Flow

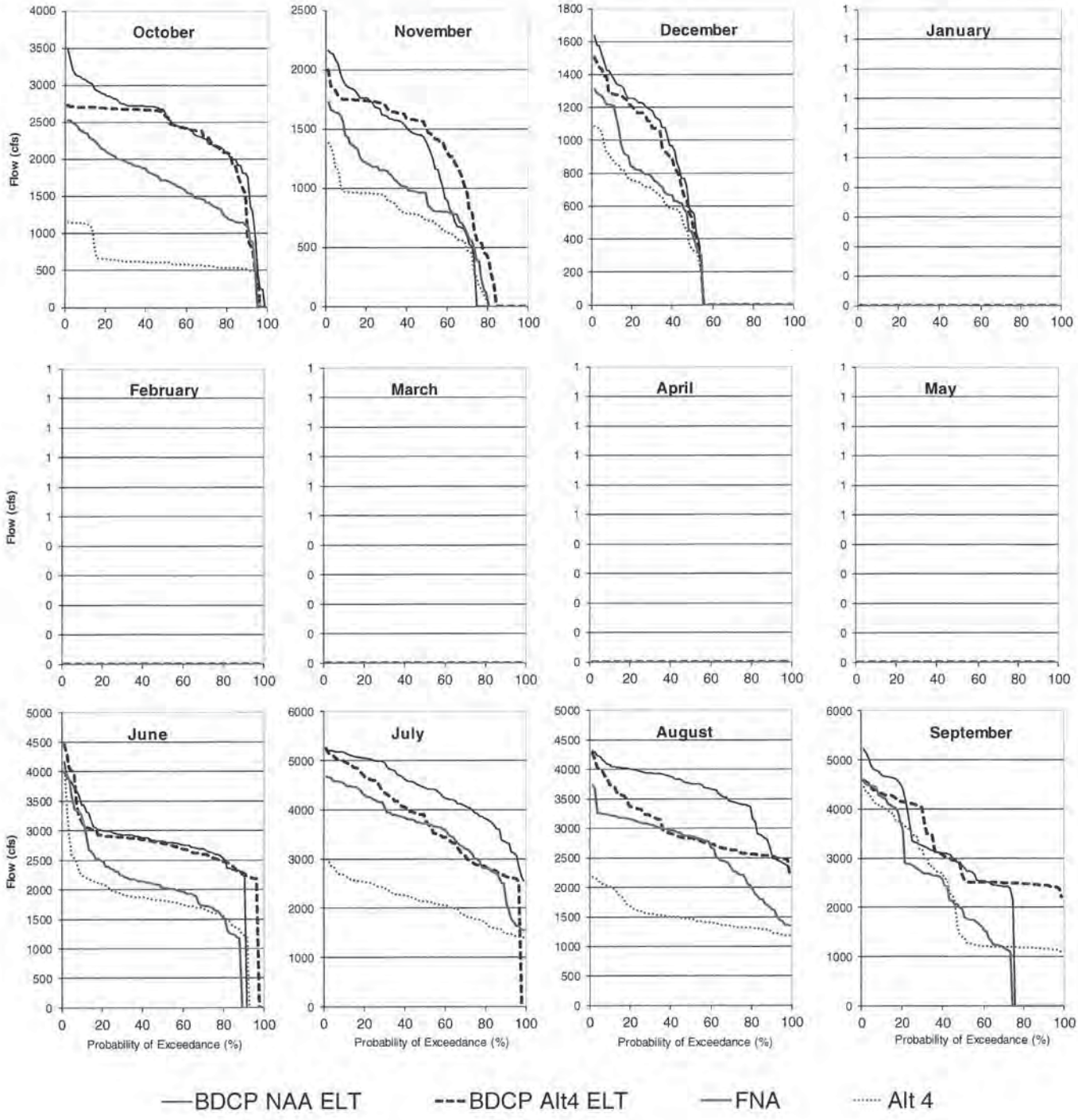
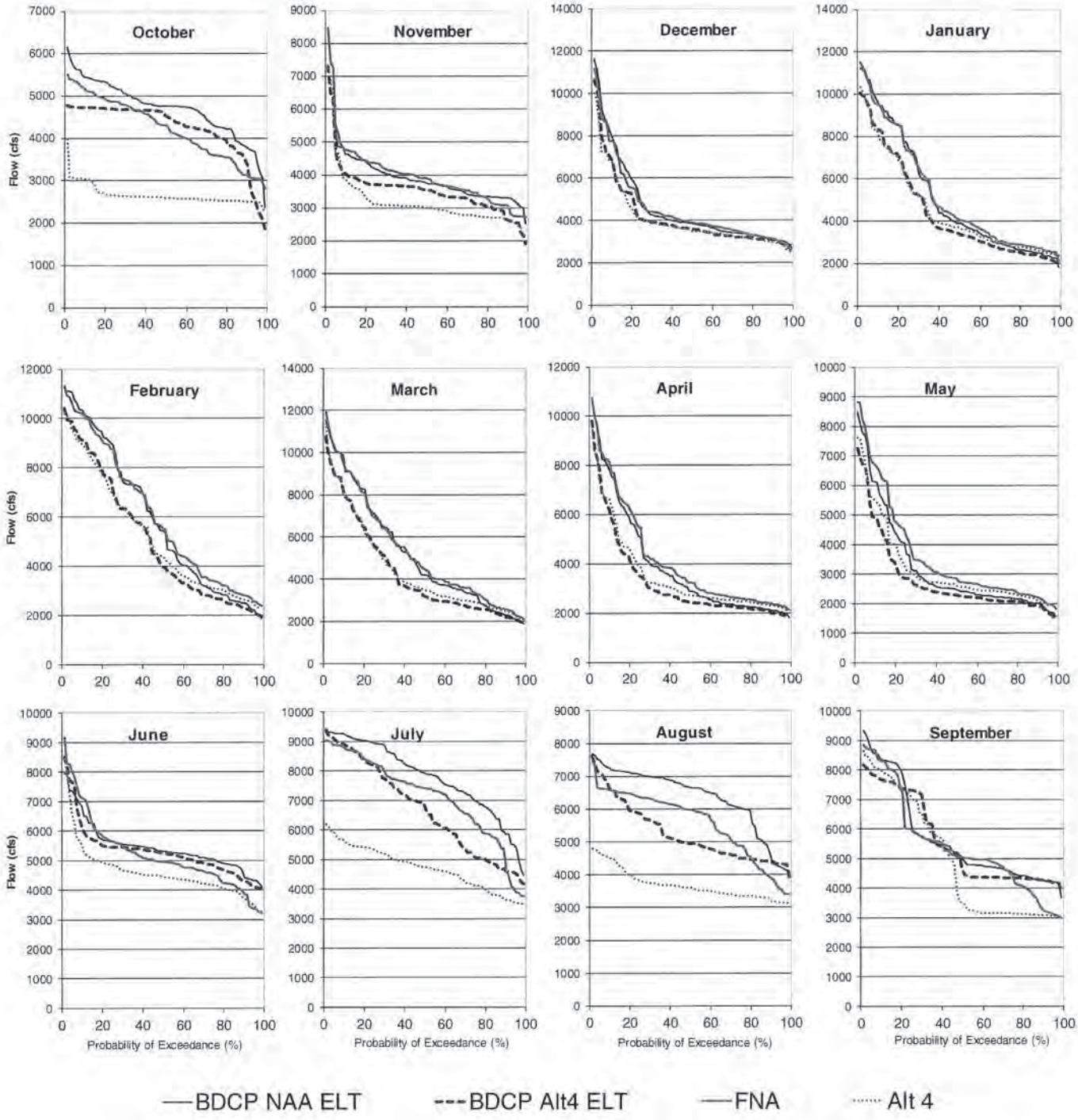


Figure 64. Flow through Delta Cross Channel and Georgiana Slough



Conclusions regarding BDCP effects

Based on the Independent Modeling, the amount of water exported (diverted from the Delta) may be approximately 200 thousand acre-feet (TAF) per year higher than the amount disclosed in the Draft EIR/S. This total represents

- approximately 40 TAF/yr more water diverted and delivered to the SWP south of Delta contractors, and
- approximately 160 TAF/yr more water diverted and delivered to the CVP south of Delta contractors.

The BDCP Model estimates that, under the NAA ELT (without the BDCP), total average annual exports for CVP and SWP combined are estimated to be 4.73 million acre feet (MAF) and in the Independent Modeling FNA combined exports are 5.61 MAF. The BDCP Model indicates an increase in exports of approximately 540 TAF and the Independent Modeling shows an increase of approximately 750 TAF in Alt 4.

The Independent Modeling suggests that Delta outflow would decrease by approximately 200 TAF/yr compared to the amount indicated in the Draft EIR/S.

- This lesser amount of Delta outflow has the potential to cause greater water quality and supply impacts for in-Delta beneficial uses and additional adverse effects on species. To determine the potential effects of the reduced amount of outflow, additional modeling is needed using tools such as DSM2.

The BDCP Model does not accurately reflect the location of the diversions that the SWP and CVP will make from the Delta.

- When the errors in the model are corrected, it reveals that the North Delta intakes could divert approximately 680 TAF/yr more than what was disclosed in the BDCP Draft EIR/S, and
- the amount of water diverted at the existing South Delta facilities would be approximately 460 TAF/yr less than what is projected in the BDCP Draft EIR/S.

Hydrologic modeling of BDCP alternatives using CalSim II has not been refined enough to understand how BDCP may affect CVP and SWP operations and changes in Delta flow dynamics. Better defined operating criteria for project alternatives is needed along with adequate modeling rules to analyze how BDCP may affect water operations. Without a clear understanding of how BDCP may change operations, affects analysis based on this modeling may not produce reliable results and should be revised as improved modeling is developed.

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Southern California World Water Forum

Innovative Conservation, Technology, Policy and Communications Grants for Southern California Universities and Community Colleges

Project Overview

Grants of $10,000 will be awarded for research and development on the implementation of water-use efficiency technology, policy research and communication strategies that can be cost-effectively implemented in Southern California and internationally, including developing nations.

In accordance with the 2002 UN World Summit on Sustainable Development in Johannesburg, South Africa, "...proposals should improve efficient use of water resources...while preserving or restoring ecological integrity, with human domestic or industrial and agricultural needs."

CO E E EA S S DO A OF E FO OW N

Design a project, rendering or prototype with a local or global focus of either:
- An applied research concept (i.e., local watersheds)
- An efficient water-use technology or process
- A communications strategy

Develop a business plan for implementation that includes:
- A budget
- Timeline
- An environmental, financial, societal and public policy implementation of the proposed concept, technology or process
- An estimate of project benefits

Complete a final report that provides:
- A summary of research and outcomes
- Qualitative and quantitative benefits
- Evidence that the project could become fully sustainable

Contact

Please contact Benita Lynn Horn at (888) 42-WATER (1-888-429-2837) if you have any questions.

Calendar

World Water Forum Grant Recipients 2011-2013

Co-Sponsoring Organizations and Resources

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P O A SC ED E

FA Grant funds disbursed and projects' research and development phase begins
W N E Conduct on-site visits, research stage is completed; progress reports submitted
SP N WWF Expo to showcase grant recipient projects

Links to current grant recipient's project proposals:

- California State University, Long Beach
- Fullerton College
- Loma Linda University
- Loyola Marymount University
- Loyola Marymount University
- Mt. San Antonio College
- Pasadena City College
- San Diego State University
- San Diego State University
- UCLA
- UC Riverside
- UC Riverside

- UC Santa Barbara
- UC Santa Barbara
- Woodbury University

Eligibility

This is an inter-disciplinary project -- student teams from the following schools or Institutes for Water Resources are eligible to apply:

Communications	Civil Engineering
Agriculture	Political Science
Communications	Landscape Irrigation Science
International Studies	Economics
Urban Planning	Public Administration
Geography	Environmental Science

Program Background

The **nternational Decade of Fresh Water** (2005 to 2015) was proclaimed by the United Nations to raise awareness about global water issues. To underscore the importance of water quality and conservation issues, Metropolitan has partnered with several local and national organizations by hosting a grant competition for local colleges and universities.

Creating new water conservation technologies, policies or communications programs will result in generating student interest in engineering, environmental science and related careers in the water industry, while promoting economic and workforce development in Southern California. It will help establish much-needed cost-effective prototypes in Southern California and internationally, including developing nations.

Information

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The Human Right to Water & Sanitation
Water Conservation Field Services Program
Water for People: An Introduction
Water for People: World Water Corps
Water Recycling: Just Doing What Comes Naturally

Spring E po

At the Spring Expo, the college teams presented their final projects to industry professionals and the program sponsors.
Spring Expo Photos

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A *N*-Nitrosodimethylamine (NDMA) precursor analysis for chlorination of water and wastewater

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Abstract

N-nitrosodimethylamine (NDMA) is a potent carcinogen formed during chloramination of water and wastewater treatment plant effluents. A procedure is described for quantifying the concentration of the organic precursors of NDMA that could be formed during chlorination of wastewaters and natural waters. The method involves applying a high dose of monochloramine to a pH-buffered sample followed by a 10-day contact period, during which the monochloramine decays at a rate unrelated to the composition of the sample. Analyses of samples of municipal wastewater effluents and surface waters indicate that the method provides a robust and reproducible measurement of NDMA precursors over a wide range of conditions. A sensitive GC/CI/MS/MS analytical procedure for dimethylamine also is described and used to demonstrate that NDMA formation during chlorination of wastewater and natural waters cannot be explained by dimethylamine concentrations alone.
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Keywords: Dimethylamine; Precursor; Disinfection byproduct; Surface water; Nitrosamine

1. Introduction

Recently, several water agencies in California have observed the presence of the potent carcinogen *N*-nitrosodimethylamine (NDMA) in drinking water supplies [1]. In response, the California Department of Health Services has set an action level of 10 ng/L for NDMA [2]. The presence of NDMA is particularly important in locations where wastewater effluents are used for indirect potable reuse because chlorination of wastewater effluents leads to formation of relatively high concentrations of NDMA [3]. For example, two drinking water production wells, under the influence of recharge water from the reverse osmosis wastewater treatment system of the Orange County Water District's Water Factory 21, recently suspended operations due to their inability to meet the previous 20 ng/L interim action level [4]. Groundwater injection of treated wastewater from Water Factory 21 was reduced from 0.31 to 0.04 m^3/s pending the installation of an expensive ultraviolet treatment system to remove the NDMA prior to injection [5]. Under conditions employed during chlorine disinfection, NDMA formation can exceed 100 ng/L during chlorination of secondary wastewater effluent [6,7], whereas chlorination of surface waters typically results in the formation of less than 10 ng/L of NDMA [6,8].

In previous studies, it has been shown that the formation of NDMA during chlorination can be explained by the slow reaction of monochloramine with dimethylamine to form an unsymmetrical dimethylhydrazine (UDMH) intermediate [3,9,10]. The UDMH intermediate is rapidly oxidized by monochloramine or other oxidants to form NDMA and a variety of other products. The formation rate is highest between pH 6 and 8, the pH range over which chlorination is usually conducted. Overall, the reaction results in the slow formation of NDMA at low yields (less than 12%

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compared to total chlorine loss after 1 week). Chlorination using hypochlorite results in the formation of approximately an order of magnitude less NDMA than chlorination using monochloramine [3,9].

As part of our previous research, we found that, in addition to dimethylamine, tertiary amines containing dimethylamine functional groups also serve as NDMA precursors [3]. However, the rates of NDMA formation from chloramination of these compounds is approximately an order of magnitude less than that of dimethylamine. Other important nitrogenous constituents of wastewater, such as amino acids and proteins, do not form significant quantities of NDMA when exposed to monochloramine.

These findings indicate that there are two key precursors of concern for NDMA formation: monochloramine and organic nitrogen compounds (i.e., either dimethylamine or tertiary amines with dimethylamine functional groups). To identify and control the organic nitrogen-containing precursors, we have developed a test for quantifying the total concentration of NDMA that could be formed when a water sample is disinfected with monochloramine. In the case of the trihalomethane disinfection by-products, the trihalomethane formation potential test (THMFP; [11,12]) has been used to predict THM formation during chlorination. The NDMA precursor test described here can be used to identify sources of NDMA precursors. However, it cannot be used to accurately predict NDMA formation without additional kinetic studies designed to simulate conditions in water and wastewater disinfection systems.

The NDMA precursor analysis described here involves the application of a relatively high dose of monochloramine for an extended contact period to convert organic NDMA precursors to products. The analysis uses the concentration of NDMA formed during the test as a surrogate for the total concentration of organic NDMA precursors. A standard procedure was devised that would be equally applicable to waters of different quality (i.e., primary wastewater effluents through natural surface waters and reverse osmosis permeate). By converting all of the NDMA precursors into products, the concentration of NDMA usually is high enough to minimize many of the analytical problems associated with the detection of trace concentrations of NDMA encountered in full-scale treatment systems. As a result of the extreme chlorination conditions used in the test, the results are not necessarily indicative of the NDMA concentration that will be produced when the water is disinfected under conditions typically encountered in water and wastewater treatment plants. In addition, a method capable of measuring dimethylamine at low concentrations in a variety of waters and wastewaters also is described. The method can be used to evaluate the importance of dimethylamine as a NDMA precursor.

2. Materials and methods

2.1. Materials

Avocado Research Chemicals Ltd. (Heysham, England), 4-methoxybenzenesulfonyl chloride (98%), Acros Organics 4-methoxybenzenesulfonyl chloride (99%), Aldrich 4-methoxybenzenesulfonyl chloride (99%), and Lancaster 4-methoxybenzenesulfonyl chloride (98%) were used without further purification. Fisher Optima acetone (>99%), ammonium chloride (USP/FCC), ascorbic acid (USP powder), and sodium bicarbonate (>99%), and J.T. Baker disodium carbonate (>99%) were used without further purification. Cambridge Isotope Laboratories (Andover, MA) NDMA-d_6 was used as an internal standard for NDMA analyses. CDN Isotopes (Quebec, Canada) dimethylamine-d_6 hydrochloride (99.8%) was used as an internal standard for dimethylamine analyses. EM Science (Darmstadt, Germany) HR-GC methylene chloride was used for liquid–liquid extractions of samples. Acros HPLC water was used for NDMA analysis blanks. An equimolar mixture of Fisher Scientific sodium phosphate monobasic and sodium phosphate dibasic was used to produce a 0.5 M phosphate buffer stock solution. Environmental Express (Mt. Pleasant, SC) borosilicate microfiber filters with a nominal pore size of 0.7 μm were used to filter some samples. These filters were chosen because they do not contain a binding agent which might leach NDMA precursors. Other reagents were described previously [9].

2.2. Standard NDMA precursor analysis

Samples of wastewater effluent were collected in PFE-lined polyethylene containers and stored at 4°C. In most cases, samples were not filtered. However, to assess the effect of filtration, some samples were filtered through 0.7 μm nominal pore size glass fiber filters. Filters were baked at 400°C for 3 h prior to use. Samples were filtered (when applicable) and chlorinated upon receipt at the laboratory, but always within 2 days of sample collection. Deionized water, produced from a Barnstead Nanopure II water purifying system, was used for preparation of buffer stock solutions.

Reactions were conducted at room temperature in 1-L volumetric flasks shielded from light. All glassware used during these experiments was rinsed with acetone and baked at 400°C for at least 3 h prior to use. Unless otherwise specified, reactions were conducted at pH 6.8, using a 10 mM phosphate buffer. Monochloramine stock solutions (20 mM) were prepared as described previously [9] and standardized iodometrically [12]. Unless otherwise specified, samples (900 mL) were dosed with 100 mL of the monochloramine stock solution (final monochloramine concentration is 2.0 mM or 140 mg/L as Cl_2). Total chlorine was determined by

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the DPD colorimetric method [12] at the end of each reaction and at other relevant times. Reactions were halted by the addition of excess ascorbic acid (200 mM) to quench the chlorinating agent. A 900-mL aliquot of deionized water was also processed according to this procedure to serve as a control blank to measure precursors that may be contributed by contamination of reagents.

2.3. NDMA analysis

Ten microliters of a 10 mg/L deuterated NDMA stock solution in a methanol solvent (100 ng d_6-NDMA) was added as an internal standard to each 1-L sample for use in isotope dilution analysis. To determine whether use of ascorbic acid to quench chloraminated samples interferes with the analysis, two aliquots of a sample of secondary wastewater effluent from the City of San Francisco Southeast wastewater treatment plant were subjected to an initial monochloramine concentration of 0.08 mM for 4 h. One aliquot was quenched with ascorbic acid prior to the addition of the d_6-NDMA internal standard, while the other aliquot was quenched with ascorbic acid following addition of the d_6-NDMA internal standard. NDMA formation in the two aliquots was measured to be 126 (±33 SD) and 127 (±28 SD) ng/L, respectively. The lack of significant difference between the two samples indicates that use of ascorbic acid to quench chloramines does not interfere with the analysis by rapidly degrading NDMA.

Natural water samples (1 L) were extracted using separatory funnels as described in US EPA SW-846 Method 3510C [13]. Samples were extracted three times using methylene chloride (60 mL for each extraction). Separatory funnel extraction of wastewater samples was not practical due to the emulsion which forms during shaking. Therefore, wastewater samples were extracted for six hours with 100 mL methylene chloride by continuous liquid–liquid extraction using Corning Accelerated One-Step™ Extractor/Concentrators. Extracts were concentrated to 1 mL using a rotary evaporator, followed by nitrogen gas (Praxair, Inc. industrial grade 99.5% purity) blowdown. When separatory funnels were used for liquid–liquid extraction, recoveries were 21% ± 10% (average ±SD for 12 samples) for NDMA-spiked deionized water samples. Recoveries from continuous liquid–liquid extraction averaged 56% ± 11% (average ±SD for 74 samples) for NDMA. Although these recoveries were relatively low compared to other organic pollutants, the use of a deuterated internal standard (i.e., d_6-NDMA) allowed us to correct the data for recoveries with a high degree of precision.

Extracts were analyzed for NDMA using a Varian CP-3900 gas chromatograph coupled to a Saturn ion trap 2100 T MS/MS. Splitless injections of 2 μL were used with an injection port temperature of 200°C, a transfer line temperature of 260°C, and a trap temperature of 150°C. Gas chromatography temperature conditions (Supelco SPB™-1701 capillary column 30 m by 0.25 mm ID by 0.25 μm) were 35°C held for 1 min followed by ramping at 10°C/min to 70°C, then ramping at 2°C/min to 83°C, and ramping at 10°C/min to 220°C held for 2.4 min. Tandem mass spectrometry was conducted using the chemical ionization mode with methanol. The emission current was set at 60 μA, the excitation amplitude at 0.32 V and the multiplier offset at 100 V. NDMA and d_6-NDMA were quantified using the 74.1 parent ion and 44, 47 and 58 daughter ions for NDMA and the 81.1 parent ion and 50 and 64 daughter ions for d_6-NDMA.

2.4. Dimethylamine analysis

Dimethylamine was analyzed using a modified version of the procedure detailed by Sacher et al. [14]. 4-methoxybenzenesulfonyl chloride was chosen as the derivatizing agent instead of benzenesulfonyl chloride to minimize interference from dimethylbenzenesulfonamide, a plasticizer that might be encountered in municipal wastewater. Ten microliters of d_6-dimethylamine from a 0.1 μg/μL stock solution in methanol (1 μg) was added as an internal standard to 100 mL samples. An equimolar mixture of sodium bicarbonate and disodium carbonate (0.5 g) was added to buffer the pH at 7.5. 4-methoxybenzenesulfonyl chloride in acetone (0.1 mL of a 0.5 g/mL solution) was added as the derivatizing agent. The solution was stirred with a magnetic stir bar for 3 h. The solution was then extracted twice using 20 mL of methylene chloride for 2 min in a separatory funnel. A back-extraction of the combined methylene chloride extracts with 40 mL of deionized water was performed for 1.5 min to remove unreacted derivatizing agent. The methylene chloride extract was then concentrated to 1 mL using a rotary evaporator followed by blowdown under nitrogen.

Samples were analyzed by GC/MS/MS using the equipment used for NDMA analyses. Splitless injections of 2 μL were used with an injection port temperature of 250°C, a transfer line temperature of 260°C, and a trap temperature of 150°C. Gas chromatography temperature conditions were 100°C held for 1 min followed by ramping at 8°C/min to 250°C held for 3 min. Tandem mass spectrometry was conducted using the chemical ionization mode with methanol. The emission current was set at 10 μA, the excitation amplitude at 0.30 V and no multiplier offset. Dimethylamine and d_6-dimethylamine were quantified using the 216 parent ion and 216 and 171 daughter ions for dimethylamine and the 222 parent ion and 222 and 171 daughter ions for d_6-dimethylamine.

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3. Results and discussion

3.1. NDMA precursor analysis

3.1.1. Effect of chlorine contact time

Fig. 1a depicts the results from a typical NDMA precursor analysis performed on effluent from the clarifier following activated sludge treatment at the Southeast plant in San Francisco, CA. The monochloramine concentration decreases rapidly at first, decreasing from 132 to 28 mg/L within 6 days. The rate of disappearance of monochloramine slows, decreasing to 5 mg/L after 475 h (approximately 20 days). The NDMA concentration increases rapidly at first, increasing from 44 to 5510 ng/L within the first 19 h. However, the concentration eventually plateaus, increasing to 7560 ng/L after 475 h.

The rapid formation of NDMA during the first 2 days of chloramination also is observed with waters of widely varying quality including primary effluent, secondary effluent from a trickling filter, microfilter effluent and effluent from a reverse osmosis unit (Fig. 1b). While the concentration of NDMA plateaus within 5 days (120 h), a minimum of 10 days (240 h) was chosen for the final contact time for the standard NDMA precursor analysis to ensure consistency. Fig. 1c portrays the same data, but with NDMA concentration plotted against chloramine contact time (i.e., *Ct*), as determined by integrating polynomial functions fitted to the monochloramine decay curves. The data indicate that the leveling off in NDMA concentrations is not a result of the disappearance of monochloramine. Even when the chloramine contact time is doubled, the NDMA concentration shows no significant increase after the initial 55 mM h exposure. In fact, the disappearance of monochloramine in waters of vastly different quality, ranging from primary wastewater effluent to reverse osmosis permeate, exhibited similar kinetics (Fig. 1d). Therefore,

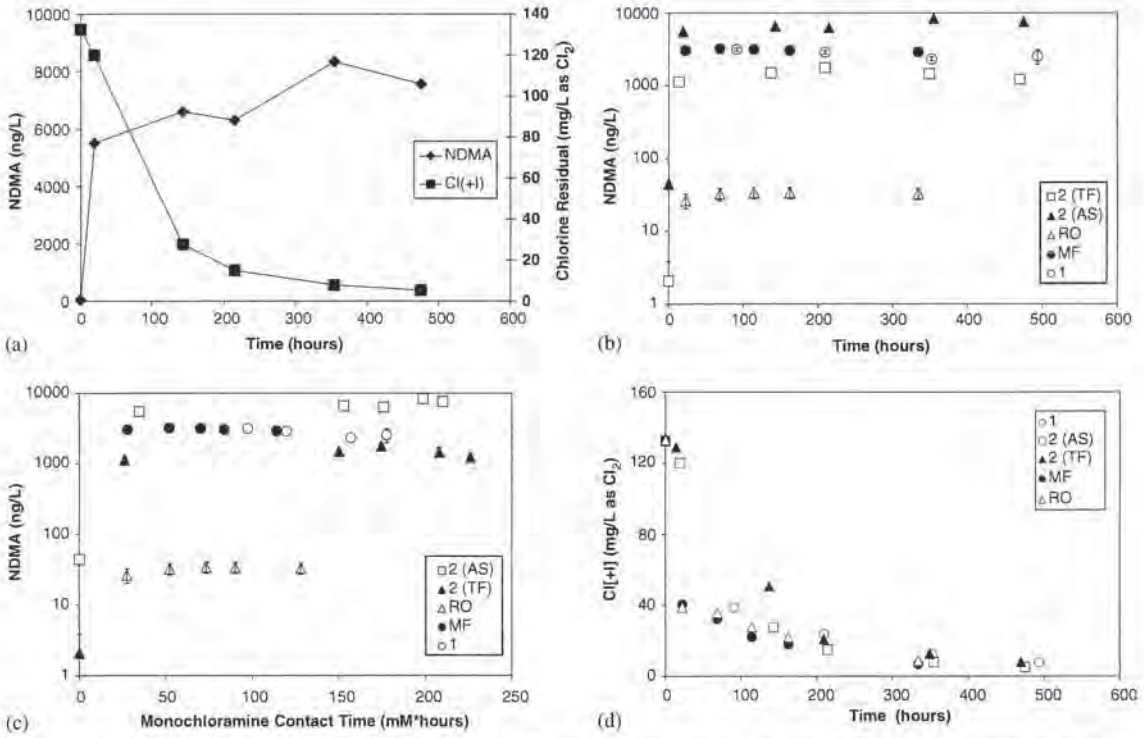


Fig. 1. (a) NDMA formation and monochloramine concentration decrease for secondary activated sludge effluent from the Southeast Plant, San Francisco, CA subjected to the standard NDMA precursor analysis conditions. (b) NDMA formation vs. time for a variety of wastewaters subjected to the standard NDMA precursor analysis conditions. (c) NDMA formation vs. monochloramine contact time for a variety of wastewaters subjected to the standard NDMA precursor analysis conditions. (d) Cl[I] vs. time for a variety of wastewaters subjected to the standard NDMA precursor analysis conditions. 1 = primary effluent from the Southeast Plant, San Francisco, CA (pH 7.3 with 5 mM phosphate buffer). 2 (AS) = secondary activated sludge effluent from the Southeast Plant, San Francisco, CA (pH = 6.5 with no buffer). 2 (TF) = secondary trickling filter effluent from the Mountain View Sanitary District Plant, Martinez, CA (pH = 7.3 with no buffer). MF = microfiltration effluent from the West Basin Water Recycling Plant, Los Angeles, CA (pH = 6.5 with 2.5 mM phosphate buffer). RO = reverse osmosis effluent from the West Basin Water Recycling Plant, Los Angeles, CA (pH = 6.8 with 2.5 mM phosphate buffer). Error bars indicate one standard deviation.

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monochloramine disappearance was controlled by auto-decomposition [15,16] rather than by chlorine demand.

Two further results indicate that the leveling off of NDMA concentrations is due to consumption of the organic precursor, and not the disappearance of monochloramine. Firstly, an activated sludge effluent was filtered through a 0.7 μm glass fiber filter and split prior to subjecting the sample to two treatments: (1) the typical NDMA precursor analysis (2.0 mM monochloramine) and (2) the same test followed by a second monochloramine dose (2.0 mM monochloramine) added 5 days after the first test (pH = 6.4 with no buffer for both treatments). The NDMA concentrations produced by these treatments were 1150 ng/L (±420 ng/L SD) and 1320 ng/L (±420 ng/L SD), respectively. A Student's *t*-test indicated that these results are not statistically different ($p<0.05$). Secondly, a 73 μg/L solution of dimethylamine in deionized water was subjected to the standard NDMA precursor analysis (pH = 6.8 with 2.5 mM phosphate buffer). After 11 days, the NDMA concentration was 569 ng/L (±84 ng/L SD) and the dimethylamine concentration was below 2.8 μg/L (the practical quantitation limit that day). These results indicate that, under the conditions of the standard NDMA precursor analysis, the NDMA concentration plateaus within 10 days because organic precursors have been consumed.

The results of the NDMA precursor test are reproducible. For example, duplicate samples of secondary trickling filter effluent from the Sewerage Agency of Southern Marin's treatment plant in Marin County, CA subjected to the standard NDMA precursor analysis exhibited results of 560 ng/L (±90 ng/L SD) and 520 ng/L (±88 ng/L SD). The difference between the results is not statistically significant (i.e., $p<0.05$).

The concentration of NDMA formed during the test does not depend on the initial monochloramine dose (Fig. 2). A monochloramine dose of 2.0 mM was selected for the final test procedure because it was found to provide a chlorine residual of at least 0.07 mM (5 mg/L as Cl_2) at the end of 10 days for wastewaters, irrespective of the level of treatment from primary effluent to reverse osmosis effluent.

Although the NDMA precursor test cannot be used to predict differences in NDMA formation between different treatment plants, it may be useful in predicting NDMA formation in a treatment plant employing similar disinfectant doses. For example, at the Southeast wastewater treatment plant in San Francisco, CA, which is a secondary wastewater treatment plant that employs hypochlorite dosages of 5–20 mg/L as Cl_2 for contact times of approximately 1 h, a correlation was observed between the results of the precursor analysis and the NDMA concentrations detected in samples collected after chlorination (Fig. 3). Therefore, the results of this test can be useful not only as a surrogate for total organic precursor concentration, but also to predict the relative concentration of NDMA that a particular wastewater would form after chlorination. As discussed in a forthcoming publication [17], this assumes that sufficient ammonia is present to allow for monochloramine formation from the applied hypochlorite.

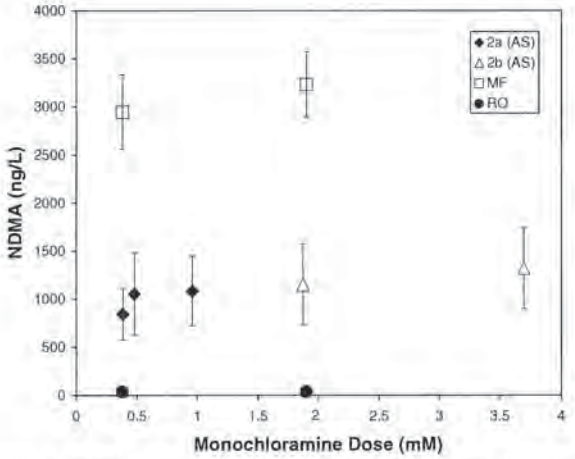


Fig. 2. NDMA formation vs. different initial monochloramine dosages for a variety of wastewaters. 2a (AS) = secondary activated sludge effluent from the Southeast Plant, San Francisco, CA, pre-filtered (filtered prior to the NDMA precursor analysis) through a 0.7 μm filter (6 days, pH = 6.7 no buffer). 2b (AS) = secondary activated sludge effluent from the Southeast Plant, San Francisco, CA, pre-filtered through a 0.7 μm filter (10 days, pH = 6.4 no buffer). MF = microfiltration effluent from the West Basin Water Recycling Plant, Los Angeles, CA (14 days, pH = 6.5 with 2.5 mM phosphate buffer). RO = reverse osmosis effluent from the West Basin Water Recycling Plant, Los Angeles, CA (14 days, pH = 6.8 with 2.5 mM phosphate buffer). Error bars indicate one standard deviation.

The kinetics of NDMA formation are different in surface waters that do not receive significant wastewater inputs. When the NDMA precursor analysis was performed with a natural surface water from the Upper San Leandro Reservoir in Alameda County, CA, the precursors were not completely exhausted even after 20 days of exposure with monochloramine (Fig. 4). These results indicate that the organic NDMA precursors in natural waters, which likely consist of humic substances [18], react much more slowly with monochloramine to form NDMA than those precursors present in wastewater effluent. Because wastewater may derive from treated surface water, slow-reacting NDMA precursors also may be present in wastewater effluent. However, the concentration of NDMA formed from surface water precursors is usually insignificant relative to the other wastewater-derived precursors. Therefore, the slow-forming NDMA precursors attributable to residual

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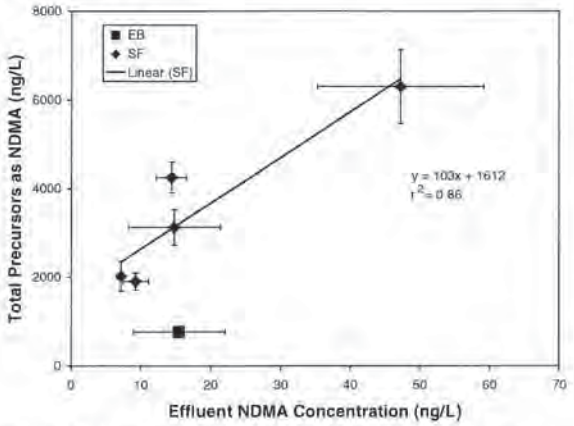


Fig. 3. NDMA precursor analysis results vs. NDMA observed in chlorinated plant effluents. EB = NDMA formation from secondary activated sludge effluent from the East Bay Municipal Utility District plant, Oakland, CA, unfiltered (12 days, pH = 6.4 no buffer) vs. actual plant effluent NDMA concentration. SF = NDMA formation from secondary activated sludge effluent from the Southeast Plant, San Francisco, CA, unfiltered (9 day minimum, pH and buffer concentrations vary for pH values between 6.1 and 6.8) vs. actual plant effluent NDMA concentrations. Error bars indicate one standard deviation. Line indicates linear regression of data for Southeast Plant.

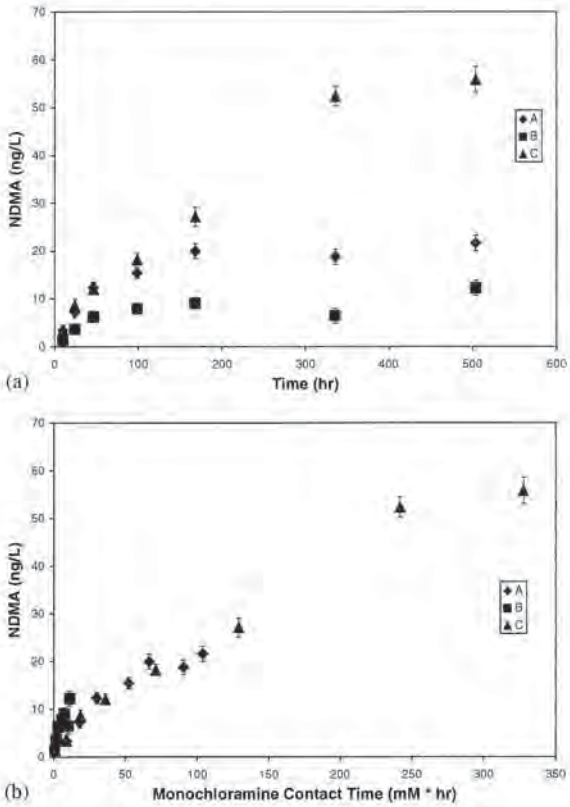


Fig. 4. (a) NDMA formation vs. time for surface water (pH = 7.2 with 10 mM phosphate buffer) from the top meter of the Upper San Leandro Reservoir, Alameda County, CA. (b) NDMA formation vs. monochloramine contact time (pH = 7.2 with 10 mM phosphate buffer) for surface water from the top meter of the Upper San Leandro Reservoir, Alameda County, CA. A = 1 mM monochloramine initial dose. B = 0.1 mM monochloramine initial dose. C = monochloramine added daily throughout test to maintain 1 mM concentration. Error bars indicate one standard deviation.

surface water precursors would be difficult to detect when the test is used for wastewaters.

Because application of a standard NDMA precursor analysis to surface waters does not appear to exhaust NDMA precursors, even after 20 days of monochloramine contact, a different procedure may be appropriate when applying the test to natural waters. Application of an NDMA precursor analysis to natural waters still could be used to measure relative levels of organic NDMA precursors in different waters if the samples are subjected to a standard monochloramine contact time. For example, concentrations of NDMA precursors in a reservoir were affected by thermal stratification, with higher concentrations occurring in the epilimnion [18].

The results of such a precursor analysis of surface waters are reproducible. For example, duplicate samples of water from the Upper San Leandro Reservoir in Alameda County, CA subjected to the standard NDMA precursor analysis (pH = 7.2, 10 mM phosphate buffer, monochloramine contact time = 63 mM h) exhibited NDMA concentrations of 7.9 ng/L (±2.4 ng/L SD) and 8.4 ng/L (±1.5 ng/L SD). A Student's *t*-test indicated that these results are not statistically different ($p < 0.05$).

3.1.2. Effect of sample storage

Under certain conditions, it may not be practical to begin chloramination immediately after sample collection. Analysis of NDMA precursors in samples did not change when the samples were analyzed within 8 h of sample collection and after storage for 2 days at 4°C (Fig. 5). Storage of surface water samples at 4°C for up to one month did not significantly alter results of the NDMA precursor analysis. For example, when a sample from the top meter of the Upper San Leandro Reservoir in Alameda County, CA was subjected to the NDMA precursor analysis (pH = 7.2, 20 mM phosphate buffer), 12.6 ng/L (±1.6 ng/L SD) of NDMA were formed when the test was begun the same day of sample collection ($[NH_2Cl]_{init} = 1.1$ mM applied for 54 h) and 11.4 ng/L (±1.5 ng/L SD) when the test was begun 22 days after sample collection ($[NH_2Cl]_{init} = 1.1$ mM applied for 48 h). A Student's *t*-test indicated that these results are not statistically different ($p < 0.05$). These data indicate that the results of the test will not be adversely affected

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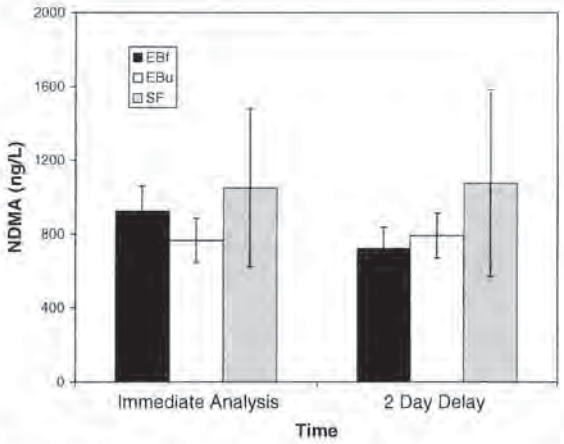


Fig. 5. NDMA formation vs. storage time. EBf = secondary activated sludge effluent from the East Bay Municipal Utility District plant, Oakland, CA, pre-filtered through a 0.7 μm filter (12 days for 8 hour storage, 10 days for 2 day storage, pH = 6.4 no buffer). EBu = secondary activated sludge effluent from the East Bay Municipal Utility District plant, Oakland, CA, unfiltered (12 days for 8 hour storage, 10 days for 2 day storage, pH = 6.4 no buffer). SF = secondary activated sludge effluent from the Southeast Plant, San Francisco, CA, pre-filtered through a 0.7 μm filter (6 days, pH = 6.7 no buffer). Error bars indicate one standard deviation.

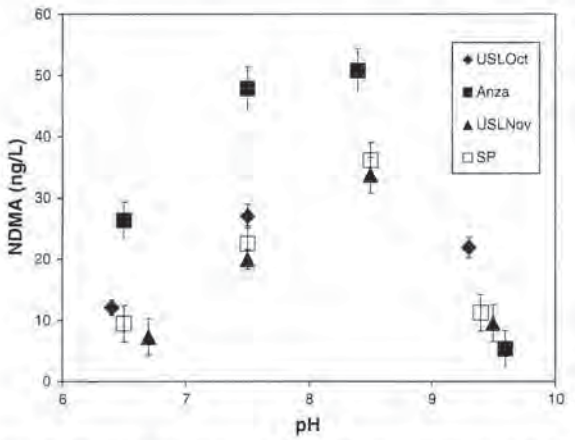


Fig. 6. NDMA formation vs. pH. Monochloramine (1 mM) was applied to unfiltered natural water samples buffered at various pH values for 7 days with 10 mM buffer (phosphate for pH < 9 and borate for pH > 9). USLOct = top meter of the Upper San Leandro Reservoir, Alameda County, CA in October, 2001. Anza = Lake Anza, Alameda County, CA. USLNov = USLOct = top meter of the Upper San Leandro Reservoir, Alameda County, CA in November, 2001. SP = San Pablo Reservoir, Alameda County, CA. Error bars indicate one standard deviation.

by conditions typically encountered during sample shipment or even extended sample storage. However, when samples are stored for more than 2 days, stability experiments should be performed to evaluate matrix effects.

3.1.3. Effect of filtration

Filtration of activated sludge wastewater effluent through a 0.7 μm glass fiber filter prior to the NDMA precursor analysis resulted in a decrease in the NDMA concentration formed. For example, the NDMA formed from secondary activated sludge wastewater effluent collected from the Southeast Plant, San Francisco, CA subjected to the standard NDMA precursor analysis decreased from 2050 ng/L (±190 ng/L SD) in an unfiltered sample to 880 ng/L (±100 ng/L SD) in the same sample pre-filtered through a 0.7 μm glass fiber filter. Further investigations suggested that the particle-associated precursors are attributable to certain polyacrylamide polymers that contain tertiary amines with dimethylamine functional groups [17]. Filtration of surface water samples through 0.7 μm glass fiber filters did not reduce NDMA concentrations formed during the test. For example, when a surface water sample from Lake Anza in Alameda County, CA was subjected to the NDMA precursor analysis at pH = 7.2, the results were 18.7 ng/L (±3.1 ng/L SD) for an unfiltered sample (NH_2Cl contact = 36 mM h) and 18.3 ng/L (±3.1 ng/L SD) for a filtered sample (NH_2Cl contact = 33 mM h). A Student's *t*-test indicated that these results are not statistically different ($p < 0.05$).

3.1.4. Effect of pH

Results of the previous studies [3,9] indicate that NDMA formation during chloramination of dimethylamine [9] and wastewater effluent [3] is affected by pH with maximum rates of formation occurring between pH 6 and 8. The differences in NDMA formation were attributed to competing reactions among the complex branching pathways through which the unsymmetrical dimethylhydrazine intermediate is oxidized to various compounds, including NDMA [3,9]. Similar behavior also was observed when pH was varied in the precursor test conducted with several surface water samples (Fig. 6).

Small variations in pH do not affect the results of the precursor analysis when applied to wastewaters. For example, application of the standard NDMA precursor analysis for 10 days to secondary activated sludge effluent from the Southeast plant in San Francisco, CA, buffered at pH = 6.7 (10 mM phosphate buffer) and at pH = 7.2 (15 mM phosphate buffer adjusted with sodium hydroxide) resulted in 2050 ng/L (±190 ng/L SD) and 1910 ng/L (±190 ng/L standard deviation), respectively. A Student's *t*-test indicated that these results are not statistically different ($p < 0.05$). As a result of the effect of pH on NDMA yield, precursor tests can only be compared if the pH is maintained

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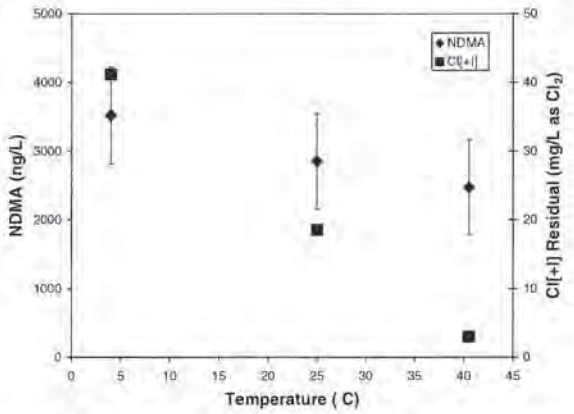


Fig. 7. NDMA formation and residual chlorine vs. temperature. Unfiltered secondary activated sludge effluent sample from the Southeast Plant, San Francisco, CA (9 days, pH = 6.5 with no buffer). Error bars indicate one standard deviation.

within a relatively narrow range. Because the phosphate buffer intensity is highest near pH 6.8, we recommend buffering samples at pH of approximately 6.8 with 10 mM phosphate buffer. If NDMA precursor tests are performed at significantly higher or lower pH values, additional testing may be necessary to verify consistency of results for chlorine disappearance and NDMA formation.

3.1.5. Effect of temperature

Fig. 7 presents the results of the NDMA precursor analysis conducted at different temperatures. The results do not suggest a large temperature effect on NDMA precursor concentrations. However, a moderate increase in the concentrations of NDMA formed is observed with decreases in temperature. The monochloramine residual data indicate that this could be the result of a reduction in monochloramine contact time with increasing temperature as monochloramine is removed more rapidly by auto-decomposition at high temperatures.

4. Dimethylamine analysis

The dimethylamine analysis is extremely sensitive. In practice, the detection limit is limited by dimethylamine contamination of the reagents rather than noise resulting from environmental matrices. Using reagent blanks and the standard protocol of estimating the method detection limit [19], the method detection limit was determined to be 0.09 μg/L using 4-methoxybenzenesulfonyl chloride supplied by Avocado Research Chemicals, Ltd. A linear relationship between concentration and peak area ($r^2 > 0.98$) was observed over the whole range of concentrations analyzed (0.1–100 μg/L). Use of 4-methoxybenzenesulfonyl chloride reagents from other suppliers resulted in higher detection limits, due to contamination of the reagent with dimethylamine. Increasing the concentration of the derivatizing agent by an order of magnitude (i.e., 1 mL of 0.5 g 4-methoxybenzenesulfonyl chloride/mL acetone) with 25 mL acetone to aid in reagent dissolution for an unfiltered primary wastewater effluent sample from the Orange County Sanitation District facility in Orange County, CA resulted in 82 μg/L (±9 μg/L SD) for the high derivatizing agent concentration and 75 μg/L (±8 μg/L SD) for the low derivatizing agent concentration. A Student's *t*-test indicated that these results are not statistically different ($p < 0.05$). The dimethylamine analysis procedure did not quantify compounds with readily hydrolyzable dimethylamine functional groups such as dimethyldithiocarbamate (data not shown).

No loss of dimethylamine was observed when 1-L samples of surface water or wastewater were filtered through 0.7 μm glass fiber filters. However, significant losses of dimethylamine were observed when deionized water containing dimethylamine was filtered. To avoid the possibility of dimethylamine losses during filtration, derivatization was performed on unfiltered samples.

5. Field results and conclusions

Table 1 presents the results for NDMA precursor analyses and dimethylamine analyses on waters from two wastewater treatment plant process units and from two surface waters. As mentioned above, the application of the NDMA precursor test to a solution of 73 μg/L of dimethylamine in deionized water resulted in the formation of 569 ng/L of NDMA, a molar yield of approximately 0.5% from dimethylamine. The fourth column in Table 1 provides the NDMA concentration that would be expected if a 0.5% yield of NDMA were formed during the NDMA precursor analysis from the measured dimethylamine concentrations. These results suggest that NDMA formation in wastewaters and natural waters cannot all be accounted for by dimethylamine concentrations. Although NDMA precursors in surface waters exhibit a correlation with dissolved organic carbon [18], the correlation is not always observed [6] and is too coarse to permit reliable estimates of the potential of a particular water to form NDMA upon chlorination. Therefore, use of the total precursor analysis is necessary for determining NDMA precursor concentrations.

The NDMA precursor analysis presented in this paper provides a tool for estimating the concentrations of organic NDMA precursors in wastewaters and natural waters. This test can be used to identify sources of NDMA precursors in wastewater or surface water and to assess the ability of various treatment technologies to remove organic NDMA precursors prior to

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Table 1
NDMA precursor analysis and dimethylamine analysis on wastewaters and natural waters

Location	Dimethylamine	NDMA precursor analysis	Projected NDMA concentration[a]
	μg/L (±1 SD)	ng/L (±1 SD)	ng/L
Orange County Sanitation District primary wastewater effluent	75 (±8)	5100 (±1080)	600
Orange County Sanitation District secondary wastewater effluent[b]	1.2 (±0.8)	2780 (±480)	10
Upper San Leandro reservoir[c]	<0.1	27 (±2)	0.8
Lake Anza[d]	<0.1	48 (±4)	0.8

[a] Results for a 0.5% yield of NDMA from measured dimethylamine concentration (or dimethylamine detection limit for non-detect samples).
[b] Orange County, CA. Activated sludge sample.
[c] Alameda County, CA. Sample from the top meter taken in October, 2001. For the precursor test: monochloramine contact time = 65 mmol h, pH = 7.2.
[d] Alameda County, CA. For the precursor test: monochloramine contact time = 67 mmol h, pH = 7.2.

chlorination. Measurement of dimethylamine concentrations may not be as useful in this regard because dimethylamine is not the only precursor responsible for NDMA formation in either wastewaters or natural waters.

Acknowledgements

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A comment on the use of flushing time, residence time, and age as transport time scales

Abstract—Applications of transport time scales are pervasive in biological, hydrologic, and geochemical studies yet these times scales are not consistently defined and applied with rigor in the literature. We compare three transport time scales (flushing time, age, and residence time) commonly used to measure the retention of water or scalar quantities transported with water. We identify the underlying assumptions associated with each time scale, describe procedures for computing these time scales in idealized cases, and identify pitfalls when real-world systems deviate from these idealizations. We then apply the time scale definitions to a shallow 378 ha tidal lake to illustrate how deviations between real water bodies and the idealized examples can result from: (1) non-steady flow; (2) spatial variability in bathymetry, circulation, and transport time scales; and (3) tides that introduce complexities not accounted for in the idealized cases. These examples illustrate that no single transport time scale is valid for all time periods, locations, and constituents, and no one time scale describes all transport processes. We encourage aquatic scientists to rigorously define the transport time scale when it is applied, identify the underlying assumptions in the application of that concept, and ask if those assumptions are valid in the application of that approach for computing transport time scales in real systems.

In aquatic systems, most of the living biomass and masses of nutrients, contaminants, dissolved gases, and suspended particles are carried in a fluid medium, so it is essential to understand hydrodynamic processes that transport water and its constituents. A first-order description of transport is expressed as "residence time" or "flushing time," which we conceive as measures of water-mass retention within defined boundaries. Aquatic scientists often estimate retention time and compare it to time scales of inputs or biogeochemical processes to calculate mass balances or understand dynamics of populations and chemical properties. Boynton et al. (1995) argue that residence time is such an important attribute that it should be the basis for comparative analyses of ecosystem-scale nutrient budgets.

The classical empirical model of lake eutrophication (Vollenweider 1976) describes algal biomass as a function of phosphorus loading rate scaled by the hydraulic residence time. Since Vollenweider's recognition that the biogeochemical processing of phosphorus varies with residence time, variable water retention or flushing has been used to describe variability of lake thermal stratification (Hamilton and Lewis 1987), isotopic composition (Herczeg and Imboden 1988), alkalinity (Eshleman and Hemond 1988), dissolved organic carbon concentration (Christensen et al. 1996), elemental ratios of heavy metals (Hilton et al. 1995) and nutrients (Hecky et al. 1993), mineralization rates of organic matter (den Heyer and Kalff 1998), and primary production (Jassby et al. 1990). The mechanistic explanation of low plankton abundance in rivers is short residence time relative to population growth rate (Basu and Pick 1996). The occurrence of harmful algal blooms (Bricelj and Lonsdale 1997), distribution of pelagic bacteria (Painchaud et al. 1996), export of copepod life stages (Ohman and Wood 1996), partitioning of primary production between macroalgae and phytoplankton (Valiela et al. 1997), and variability of dissolved nutrient concentrations (Andrews and Müller 1983) in estuaries and other coastal ecosystems are all strongly influenced by residence time.

These examples, all published in *Limnology and Oceanography*, illustrate that applications of transport time scales are pervasive in biological, hydrologic, and geochemical studies. From a survey of these applications and other literature, we identified flushing time, age, and residence time as three fundamentally different concepts of transport time leading to three different approaches for calculating this scale. In some applications (e.g., Hecky et al. 1993; den Heyer and Kalff 1998) the computation of transport time has been done without specification of the underlying concept used. In other cases (e.g., Andrews and Müller 1983; Hilton et al. 1995; Painchaud et al. 1996), the underlying concept and computational steps have been based on an idealized circumstance that is constrained by critical assumptions, but the validation (or even recognition) of those assumptions has not always been considered when applied to a real river, lake, or estuary. Given the central importance of the transport time concept and the varied approaches used, we imagined the usefulness of a comment to reprise the advice of Bolin and Rodhe (1973, p. 58): "To avoid misunderstandings and even erroneous conclusions it is important to introduce precise definitions and to use them with care."

Our goals are to (1) compare three transport time scales commonly used to measure the retention of water or scalar quantities transported with water, (2) identify the underlying assumptions associated with each time scale, (3) describe procedures for computing these time scales in idealized cases, and (4) identify pitfalls when real-world systems deviate from these idealizations. We illustrate how different approaches can yield time scales differing by an order of magnitude, even when applied to the same problem. These differences occur either because a key transport process (e.g., tidal dispersion) is not accounted for in an approach or because the approaches include assumptions that constrain their applicability to either system-level or local-level processes. Furthermore, we explain how the complexities of real aquatic systems—including nonsteady flows, spatial heterogeneity, and oscillatory tidal transports—violate the theory built from idealized circumstances and influence the magnitude of transport times. Our purpose is to stimulate critical thinking in the application of transport time concepts and in the computation of these

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time scales where hydrodynamics are more complex than in the idealized cases.

Three transport time scales: The idealized cases—Flushing time: Flushing time (T_f) is a bulk or integrative parameter that describes the general exchange characteristics of a waterbody without identifying the underlying physical processes, the relative importance of those processes, or their spatial distribution. Geyer et al. (2000, p. 191) defined flushing as "the ratio of the mass of a scalar in a reservoir to the rate of renewal of the scalar." T_f can be calculated as the volume of water in a defined (bounded) system (V) divided by the volumetric flow rate (Q) through the system.

$$T_f = \frac{V}{Q} \tag{1}$$

For conservative, miscible quantities associated with the water, flushing can be defined alternatively (Fischer et al. 1979) as

$$T_f = \frac{M}{F} \tag{2}$$

where M is mass of the scalar in the domain and F is flux of the scalar through the domain. Application of this definition requires estimates of both the system volume (or its contained mass) and the exchange rate through the system (flow or mass flux).

Because the quantities V (or M) and Q (or F) often are not known, computation of T_f is sometimes based on the assumption that a waterbody functions as a continuously stirred tank reactor (CSTR), so that flushing time can be estimated from observations of outflow concentration over time. For example, Eshleman and Hemond (1988) assumed a CSTR model to predict alkalinity in a reservoir and compared model results to measured alkalinity at the outflow spillway.

The major assumption for the CSTR model is that any introduction of mass is instantaneously and evenly mixed throughout the domain, so the concentration of a constituent exiting the system is equal to the concentration everywhere inside the CSTR. If we assume that (1) a load of known mass is injected into a CSTR at (time) $t = 0$, resulting in an initial concentration C_0, (2) no further mass is introduced after $t = 0$, and (3) flow and the volume of the CSTR remain constant over time, the concentration inside the CSTR is (Thomann and Mueller 1987)

$$C(t) = C_0 e^{-(Q/V)t} = C_0 e^{-t/T_f} \tag{3}$$

For example, Fig. 1a compares exit concentration calculated by Eq. 3 with experimental data for a CSTR used for blending chemicals into water (Viessman and Hammer 1993). Equation 3 can be rearranged to solve for T_f from a linear regression of time series of measured exit concentrations, yielding the e-folding flushing time as defined by Eq. 4.

$$\ln C(t) = -\left(\frac{1}{T_f}\right)t + \ln C_0 \tag{4}$$

A few subtleties of this approach should be noted. Although "flushing time" implies complete renewal of the system, the solution to the CSTR model is an exponential curve, so the introduced mass never completely leaves the system and flushing is never complete. The CSTR flushing time only reflects the average amount of time the mass spends in a system. Notice in Fig. 1a that 37% (e^{-1}) of the initial mass still remains in the system at $t = T_f$. Also notice that the calculated mass exits the system immediately, a consequence of the zero-dimensional assumption of instantaneous homogenization of the introduced mass. The experimental results in Fig. 1a were from a chemical processing operation. Even in these ideal circumstances, there is a lag between actual mass introduction and nonzero effluent concentration. In natural systems such as lakes, there is also a time lag between introduction of a scalar quantity and its arrival at the outlet. Textbooks (e.g., Levenspiel 1972) address the problem of how to account for differences between an ideal CSTR and a real stirred tank. Here, it is sufficient to recognize that the "ideal" case of a CSTR does not completely represent real systems.

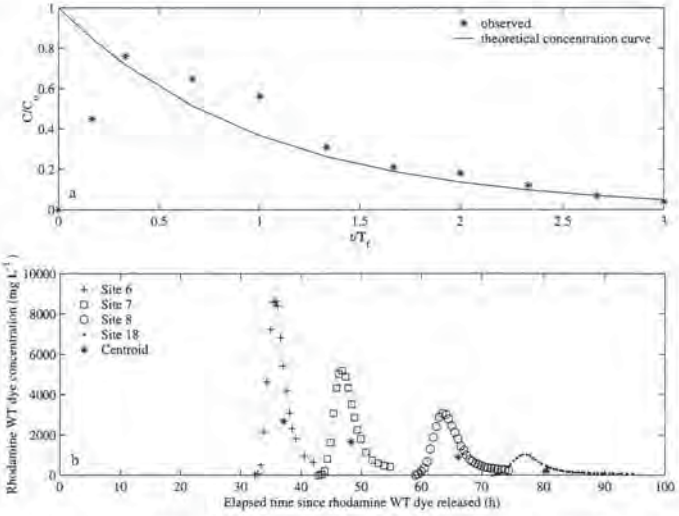


Fig. 1. (a) Theoretical concentration curve for a CSTR based on the analytical solution (Eq. 3) compared to observed effluent concentrations from a completely mixed reactor experiment. (Data are from table 10.1 in Viessman and Hammer [1993] and originally appeared in Marske and Boyle [1973].) The theoretical residence time of the experimental tank was 60 s. (b) Dye release study on the San Joaquin River. Figure re-drawn from Kratzer and Biagtan (1997). Rhodamine WT dye was released 45.9 river km upstream of Site 6 as a slug in the center of the channel. Water was sampled over time at four downstream locations. The distance between Site 6 and Site 18 was 57.1 river km. The centroid value designates the mean age of the dye mass at each station.

The tidal prism method is an alternative, classical approach to estimating flushing time in tidal systems when only basin geometry and tidal range information are available. The approach assumes that tides exclusively flush the system (Dyer 1973). Flushing time using this approach is

$$T_f = \frac{VT}{(1 - b)P} \tag{5}$$

The tidal prism (P) is the domain volume between high and low tide marks. This volume is sometimes estimated as the

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tidal range (R) multiplied by the surface area at mean sea level. Dividing P by the tidal period (T) converts the prism volume into a flow rate. V is the mean basin volume. Equation 5 is modified by the return flow factor (b), the fraction (0.0–1.0) of effluent water returning to the domain each flood tide. This factor is a function of the fate of the effluent once it leaves the domain and cannot be estimated from basin geometry (Sanford et al. 1992).

Several assumptions form the basis of the tidal prism method. First, the system must be well mixed. Second, river flow must be small compared to tidal flow. Third, the receiving water (water directly outside the domain) must be large enough to dilute the water exiting the basin so that receiving water quality does not change over time and is not materially affected by the effluent (Sanford et al. 1992). Finally, the system should be at steady state with a sinusoidal tide signal.

The tidal prism method tends to underestimate flushing time because the method assumes that the system is well mixed (Dyer 1973; Sanford et al. 1992; Oliveira and Baptista 1997). Luketina (1998) gives an extensive derivation of the tidal prism method and suggests several approaches to improve the results.

Age: Unlike flushing time, age is unique to each water parcel that enters the domain of interest. Zimmerman (1988, p. 76) defines age as "the time [a water parcel] has spent since entering the estuary through one of the boundaries." Inherent to the age time scale is recognition of spatial heterogeneity: particles at different locations within a waterbody have different ages. Consider a pulse dye release study in a nontidal, near-steady-state, one-dimensional river (Kratzer and Biagtan 1997; Fig. 1b). As the pulse of dye travels downstream, dye is observed at different stations at different times. Therefore, the average dye mass age at a downstream location (e.g., Site 18) will be greater than the average dye mass age at an upstream station (e.g., Site 6). In addition, dispersion causes the initial scalar spike to spread. Therefore, at each site some mass arrives having a greater than average age while other mass arrives having a less than average age. In this example, all the dye mass entered the system at the same time. In real systems, mass can enter continuously; therefore, a parcel at a specified location can contain mass with a distribution of ages.

Residence time: Residence time is "the time it takes for any waterparcel of the sample to leave the lagoon through its outlet to the sea" (Dronkers and Zimmerman 1982, p. 108). Residence time is measured from an arbitrary start location within the waterbody. For example, Brooks et al. (1999) quantified the residence time of nutrients (represented as neutrally buoyant particles) released from salmon aquaculture locations in Cobscook Bay to determine whether eutrophication would become a problem between the release location and the bay exit.

Residence time is the complement to age: age is the time required for a parcel to travel from a boundary to a specified location within a waterbody; residence time is how long a parcel, starting from a specified location within a waterbody, will remain in the waterbody before exiting. Age and residence time depend on the specification of the boundary, the measurement point of interest within the domain, and in tidal systems, the time of release. Unlike the (zero-dimensional) CSTR model, the concepts of residence time and age inherently acknowledge finite transport times through the system.

Deviations between theory and reality: Application to a tidal lake—We illustrate here three major differences between real systems and the idealized examples illustrated above: (1) nonsteady flow; (2) spatial variability in bathymetry, circulation, and transport time scales; and (3) tides that introduce complexities not accounted for in the idealized cases. To illustrate these differences, we apply the time scale definitions described above to Mildred Island (MI), a shallow 378-ha tidal lake in the Sacramento–San Joaquin River Delta (Fig. 2). MI is bounded by a levee with two main openings (the larger in the northeast and the smaller in the south) that provide hydrodynamic connection with adjacent channels. Mean water depth inside MI is a relatively uniform ~5 m, except for a deep (~20 m) area at the northeast entrance. MI is ~1.5 km wide by ~3 km long. Its geometry is irregular, with sharply curved levees creating quiescent side embayments. Bottom friction damps the currents inside MI (maximum tidal velocity ~0.1 m s^{-1}) relative to currents in the deeper neighboring channels (~0.4 m s^{-1}). Flows through the levee breaks are driven by tides and freshwater inputs from the Sacramento and San Joaquin Rivers. Tidal fluctuations in water elevation (tidal range is ~1 m) and currents occur predominantly over the semidiurnal (~12.4-h period) and neap-spring (~14-d period) cycles. This system is characterized by natural and anthropogenic forcings representing a broad range of characteristic frequencies and resulting in the absence of any hydrodynamic steady state.

A series of recent field experiments (Fig. 3) revealed that MI is characterized by substantial spatial and temporal variability in currents and mixing. Drifter studies (http://sfbay.wr.usgs.gov/access/flow/drifterstudies/, pers. comm.; Fig. 3a) show that tidal excursions and dispersion are greater in the north, where the levee opening is wider and deeper than in the south. Lucas et al. (in press) measured sharp north–south gradients in temperature (Fig. 3b), specific (i.e., standardized to 25°C) conductivity (Fig. 3c), chlorophyll *a* (Chl *a*, Fig. 3d), and dissolved oxygen (Fig. 3e), with maxima for all in southeast MI, suggesting longer retention of water, dissolved substances, and particles in the south than in the north. Our interest in quantifying transport time scales in MI was stimulated by the search for a mechanistic understanding of this spatial variability, which is consistent with the notion of spatially variable transport time scales.

To illustrate the concepts of flushing time, age, and residence time for MI, we used Delta TRIM3D, a multidimensional hydrodynamic and scalar transport model. The core of the hydrodynamic model was developed by Casulli and Cattani (1994), and the associated scalar transport routines were incorporated by Gross et al. (1999). The model has been applied to the bathymetry of the Delta and then calibrated and compared against measured stage, flow, and salinity (Monsen 2001). The numerical model is driven at the western boundary with measured tides at Martinez (Fig. 2), and the river boundaries are specified with measured flows

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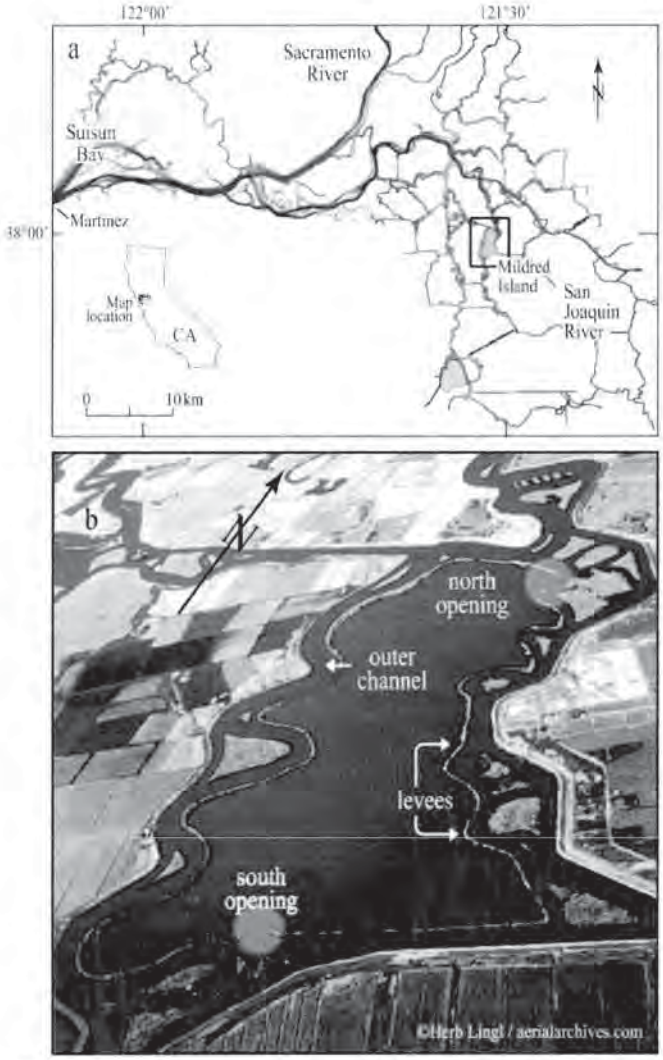


Fig. 2. (a) Map of the Sacramento–San Joaquin Delta. (b) Infrared aerial photograph of Mildred Island. The main levee break is in the northeast corner (upper right, ~18 m deep and ~170 m wide). A secondary break in the south is ~1 m deep and ~50 m wide. Other small breaks (<50 m wide) along the eastern and south sides are too small to be resolved with the numerical model. The interior of Mildred Island is fairly uniform in depth (~5.0 m), except for a deeper region in the northeast corner.

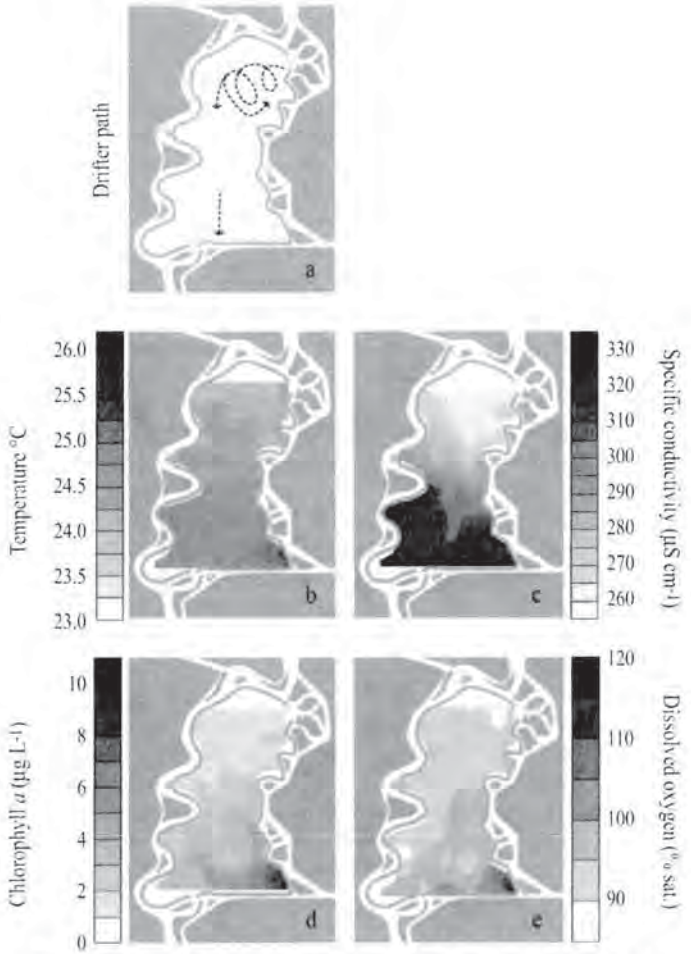


Fig. 3. (a) Mildred Island drifter study, November 1998 (Cuetara and Burau, pers. comm.). Near-surface distributions of (b) water temperature, (c) specific conductivity, (d) Chl *a* concentration, and (e) dissolved oxygen concentration from continuous water quality mapping on 16 June 1999 (Lucas et al. in press).

on the Sacramento and San Joaquin Rivers. Results presented here were calculated using the model in two-dimensional depth-averaged mode, with a grid resolution of 50 m and a 40-s time step. In the following illustrations, the trajectories of neutrally buoyant conservative particles were calculated from the velocity field produced by the hydrodynamic model. The velocity at each particle location was calculated during each time step by linearly interpolating velocities at grid cell walls using the approach of Cheng et al. (1993). We focus on the low-flow conditions of June 1999, a period for which results of drifter experiments and water quality mapping are available for model validation. Each simulation began on 1 June 1999, and transport time scale calculations were initiated on 5 June 1999 to allow for model "ramp-up" and purging of initial condition information.

Recall that flushing time is an integrative system measure, whereas both residence time and age are local measures (i.e., spatially variable within the domain). Selection of the most appropriate transport time scale depends on the guiding question. If the question involves a comparison of general characteristics between different water systems, a system measure might be appropriate. However, if the question involves the importance of a chemical reaction or biological process in a subembayment of the domain, then a local transport estimate might be necessary. Here we will demonstrate the calculation of both system and local parameters for MI in June 1999.

Flushing time of Mildred Island: Hydrodynamic simulations show that instantaneous flow at the primary (north) MI entrance was strongly influenced by tides (Fig. 4), with flow alternating between a maximum of about $+200$ m^3 s^{-1} (flood) and a minimum of about -200 m^3 s^{-1} (ebb); however, residual (tidally averaged) flow was two orders of mag-

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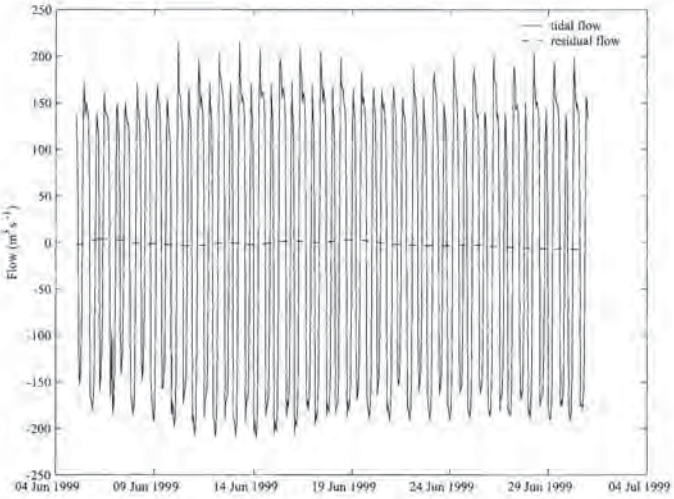


Fig. 4. Tidal and residual flow (flood positive) through Mildred Island north entrance. The residual flow is two orders of magnitude smaller than the tidal flow. This flow was calculated by the Delta TRIM hydrodynamic model for June 1999.

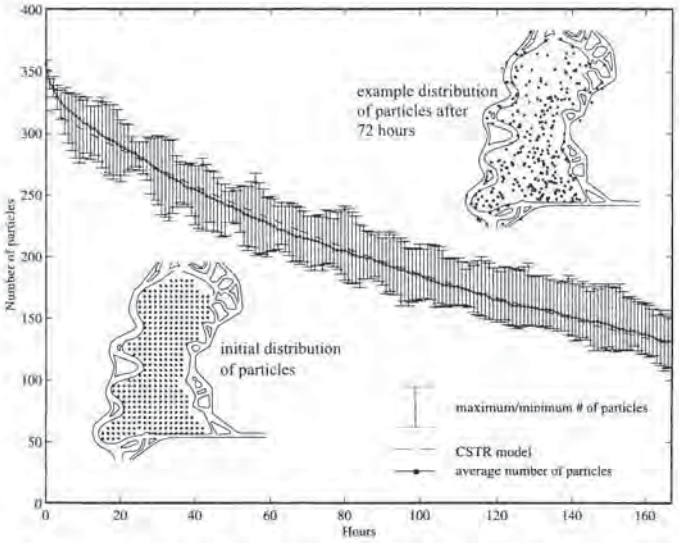


Fig. 5. Estimate of e-folding flushing time for June 1999 using numerical particles and the assumption of a CSTR. The vertical bars indicate the maximum and minimum number of particles present after t hours for all 24 simulations. The solid dark line shows the time series of mean number of particles (averaged over the 24 simulations) retained in MI over the 168-h simulation. Based on the mean particle concentration over time, T_f = 184.6 h. (Lower-left inset) Initial particle locations; (upper-right inset) representative particle locations 72 h after release.

nitude smaller, varying slightly over the spring-neap tidal cycle. For this period, the maximum residual flow at the north opening ranged from +4.4 m^3 s^{-1} (into MI) to −7.1 m^3 s^{-1} (out of MI). Using these extreme residual flows (Q) and Eq. 1 to calculate flushing time (where the volume of MI at mean sea level is 1.9×10^7 m^3), T_f ranges from 31 to 50 d for these low-flow conditions.

For comparison, we used the same hydrodynamic simulation to calculate the e-folding flushing time, assuming that MI was a CSTR. We initialized the MI model domain with a uniform distribution of 365 particles (Fig. 5) and then calculated the location of each particle over time. During every hour of the simulation period, we recorded the number of particles remaining inside MI. Recognizing that the tidal phase of particle release might influence the calculated flushing time, we conducted 24 different simulations by initializing the same particle field at the beginning of every hour on 5 June 1999 and tracking particles for the subsequent 168 h. Figure 5 shows the summary of these simulations. Using the mean number of particles inside MI at each time step as the concentration time series, we used Eq. 4 to determine the CSTR representation of MI for June 1999. The resulting regression equation (R^2 = 0.995) with t in hours is

$$\ln C(t) = -0.00542t + 5.767 \quad (6)$$

This approach yields a mean flushing time of 7.7 d (184.6 h)—four to six times shorter than the flushing time estimated as V/Q.

The difference between the V/Q estimate and the e-folding estimate of flushing is caused by differences in the basic assumptions inherent in each approach. In the V/Q approach, we assume that the only mechanism of transport is mean advective flux. The particle tracking analysis used in our CSTR approach accounts for additional transport processes such as dispersion (Fischer et al. 1979).

An alternative approach for estimating flushing time that accounts for dispersion is to load the domain of interest with a continuous point source (Dronkers and Zimmerman 1982). Assuming the system eventually reaches equilibrium, the flushing time can be estimated as

$$T_f = \frac{M}{\dot{M}} \quad (7)$$

where M is the total tracer mass in the system at equilibrium and $\dot{M}$ is a tracer loading rate (mass $time^{-1}$). Figure 6a shows an application of this approach for MI in June 1999 by specifying a continuous point loading rate $\dot{M}$ = 100 kg s^{-1} at the center of MI. Initially, M within MI increases linearly with time (the period before any mass leaves the domain). After about 3 d, the mass begins to display a tidal signal, and toward the end of the simulation the mass appears to peak and then decline, never sustaining a true steady state. This example illustrates a complication of estimating flushing time in tidal, river-influenced systems where currents and transports vary continuously over multiple frequencies, precluding hydrodynamic steady state. From this numerical experiment, we can estimate the flushing time to be 9.1 d if we estimate M with the peak mass or 8.3 d if we estimate M with the tidally filtered tracer mass at the end of the simulation.

We used this same approach to illustrate the effect of nonsteady flow by applying the same loading rate, $\dot{M}$, but for a period (February 1999) of variable river flow (Fig. 6b). In this case, the loading of tracer began at 1200 h 2 February 1999 during low flow. On about 10 February 1999, a large inflow of water from a winter storm occurred (Fig. 6c) and rapidly diluted the tracer mass. After 18 February 1999, the total mass reached quasi-steady state. Using the tidally fil-

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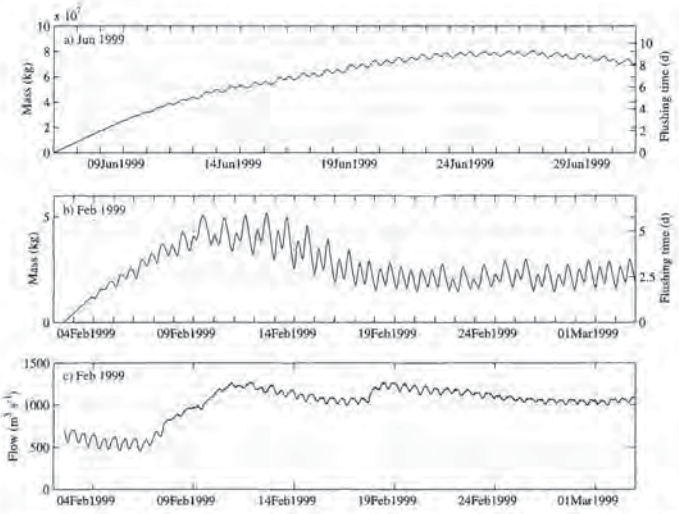


Fig. 6. Time series of total tracer mass in Mildred Island used for the continuous source flushing time estimate for (a) June 1999 and (b) February 1999. Under steady-state conditions, the total mass will plateau to a constant total mass. The flushing time is calculated as the steady-state total mass divided by the rate of loading $\dot{M}$ = 100 kg s^{-1}. (c) Observed Sacramento River flow near Locke (RSAC128) for February 1999.

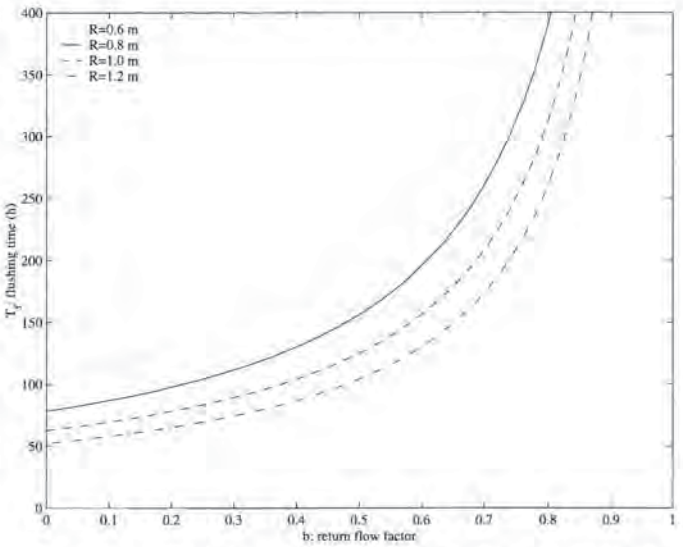


Fig. 7. Possible range of flushing time using the tidal prism approach for Mildred Island for a variable return flow factor (b) and tidal range (R).

tered total mass at the end of the simulation, the flushing time was ~2.4 d. If the flow had remained constant (~600 m^3 s^{-1}) throughout the simulation, the flushing time would have been greater than 5 d.

In the tidal prism approach for calculating flushing time (Eq. 5), basin geometry (mean volume, surface area), tidal range (R), and the return flow factor (b) are required. Figure 7 shows the range of flushing times expected for MI for four tide ranges (representing the standard range of R in MI over the spring-neap cycle) and all possible return flow factors. For a given tide range, flushing time is sensitive (especially for b > 0.5) to the return flow factor.

Because no guidelines exist for selecting a return flow factor, b, for MI, we will assume here that the flushing times calculated by the CSTR and continuous loading approaches are correct. Using Eq. 5, b = 0.6 for June 1999 (T_f = 8.0 d, R = 0.8 m), and b = −0.1 for February 1999 (T_f = 2.4 d, R = 1.0 m). Therefore, b is not constant for MI, and although the former value of b is plausible, the latter clearly is not. This calculation demonstrates that MI violates several criteria for this approach. First, MI is influenced by river flow. The tidal prism approach worked better for June 1999, a dry period, than for February 1999, a wet period. Second, MI discharges into small channels that are directly affected by exchanges with MI. Third, the tidal range in MI varies over the spring-neap cycle. Finally, hydrologic inputs are unsteady in February 1999 (Fig. 6c). Before applying a time scale approach, consistency between the system and the assumptions of the approach should be checked. This exercise demonstrated that the tidal prism method cannot be appropriately applied to MI.

Age of water parcels in Mildred Island: To illustrate the age concept, we used the particle tracks calculated for the June 1999 simulations of MI. Many of the particles initialized inside MI exited the lake on an ebb tide and returned on a later flood tide. We recorded the time when each particle reentered MI and used that entry time as the starting point for calculating that particle's age. We selected 300 × 300 m sampling domains in northern and southern MI (Fig. 8). After each of two periods, T = 84 h and T = 168 h, ages were calculated for all particles in these sampling domains. Note from the results in Fig. 8 that there was a dis-

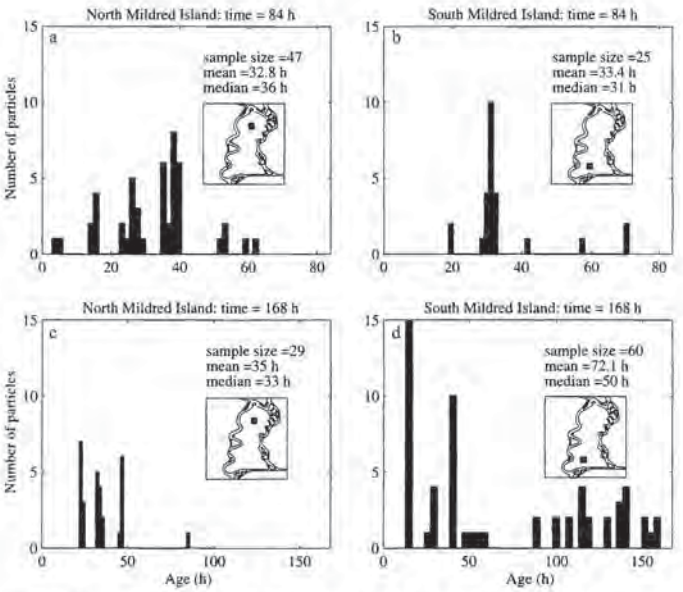


Fig. 8. Numerical particle age distribution for June 1999 within 300- × 300-m sampling domains in (a, c) northern and (b, d) southern Mildred Island. Particles were sampled two times after the simulation began: (a, b) t = 84 h and (c, d) t = 168 h. Transport of particles was calculated by Delta TRIM. Note the change in x-axis scale between the two sampling periods.

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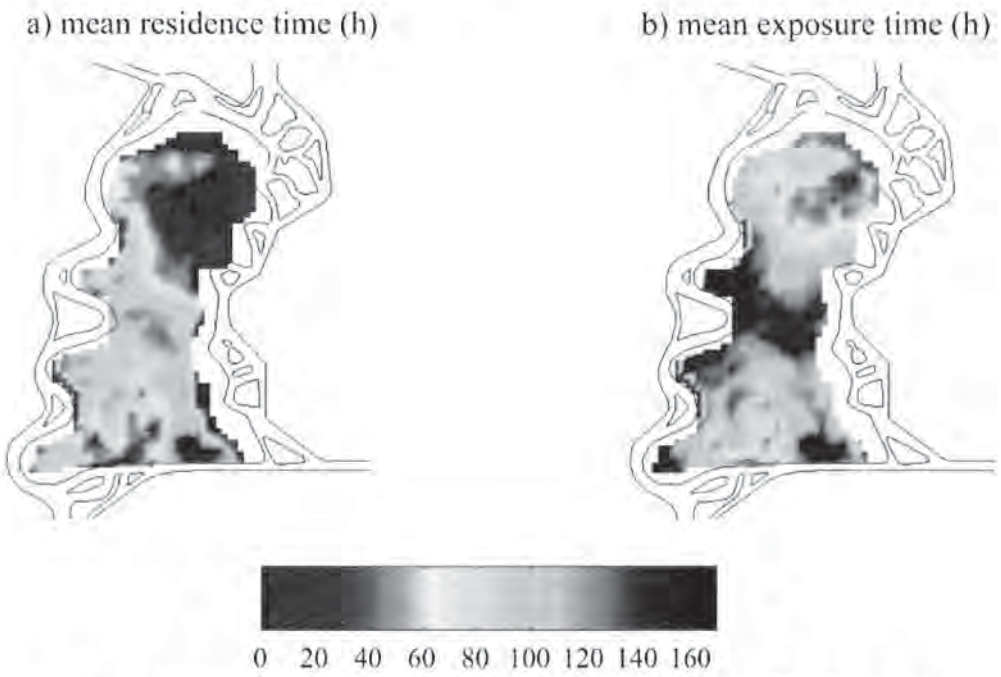


Fig. 9. (a) Mean residence time and (b) mean exposure time for June 1999. The mean reflects the average value at each particle release point for 24 different simulations. The maximum time of 168 h reflects the end of the simulation rather than the maximum residence or exposure time. Exposure is the measure of the total time a particle spends inside the boundaries of MI during the simulation, whereas residence time reflects the time the particle stayed in the domain before exiting once.

tribution of particle ages for any sample location and sample period.

These results reveal important lessons about transport and mixing in MI and provide evidence in support of our field-based hypotheses. First, the field data (Fig. 3b–e) suggest that water resided longer in the south than the north. The mean age at the later sampling time in the south (Fig. 8d) is at least twice that in the north (Fig. 8c). The field drifter studies (Fig. 3a) also suggest a more rapid exchange of water with the channels in the north. The mean and median age of particles in the north (Fig. 8a,c) is the same (~33–36 h) for both sample periods, suggesting this region has reached a quasi-steady-state exchange condition with the channel. The south station (Fig. 8b,d) does not reach a quasi-steady-state condition as rapidly. The mean age at the south station approximately doubles between the sampling periods. These results cannot tell us when (or if) the south region reached equilibrium during the simulation period.

Residence time of Mildred Island: Residence time provides a method for quantifying spatial heterogeneity in the distribution of particles (Fig. 5, upper inset) and how long those particles spend in MI before exiting. Recall that residence time is the time required for a water parcel to exit the domain for the first time. Using the particle tracking simulation for MI in June 1999, we recorded the time when individual particles first left the system and from these records created a residence time map. Because MI is a tidal system with time-varying currents, the residence time map will be different if particles are released on different phases of the tide. Therefore, 24 model simulations were executed, with particles released at the beginning of 24 different hours on 5 June 1999. Particle locations were recorded over 168 h. Figure 9a is a map of spatially variable residence time calculated as the mean residence time from all 24 simulations. Note that mean residence time is extremely heterogeneous, ranging from <1 to >168 h depending on location. As would be expected, locations nearer the entrances to MI have shorter residence times than those far from the openings. Notice, for instance, that residence time is long for particles released at the center of MI because travel times for particles in the center of the domain to an exit are longer than for particles initialized near an exit. Long residence times also appear in the subembayment on the southeastern side of MI. Hydrodynamic simulations show that a circulation gyre sets up in this area and there is little exchange between this corner and the rest of MI, resulting in a longer residence time. (Animations of model results illustrating this concept will be available at Ecological Archives Lucas et al. in press; http://www.esapubs.org/archive/archive_A.htm).

Application of the residence time concept to MI illustrates one of the complications in applying idealized transport time scale definitions to tidal systems. Here, we define residence time as the time for a particle to leave MI once and assign values of residence time to the locations of particle release. This definition does not include consideration of oscillating tidal transport of water and scalars into and out of the lake over multiple tide cycles. The total amount of time a particle spends in the domain ("exposure time") might be a more relevant time scale than residence time for some geochem-

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ical or biological processes. For example, the long-term net growth of phytoplankton depends on the full range of growth–consumption conditions along tidal trajectories, and these conditions vary along bathymetry gradients (Lucas et al. 1999). Therefore, the growth dynamics of a patch of phytoplankton in a tidal flow could be a strong function of the total amount of time spent in a particular (e.g., high-growth) environment. In Fig. 9b, we see that the exposure time of particles is longer than the residence time in many regions because particles that exit the system can subsequently reenter MI. Therefore, the influence of MI habitat might be greater on the particle than would be indicated by the formal residence time concept.

Maps depicting spatial variability of residence and exposure times (Fig. 9) provide strong clues about the importance of transport processes in shaping the spatial patterns of nonconservative quantities such as temperature, specific conductivity, Chl *a*, and dissolved oxygen (Fig. 3). The strong north–south gradients of these quantities reflect the gradients of residence time, suggesting that heat, plankton, and dissolved substances accumulate in the southeastern region because of slow tidal mixing, but not in the northeast region where tidal exchanges with the outer channel system are rapid. Integrative time scales, such as flushing time, provide no information about the connections between transport and spatial heterogeneity of these scalars.

In presenting these calculations of flushing time, age, and residence time for MI, our intent was not to compare the calculated values directly but rather to illustrate and compare various approaches used to estimate transport times. Direct comparison of flushing time, a system-level measure, with residence time, a spatially varying local measure, would require statistical averaging to produce a system residence time. Using a similar particle tracking approach as that used here, Oliveira and Baptista (1997) found that, for their case, the average residence time was the same order of magnitude as the globally calculated flushing time when numerical particles were released at a high enough density and statistically averaged. Therefore, results from a flushing time approach, such as the e-folding time shown in Fig. 5, might not be in conflict with those found with the residence time approach. However, as illustrated in Fig. 9, the particle tracking approach provides more information about local processes and gives strong clues about the mechanisms of spatial heterogeneity. This discussion, however, does demonstrate that local biogeochemical rates should be compared to the appropriate local transport time scale rather than a system-level measure of transport, which might not reflect local conditions.

Our purpose is to encourage aquatic scientists (including ourselves) to develop a practice of (1) defining the transport time scale when it is applied, (2) identifying the underlying assumptions in the application of that concept, and (3) asking if those assumptions are valid in the application of that approach for computing transport time scales in real systems.

The examples used in this Comment were selected to show that there is no single transport time scale for a system that is valid for all time periods, locations, and constituents, and that no one time scale describes all transport processes. By selecting time scales most appropriate for the questions being addressed and explicitly defining the calculation approach, we can develop a practice that adds rigor to our application of transport time scales for revealing mechanisms of spatial and temporal variability in aquatic systems.

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National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
1335 East-West Highway
Silver Spring, MD 20910
THE DIRECTOR

BDCP1563.

MAR 18 1993

Mr. Roger Patterson
Regional Director
Bureau of Reclamation
2800 Cottage Way
Sacramento, California 95825

Dear Mr. Patterson:

Enclosed is a biological opinion that addresses the potential effects on Sacramento River winter-run chinook salmon from the Bureau of Reclamation's (Bureau) proposed Los Vaqueros Project.

Based on the best available scientific information, the biological opinion concludes that the Bureau's proposed construction of new supplemental intake facilities on Old River and the Los Vaqueros Reservoir is not likely to jeopardize the continued existence of the Sacramento River winter-run chinook salmon or result in the destruction or adverse modification of its critical habitat.

However, because NMFS believes there will continue to be some incidental taking of juvenile winter-run chinook salmon as a result of the project, an incidental take of this species is authorized if the Bureau complies with the terms and conditions of the incidental take statement.

Consultation must be reinitiated if the amount or extent of taking specified in the incidental take statement is exceeded, new information reveals that the project may affect winter-run chinook salmon in a manner or to an extent not previously considered, or a new species or critical habitat is designated that may be affected by the Bureau's actions.

Sincerely,

Nancy Foster

Nancy Foster, Ph.D.
Acting Assistant Administrator
for Fisheries

Enclosure

THE ASSISTANT ADMINISTRATOR
FOR FISHERIES

PROJ. FILES

BIOLOGICAL OPINION

Agency: Mid-Pacific Region, Bureau of Reclamation

Activity: Los Vaqueros Project.

Consultation Conducted By: Southwest Region, National Marine Fisheries Service.

Date Issued: MAR 18 1993

Background:

The Contra Costa Water District (District) has an existing contract with the Bureau of Reclamation (Bureau) to divert up to 195,000 acre feet (AF) of water at their Rock Slough intake and deliver the water through the Contra Costa Canal. The Contra Costa Canal system is the District's principal water supply and delivery system. The Bureau provides this water by releasing Central Valley Project (CVP) reservoir storage (Shasta, Folsom, and Claire Engle reservoirs) into the Sacramento River. However, the Bureau can only deliver approximately 135,000 AF/year at this time because of physical constraints in the District's delivery system. The District is currently using approximately 120,000 to 130,000 AF/year of water.

The District needs to improve the quality of water supplied to its customers, minimize seasonal water quality changes in delivered water, and improve reliability of its water supply during extended emergencies. Water from the existing Bureau contract is subject to substantial variations in quality due to seasonal periods of seawater intrusion from San Francisco Bay into the Delta where the existing Rock Slough intake is located. The most serious increases in saltwater intrusion occur in dry or critically dry years.

The District currently depends on the Rock Slough intake to obtain its water, and on its four pumping plants along the Contra Costa Canal to deliver the water. In the event of an emergency, such as a levee failure, earthquake, Delta chemical spill or other water quality problem, the District can meet unconstrained water demands by drawing from its existing small storage reservoirs (Contra Loma, Martinez, and Mallard) which store a total of only 5,000 AF of water at full capacity. This storage can provide a 3-to-5-day water supply during peak demands, or

7-to-10-days of average demand. The District believes this storage is insufficient for its approximately 400,000 customers.

To increase water quality and reliability, the District has applied to the State Water Resources Control Board for an amendment to their existing Bureau water right to divert up to 163,000 AF/year of surplus water from Old River between November 1 and June 30. This water would be stored at the proposed Los Vaqueros Reservoir (Reservoir) on Kellogg Creek, and would be in addition to the District's existing contract with the Bureau for 195,000 AF/year of water. In addition, the District has applied for a partial assignment of state water to allow the District to divert up to 14,800 AF/yr from Kellogg Creek to Old River from January 1 to December 31. This water would also be stored in proposed onstream facilities at the Reservoir. The District has stated that it does not intend to divert more than 195,000 AF/yr in any combination of Bureau and state water, and has indicated that the pending application will be amended to reflect this commitment.

The Bureau requested formal consultation on August 25, 1992, and also submitted a biological assessment (BA) for the Los Vaqueros Project (Project). This BA addressed impacts from the proposed additional water rights applications and the associated construction and operation of the Project (i.e. starting with existing conditions of 120-130,000 AF of diversion to full buildout at 195,000).

Proposed Activity

The District's proposed Project involves construction of new supplemental intake facilities on Old River and the Reservoir. The project will deliver water diverted from the Delta to the Reservoir which will have a capacity of 100,000 AF. Water would be stored at this facility for later release to the Contra Costa Canal. This water would be of high quality and would be used during the seasonal intrusion of salinity into Delta waters. Water stored at the Reservoir would also provide an emergency water source. The Reservoir would be filled from only the Old River intake.

Project operations would involve increasing Delta diversions in wetter years (periods of good water quality) and storage water in the Reservoir. In the fall of drier years, the District would reduce diversions from the Delta and instead use water stored in the Reservoir. This stored water would meet a portion of the District's water demand and would be blended with water diverted directly from the Delta to meet the District's water quality objectives. These diversions would be made from varying

combinations of the District's water contracts with the Bureau and the state, and would not exceed a total of 195,000 AF/year.

Various operational scenarios have been designed to meet the District's water quality and emergency storage goals while attempting to mitigate impacts to winter-run chinook salmon and providing beneficial impacts to other fisheries resources. Water would be diverted from the Delta to meet direct customer demand when Delta water quality met the District's water quality goals. When diverting water to the Contra Costa Canal for direct use (not storage), the District would generally give preference to the intake that could deliver the highest water quality. Neither the existing Rock Slough intake or the proposed Old River intake is designed to fully meet the District's peak water demands, and therefore, both intakes are likely to be used in combination to supply peak water demands and/or achieve high water quality. When a sufficient quantity of high-quality water is unavailable from the intakes to meet the District's demands and water quality goals, water would be released from the Reservoir and blended with supplies in the Contra Costa Canal.

The District has proposed the following rules for future operation of the Project and their existing facilities:

Rule 1 - Except as provided for below, the District will operate its water delivery system to meet the Project objectives which are to improve water quality and system reliability to the maximum extent possible on a year-round basis.

Rule 2 - From March 15 through May 15 of each year, the District will divert, as much of its water requirement as possible, consistent with applicable permits and licenses, to the new Old River intake that will be screened.

Rule 3 - Except as described in Rules 4,5, and 6 below, the District will fill the Reservoir either by diverting CVP water rights contractual water storage or by diverting surplus water whenever the water quality goals of the project can be satisfied with the storage of that water.

Rule 4 - The District will not divert water to storage in the Reservoir from March 15 through May 31 except when reservoir storage is below emergency storage levels. For the purposes of this rule, the term "emergency storage" will mean at least 70,000 AF in storage in below normal years, above normal years, and wet years and 44,000 AF in dry years and critical years. Year types will be defined in the February edition of the California Department of Water Resources Bulletin 120 and the Four Basin Index defined by water right decision 1485.

Rule 5 - From April 1 through 30, the District will avoid diversions from the Delta and will instead release up to 12,500

AF of water (equivalent to the District's projected critical-year buildout demands in April) from the Reservoir to meet demands in the District's service area. These releases will occur only if storage in the reservoir is above emergency storage levels and will continue until reservoir emergency storage levels (70,000 AF in wet, above normal, and below normal years and 44,000 AF in dry and critical years) are reached. When emergency storage levels are reached, the District will, without limitation, continue or initiate diversions from the Delta for direct use within the District's service area.

Rule 6 - If the California Department of Fish and Game (CDFG), U.S. Fish and Wildlife Service (FWS), and NMFS mutually agree that a change in the periods described in rules 4 or 5 is desirable, then they will, no later than February 15 of any year, provide the Bureau and the District with a written request to modify the operational rules 4 and 5. Operations will be modified only after the Bureau and the District provide written concurrence with the fishery agencies' request. In no event will operational modifications made between March 15 and May 15 involve ceasing diversion for more than 30 days, although such cessation of diversion will not be for consecutive periods of less than 7 days. The emergency storage level limitations set forth in rule 4 above will be fully applicable to and will limit the operation of this rule.

Rule 7 - These operational rules will not become effective until the Reservoir is initially filled to a storage level of 90,000 AF.

The proposed Reservoir will accommodate 100,000 AF of water with a maximum allocation of 56,000 AF to emergency storage, 30,000 AF to water quality enhancement storage, approximately 10,000 AF to unused storage, and 4,000 AF to evaporation storage. The proposed Reservoir was designed to provide an emergency water supply equal to 90 days at the peak 3-month demand level at full buildout (equivalent to 56,000 AF of emergency storage) during wet and normal years, assuming customer cutbacks of 25 percent during the emergency period. During a critical dry year or series of such years, up to 26,000 AF of this emergency storage may be used for water quality blending, in addition to the 30,000 AF of water quality enhancement storage described above. Under these circumstances, an emergency supply equal to 30 days at the peak 1-month demand level at belted (equivalent to 30,000 AF of emergency storage) will be maintained in the reservoir for use when an emergency renders the water supply available through the proposed Old River intake or the existing Rock Slough intake unusable.

Listed Species and Critical Habitat:

The threatened Sacramento River winter-run chinook salmon (Oncorhynchus tshawytscha) is distinguishable from the other Sacramento River chinook runs by the timing of its upstream migration and spawning season. NMFS listed winter-run chinook salmon as threatened under the emergency provisions of the Endangered Species Act in August 1989 and formally listed the species as threatened in November 1990. The State of California listed winter-run chinook salmon as endangered in 1989 under the California State Endangered Species Act. On June 19, 1992, NMFS proposed that winter-run chinook salmon be reclassified as an endangered species (57 FR 27416). On August 14, 1992, NMFS also proposed critical habitat for winter-run chinook salmon (57 FR 36626).

Before construction of Shasta and Keswick Dams in 1945 and 1950, respectively, winter-run chinook salmon were reported to spawn in the upper reaches of the Little Sacramento, McCloud, and lower Pit Rivers (Moyle et al. 1989). Specific data relative to the historic run sizes of winter-run chinook salmon prior to 1967 are sparse and mostly anecdotal. Numerous fishery researchers have cited Slater (1963) who indicated that the winter-run chinook salmon population may have been fairly small and limited to the spring fed areas of the McCloud River before the construction of Shasta Dam. However, recent CDFG research in State Archives uncovered several fisheries reports that suggest the winter-run chinook salmon population may have been much larger than previously thought prior to the construction of Shasta and Keswick dams. According to these anecdotal reports, winter-run chinook salmon spawned in the McCloud, Pitt and Little Sacramento Rivers with the run size numbering over 200,000 fish (Rectenwald 1989). Construction of Shasta and Keswick Dams blocked access to all of the winter-run chinook salmon's historic spawning grounds.

Completion of Red Bluff Diversion Dam in 1966 enabled accurate estimates of all salmon runs to the upper Sacramento River and documented the dramatic decline of the winter-run chinook salmon population. The estimated numbers of winter-run chinook salmon passing the dam from 1967-1969 averaged 86,509 fish. During 1989, 1990, 1991, and 1992, however, the spawning escapement of winter-run chinook salmon past the dam was estimated at only 547, 441, 191, and 1,180 fish, respectively. These recent run sizes are thought to be dangerously low since run sizes of 400 to 1,000 fish are considered necessary to maintain genetic diversity in the winter-run chinook salmon population (52 FR 6041).

The first upstream migrants appear in the Sacramento-San Joaquin Delta during the early winter months (Skinner 1972). On the upper Sacramento River, the first upstream migrants appear during December (Vogel and Marine 1991). Due to the lack of fish

passage facilities at Keswick Dam, adult winter-run tend to migrate to and hold in deep pools between RBDD and Keswick dam prior to initiating spawning activities. The upstream migration of winter-run chinook salmon typically peaks during the month of March, but may vary with river flow, water year type, and operation of the RBDD.

Since the construction of Shasta and Keswick Dams, winter-run chinook salmon spawning has primarily occurred between RBDD and Keswick Dam. The spawning period of winter-run chinook salmon generally extends from late April to mid-August with peak activity occurring in June (Vogel and Marine 1991). Aerial surveys of winter-run chinook salmon redds have been conducted annually by CDFG since 1987. These surveys have shown that the majority of winter-run chinook spawning occurs between the Anderson-Cottonwood Irrigation District dam at RM 298 and the upper Anderson Bridge at RM 284. However, significant numbers of salmon may spawn below Red Bluff (RM 245) under certain conditions. For example, in 1988, winter-run chinook salmon redds were observed as far downstream as the Woodson Bridge (RM 218).

Eggs hatch after an incubation period of about 40-60 days, depending on water temperature. Maximum survival of incubating eggs and preemergent fry occurs at water temperatures between 40 and 56 degrees fahrenheit. Mortality of eggs and preemergent fry commences at 57.5 degrees fahrenheit and reaches 100 percent at 62 degrees fahrenheit (Boles 1988). Other potential sources of mortality during the incubation period include redd dewatering, insufficient oxygenation, physical disturbance, and water-borne contaminants.

The preemergent fry remain in the redd and absorb the yolk stored in their yolk-sac as they grow into fry. This period of larval incubation lasts approximately 2-4 weeks, depending on water temperatures. Emergence of the fry from the gravel begins during late June and continues through September. The fry seek out shallow nearshore areas with slow current and good cover, and begin feeding on small terrestrial and aquatic insects and aquatic crustaceans. As juveniles grow to 50-75 millimeters in length they move into deeper and swifter water, but continue to use available cover to minimize the risk of predation and reduce energy expenditure.

The emigration of winter-run chinook salmon from the upper Sacramento River is highly dependent on streamflow conditions and water year type. Once fry are present in the river, storm events can cause mass emigration pulses. Emigration past Red Bluff may occur as early as late July or August, generally peaks in September, and may continue until mid-March in drier years (Vogel and Marine 1991). During the combined periods of 1978-1979 and 1981-1989, an average of 60 percent of the total downstream

emigration occurred in September and October (Vogel and Marine, 1991).

Assessment of Impacts:

Numerous factors have contributed to decline of the Sacramento River winter-run chinook salmon population. The principal factors thought to be responsible for this decline include blockage or interference with adult passage to suitable spawning and rearing areas in the upper River (e.g., RBDD and ACID dam), temperature induced mortality during egg incubation and early fry development, entrainment of juveniles by water diversions, high levels of juvenile mortality due to downstream passage problems at the RBDD, and the diversion of outmigrating juveniles from the Sacramento River into the Delta via the Delta Cross Channel and other natural waterways where their survival is lower.

These and other factors were evaluated in a biological opinion that NMFS issued to the Bureau and Department of Water Resources (DWR) on February 12, 1993, concerning the effects of long-term operation of the CVP and SWP on winter-run chinook salmon. The opinion concluded that long-term operations of the CVP and SWP would jeopardize the continued existence of winter-run chinook salmon and specifically identified temperature induced mortality in the upper river, passage problems for adults and juveniles at the RBDD, the diversion of Sacramento River water into the Delta via the Delta Cross Channel, and reverse flow conditions in the Delta caused by CVP/SWP export pumping as the key factors responsible for impacting winter-run chinook salmon.

Several reasonable and prudent alternative actions were identified in the biological opinion that the Bureau and DWR are expected to implement to avoid jeopardizing winter-run chinook salmon. These long-term actions include: maintenance of a minimum end-of-year carryover storage in Shasta reservoir for temperature control, minimum flows from Keswick dam in the upper Sacramento River, maintenance of daily average temperatures in the upper Sacramento River that protect incubating winter-run chinook salmon eggs and fry, operations of the RBDD to minimize effects on upstream and downstream passage, closure of the Delta Cross Channel from February 1 through April 30, elimination or reduction in reverse flows in the western delta, expanded monitoring of juvenile winter-run chinook salmon, and monitoring of juvenile winter-run taking at the delta export facilities of the CVP and SWP.

The District's proposed diversion operations when the Project is operational are expected to adversely affect winter-run chinook salmon directly. However, the extent to which these activities are expected to affect winter-run chinook salmon is expected to

be relatively small, particularly in comparison with the potential effects of CVP and SWP operations. The extent to which the District's existing and proposed Project operations are expected to contribute to the overall cumulative impact on winter-run chinook salmon is discussed below.

Temperature

Elevated water temperatures between Keswick Dam and the RBDD can adversely affect the survival of winter-run chinook salmon eggs and fry during summer and early months. Control of water temperatures in the upper Sacramento River are in large part related to the availability of cold water stored in Shasta reservoir and the Bureau's operation of Shasta and Keswick reservoirs. The volume and temperature of water that is released affects the distance over which downstream river temperatures can be effectively controlled. However, the potential adverse effects of elevated upper river temperatures on winter-run chinook salmon are expected to be minimized if the Bureau meets the end-of-year Shasta reservoir storage requirement and the upper Sacramento river water temperature criteria included as reasonable and prudent alternative actions in the NMFS's February 12, 1993, biological opinion addressing long-term operations of the CVP.

Since a portion of future diversions at both the Rock Slough intake and the proposed Old River intake will be supplied by releases from CVP reservoir storage, the Bureau's ability to control upper Sacramento River temperatures could be adversely affected by Project operations. Based on worst case analyses presented in the Project biological assessment (Jones and Stokes 1992), the Bureau's delivery of water to the District to meet both existing and future diversion demands is predicted to have only a minimal effect on Shasta reservoir storage and the Bureau's ability to control water temperature under most hydrologic conditions. Moreover, the District's proposed operational rules for the Project could actually increase Shasta reservoir storage and further improve the Bureau's ability to control upper river temperatures since April water demand would be supplied by the Reservoir rather than Delta diversions from either the Rock Slough or Old River intakes. In any event, the Bureau is expected to reduce future CVP water deliveries, possibly including water delivered to the District, to meet the end-of-year Shasta storage requirement and in-river temperature criteria for the protection of winter-run chinook salmon.

Delta Diversions and Reverse Flows

The diversion of Sacramento River water through the Delta Cross Channel and other natural waterways into the central and southern Delta entrains juvenile winter-run chinook salmon into the Delta where they are subjected to adverse conditions that reduce their survival. In addition, juveniles reaching the confluence of the Mokelumne and lower San Joaquin Rivers are often exposed to reverse flow conditions that contribute to the reduced survival of outmigrants. Operation of the CVP and SWP export facilities in the southern Delta is considered to be the principal cause of the diversion of Sacramento River water into the Delta and the reverse flows that also occur within the Delta. When the CVP and SWP export more water than the flow from the San Joaquin River, the balance of the water exported comes from the Sacramento River via the Delta Cross Channel, Georgiana Slough, the Mokelumne River, and lower Old and Middle Rivers. Water is also drawn from the San Joaquin River upstream into the Old and Middle Rivers. Under most conditions, the magnitude of reverse flows in the central and southern Delta waterways increases with export pump rates.

The adverse effects of existing and future Delta Cross Channel operations and reverse flow conditions in the western delta on winter-run chinook salmon were addressed in NMFS's February 12, 1993, biological opinion addressing the long-term operational effects of the CVP and the SWP. Reasonable and prudent alternative actions were included in the opinion to minimize these adverse conditions and to avoid jeopardizing winter-run chinook salmon including: operation of the Delta Cross Channel to minimize the diversion of juvenile winter-run chinook into the delta between October 1 and April 30, and operation of the delta export facilities to maintain reduced or no reverse flows in the western delta from November 1 through April 30.

Based on information provided in the Long-term CVP-OCAP report prepared by the Bureau for the consultation addressing the effects of long-term CVP and SWP operations on winter-run chinook salmon (Bureau 1992), the District's existing diversion from the Rock Slough intake without the proposed Project is generally expected to be no higher than 1-3 percent of total CVP and SWP exports (in TAF per month) under a wide range of possible reservoir storage and hydrologic conditions. This comparison is based on the District's current annual diversion maximum of approximately 130,000 AF. Since the current rate of diversion at the Rock Slough intake is only a small percentage of the overall CVP and SWP export rate, it is very unlikely that the District's existing operations significantly contribute to the overall diversion of Sacramento River water into the Delta or the reverse flow conditions that often occur within the Delta. After construction of the Project, the District proposes to divert up

to approximately 195,000 AF of water annually from the existing Rock Slough intake and the proposed Old River intake. However, even with this 50 percent increase in the District's annual diversion, the total diversion will still represent no more than 2-5 percent of the total CVP and SWP exports that would be expected under a wide range of reservoir storage and hydrologic conditions. Thus, the District's proposed level of diversion with the Project operational is not expected to significantly contribute to the overall diversion of Sacramento River water into the Delta or the reverse flow conditions that occur in the Delta.

Entrainment

Available information suggests that the peak period of juvenile winter-run chinook salmon emigration through the Delta extends from late January through April; however, high flows in November or December may bring juveniles into the lower Sacramento River and the Delta much earlier (Brown and Greene 1992, Perry 1992, Stevens 1989). Once juvenile winter-run chinook salmon have been diverted into the central Delta through either the Delta Cross Channel or another waterway, they are susceptible to entrainment by poorly screened or unscreened diversions. Entrainment of juvenile chinook salmon by unscreened diversions generally leads to their death (Odenweller, personal communication).

After the Reservoir and associated Old River intake become operational, the District will meet its water demand by diverting water from both the existing Rock Slough intake and the new Old River intake. However, the proposed fish protection system for the new Old River intake will be designed and constructed to meet CDFG and NMFS screening criteria to minimize entrainment losses (LVP-BA Jones and Stokes 1992). For this reason, the entrainment of juveniles by the unscreened Rock Slough intake is expected to be the principal source of entrainment loss for winter-run chinook salmon during operation of the Project.

The District's proposed operational rules for the Project would avoid or limit water diversions from either of these intakes during the month of April and, instead, use releases from the Reservoir to supply water demand. Although this operational practice would eliminate or substantially reduce entrainment impacts at either intake during April, it would not serve to minimize impacts during the remainder of the winter-run chinook salmon outmigration period.

Although not proposed by the District, entrainment-related losses of winter-run chinook salmon could be eliminated or reduced either by halting or substantially reducing diversions from the Rock Slough intake during the months of February through March,

or by screening the intake. Additional benefits may also accrue to winter-run chinook salmon by limiting diversions from the Rock Slough intake during December and January depending on the water year type and results of juvenile monitoring in the Sacramento River and the Delta.

Since the intake facilities on Old River are not yet designed or operational, it is impossible to predict exactly the number of juvenile winter-run chinook salmon that may be entrained by the facilities. However, it is expected that less than 0.05 percent of each year's juvenile production will be entrained. This estimate is based on the maximum expected volume of water diverted by the facilities relative to total CVP and SWP exports (5 percent), the maximum allowable take authorized in February 12, 1993, biological opinion that NMFS issued to the Bureau concerning long-term operations of the CVP and SWP (1 percent of juveniles entering the delta), and the assumption that the number of fish per unit volume of exported water is comparable for the Old River facilities and the CVP and SWP facilities.

Cumulative Effects

Under the ESA, cumulative effects are defined as those impacts from unrelated, future state and private activities (where there is no Federal involvement) that are reasonably certain to occur within the area of the Federal action under review. Based on this definition, it is unlikely that cumulative effects will occur. Impacts to winter-run chinook salmon are expected to be limited to environmental baseline impacts, defined as those impacts from existing activities and other Federal projects or activities that have been evaluated under section 7 of the ESA. The ongoing efforts to restore the winter-run chinook salmon and its habitat should reduce existing environmental baseline impacts over the long term.

Conclusion

Based on the available information, the District's operation of the proposed Project facilities, including the existing Rock Slough intake to divert water delivered under contract by the Bureau, is not likely to jeopardize the continued existence of winter-run chinook salmon or result in the destruction or adverse modification of its critical habitat.

Operation of the Project to divert water delivered by the Bureau is expected to have only minimal adverse effects on Shasta reservoir storage, the Bureau's ability to control upper Sacramento River water temperatures, the diversion of Sacramento River into the Delta, or reverse flow conditions that occur in the Delta. However, operation of the existing Rock Slough intake and the proposed Project diversion facility on Old River are expected to adversely affect juvenile winter-run chinook salmon by direct entrainment. Therefore, the attached incidental take statement provides for a take of juveniles, provided the reasonable and prudent measures included in the statement are implemented and followed.

Reinitiation of Consultation

Reinitiation of formal consultation is required if (1) the amount or extent of taking specified in any incidental take statement is exceeded; (2) new information reveals effects of the action that may affect listed species or critical habitat in a manner or to an extent not previously considered; (3) the action is subsequently modified in a manner that causes an effect to the listed species or critical habitat that was not considered in the biological opinion; or (4) a new species is listed or critical habitat designated that may be affected by the action.

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INCIDENTAL TAKE STATEMENT

Section 9 of the ESA and regulations implementing Section 4 of the ESA prohibit any taking (harassment, harm, capture, etc.) of listed species without a specific permit or exemption. When a proposed Federal action is found to be consistent with Section 7(a)(2) of the ESA and that action may incidentally take individuals of listed species, an incidental take statement is issued under Section 7(b)(4) that specifies the anticipated incidental take and the terms and conditions that must be followed. Only incidental taking by the Federal agency or applicant, in this case the Contra Costa Water District, that complies with the specified terms and conditions is authorized by NMFS.

The attached biological opinion concluded that the proposed operation of the Los Vaqueros Project is not likely to jeopardize the continued existence of winter-run chinook salmon. However, operation of the proposed Old River intake facilities as part of the Project is expected to result in the incidental taking of winter-run chinook salmon since it will not be possible to completely eliminate entrainment and impingement impacts even with state-of-the-art fish protection facilities. This level of taking is expected to be small if the fish protection facilities are designed, installed, and operated in accordance with NMFS and CDFG design and operational criteria.

Pursuant to Section 7(b)(4) of the ESA, NMFS authorizes a level of juvenile winter-run chinook taking equivalent to 0.05 percent of the total juvenile production as part of the proposed Old River intake operations. NMFS anticipates that the Rock Slough entrainment monitoring program identified as a reasonable and prudent alternative action in the February 12, 1993, biological opinion issued to the Bureau will provide information necessary to determine an acceptable level and impact of taking during operation of the Project.

This level of incidental take is authorized by NMFS provided the Bureau and District comply with the following terms and conditions necessary to minimize the taking of winter-run chinook salmon:

(1) **The Bureau must ensure that the District coordinates all Old River intake fish protection facility design with NMFS, and that the proposed facilities conform to NMFS screening and design criteria.**

NMFS must approve the final design for the Old River intake fish protection facilities prior to construction. Following approval of the design for these facilities, NMFS will reevaluate the authorized level of juvenile winter-run chinook salmon incidental take for the Old River intake.

(2) **The Bureau must ensure that the District develops and implements a monitoring and evaluation program to assess the screening efficiency and effectiveness of the proposed fish protection facility at the Old River intake.**

The proposed program must be developed in conjunction with NMFS and CDFG and approved by NMFS. The approved program must be implemented prior to the initiation of Project operations at the Old River intake.

(3) **The Bureau is authorized to take up to 0.05 percent of each year's juvenile winter-run chinook salmon incidental to the operation of the Old River intake facilities as part of the Project.**

The Bureau and District must monitor the taking of juvenile winter-run chinook salmon at the Old River intake facilities to determine if the rate of taking is higher than expected or if the authorized level of taking will be exceeded. If the rate of taking is higher than expected or the authorized level of take may be exceeded, the Bureau must reinitiate consultation to determine what measures should be implemented to reduce the rate of total level of take.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southwest Region
501 West Ocean Boulevard Suite 4200
Long Beach, California 90802-4213

In response reply to:
2008/09022

JUN - 4 2009

Mr. Donald Glaser
Regional Director
Mid-Pacific Region
U.S. Bureau of Reclamation
2800 Cottage Way, MP-3700
Sacramento, California 95825-1898

Dear Mr. Glaser:

This document transmits NOAA's National Marine Fisheries Service's (NMFS) final biological opinion and conference opinion (Opinion, enclosure 1) based on NMFS review of the proposed long-term operations of the Central Valley Project and State Water Project (hereafter referred to as CVP/SWP operations) in the Central Valley, California, and its effects on listed anadromous fishes and marine mammal species, and designated and proposed critical habitats, in accordance with section 7 of the Endangered Species Act (ESA) of 1973, as amended (16 U.S.C. 1531 *et seq.*). This final Opinion is based on information provided in the Bureau of Reclamation's (Reclamation) October 1, 2008, transmittal letter and biological assessment (BA), discussions between NMFS and Reclamation staff, declarations filed pursuant to Pacific Coast Federation of Fishermen Association *et al. v.* Gutierrez *et al.* 1:06-cv-245-OWW-GSA (E.D. Cal. 2008), comments received from Reclamation, peer review reports from CALFED and the Center for Independent Experts, and an extensive literature review completed by NMFS staff. A complete administrative record of this consultation is on file at the NMFS Sacramento Area Office.

Based on the best available scientific and commercial information, NMFS' final Opinion concludes that the CVP/SWP operations are likely to jeopardize the continued existence of Federally listed:

- Endangered Sacramento River winter-run Chinook salmon (*Oncorhynchus tshawytscha*),
- Threatened Central Valley spring-run Chinook salmon (*O. tshawytscha*),
- Threatened Central Valley steelhead (*O. mykiss*),
- Threatened Southern Distinct Population Segment (DPS) of North American green sturgeon (*Acipenser medirostris*), and
- Southern Resident killer whales (*Orcinus orca*).

NMFS also concludes that the proposed action is likely to destroy or adversely modify the designated critical habitats of:

- Sacramento River winter-run Chinook salmon,

- Central Valley spring-run Chinook salmon, and
- Central Valley steelhead, and
- proposed critical habitat for the Southern DPS of North American green sturgeon.

The final Opinion concludes that the CVP/SWP operations are not likely to jeopardize the continued existence of Central California Coast steelhead (O. *mykiss*).

The conference opinion concerning proposed critical habitat for Southern DPS of North American green sturgeon does not take the place of a biological opinion under section 7(a)(2) of the ESA unless and until the conference opinion is adopted as a biological opinion when the proposed critical habitat designation for the Southern DPS of North American green sturgeon becomes final. Adoption may occur if no significant new information is developed, and no significant changes to the project are made that would alter the contents, analyses, or conclusions of this Opinion.

Take of threatened green sturgeon is currently not prohibited by Section 9 of the ESA. When the rule proposed on May 21, 2009 (74 FR 23822) under section 4(d) of the ESA becomes effective as a final rule, all take of threatened green sturgeon not in conformance with that rule will be prohibited under the ESA. Upon the effectiveness of the final green sturgeon take rule, compliance with this Incidental Take Statement provides exemption for take under section 7(o).

The ESA provides that if NMFS has reached a jeopardy or adverse modification conclusion, it must identify a reasonable and prudent alternative (RPA) to the proposed action that is expected to avoid the likelihood of jeopardy to the species and adverse modification of designated and proposed critical habitat, if such an alternative action can be offered. NMFS includes with this Opinion a RPA that we believe meets all four regulatory requirements, as set forth in 50 CFR 402.02. This has been a very challenging consultation for our agencies due to its complexity, long-term nature, and importance to the people of California and the resources we are required to manage. NMFS and Reclamation have had extensive discussions on the preparation of the BA, the draft Opinion, and the draft RPA, and while NMFS understands that Reclamation may have reservations with portions of the Opinion, NMFS understands that it is a package that Reclamation can accept. Because this is a jeopardy Opinion, Reclamation is required (402.15(b)) to notify NMFS "...of its final decision on the action." NMFS, therefore, requests that Reclamation provide NMFS with timely notification as to your agency's final decision.

Also enclosed are Essential Fish Habitat (EFH) Conservation Recommendations for Pacific Coast Salmon species, as required by the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) as amended (16 U.S.C. 1801 *et seq.*; enclosure 2). NMFS EFH analysis concludes that the CVP/SWP operations will adversely affect EFH for Pacific Coast Salmon species in the action area. The RPA that was developed for the ESA-listed salmon was designed to avoid jeopardy and adverse modification for those species but it also has substantial benefits to Pacific salmon EFH, and commercially valuable Central Valley fall-run Chinook salmon. Pursuant to the MSFCMA, Conservation Recommendations are also provided to further reduce adverse effects on EFH.

I want to express my sincere appreciation to you and to your staff for their professionalism and commitment to find a solution that comports with our various Federal mandates. You have my commitment that NMFS will continue to be close partner with Reclamation, CA Department of Water Resources, CA Fish and Game, and US Fish and Wildlife Service as we embark on implementation. I also look forward to continuing our participation with Reclamation, partner agencies and stakeholders in the Bay Delta Conservation Planning effort, a very important action to boost habitat improvements in the Delta and counterbalance some of the aging infrastructure limitations. If you have any questions regarding this consultation, please contact Mr. Garwin Yip, of my staff, at (916) 930-3611 or via e-mail at garwin.yip@noaa.gov.

Sincerely,

Rodney R McInnis

Rodney R. McInnis
Regional Administrator

Enclosures:

Enclosure 1: Biological and conference opinion on the long-term operations of the Central Valley Project and State Water Project

- Appendix 1: Project Description
- Appendix 2: Supporting documents for the RPA
- Appendix 3: Fall-run and late fall-run Chinook salmon analysis
- Appendix 4: Responses to CALFED peer review recommendations
- Appendix 5: Technical memorandum for the San Joaquin actions

Enclosure 2: EFH Conservation Recommendations

cc: Copy to file ARN: 151422SWR2004SA9116
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Endangered Species Act
Section 7 Consultation

BIOLOGICAL OPINION
and CONFERENCE OPINION

on the

LONG-TERM OPERATIONS OF THE CENTRAL VALLEY PROJECT AND STATE WATER PROJECT

National Marine Fisheries Service
Southwest Region

June 4, 2009

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11.2.2 Actions Listed by Division

I. SACRAMENTO RIVER DIVISION

Introduction to the Sacramento River Division: Project operations of the Sacramento River Division affect winter-run, spring-run, CV steelhead, the Southern DPS of green sturgeon. In addition, project operations affect fall-run, which are not listed. Fall-run salmon are considered in developing the actions as a prey base for Southern Residents. This Division section of the RPA includes actions related to minimizing adverse effects to spring-run and steelhead spawning and rearing in Clear Creek and all species in the main stem Sacramento River. Actions include those necessary to reduce the risk to temperature effects to egg incubation in the upper river, especially to winter-run and spring-run spawning below Shasta Dam. Also, the RPA contains actions for operation of RBDD – a major impediment to salmonid and green sturgeon migration. In addition, the RPA includes an action related to adjusting the antiquated Wilkins Slough navigation requirement, mandates the continuation of the fish screening program, and calls for restoration of essential rearing habitat in the lower river/northern Delta.

Operations of the Sacramento River Division are interconnected with those of the Trinity River Division. NMFS is in the process of conducting a separate consultation on the effects of the Trinity River Division operations on listed coho salmon in the Trinity River. NMFS is committed to ensuring appropriate coordination between the analysis and results of this Opinion and the forthcoming coho opinion. The Sacramento River Division RPA will be analyzed in that Opinion, and may be adjusted as necessary to avoid jeopardy to coho salmon and adverse modification of critical habitat.

Action Suite I.1. Clear Creek

Suite Objective: The proposed action includes a static flow regime (no greater than 200 cfs all year) and uncertainty as to the availability of b(2) water in the future pose significant risk to these species. The RPA actions described below were developed based on a careful review of past flow studies, current operations, and future climate change scenarios. Although not all of the flow studies have been completed, NMFS believes these actions are necessary to address adverse project effects on flow and water temperature that reduce the viability of spring-run and CV steelhead in Clear Creek.

Action I.1.1. Spring Attraction Flows

Objective: Encourage spring-run movement to upstream Clear Creek habitat for spawning.

Action: 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).

Rationale: In order to prevent spring-run from hybridizing with fall-run in the Sacramento River, it is important to attract early spring-run adults as far upstream in Clear Creek as possible, where cooler water temperatures can be maintained over the summer holding period through releases from Whiskeytown Dam. This action will also prevent spring-run adults from spawning in the lower reaches of Clear Creek, where water temperatures are inadequate to support eggs and pre-emergent fry during September and October.

Action I.1.2. Channel Maintenance Flows

Objective: Minimize project effects by enhancing and maintain previously degraded spawning habitat for spring-run and CV steelhead

Action: 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).

Rationale: Channel maintenance flows are a necessary element of critical habitat (see PCEs) in order to restore proper functioning rivers. This modified operation allows higher flows necessary to move spawning gravels downstream from injection sites, which will increase the amount of spawning habitat available to spring-run and steelhead. Previous studies (McBain and Trush 1999) have shown that Clear Creek lacks sufficient gravel for spawning habitat. Both spring-run and steelhead need higher flows to provide the spawning and rearing habitat elements essential for survival and recovery.

Action I.1.3. Spawning Gravel Augmentation

Objective: Enhance and maintain previously degraded spawning habitat for spring-run and CV steelhead.

Action: Reclamation, in coordination with the Clear Creek Technical team, shall continue spawning gravel augmentation efforts. By December 31 each year, Reclamation shall provide a report to NMFS on implementation and effectiveness of the gravel augmentation program.

Rationale: Similar to above for Action I.1.2. Recent studies (USFWS 2007, 2008) have shown steelhead and spring-run utilize gravel injection sites for spawning. Gravel augmentation has increased the steelhead spawning habitat available in the lower reaches of Clear Creek and directly relates to higher abundance in recent years. The gravel augmentation program also benefits fall-run and late fall-run spawning. Including the gravel augmentation program in the RPA ensures that it is reasonably certain to occur in the future.

Action I.1.4. Spring Creek Temperature Control Curtain *(Note: This action benefits Sacramento River conditions, but is part of Clear Creek operations)*

Objective: Reduce adverse impacts of project operations on water temperature for listed salmonids in the Sacramento River.

Action: Reclamation shall replace the Spring Creek Temperature Control Curtain in Whiskeytown Lake by June 2011 .

Rationale: The Spring Creek Tunnel releases provide cold water to Keswick Reservoir, which improves the ability to lower water temperatures during the summer for winter-run spawning and incubation. Recent underwater surveys concluded that the Whiskeytown Curtain is in poor condition and needs a major overhaul (Reclamation 2008b). Six rips in the fabric run the full depth of the curtain to 55 feet.

Action I.1.5. Thermal Stress Reduction

Objective: To reduce thermal stress to over-summering steelhead and spring-run during holding, spawning, and embryo incubation.

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

1) 60°F at the Igo gage from June 1 through September 15; and

2) 56°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.

Rationale: The water temperature criteria address the critical need for colder water that historically was available to salmonids above Whiskeytown Dam. If the criteria are not met, juvenile steelhead rearing habitat is limited, predation is higher, and disease is more prevalent. Spring-run adults need colder water to hold over during the summer until September. If water temperature is too warm, spring-run experience pre-spawn mortality and reduced production. The lower water temperature in September is necessary to reduce mortality of spring-run eggs and pre-emergent fry.

Action I.1.6. Adaptively Manage to Habitat Suitability/IFIM Study Results

Objective: Decrease risk to Clear Creek spring-run and CV steelhead population through improved flow management designed to implement state-of-the-art scientific analysis on habitat suitability.

Action: 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 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.

Rationale: Past project operations have reduced spring-run and CV steelhead abundance in Clear Creek by creating passage barriers, raising water temperature, and reducing spawning gravels in key areas of critical habitat. Abundance has increased in recent years as a result of passage improvements, habitat restoration, and operational changes to improve temperature control. Persistence of the population and maintenance of its critical habitat will require continuation of flows adequate for migration and maintenance of spawning gravels and suitable water temperatures.

Action Suite I.2. Shasta Operations

Introduction to Shasta Operations: Maintaining suitable temperatures for egg incubation, fry emergence, and juvenile rearing in the Sacramento River is critically important for survival and recovery of the winter-run ESU. The winter-run ESU has been reduced to a single population, which has been blocked from its historical range above Shasta Dam. Consequently, suitable temperatures and habitat for this population must be maintained downstream of Shasta Dam through management of the cold water pool behind the dam in the summer. Maintaining optimum conditions for this species below Shasta is crucial until additional populations are established in other habitats or this population is restored to its historical range. Spring-run are also affected by temperature management actions from Shasta Reservoir.

The effects analysis in this Opinion highlights the very challenging nature of maintaining an adequate cold water pool in critically dry years, extended dry periods, and under future conditions, which will be affected by increased downstream water demands and climate change. 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. In most

years, reservoir releases through the use of the TCD are a necessity in order to maintain the bare minimum population levels necessary for survival (Yates *et al.* 2008, Angilletta *et al.* 2008).

The effects analysis in this Opinion, and supplemental information provided by Reclamation, make it clear that despite Reclamation's best efforts, severe temperature-related effects cannot be avoided in some years. The RPA includes exception procedures to deal with this reality. Due to these unavoidable adverse effects, the RPA also specifies other actions that Reclamation must take, within its existing authority and discretion, to compensate for these periods of unavoidably high temperatures. These actions include restoration of habitat at Battle Creek that may be support a second population of winter-run, and a fish passage program at Keswick and Shasta dams to partially restore winter-run to their historical cold water habitat.

Objectives: The following objectives must be achieved to address the avoidable and unavoidable adverse effects of Shasta operations on winter-run and spring-run:

1) Ensure a sufficient cold water pool to provide suitable temperatures for winter-run spawning between Balls Ferry and Bend Bridge in most years, without sacrificing the potential for cold water management in a subsequent year. Additional actions to those in the 2004 CVP/SWP operations Opinion are needed, due to increased vulnerability of the population to temperature effects attributable to changes in Trinity River ROD operations, projected climate change hydrology, and increased water demands in the Sacramento River system.

2) Ensure suitable spring-run temperature regimes, especially in September and October. Suitable spring-run temperatures will also partially minimize temperature effects to naturally-spawning, non-listed Sacramento River fall-run, an important prey base for endangered Southern Residents.

3) Establish a second population of winter-run in Battle Creek as soon as possible, to partially compensate for unavoidable project-related effects on the one remaining population.

4) Restore passage at Shasta Reservoir with experimental reintroductions of winter-run to the upper Sacramento and/or McCloud rivers, to partially compensate for unavoidable project-related effects on the remaining population.

Action 1.2.1 Performance Measures.

Objective: To establish and operate to a set of performance measures for temperature compliance points and End-of-September (EOS) carryover storage, enabling Reclamation and NMFS to assess the effectiveness of this suite of actions over time. Performance measures will help to ensure that the beneficial variability of the system from changes in hydrology will be measured and maintained.

Action: 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 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

Rationale: Evaluating long-term operations against a set of performance measures is the only way to determine the effectiveness of operations in preserving key aspects of life history and run time diversity. For example, maintaining suitable spawning temperatures down to Bend Bridge in years when this is feasible will help to preserve the part of winter-run distribution and run timing that relies on this habitat and spawning strategy. This will help to ensure that diversity is preserved when feasible. The percentages are taken from those presented in the CVP/SWP operations BA, effects analysis in the Opinion, and NMFS technical memo on historic Shasta operations.

Action 1.2.2. November through February Keswick Release Schedule (Fall Actions)

Objective: Minimize impacts to listed species and naturally spawning non-listed fall-run from high water temperatures by implementing standard procedures for release of cold water from Shasta Reservoir.

Action: Depending on EOS carryover storage and hydrology, Reclamation shall develop and implement a Keswick release schedule, and reduce deliveries and exports as detailed below.

Action I.2.2.A Implementation Procedures for EOS Storage at 2.4 MAF and Above

If the EOS storage is at 2.4 MAF or above, by October 15, Reclamation shall convene a group including NMFS, USFWS, and CDFG, through B2IT or other comparable process, to consider a range of fall actions. A written monthly average Keswick release schedule shall be developed and submitted to NMFS by November 1 of each year, based on the criteria below. The monthly release schedule shall be tracked through the work group. If there is any disagreement in the group, including NMFS technical staff, the issue/action shall be elevated to the WOMT for resolution per standard procedures.

The workgroup shall consider and the following criteria in developing a Keswick release schedule:

1) Need for flood control space: A maximum 3.25 MAF end-of-November storage is necessary to maintain space in Shasta Reservoir for flood control.

2) Need for stable Sacramento River level/stage to increase habitat for optimal spring-run and fall-run redds/egg incubation and minimization of redd dewatering and juvenile stranding.

3) Need/recommendation to implement USFWS' Delta smelt Fall X2 action as determined by the Habitat Study Group formed in accordance with the 2008 Delta smelt Opinion. NMFS will continue to participate in the Habitat Study Group (HSG) chartered through the 2008 Delta smelt biological opinion. If, through the HSG, a fall flow action is recommended that draws down fall storage significantly from historical patterns, then NMFS and USFWS will confer and recommend to Reclamation an optimal storage and fall flow pattern to address multiple species' needs.

If there is a disagreement at the workgroup level, actions may be elevated to NMFS Sacramento Area Office Supervisor and resolved through the WOMT's standard operating procedures.

Rationale: 2.2 MAF EOS storage is linked to the potential to provide sufficient cold water to meet the minimum Balls Ferry Compliance point in the following year, and it is achievable approximately 85 percent of the time. Based on historical patterns, EOS storage will be above 2.4 MAF 70 percent of the time. The 2.4 MAF storage value provides a reasonable margin above the 2.2 level to increase the likelihood that the Balls Ferry Compliance Point will be reached while also implementing fall releases to benefit other species and life stages.

Therefore, in these circumstances, actions should target the fall life history stages of the species covered by this Opinion *(i.e.*, spring-run spawning, winter-run emigration). The development of a Keswick release schedule is a direct method for controlling storage maintained in Shasta Reservoir. It allows Reclamation to operate in a predictable way, while meeting the biological requirements of the species. The B2IT workgroup has been used in the past to target actions to benefit fall-run during this time of year using b(2) resources, and, because of its expertise, may also be used by Reclamation to develop this flow schedule. In the past, the B2IT group has used the CVPIA AFRP guidelines to target reservoir releases. Over time, it may be possible to develop a generic release schedule for these months, based on the experience of the work group.

Action I.2.2.B Implementation Procedures for EOS Storage Above 1.9 MAF and Below 2.4 MAF

If EOS storage is between 1.9 and 2.4 MAF, then Reclamation shall convene a group including NMFS, USFWS, and CDFG, through B2IT or other comparable workgroup, to consider a range of fall actions. Reclamation shall provide NMFS and the work group with storage projections based on 50 percent, 70 percent, and 90 percent hydrology through February, and develop a monthly average Keswick release schedule based on the criteria below. The monthly release schedule shall be submitted to NMFS by November 1.

Criteria for the release schedule shall include:

1) Maintain Keswick releases between 7000 cfs and 3250 cfs to reduce adverse effects on mainstem spring-run and conserve storage for next year's cold water pool.

2) Consider fall-run needs per CVPIA AFRP guidelines, through January, including stabilizing flows to keep redds from de-watering.

3) Be more conservative in Keswick releases throughout fall and early winter if hydrology is dry, and release more water for other purposes if hydrology becomes wet. For example, release no more than 4,000 cfs if hydrology remains dry.

The Keswick release schedule shall follow this or a similar format, to be refined by the workgroup:

	October forecast based on EOS storage	50% hydrology		70% hydrology		90% hydrology	
		Projected storage MAF	Planned release CFS	Projected storage MAF	Planned release CFS	Projected storage MAF	Planned release CFS
Monthly average Keswick	November						
	December						
	January						

release	February						

Reclamation, in coordination with the work group, shall review updated hydrology and choose a monthly average release for every month (November, December, January, February), based on the release schedule. In the event that the updated hydrology indicates a very dry pattern and consequent likely reduction in storage, the work group may advise Reclamation to take additional actions, including export curtailments, if necessary to conserve storage

If there is a disagreement at the work group level, actions may be elevated to NMFS and resolved through the WOMT's standard operating procedures.

Rationale: It is necessary to be reasonably conservative with fall releases to increase the likelihood of adequate storage in the following year to provide cold water releases for winter-run. This action is intended to reduce adverse effects on each species without compromising the ability to reduce adverse effects on another species. A work group with biologists from multiple agencies will refine the flow schedule, providing operational certainty while allowing for real-time operational changes based on updated hydrology. Over time, it may be possible to develop a generic release schedule for these months, based on the experience of the work group.

Action I.2.2.C. Implementation and Exception Procedures for EOS Storage of 1.9 MAF or Below

If the EOS storage is at or below 1.9 MAF, then Reclamation shall:

1) In early October, reduce Keswick releases to 3,250 cfs as soon as possible, unless higher releases are necessary to meet temperature compliance points (see action I.2.3).

2) Starting in early October, if cool weather prevails and temperature control does not mandate higher flows, curtail discretionary water deliveries (including, but not limited to agricultural rice decomposition deliveries) to the extent that these do not coincide with temperature management for the species. It is important to maintain suitable temperatures targeted to each life stage. Depending on air and water temperatures, delivery of water for rice decomposition, and any other discretionary purposes at this time of year, may coincide with the temperature management regime for spring-run and fall-run. This action shall be closely coordinated with NMFS, USFWS, and CDFG.

3) By November 1, submit to NMFS storage projections based on 50 percent, 70 percent, and 90 percent hydrology through February. In coordination with NMFS, Reclamation shall: (1) develop a monthly average Keswick release schedule similar in format to that in Action I.2.2.B, based on the criteria below and including actions specified below; and (2) review updated hydrology and choose a monthly average release for every month, based on the release schedule. November releases shall be based on a 90 percent hydrology estimate.

Criteria and actions:

1) Keswick releases shall be managed to improve storage and maintained at 3,250 cfs unless hydrology improves.

2) November monthly releases will be based on 90 percent hydrology.

3) Consider fall-run needs through January as per CVPIA AFRP guidelines, including stabilizing flows to keep redds from dewatering.

4) Continue to curtail discretionary agricultural rice decomposition deliveries to the extent that these do not coincide with temperature management for the species, or impact other ESA-listed species. It is important to maintain suitable temperatures targeted to each life stage. Depending on air and water temperatures, delivery of water for rice decomposition may coincide with the temperature management regime for spring-run and fall-run. This action shall be closely coordinated with NMFS. USFWS, and CDFG.

5) If operational changes are necessary to meet Delta outflow, X2, or other legal requirements during this time, then:

   a) CVP/SWP Delta combined exports shall be curtailed to 2,000 cfs if necessary to meet legal requirements while maintaining a 3,250 cfs Keswick release (or other planned release based on biological needs of species); and
   b) if it is necessary to curtail combined exports to values more restrictive than 2000 cfs in order to meet Delta outflow, X2, or other legal requirements, then Reclamation and DWR shall, as an overall strategy, first, increase releases from Oroville or Folsom; and
   c) in general, Reclamation shall increase releases from Keswick as a last resort.
   d) Based on updated monthly hydrology, this restriction may be relaxed, with NMFS' concurrence.

6) If the hydrology and storage have not improved by January, additional restrictions apply – see Action I.2.4.

Rationale: Per actions I.2.3 and I.2.4 below, Reclamation is required to meet 1.9 MAF EOS. The BA's CALSIM modeling shows that during a severe or extended drought, 1.9 EOS storage may not be achievable. In this circumstance, Reclamation should take additional steps in the fall and winter months to conserve Shasta storage to the maximum extent possible, in order to increase the probability of maintaining cold water supplies necessary for egg incubation for the following summer's cohort of winter-run.

Assessment of the hydrologic record and CALSIM modeling shows that operational actions taken during the first year of a drought sequence are very important to providing adequate storage and operations in subsequent drought years. The biological effects of an extended

drought are particularly severe for winter-run. Extended drought conditions are predicted to increase in the future in response to climate change. While it is not possible to predict the onset of a drought sequence, in order to ensure that project operations avoid jeopardizing listed species, Reclamation should operate in any year in which storage falls below 1.9 MAF EOS as potentially the first year of a drought sequence. The CVP storage system is likely to recover more quickly in the winter and spring months if additional storage conservation measures are taken in the fall and winter.

The curtailments to discretionary rice decomposition deliveries and combined export curtailment of 2,000 cfs are necessary to conserve storage when EOS storage is low. These actions were developed through an exchange of information and expertise with Reclamation operators.

This action is consistent with comments from the Calfed Science Peer Review panel. That panel recommended that Shasta be operated on a two-year (as opposed to single year) hydrologic planning cycle and that Reclamation take additional steps to incorporate planning for potential drought and extended drought into its operations.

Action I.2.3. February Forecast; March – May 14 Keswick Release Schedule (Spring Actions)

Objective: To conserve water in Shasta Reservoir in the spring in order to provide sufficient water to reduce adverse effects of high water temperature in the summer months for winter-run, without sacrificing carryover storage in the fall.

Actions:

1) Reclamation shall make its February 15 forecast of deliverable water based on an estimate of precipitation and runoff within the Sacramento River basin at least as conservative as the 90 percent probability of exceedence. Subsequent updates of water delivery commitments must be based on monthly forecasts at least as conservative as the 90 percent probability of exceedence.

    a) Reclamation shall provide the draft February forecast, and a projection of temperature management operations for the summer months, to NMFS no later than seven business days after receipt of the official DWR runoff forecast.
    b) NMFS shall be provided at 3 three business days to review the draft forecast.
    c) NMFS shall review the draft February forecast to determine whether the predicted delivery schedule is likely to leave sufficient water for temperature management to meet ESA requirements.
    d) NMFS shall provide a written evaluation to Reclamation prior to Reclamation making the first allocation announcements and for each subsequent month for discretionary contract deliveries.
    e) Reclamation shall manage releases from Keswick consistent with the February forecast and subsequent monthly hydrology updates.

2) Reclamation shall make releases to maintain a temperature compliance point not in excess of 56 degrees between Balls Ferry and Bend Bridge from April 15 through May 15.

Action I.2.3.A Implementation Procedures if February Forecast, Based on 90 Percent Hydrology, Shows that Balls Ferry Temperature Compliance Point and 2.2 MAF EOS are Both Achievable

NMFS will review the draft February forecast to determine whether both a temperature compliance point at Balls Ferry during the temperature control season (May – October), and EOS storage of at least 2.2 MAF, is likely to be achieved. If both are likely, then Reclamation shall announce allocations and operate Keswick releases in March, April, and May consistent with its standard plan of operation. Preparation of a separate Keswick release schedule is not necessary in these circumstances.

Rationale: The 90 percent forecast is a conservative approach for assessing the potential to meet both the Balls Ferry TCP and 2.2 MAF EOS performance goals. If both of these performance goals are projected to be met at the time of the February forecast, then no restrictions on allocations due to this suite of actions are necessary.

Action I.2.3.B Implementation Procedures if February Forecast, Based on 90 Percent Hydrology, Shows that Only Balls Ferry Compliance or 2.2 MAF EOS, but Not Both, Is Achievable

1) On or before February 15, Reclamation shall reduce Keswick releases to 3,250 cfs, unless NMFS concurs on an alternative release schedule. This reduction shall be maintained until a flow schedule is developed per procedures below.

2) In coordination with NMFS, by March 1, Reclamation shall develop an initial monthly Keswick release schedule, based on varying hydrology of 50 percent, 70 percent, and 90 percent (similar in format to the fall and winter action implementation procedures – see table above). These schedules shall be used as guidance for monthly updates and consultations.

3) Based on this guidance, Reclamation shall consult with NMFS monthly on Keswick releases. Reclamation shall submit a projected forecast, including monthly average release schedules and temperature compliance point to NMFS every month, within 7 business days of receiving the DWR runoff projections for that month. Within 3 business days of receiving this information from Reclamation, NMFS will review the draft schedule for consistency with the criteria below and provide written recommendations to Reclamation.

4) The initial monthly Keswick release schedule, and subsequent monthly updates, shall be developed based on the following criteria and including the following actions:

a) Maintain minimum monthly average flows necessary to meet nondiscretionary delivery obligations and legal requirements.
b) Provide for flow-related biological needs of spring life stages of all species covered by this Opinion in the Sacramento River and Delta, to the greatest extent possible.
c) If operational changes are necessary to meet Delta outflow, X2, or other legal requirements during this time, then:

- CVP/SWP Delta combined exports shall be curtailed to 2,000 cfs if necessary to meet legal requirements while maintaining a 3,250 cfs Keswick Dam release (or other planned release based on biological needs of species); and
- if it is necessary to curtail combined exports to values more restrictive than 2000 cfs in order to meet Delta outflow, X2, or other legal requirements, then Reclamation and DWR shall, as an overall strategy, first, increase releases from Oroville or Folsom Dam; and
- in general, Reclamation shall increase releases from Keswick Dam as a last resort.
- Based on improvements in updated monthly hydrology, this restriction may be relaxed, with NMFS' concurrence.

Rationale: It is necessary to manage storage for potential dry years, to reduce adverse effects on winter-run egg incubation in summer months, and on spring-run in fall months. According to information provided by Reclamation, the hydrology is too variable this time of year to provide for a meaningful 3-month release schedule. Instead, monthly consultations between NMFS and Reclamation are needed to ensure that operations are based on biological criteria.

Action I. 2.3. C. Drought Exception Procedures if February Forecast, Based on 90 Percent Hydrology, Shows that Clear Creek Temperature Compliance Point or 1.9 MAF EOS Storage is Not Achievable

Reclamation shall follow all procedures immediately above (Action I.2.3.B) and, in addition, shall:

1) By March 1, provide a contingency plan with a written justification that all actions within Reclamation's authorities and discretion are being taken to preserve cold water at Shasta Reservoir for the protection of winter-run.

2) The contingency plan shall also, at a minimum, include the following assessments and actions:

   a) Relaxation of Wilkins Slough navigation criteria to at most 4,000 cfs.
   b) An assessment of any additional technological or operational measures that may be feasible and may increase the ability to manage the cold water pool.
   c) Notification to State Water Resources Control Board that meeting the biological needs of winter-run and the needs of resident species in the Delta, delivery of water to nondiscretionary Sacramento Settlement Contractors, and Delta outflow requirements per D-1641, may be in conflict in the coming season and requesting the Board's assistance in determining appropriate contingency measures, and exercising their authorities to put these measures in place.

3) If, during the temperature control season, a Clear Creek TCP on the Sacramento River cannot be achieved, then Reclamation shall bypass power at Shasta Dam if NMFS determines a bypass is necessary for preserving the cold water pool. This power by-pass may be necessary to maintain temperature controls for winter-run, or later in the temperature season, for spring-run.

Rationale: In these circumstances, there is a one-in-ten likelihood that minimal requirements for winter-run egg survival will not be achieved due to depletion of the cold water pool, resulting in temperature-related mortality of winter-run and, in addition, most likely contributing to temperature-related mortality of spring-run spawning in the fall. This is a conservative forecast, since there is a 90 percent probability that conditions will improve. However, the effects analysis in this Opinion concludes that these poor conditions could be catastrophic to the species, potentially leading to a significant reduction in the viability of winter-run. Delta objectives (salinity, X2, E/I ratio, OMR flow restrictions for both smelt and salmon) are also controlling at this time of year. There is potential for conflict between the need to maintain storage at Shasta and other legal and ecological requirements. Consequently, it is necessary to immediately limit releases from Shasta and develop a contingency plan.

Notification to the State Water Resources Control Board (SWRCB) is essential. Sacramento Settlement Contract withdrawal volumes from the Sacramento River can be quite substantial during these months. The court has recently concluded that Reclamation does not have discretion to curtail the Sacramento Settlement contractors to meet Federal ESA requirements. Therefore, NMFS is limited in developing an RPA that minimizes take to acceptable levels in these circumstances. Consequently, other actions are necessary to avoid jeopardy to the species, including fish passage at Shasta Dam in the long term.

Separate from this consultation, NMFS will work with the SWRCB to determine whether contingency plans within the Board's authority are warranted, and to assist in developing such plans that will allow Reclamation to meet ESA requirements. The incidental take statement for this Opinion also provides limitations of ESA incidental take coverage for Settlement Contractors under the terms of this Opinion.

Action 1.2.4 May 15 Through October Keswick Release Schedule (Summer Action)

Objective: To manage the cold water storage within Shasta Reservoir and make cold water releases from Shasta Reservoir to provide suitable habitat temperatures for winter-run, spring-run, CV steelhead, and Southern DPS of green sturgeon in the Sacramento River between Keswick Dam and Bend Bridge, while retaining sufficient carryover storage to manage for next year's cohorts. To the extent feasible, manage for suitable temperatures for naturally spawning fall-run.

Action: Reclamation shall develop and implement an annual Temperature Management Plan by May 15 to manage the cold water supply within Shasta Reservoir and make cold water releases from Shasta Reservoir and Spring Creek to provide suitable temperatures for listed species, and, when feasible, fall-run.

Reclamation shall manage operations to achieve daily average water temperatures in the Sacramento River between Keswick Dam and Bend Bridge as follows:

1) Not in excess of 56°F at compliance locations between Balls Ferry and Bend Bridge from May 15 through September 30 for protection of winter-run, and not in excess of 56°F at the same compliance locations between Balls Ferry and Bend Bridge from October 1 through October 31 for protection of mainstem spring run, whenever possible.

2) Reclamation shall operate to a final Temperature Management Plan starting May 15 and ending October 31.

3) As part of the adaptive management process, and in coordination with NMFS, by March 2010, Reclamation shall fund an independent modeler to review these procedures and the recommendations of the Calfed Science Panel report on temperature management and recommend specific refinements to these procedures to achieve optimal temperature management, with due consideration of the Calfed Science panel's recommendations (Deas *et al.*, 2009) regarding temperature management. Upon written concurrence of

NMFS, refinements to the implementation procedures for this action suite, based on the independent contractor's report, may be adopted and implemented.

Implementation Procedures: Reclamation shall take the following steps to develop an annual Temperature Management plan:

1) By April 15, Reclamation shall develop and submit to NMFS both 50 percent and 90 percent forecasts, consistent with its draft plan of summer operations. Reclamation shall model two complete runs for each forecast, one with an upstream TCP and one with a downstream TCP. Together, Reclamation will present four risk-management options to NMFS for review. EOS Storage will be projected for each of the four runs. If it is very wet or very dry, there will be fewer options to present to NMFS.
2) NMFS will provide comments within five business days to Reclamation, recommending that Reclamation either: (1) operate to one of the options; or (2) develop an alternative operations plan necessary to meet reasonably attainable preferred TCP and EOS storage.
3) Within five business days of receiving NMFS' recommendations, and based on NMFS' comments, Reclamation will develop an operations plan with specific monthly average Keswick releases to attain both TCP from May 15 through the EOS and EOS storage, and submit the plan to NMFS for concurrence.
4) By May 15, Reclamation and NMFS shall jointly submit a final Temperature Management Plan to meet the SWRCB 90-5 requirements using the SRTTG. From May 15 through October 31, the SRTTG shall track implementation of this plan, and shall refine it based real-time information, including run timing, location of redds, air and surface water temperature modeling, and projected versus actual extent of the cold water pool. Any disagreement at the work group level regarding how to implement or modify the plan will be elevated to NMFS and resolved through WOMT standard operating procedures.

Rationale: Depending on hydrology and air temperature, from May through October, it is necessary to use the cold water pool in Shasta Reservoir to provide cold water releases to maintain suitable water temperatures for listed anadromous fish below Shasta. Without access to the cold water pool, suitable temperatures for egg incubation are not attainable. Preparation of an annual Temperature Management Plan allows Reclamation, in consultation with NMFS, to achieve optimal cold water management in a given year. Temperature management requires tradeoffs between extending the range of suitable habitat by moving the compliance point downstream from Balls Ferry, and conserving EOS storage. The storage level at the EOS is important to manage the risk of unsuitably warm water temperatures for winter-run in the following summer. Maintaining suitable temperatures in September and October is also important to minimize adverse effects of project operations to main stem Sacramento River spring-run. Fall-run, a non-listed species that is important as a prey base for Southern Resident Killer Whale, also benefits from suitable temperatures in the Fall.

Development of 2 to 4 options for temperature management, prior to finalizing a plan allows for meaningful discussion of appropriate risk management strategies in a given year, based

on timely hydrologic and biological considerations. Important factors differ from year to year, and need to be considered in operations planning. They include the projected size of the winter-run year class (and thus the extent of habitat needed); timing and location of spawning and redds based on aerial surveys; the extent of the cold water pool, given air temperatures; and operation of the Temperature Control Device to provide optimal use of the cold water pool. Preparation of a draft plan also allows for iterative planning and feedback. Operations can be tailored each year to achieve the optimal approach to temperature management to maintain viable populations of anadromous fish, based on the best available information.

The Calfed Science Program peer review report on temperature management emphasized the importance of refining temperature management practices in the long term and included recommendations for doing so. The requirement to hire an independent contractor to recommend specific refinements to the procedures in this RPA responds to these recommendations.

Action I.2.5. Winter-Run Passage and Re-Introduction Program at Shasta Dam

See Fish Passage Program, Action V

Action I.2.6. Restore Battle Creek for Winter-Run, Spring-Run, and CV Steelhead

Objective: To partially compensate for unavoidable adverse effects of project operations by restoring winter-run and spring-run to the Battle Creek watershed. A second population of winter-run would reduce the risk of extinction of the species from lost resiliency and increased vulnerability to catastrophic events.

Description of Action: Reclamation shall direct discretionary funds to implement the Battle Creek Salmon and Steelhead Restoration Project. Phase 1A funding is currently allocated through various partners and scheduled to commence in Summer 2009 (Reclamation 2008c). DWR shall direct discretionary funds for Phase 1B and Phase 2, consistent with the proposed amended Delta Fish Agreement by December 31 of each year, Reclamation and DWR will submit a written report to NMFS on the status of the project, including phases completed, funds expended, effectiveness of project actions, additional actions planned (including a schedule for further actions), and additional funds needed. The Battle Creek Salmon and Steelhead Restoration Project shall be completed no later than 2019.

Rationale: Modeling projections in the BA show that adverse effects of ongoing project operations cannot be fully minimized. Severe temperature-related effects due to project operations will occur in some years. This RPA includes an exception procedure in anticipation of these occurrences (see Action I.2.2). Establishing additional populations of winter-run is critical to stabilize the high risk of extinction resulting from the proposed action on the only existing population of this species. $26 million has been identified for this project in the American Recovery and Reinvestment Act of 2009.

Action Suite I.3. Red Bluff Diversion Dam (RBDD) Operations

Objectives: Reduce mortality and delay of adult and juvenile migration of winter-run, spring-run, CV steelhead, and Southern DPS of green sturgeon caused by the presence of the diversion dam and the configuration of the operable gates. Reduce adverse modification of the passage element of critical habitat for these species. Provide unimpeded upstream and downstream fish passage in the long term by raising the gates year-round, and minimize adverse effects of continuing dam operations, while pumps are constructed replace the loss of the diversion structure.

Action I.3.1. Operations after May 14, 2012: Operate RBDD with Gates Out

Action: No later than May 15, 2012, Reclamation shall operate RBDD with gates out all year to allow unimpeded passage for listed anadromous fish. If the Red Bluff Alternative Intake Structure is not anticipated to be operational by May 15, 2012, Reclamation may submit a request to NMFS, no later than January 31, 2012, to close the gates from June 15 to September 1, 2012. This request must document that all milestones for construction of the alternative pumping plant have been met and that all other conservation measures (see below) have been implemented.

Rationale: RBDD impedes and delays upstream migration of adult winter-run, spring-run, CV steelhead, and Southern DPS of green sturgeon. It also impedes and delays downstream passage of juveniles of the same species. It adversely modifies critical habitat for these species by impairing important mainstem passage. Pumps can be used to deliver water currently made available by placing gates in the river, and $109 million has been identified in the recent American Recovery and Reinvestment Act of 2009 for the Red Bluff Pumping Plant.

Action I.3.2. Interim Operations

Action: Until May 14, 2012, Reclamation shall operate RBDD according to the following schedule:

- September 1 - June 14: Gates open. No emergency closures of gates are allowed.
- June 15 - August 31: Gates may be closed at Reclamation's discretion, if necessary to deliver water to TCCA.

Rationale: Having gates out until June 15 is necessary for winter-run, spring-run and green sturgeon adult passage to spawning habitat. TCCA can withdraw 465 cfs without the gates in the river. Their water demand typically reaches 800 cfs by June 15, therefore, TCCA will need supplemental pumping capacity to meet water demand until June 15. NMFS has consulted with Reclamation separately on the effects of an interim pumping operation. Implementation of these improvements to passage conditions at RBDD, in conjunction with several other conservation and research measures proposed by TCCA (Appendix 2-B), is

expected to reduce the effects of continuing (for the next three years) the (modified) operations of RBDD to a level that will not reduce the likelihood of survival and recovery of these ESUs and DPSs.

Action I.3.3. Interim Operation for Green Sturgeon

Objective: Allow passage of green sturgeon during interim operations.

Action: When gates are in, Reclamation shall retain a minimum 18-inch opening under the gates that are open, to allow safe downstream passage of adult green sturgeon. The 18-inch opening may be modified to 12 inches by the RBDD technical team if necessary to maintain the structural integrity of the dam and/or adequate attraction flows for salmonids at the fish ladders, or in consideration of other real-time fish migratory issues.

Rationale: Twelve to 18 inches is the estimated minimum gate opening that would allow adult green sturgeon to pass downstream underneath the RBDD gates uninjured.

Action I.3.4: Measures to Compensate for Adverse Effects of Interim Operations on Green Sturgeon

Objective: Offset short-term effects to green sturgeon due to interim gate operations by investing in geographically specific research needed to determine green sturgeon life history and recovery needs.

Action: Reclamation shall continue ongoing funded research to characterize green sturgeon populations in the upper Sacramento River Basin, their movements, and habitat usage, as planned through fiscal year 2009. In addition, Reclamation (or TCCA) shall convene a technical team, including representatives from NMFS, CDFG, USFWS, Corps, the University of California at Davis (UCD), and other cooperators, to review studies and results and coordinate research needs for green sturgeon. Reclamation and/or TCCA shall provide the necessary funding to insure that research will continue to be conducted in a coordinated and cooperative manner with the express intent of fully implementing the research projects described in the UCD proposal in Appendix 2-B to this Opinion.

Rationale: The exact timing of spawning migration for green sturgeon is not known, and during interim operations the potential remains for late arriving green sturgeon to be blocked by the dam after June 14. There is also a potential for post-spawn adult migrants and post-hatch juvenile migrants to be adversely affected, since they must pass downstream through the narrow clearance and high turbulence caused by the closed dam gates between June 14 and August 31.

Although the proposed studies will not directly benefit the green sturgeon that will be impacted by the dam during the interim period before the gates are permanently lifted, these studies will greatly benefit the Southern DPS of green sturgeon as a whole by revealing important information that will improve their likelihood of survival and recovery over the

long term. The studies will provide vital information on the life history and biological requirements of green sturgeon, which will allow NMFS to develop and implement a comprehensive and effective recovery plan for the DPS. By combining these long-term benefits to the survival and recovery of the Southern DPS of green sturgeon with the other significant improvements to habitat conditions required within this RPA (reduced gates-in periods, increased minimum gate openings, improved water temperature conditions for spawning and rearing, improved migration and rearing conditions in the lower river and Delta), the full implementation of this RPA is expected to offset the effects of continuing (for the next three years) the (modified) operations of RBDD to a level that will not reduce the likelihood of survival and recovery of the green sturgeon DPSs.

Action I.3.5. Measures to Compensate for Adverse Effects of Interim Operations on Spring-Run

Objective: Offset unavoidable short-term effects to spring-run from passage impediments of RBDD by restoring spring-run passage elsewhere in the Sacramento River system.

Action: Reclamation shall provide $500,000 for implementation of spring- run passage improvement projects in the Sacramento River. Appendix 2-B describes specific projects that may be implemented. By December 15, 2009, Reclamation shall provide NMFS with a prioritized list of projects from Appendix 2-B and an implementation schedule. Reclamation shall provide an annual report to NMFS on implementation and effectiveness of projects. Reclamation shall monitor and maintain these projects for five years.

Rationale: During interim operations, late arriving spring-run may be adversely affected by the dam after June 14. Construction and maintenance of the interim pumping facility also may have short-term adverse effects on spring-run.

The proposed passage restoration projects are likely to benefit the spring-run ESU as a whole by improving access to spawning habitat for some of the key populations within the ESU. Although the proposed improvements will not provide passage benefits to the small dependent populations that spawn upstream of RBDD, they will benefit the large independent populations that spawn in downstream tributaries. Passage improvements for the large independent population, in turn, will benefit the smaller populations throughout the Central Valley that depend on these larger populations to supplement their numbers and genetic diversity.

Action I.4. Wilkins Slough Operations

Objective: Enhance the ability to manage temperatures for anadromous fish below Shasta Dam by operating Wilkins Slough in the manner that best conserves the dam's cold water pool for summer releases.

Action: Reclamation shall convene the SRTTG to review past operational data, hydrology, and fisheries needs for Wilkins Slough. The SRTTG shall recommend Wilkins Slough

minimum flows for anadromous fish in critically dry years, in lieu of the current 5,000 cfs navigation criterion. Recommendations shall be made to NMFS by December 1, 2009. The recommendations will be implemented upon NMFS' concurrence.

In years other than critically dry years, the need for a variance from the 5,000 cfs navigation criterion will be considered during the process of developing the Keswick release schedules (Action I.2.2-4).

Rationale: In some circumstances, maintaining the Wilkins Slough navigation channel at 5,000 cfs may be a significant draw on Shasta reservoir levels and affect the summer cold water pool necessary to maintain suitable temperatures for winter-run egg incubation and emergence. Reclamation has stated that it is no longer necessary to maintain 5,000 cfs for navigation (CVP/SWP operations BA, page 2-39). Operating to a minimal flow level based on fish needs, rather than on outdated navigational requirements, will enhance the ability to use cold-water releases to maintain cooler summer temperatures in the Sacramento River.

Action I.5. Funding for CVPIA Anadromous Fish Screen Program (AFSP)

Objective: To reduce entrainment of juvenile anadromous fish from unscreened diversions.

Action: Reclamation shall screen priority diversions as identified in the CVPIA AFSP, consistent with previous funding levels for this program. In addition, Reclamation/CVPIA Program shall evaluate the potential to develop alternative screened intakes that allow diverters to withdraw water below surface levels required by the antiquated Wilkins Slough navigation requirement criterion of 5,000 cfs.

Rationale: Approximately ten percent of 129 CVP diversions listed in Appendix D-1 of the CVP/SWP operations BA are currently screened. Of these, most of the largest diversions (greater than 250 cfs) have already been screened; however, a large number of smaller diversions (less than 250 cfs) remain unscreened or do not meet NMFS fish screening criteria (NMFS 1997; *e.g.*, CVP and SWP Delta diversions, Rock Slough diversion). The AFSP has identified priorities for screening that is consistent with the needs of listed fish species. Screening will reduce the loss of listed fish in water diversion channels. In addition, if new fish screens can be extended to allow diversions below 5,000 cfs at Wilkins Slough, then cold water can be conserved during critically dry years at Shasta Reservoir for winter-run and spring-run life history needs.

Action Suite I.6: Sacramento River Basin Salmonid Rearing Habitat Improvements

Objective: To restore floodplain rearing habitat for juvenile winter-run, spring-run, and CV steelhead in the lower Sacramento River basin, to compensate for unavoidable adverse effects of project operations. This objective may be achieved at the Yolo Bypass, and/or through actions in other suitable areas of the lower Sacramento River.

The suite of actions includes near term and long-term actions. The near-term action (Action I.6.2) is ready to be implemented and can provide rearing benefits within two years of issuing this Opinion. The long-term actions (Actions I.6.1, I.6.3, and I.6.4) require additional planning and coordination over a five- to ten-year time frame.

These actions are consistent with Reclamation's broad authorities in CVPIA to develop and implement these types of restoration projects. When necessary to achieve the overall objectives of this action, Reclamation and DWR, in cooperation with other agencies and funding sources, including the Delta Fish Agreement and any amendments, shall: (1) apply for necessary permits; (2) seek to purchase land, easements, and/or water rights from willing sellers; (3) seek additional authority and/or funding from Congress or the California State Legislature, respectively; and (4) pursue a Memorandum of Agreement with the Corps.

Similar actions addressing rearing and fish passage are under consideration in the BDCP development process and may ultimately satisfy the requirements in Actions I.6 and I.7. BDCP is scheduled to be completed by December 31, 2010.

Action I.6.1. Restoration of Floodplain Rearing Habitat

Objective: To restore floodplain rearing habitat for juvenile winter-run, spring-run, and CV steelhead in the lower Sacramento River basin. This objective may be achieved at the Yolo Bypass, and/or through actions in other suitable areas of the lower Sacramento River.

Action: In cooperation with CDFG, USFWS, NMFS, and the Corps, Reclamation and DWR shall, to the maximum extent of their authorities (excluding condemnation authority), provide significantly increased acreage of seasonal floodplain rearing habitat, with biologically appropriate durations and magnitudes, from December through April, in the lower Sacramento River basin, on a return rate of approximately one to three years, depending on water year type. In the event that this action conflicts with Shasta Operations Actions I.2.1 to I.2.3, the Shasta Operations Actions shall prevail.

Implementation procedures: By December 31, 2011, Reclamation and DWR shall submit to NMFS a plan to implement this action. This plan should include an evaluation of options to: (1) restore juvenile rearing areas that provide seasonal inundation at appropriate intervals, such as areas identified in Appendix 2-C or by using the Sacramento River Ecological Flow Tool (ESSA/The Nature Conservancy 2009) or other habitat modeling tools; (2) increase inundation of publicly and privately owned suitable acreage within the Yolo Bypass; (3) modify operations of the Sacramento Weir (which is owned and operated by the Department of Water Resources) or Fremont Weir to increase rearing habitat; and (4) achieve the restoration objective through other operational or engineering solutions. An initial performance measure shall be 17,000-20,000 acres (excluding tidally-influenced areas), with appropriate frequency and duration. This measure is based on the work by Sommer *et al.* (2001, 2004) at Yolo Bypass and on recent analyses conducted for the BDCP process of

inundation levels at various river stages. (BDCP Integration Team 2009).[28] The plan may include a proposal to modify this performance measure, based on best available science or on a scientifically based adaptive management process patterned after Walters (1997).

This plan also shall include: (1) specific biological objectives, restoration actions, and locations; (2) specific operational criteria; (3) a timeline with key milestones, including restoration of significant acreage by December 31, 2013; (4) performance goals and associated monitoring, including habitat attributes, juvenile and adult metrics, and inundation depth and duration criteria; (5) specific actions to minimize stranding or migration barriers for juvenile salmon; and (6) identification of regulatory and legal constraints that may delay implementation, and a strategy to address those constraints. Reclamation and DWR shall, to the maximum extent of their authorities and in cooperation with other agencies and funding sources, implement the plan upon completion, and shall provide annual progress reports to NMFS. In the event that less than one half of the total acreage identified in the plan's performance goal is implemented by 2016, then Reclamation and DWR shall re-initiate consultation.

The USFWS' Delta smelt biological opinion includes an action to restore 8,000 acres of tidal habitat for the benefit of Delta smelt. If these 8,000 acres also provide suitable rearing habitat for salmonids, they may be used in partial satisfaction of the objective of this action.

This action is not intended to conflict with or replace habitat restoration planning in the BDCP process.

Rationale: Rearing and migration habitats for all anadromous fish species in the Sacramento basin are in short supply. Project operations limit the availability of such habitats by reducing the frequency and duration of seasonal over-bank flows as a result of flood management and storage operational criteria. Recent evaluations on the Yolo Bypass and Cosumnes River have shown that juvenile Chinook salmon grow faster when seasonal floodplain habitats are available (Sommer *et al.* 2001, 2005; Jeffres *et al.* 2008). Sommer *et al.* (2005) suggest these floodplain benefits are reflected in adult return rates. This action is intended to offset unavoidable adverse effects to rearing habitat and juvenile productivity of winter-run, spring-run, and CV steelhead in the Sacramento River basin, by increasing available habitat that is inundated with the frequency and duration of suitable floodplain rearing habitats during December through April.

In high flow years (*e.g.*, similar to 1998), this action can be achieved solely by inundation of the Yolo Bypass. In other years, this action may be accomplished by a combination of actions such as increasing the year-to-year inundation frequency of existing floodplains such as portions of the Yolo Bypass, by restoring rearing habitat attributes to suitable areas, through restoration or enhancement of intertidal areas such as Liberty Island, creation or re-establishment of side channels, and re-created floodplain terrace areas.

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[28] The analyses assumed a notch in the Fremont Weir.

Action I.6.2. Near-Term Actions at Liberty Island/Lower Cache Slough and Lower Yolo Bypass

Description of Action: By September 30, 2010, Reclamation and/or DWR shall take all necessary steps to ensure that an enhancement plan is completed and implemented for Liberty Island/Lower Cache Slough, as described in Appendix 2-C. This action shall be monitored for the subsequent five years, at a minimum, to evaluate the use of the area by juvenile salmonids and to measure changes in growth rates. Interim monitoring reports shall be submitted to NMFS annually, by September 30 each year, and a final monitoring report shall be submitted on September 30, 2015, or in the fifth year following implementation of enhancement actions. NMFS will determine at that time whether modification of the action or additional monitoring is necessary to achieve or confirm the desired results. This action shall be designed to avoid stranding or migration barriers for juvenile salmon.

Action I.6.3. Lower Putah Creek Enhancements

Description of Action: By December 31, 2015, Reclamation and/or DWR shall develop and implement Lower Putah Creek enhancements as described in Appendix 2-C, including stream realignment and floodplain restoration for fish passage improvement and multi-species habitat development on existing public lands. By September 1 of each year, Reclamation and/or DWR shall submit to NMFS a progress report towards the successful implementation of this action. This action shall not result in stranding or migration barriers for juvenile salmon.

Action I.6.4. Improvements to Lisbon Weir

Action: By December 31, 2015, Reclamation and/or DWR shall, to the maximum extent of their authorities, assure that improvements to the Lisbon Weir are made that are likely to achieve the fish and wildlife benefits described in Appendix 2-C. Improvements will include modification or replacement of Lisbon Weir, if necessary to achieve the desired benefits for fish. If neither Reclamation nor DWR has authority to make structural or operational modifications to the weir, they shall work with the owners and operators of the weir to make the desired improvements, including providing funding and technical assistance. By September 1 of each year, Reclamation and/or DWR shall submit to NMFS a report on progress toward the successful implementation of this action. Reclamation and DWR must assure that this action does not result in migration barriers or stranding of juvenile salmon.

Rationale for Actions I.6.2 to I.6.4: These actions have been fully vetted by CDFG and found to be necessary initial steps in improving rearing habitat for listed species in the lower Sacramento River basin. These improvements are necessary to off-set ongoing adverse effects of project operations, primary due to flood control operations. Additional descriptions of these actions are contained in the draft amendment to the Delta Fish Agreement (CVP/SWP operations BA appendix Y).

Action I.7. Reduce Migratory Delays and Loss of Salmon, Steelhead, and Sturgeon at Fremont Weir and Other Structures in the Yolo Bypass

Objective: Reduce migratory delays and loss of adult and juvenile winter-run, spring-run, CV steelhead and Southern DPS of green sturgeon at Fremont Weir and other structures in the Yolo Bypass.

Description of Action: By December 31, 2011, as part of the plan described in Action I.6.1, Reclamation and/or DWR shall submit a plan to NMFS to provide for high quality, reliable migratory passage for Sacramento Basin adult and juvenile anadromous fishes through the Yolo Bypass. By June 30, 2011, Reclamation and/or DWR shall obtain NMFS concurrence and, to the maximum extent of their authorities, and in cooperation with other agencies and funding sources, begin implementation of the plan, including any physical modifications. By September 30, 2009, Reclamation shall request in writing that the Corps take necessary steps to alter Fremont Weir and/or any other facilities or operations requirements of the Sacramento River Flood Control Project or Yolo Bypass facility in order to provide fish passage and shall offer to enter into a Memorandum of Understanding, interagency agreement, or other similar mechanism, to provide technical assistance and funding for the necessary work. By June 30, 2010, Reclamation shall provide a written report to NMFS on the status of its efforts to complete this action, in cooperation with the Corps, including milestones and timelines to complete passage improvements.

Reclamation and/or DWR shall assess the performance of improved passage and flows through the bypass, to include an adult component for salmonids and sturgeon (*i.e.*, at a minimum, acoustic receivers placed at the head and tail of the bypass to detect use by adults).

Rationale: The Yolo Bypass and Fremont Weir has been a documented source of migratory delay to, and loss of, adult winter-run, spring-run, CV steelhead and Southern DPS of green sturgeon. The existing fish passage structure is inadequate to allow normal passage at most operational levels of the Sacramento River. The project agencies must work with the Corps, which owns and operates Fremont Weir, to achieve improvements for fish. Other structures within the Yolo Bypass, such as the toe drain, Lisbon Weir, and irrigation dams in the northern end of the Tule Canal, also can impede migration of adult anadromous fish. Additionally, stranding of juvenile salmonids and sturgeon has been reported in the Yolo Bypass in scoured areas behind the weir and in other areas. This action offsets unavoidable project effects on adult migration and minimizes the direct losses from flood management activities associated with operations.

II. AMERICAN RIVER DIVISION

Introduction to American River Actions: The CV steelhead DPS is the only species addressed in this Opinion with a spawning population in the American River. The DPS includes naturally spawned steelhead in the American River (and other Central Valley stocks) and excludes steelhead spawned and reared at Nimbus Fish Hatchery. The in-river population is small, with

Action III.2.2 and Action III.1.2. These projects may also include, but shall not be limited to, evaluations to identify locations or sources of higher juvenile mortality in order to identify and implement projects with the highest likelihood to prevent CV steelhead mortality.

Rationale: Predation studies on the Tuolumne River have shown losses of up to 60 percent of outmigrating salmon smolts in run-of-river gravel mining ponds and dredged areas. Losses on the Stanislaus River have not been similarly quantified, but predation on fall run smolts and *O. mykiss* by striped bass and large mouth bass have been documented. These run-of-river ponds also reduce flow velocities as compared to incoming river channels, requiring outmigrating salmonids to expend more energy to traverse these sections. Operational releases provide flows lower than typical unimpaired flows, which exacerbates the effect of this stressor on outmigrating juveniles and degrades the habitat value of necessary freshwater migratory corridors. Additional flows or flow pulses could alleviate this added energy demand and improve survival through these problem areas. Channel modifications in these problem areas can improve migration success. Improvements in floodplain habitat quality can improve juvenile growth and larger juveniles are more likely to avoid predation mortality.

Action III.2.4. Evaluate Fish Passage at New Melones, Tulloch, and Goodwin Dams

Objective: Evaluate access for steelhead to historic cold water habitat above New Melones, Tulloch, and Goodwin dams.

Action: See Fish Passage Program, Action V.

Rationale: The effects analysis in this Opinion leads to the conclusion that steelhead will continue to be vulnerable to serious effects of elevated temperatures in dry and critically dry years, even if actions are taken to improve temperature management. The frequency of these occurrences is expected to increase with climate change and increased water demands. Therefore, it is essential to evaluate options for providing steelhead to access their historic cold water habitat above New Melones, Tulloch, and Goodwin dams and to provide access if feasible..

IV. DELTA DIVISION

Introduction: An important life history phase for all anadromous fish is their movement through an estuary as adults moving upstream to spawning grounds, and as juveniles moving downstream to the ocean. For some fish, the estuary also serves as a staging area and, for some juveniles, a rearing area prior to their entering the ocean. Within the Central Valley, all anadromous fish, including listed winter-run, spring-run, CV steelhead, and Southern DPS of green sturgeon, depend on the Sacramento-San Joaquin Delta environment during these life phases. This dependence was an important factor in designation of critical habitat in the Delta for these species. A properly functioning Delta is critical to migration pathways and rearing habitat, both of which are primary constituent elements of critical habitat for these fish.

Currently, the fish are exposed to a multitude of stressors in the Delta during passage and rearing. The Delta has been severely degraded over the past 150 years, primarily due to anthropogenic actions within its boundaries and in its surrounding watersheds. Nearly 90 percent of its fringing marshes have been lost and replaced with raised levees armored with rock riprap. The channelization of the Delta waterways through the construction of raised levees for flood control has isolated the Delta from its surrounding floodplains. These seasonally inundated floodplains served as important rearing habitats for many of the native fish species occurring in the Delta, including salmonids, and juvenile green sturgeon.

The structure of the Delta, particularly in the central and southern Delta, has been significantly altered by construction of manmade channels and dredging, for shipping traffic and water conveyance. Intentional and unintentional introductions of non-native plant and animal species have greatly altered the Delta ecosystem. Large predatory fish such as striped bass and largemouth bass have increased the vulnerability of emigrating juveniles and smolts to predation, while infestations of aquatic weeds such as *Egeria densa* have diminished the useable near-shore, shallow water habitat needed by emigrating salmonids for rearing.

The use of Delta islands for intensive agriculture has increased demand for irrigation water from the Delta, as well as increased the discharge of agricultural runoff into Delta waterways surrounding these farmed islands. These discharges carry chemicals such as fertilizers, pesticides, herbicides, and excessive nutrients, leading to degradation of water quality parameters such as DO content and suspended sediment, and increasing exposure to toxic compounds. Likewise, increasing urbanization in the areas surrounding the Delta increases the load of contaminants associated with stormwater runoff, discharges from wastewater sanitation plants, and industrial activities. Overall, conditions in the Delta make emigrating anadromous fish highly vulnerable to any added stressors and substantially reduce their chances for survival.

The proposed actions for the CVP and SWP include continued diversion of water from the Delta at the project's export facilities, with increased export levels. These actions will increase the level of stressors in the Delta beyond those previously described and exacerbate many of those already present. NMFS has identified several factors associated with operation of the CVP and SWP that affect the long-term viability and resiliency of winter-run, spring-run, CV steelhead, and the Southern DPS of green sturgeon in the Central Valley. In addition to these specific factors, the operations of the CVP and SWP alter Delta hydrodynamics and interact with other stressors to enhance the vulnerability of listed fish to morbidity and mortality during their time in the Delta.

The adverse effects of the proposed action identified in this Opinion include:

1) Diversion from the North Delta into the Delta interior of early emigrating winter-run juveniles, yearling spring-run, and CV steelhead, through the operation of the DCC gates in late fall and early winter.

2) Enhanced vulnerability of juvenile salmonids to entrainment and indirect mortality, through alteration of the hydrodynamics of the interior and south Delta waterways, due to the influence of export pumping actions in winter and spring.

3) Enhanced vulnerability of CV steelhead from the San Joaquin River basin to exports and export-related changes in hydrodynamics.

4) Direct mortality from entrainment of juvenile salmonids and green sturgeon at the CVP and SWP export facilities.

The actions prescribed below will minimize or avoid the proposed action's adverse effects on hydraulic patterns in the Delta that affect listed salmonids and green sturgeon. They will modify the interactions that listed fish have with other stressors in the Delta and thereby avoid appreciably reducing the likelihood of survival and recovery of listed fish.

The current metric for monitoring direct take and mortality of listed fish by the CVP and SWP actions is the level of salvage and calculated loss at fish collection facilities. This metric is a reflection of export levels and the diversion of large volumes of water through the facilities. Counting fish at the salvage facilities alone, however, does not account for fish that have been lost prior to the point of collection, and thus is an inaccurate measure of adverse export influence. It does not account for fish that have been drawn into the waters of the central Delta through the DCC gates or Georgiana Slough and lost to predation, toxics, or other factors before reaching the south Delta, nor does it account for fish that make it to the south Delta, where they are further influenced by the reverse flows moving toward the pumps and are delayed in their migration; which increases their vulnerability to predation, toxics, or other forms of loss, such as stranding in agricultural diversions.

Overall Objectives: The juveniles of all four listed species migrating downstream in the Sacramento River have a much greater chance of survival when they migrate directly to the estuary within the Sacramento River than when they are diverted by water operations into the southern or central Delta, where they are exposed to increased risks of predation, exposure to toxic pollutants, and entrainment into water diversions. The Delta Division measures will reduce the likelihood of diversion of emigrating juveniles into the southern or central Delta, and will reduce mortality of emigrating juveniles that have been entrained at the fish collection facilities and entered the salvage process.

There are six actions to be taken in the Delta:

- Action IV.1: Modify DCC gate operations and evaluate methods to control access to Georgiana Slough and the Interior Delta to reduce diversion of listed fish from the Sacramento River into the southern or central Delta.
- Action IV.2: Control the net negative flows toward the export pumps in Old and Middle rivers to reduce the likelihood that fish will be diverted from the San Joaquin or Sacramento River into the southern or central Delta.

- Action IV.3: Curtail exports when protected fish are observed near the export facilities to reduce mortality from entrainment and salvage.
- Action IV.4: Improve fish screening and salvage operations to reduce mortality from entrainment and salvage.
- Action IV.5: Establish a technical group to assist in determining real-time operational measures, evaluating the effectiveness of the actions, and modifying them if necessary.
- Action IV.6: Do not implement the South Delta Barriers Improvement Program.

A summary of Actions IV.1 and IV.2 and their timeframes is provided below in Figure 11-4.

Action Suite IV.1 Delta Cross Channel (DCC) Gate Operation, and Engineering Studies of Methods to Reduce Loss of Salmonids in Georgiana Slough and Interior Delta

Objective: Reduce the proportion of emigrating listed salmonids and green sturgeon that enter the interior delta through either the open DCC gates or Georgiana Slough.

Rationale: Salmon migration studies show losses of approximately 65 percent of groups of outmigrating fish that are diverted from the mainstem Sacramento River into the waterways of the central and southern Delta (Brandes and McLain 2001; Vogel 2004, 2008; Perry and Skalski 2008). Diversion into the internal Delta also increases the likelihood of entrainment and mortality associated with the pumping facilities. These effects are inferred from both particle tracking models, which derive the fate of particles over time, and direct study of acoustically tagged and CWT salmonids (Vogel 2004, SJRGA 2007).

On average, up to 25 percent of Sacramento River flows are diverted into the channels of the DCC when the gates are open, with a maximum of 35 to 40 percent. Approximately 20 percent, on average, of the Sacramento River flow is diverted into Georgiana Slough. During November and December, approximately 25 percent of the Sacramento River flow is diverted into the interior Delta through these two channels. Recent studies by Perry and Skalski (2008) indicate that by closing the DCC gates when fish are present, total through-Delta survival of marked fish to Chipps Island increases by nearly 50 percent for fish moving downstream in the Sacramento River system. Closing the DCC gates appears to redirect the migratory path of emigrating fish into Sutter and Steamboat Sloughs and away from Georgiana Slough, resulting in higher survival rates. Similar benefits have been described in previous studies (Newman 2008, Brandes and McLain 2001) with CWT fish.

Based on data from monitoring studies in the lower Sacramento River, approximately 45 percent of the annual winter-run emigration from the Sacramento River enters the Delta between November and January. During the same period, about eight percent of the annual CV steelhead emigration from the Sacramento River Basin occurs. Yearling spring-run pass into the Delta in January, but these fish account for only three percent of the total annual population of spring-run emigrants entering the Delta.

	Action - Operation of DCC to enhance protection of emigrating salmonids/green sturgeon	**Action** - Maintain San Joaquin River Inflow/Export ratio		**Action** - Acoustic Tag Experiment	**Action** - R limit negative flows on presence o
		- nteri Operations	ong ter Operations		
Oct	**Oct - Nov** - Gates closed if fish are present				
Nov					
Dec	**Dec -** - Gates closed except for experiments/water quality				
an	**Dec - an** Gates Closed				**an - une** - OMR (- 2500 cfs) until after June temperature at Mossdale ≥ days
Feb	**Feb - ay - ates Closed per D**				
ar				**arch - une**	
Apr		**April - ay** - Maintain Vernalis Inflow/Export ratio dependingon IOP water supply parameters	**April - ay** - Maintain Vernalis Inflow/Export Ratios depending on water year type		
ay	**ay - une** - up to 14 days closed per D-1641				
un					

Figure 11-4. A summary of Actions IV.1 and IV.2 and their timeframes.

Percent of Juvenile Chinook salmon and steelhead production entering the Delta from the Sacramento River by month.

Month	Sacramento River Total[1,2]	Fall-Run[3]	Spring-Run[3]	Winter-Run[3]	Sacramento Steelhead[4]
January	12	14	3	17	5
February	9	13	0	19	32
March	26	23	53	37	60
April	9	6	43	1	0
May	12	26	1	0	0
June	0	0	0	0	0
July	0	0	0	0	0
August	4	1	0	0	0
September	4	0	0	0	1
October	6	9	0	0	0
November	9	8	0	03	1
December	11	0	0	24	1
Total	100	100	100	100	100

Notes:
[1]Mid Water trawl data
[2]All runs combined
[3]Runs from Sacramento River basin only
[4]Rotary screw trap data from Knights Landing
Source: SDIP Draft EIR/EIS 2005 Tables J-23 and J-24, Appendix J.

Actions taken during the early emigration period (November through January) to reduce diversion of listed salmonids can affect a significant proportion of the populations of listed fish. As discussed earlier in the effects section, these early migrants represent life history strategies that spread the risk of mortality over a greater temporal span, increasing diversity and resiliency of the populations.

Action IV.1.1 Monitoring and Alerts to Trigger Changes in DCC Operations

Objective: To provide timely information for DCC gate operation that will reduce loss of emigrating winter-run, spring-run, CV steelhead, and green sturgeon.

Action: Monitoring of Chinook salmon migration in the Sacramento River Basin and the Delta currently occurs at the RBDD, in spring-run tributaries to the Sacramento River, on the Sacramento River at Knights Landing and Sacramento, and sites within the Delta. Reclamation and DWR shall continue to fund these ongoing monitoring programs, as well as the monitoring of salvage and loss of Chinook salmon juveniles at the Delta fish collection facilities operated by the CVP and SWP. Funding shall continue for the duration of the proposed action (2030). Reclamation and DWR may use their own fishery biologists to conduct these monitoring programs, or they may provide funds to other agencies to do the required monitoring.

Monitoring protocols shall follow established procedures utilized by the USFWS, CDFG, Reclamation, and DWR. Information collected from the monitoring programs will be used to make real-time decisions regarding DCC gate operation and export pumping.

The DOSS group (Action IV.5) and WOMT will use information from monitoring to make decisions regarding DCC closures consistent with procedures below.

The DCC gate operations in the fall are initiated through a series of alerts. These alerts are signals that gate operations may need to be altered in the near future to avoid diversion of juvenile Chinook salmon migrating down the Sacramento River.

There are two initial alerts to warn of salmon presence in the system:

First Alert: There are two components to the first alert. Either condition, when met or identified, can trigger the alert. Capture of yearling-sized (> 70 mm) spring-run at the mouths of natal tributaries between October and April indicates that emigration from the tributaries has started or is occurring. As an environmental surrogate to the capture of the yearling-sized spring-run, which are difficult to capture in the rotary screw traps at the mouths of the natal tributary creeks, tributary flow increases are used to signal conditions conducive to emigration. Starting in October, an increase in tributary flow of more than 50 percent over levels immediately preceding the flow spike is used to indicate the appropriate cues for the initiation of salmon emigration[31].

Second Alert: The second alert is based on two physical hydrologic criteria. When both criteria are met the second alert is triggered. The monitoring station used for these environmental measurements is Wilkins Slough, located near Knights Landing approximately 35 miles upstream of the Delta. When flows are greater than 7,500 cfs as measured at Wilkins Slough, and water temperatures are less than 13.5°C (56.3°F) as measured at Knights Landing, the second alert is triggered. Recoveries of emigrating Chinook salmon at the Knights Landing monitoring location have been associated with these two hydrologic conditions.

Rationale: Monitoring programs are necessary to track the movement of salmon within the Central Valley watersheds so that timely changes can be made when project actions are in conflict with the needs of listed fish. Evidence of initiation of juvenile Chinook salmon migration in the upper tributaries, or environmental conditions that would trigger such migration, is the basis for the alerts. The alerts are important to effective gate operation because the collection and dissemination of field data to the resource agencies, and coordination of responsive actions, may take several days to occur. The first two alerts warn NMFS and Reclamation that changes in DCC gate operations are likely to be necessary within a short time period.

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[31] The first significant flow in October is associated with the beginning of spring-run yearling emigration from natal tributaries - an indication that those fish are on their seaward migration and will soon be entering the Delta where they are susceptible to mortality factors associated with the Delta Cross Channel (DCC) and SWP/CVP export operations. This first tributary flow event, or "First Alert", is the early warning criteria for closing the DCC.

Action IV.1.2 DCC Gate Operation

Objective: Modify DCC gate operation to reduce direct and indirect mortality of emigrating juvenile salmonids and green sturgeon in November, December, and January.

Action: During the period between November 1 and June 15, DCC gate operations will be modified from the proposed action to reduce loss of emigrating salmonids and green sturgeon. The operating criteria provide for longer periods of gate closures during the emigration season to reduce direct and indirect mortality of yearling spring-run, winter-run, and CV steelhead. From December 1 to January 31, the gates will remain closed, except as operations are allowed using the implementation procedures/modified Salmon Decision Tree (below).

Implementation procedures: Monitoring data related to triggers in the decision tree will be reported on DAT calls and evaluated by DOSS (for formation of DOSS – see Action KK). Reclamation/DWR shall take actions within 24 hours of a triggered condition occurring. If the decision tree requires an evaluation of data or provides options, then DOSS shall convene within one day of the trigger being met. DOSS shall provide advice to NMFS, and the action shall be vetted through WOMT standard operating procedures.

October 1-November 30:

Date	VI. Action Triggers	Action Responses
October 1-November 30	Water quality criteria per D-1641 are met and either the Knights Landing Catch Index (KLCI) or the Sacramento Catch Index (SCI) are greater than 3 fish per day but less than or equal to 5 fish per day.	Within 24 hours of trigger, DCC gates are closed. Gates will remain closed for 3 days.
	Water quality criteria per D-1641 are met and either the KLCI or SCI is greater than 5 fish per day	Within 24 hours, close the DCC gates and keep closed until the catch index is less than 3 fish per day at both the Knights Landing and Sacramento monitoring sites.
	The KLCI or SCI triggers are met but water quality criteria are not met per D-1641 criteria.	DOSS reviews monitoring data and makes recommendation to NMFS and WOMT per procedures in Action IV.5.

Rationale: Depending on the catch magnitude, there are several options for closing the DCC gates, ranging from not closing them and monitoring catch at Knights Landing and the Sacramento monitoring sites, to closing the DCC gates until the catch index decreases to fewer than three fish per day at the Knights Landing and Sacramento monitoring sites. Fish and water quality needs (*i.e.*, salinity levels) are frequently mutually exclusive, with respect to the DCC position, from November through January.

December 1-14:

Date	Action Triggers	Action Responses
December 1 - December 14	Water quality criteria are met per D-1641.	DCC gates are closed. If Chinook salmon migration experiments are conducted during this time period (*e.g.*, Delta Action 8 or similar studies), the DCC gates may be opened according to the experimental design, with NMFS' prior approval of the study.
	Water quality criteria are not met but both the KLCI and SCI are less than 3 fish per day.	DCC gates may be opened until the water quality criteria are met. Once water quality criteria are met, the DCC gates will be closed within 24 hours of compliance.
	Water quality criteria are not met but either of the KLCI or SCI is greater than 3 fish per day.	DOSS reviews monitoring data and makes recommendation to NMFS and WOMT per procedures in Action IV.5

Rationale: The Spring-run Protection Plan (1998 *op. cit.* CVP/SWP operations BA Appendix B) provides that Reclamation will close the DCC gates on December 1 for the protection of spring-run yearlings unless there is a water quality issue. The DOSS can recommend opening the DCC gates for water quality purposes during this period. In addition, CDFG analysis indicates that there is a significant relationship between DCC gate operations and subsequent loss of winter-run at the Delta Fish Facilities. Closing the DCC gates between December 15 and January 15 reduces the total loss of winter-run at the Delta Fish Facilities. The report is posted at: http://www.science.calwater.ca.gov/pdf/ewa/EWA_delta_cross_channel_closures_06_111406.pdf.

The USFWS conducts a juvenile Chinook salmon Delta survival experiment each year in December and January. This is usually conducted in the first two weeks of December and may include experimental openings of the DCC gates. http://www.delta.dfg.ca.gov/jfmp/PatFiles/Delta_Action_8_Workshop.doc. These studies may be implemented if NMFS concurs that the study plan has been adapted to sufficiently reduce loss of salmonids..

December 15 – January 31:

Date	Action Triggers	Action Responses
December 15 – January 31	December 15-January 31	DCC Gates Closed.
	NMFS-approved experiments are being conducted.	Agency sponsoring the experiment may request gate opening for up to five days; NMFS will determine whether opening is consistent with ESA obligations.
	One-time event between December 15 to January 5, when necessary to maintain Delta water quality in response to the astronomical high tide, coupled with low inflow conditions.	Upon concurrence of NMFS, DCC Gates may be opened one hour after sunrise to one hour before sunset, for up to 3 days, then return to full closure. Reclamation and DWR will also reduce Delta exports down to a health and safety level during the period of this action.

Rationale: CDFG analysis indicates that there is a significant relationship between DCC gate operations and subsequent loss of winter-run at the Delta Fish Facilities. Closing the DCC gates between December 15 and January 15 reduces the total loss of winter-run at the Delta Fish Facilities. The report is posted at: http://www.science.calwater.ca.gov/pdf/ewa/EWA_delta_cross_channel_closures_06_111406.pdf

If the KLCI or SCI is less than three, and the water temperature and flow criteria are indicative of low risk to listed salmonids, then experiments on fall- and late-fall-run may be permissible; however, in a low production year, trap efficiencies and detection rates may result in under-representation of the number of fish passing these locations. Under such conditions the DOSS group shall act conservatively in this decision process even when no fish have been detected at Knights Landing or Sacramento rotary screw traps. If conditions change, indicating that risks to listed salmonids are elevated, experiments will be suspended and the DCC gates closed if NMFS determines that closure is necessary to reduce the risk to emigrating salmonids.

February 1 – June 15:

Date	Action Trigger	Action Response
February 1 – May 15	D-1641 mandatory gate closure.[9]	Gates closed, per WQCP criteria

Date	Action Trigger	Action Response
May 16 – June 15	D-1641 gate operations criteria	DCC gates may be closed for up to 14 days during this period, per 2006 WQCP, if NMFS determines it is necessary.

Overall Rationale for Action IV.1.2: Emigrating salmonids are vulnerable to diversion into the DCC when the gates are open. Fish traveling downstream in the Sacramento River move past the mouth of the DCC on the outside bend of the river. A series of studies conducted by Reclamation and USGS (Horn and Blake 2004) used acoustic tracking of released juvenile Chinook salmon to follow their movements in the vicinity of the DCC under different flows and tidal conditions. The study results indicate that the behavior of the Chinook salmon juveniles increased their exposure to entrainment through both the DCC and Georgiana Slough. Horizontal positioning along the east bank of the river during both the flood and ebb tidal conditions enhanced the probability of entrainment into the two channels. Upstream movement of fish with the flood tide demonstrated that fish could pass the channel mouths on an ebb tide and still be entrained on the subsequent flood tide cycle. In addition, diel movement of fish vertically in the water column exposed more fish at night to entrainment into the DCC than during the day, due to their higher position in the water column and the depth of the lip to the DCC channel mouth (-2.4 meters). Additional studies have shown that the mortality rate of the fish diverted into the DCC and subsequently into the Mokelumne river system is quite high (Perry and Skalski 2008; Vogel 2004, 2008). Closure of the DCC gates during periods of salmon emigration eliminates the potential for entrainment into the DCC and the Mokelumne River system with its high loss rates. In addition, closure of the gates appears to redirect the migratory paths of emigrating fish into channels with relatively less mortality (*e.g.*, Sutter and Steamboat Sloughs), due to a redistribution of river flows among the channels. The overall effect is an increase in the apparent survival rate of these salmon populations as they move through the Delta.

The closure of the DCC gates will increase the survival of salmonid emigrants through the Delta, and the early closures reduce loss of fish with unique and valuable life history strategies in the spring-run and CV steelhead populations. Spring-run emigrating through the Delta during November and December are yearling fish. These fish are larger and have a higher rate of success in surviving their entrance into the ocean environment. In addition, variation in the timing of ocean entry distributes the risk of survival over a broader temporal period. This alternative life history strategy reduces the probability that poor ocean

conditions in spring and summer will affect the entire population of spring-run. Since yearling fish enter the marine environment in late fall and winter, they avoid the conditions that young-of-the-year fish encounter in spring and summer, thus increasing the likelihood that at least a portion of the population will benefit from suitable ocean conditions during their recruitment to the ocean phase of their life cycle. For the same reasons, CV steelhead benefit from having their ocean entry spread out over several months.

Action IV.1.3 Consider Engineering Solutions to Further Reduce Diversion of Emigrating Juvenile Salmonids to the Interior and Southern Delta, and Reduce Exposure to CVP and SWP Export Facilities

Objectives: Prevent emigrating salmonids from entering the Georgiana Slough channel from the Sacramento River during their downstream migration through the Delta. Prevent emigrating salmonids from entering channels in the south Delta (*e.g.*, Old River, Turner Cut) that increase entrainment risk to CV steelhead migrating from the San Joaquin River through the Delta.

Action: Reclamation and/or DWR shall convene a working group to consider engineering solutions to further reduce diversion of emigrating juvenile salmonids to the interior Delta and consequent exposure to CVP and SWP export facilities. The working group, comprised of representatives from Reclamation, DWR, NMFS, USFWS, and CDFG, shall develop and evaluate proposed designs for their effectiveness. in reducing adverse impacts on listed fish and their critical habitat. Reclamation or DWR shall subject any proposed engineering solutions to external independent peer review and report the initial findings to NMFS by March 30, 2012. Reclamation or DWR shall provide a final report on recommended approaches by March 30, 2015. If NMFS approves an approach in the report, Reclamation or DWR shall implement it. To avoid duplication of efforts or conflicting solutions, this action should be coordinated with USFWS' Delta smelt biological opinion and BDCP's consideration of conveyance alternatives..

Rationale: One of the recommendations from the CALFED Science Panel peer review was to study engineering solutions to "separate water from fish." This action is intended to address that recommendation. Years of studies have shown that the loss of migrating salmonids within Georgiana Slough and the Delta interior is approximately twice that of fish remaining in the Sacramento River main stem (Kjelson and Brandes 1989; Brandes and McLain 2001; Vogel 2004, 2008; and Newman 2008). Based on the estimated survival rate of 35 percent in Georgiana Slough (Perry and Skalski 2008), the fraction of emigrating salmonids that would be lost to the population is 6 to 15 percent of the number entering the Delta from the Sacramento River basin. Keeping emigrating fish in the Sacramento River would increase their survival rate. This action is also intended to allow for engineering experiments and possible solutions to be explored on the San Joaquin river/Southern Delta corridor to benefit out-migrating steelhead. For example, non-physical barrier (i.e., "bubble curtain") technology can be further vetted through this action.

Action Suite IV.2 Delta Flow Management

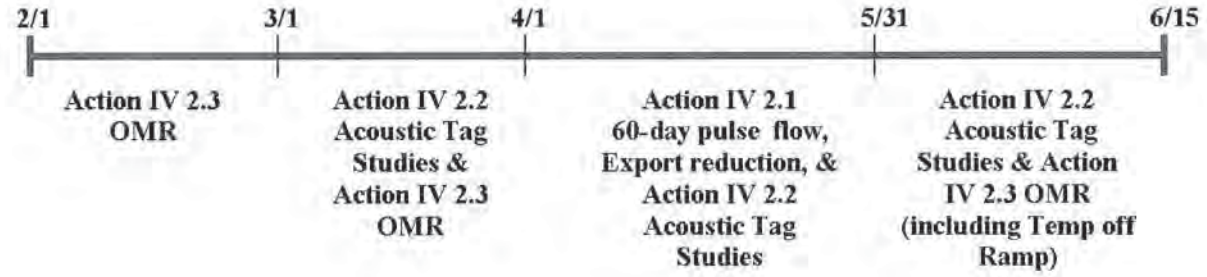
Objective: Maintain adequate flows in both the Sacramento River and San Joaquin River basins to increase survival of steelhead emigrating to the estuary from the San Joaquin River, and of winter-run, spring-run, CV steelhead, and green sturgeon emigrating from the Sacramento River through the Delta to Chipps Island.

Rationale for the Suite of Actions: Numerous studies have found positive associations between increased river flows and increased survival of salmon smolts through the Delta and the adult escapement of that cohort several years later when they return to spawn. Increased flows and greater smolt survival have been positively associated in other river systems as well Increased flows reduce the travel time of smolts moving through the river and Delta system, thus reducing the duration of their exposure to adverse effects from predators, water diversions, and exposure to contaminants.

Action IV.2.1 San Joaquin River Inflow to Export Ratio

Objectives: To reduce the vulnerability of emigrating CV steelhead within the lower San Joaquin River to entrainment into the channels of the South Delta and at the pumps due to the diversion of water by the export facilities in the South Delta, by increasing the inflow to export ratio. To enhance the likelihood of salmonids successfully exiting the Delta at Chipps Island by creating more suitable hydraulic conditions in the main stem of the San Joaquin River for emigrating fish, including greater net downstream flows.

Action: The following timeline indicates the annual schedule for implementing related San Joaquin actions that will occur concurrent with this action.



Phase I: Interim Operations in 2010-2011.

From April 1 through May 31:

1. Flows at Vernalis (7-day running average shall not be less than 7 percent of the target requirement) shall be based on the New Melones Index[32]. In addition to the Goodwin flow schedule for the Stanislaus River prescribed in Action III.1.3 and Appendix 2-E, Reclamation shall increase its releases at Goodwin Reservoir, if necessary, in order to meet the flows required at Vernalis, as provided in the following table. NMFS expects that tributary contributions of water from the Tuolumne and Merced rivers, through the SJRA, will continue through 2011 and that the installation of a fish barrier at the Head of Old River will continue to occur during this period as permitted.

New Melones Index (TAF)	Minimum flow required at Vernalis (cfs)
0-999	No new requirements
1000-1399	D1641 requirements or 1500, whichever is greater
1400-1999	D1641 requirements or 3000, whichever is greater
2000-2499	4500
2500 or greater	6000

2. Combined CVP and SWP exports shall be restricted through the following:

Flows at Vernalis (cfs)	Combined CVP and SWP Export
0-6,000	1,500 cfs
6,000-21,750[33]	4:1 (Vernalis flow:export ratio)
21,750 or greater	Unrestricted until flood recedes below 21,750

In addition:

1) Reclamation/DWR shall seek supplemental agreement with the SJRGA as soon as possible to achieve minimum long term flows at Vernalis (see following table) through all existing authorities.

San Joaquin River Index (60-20-20)	Minimum long-term flow at Vernalis (cfs)
Critically dry	1,500

[32] The New Melones Index is a summation of end of February New Melones Reservoir storage and forecasted inflow using 50% exceedance from March through September.

[33] Flood warning stage at Vernalis is 24.5 feet, flow is 21,750 cfs at this point. Flood stage is 29 feet with a corresponding flow of 34,500 cfs. Data from CDEC looking at April 8-9, 2006 period. As such, recognizing that the flows associated with these stages do vary, the trigger allowing unrestricted exports will be a Vernalis stage of 24.5 feet.

Dry	3,000
Below normal	4,500
Above normal	6,000
Wet	6,000

Rationale:

1) Flows at Vernalis: Reclamation has limited discretion to require additional flows from the Tuolumne and Merced rivers that are necessary in the long run to meet the needs of outmigrating juvenile steelhead. Modeling for our analysis of the East Side Division show that relying on New Melones Reservoir to provide the flows at Vernalis cannot be sustained, and attempting to do so would likely have additional adverse effects on CV steelhead. Reclamation and DWR have obtained additional flows in the Tuolumne and Merced rivers through CVPIA authorities, including options to purchase water from willing sellers, and entered into the SJRA which expires on December 31, 2009. Reclamation is in negotiations to extend the current agreement to 2011. The flows required in Phase I at Vernalis were developed through iterative modeling and will provide an important increment of additional flow to provide for outmigration of steelhead smolts, while not unduly depleting New Melones Reservoir storage. Using CVPIA authorities, it is important that Reclamation seek to immediately change the terms of the existing SJRA to achieve the long-term flows.

2) The rationale for the export curtailments is provided in the rationale for Phase II.

3) The SWRCB has initiated proceedings to establish minimum flows in the San Joaquin River basin. The proceedings are scheduled to conclude in 2011. Flow requirements for fish will be provided by this action in the interim.

Phase II: Beginning in 2012:

From April 1 through May 31:

1. Reclamation shall continue to implement the Goodwin flow schedule for the Stanislaus River prescribed in Action III.1.3 and Appendix 2-E.

2. Reclamation and DWR shall implement the Vernalis flow-to-combined export ratios in the following table, based on a 14-day running average.

San Joaquin Valley Classification	Vernalis flow (cfs):CVP/SWP combined export ratio[34]
Critically dry	1:1[35]

[34] Exception to the ratio is provided for floods, where exports are not restricted until the flood recedes. See footnote 2 above.

[35] Minimum combined CVP and SWP exports is for health and safety.

Dry	2:1
Below normal	3:1
Above normal	4:1
Wet	4:1
Vernalis flow equal to or greater than 21,750 cfs	Unrestricted exports until flood recedes below 21,750.

Exception procedure for multiple dry years: If the previous 2 years plus current year of San Joaquin Valley "60-20-20" Water Year Hydrologic Classification and Indicator as defined in D-1641 and provided in following table, is 6 or less, AND the New Melones Index is less than 1 MAF, exports shall be limited to a 1:1 ratio with San Joaquin River inflow, as measured at Vernalis.

San Joaquin Valley Classification	Indicator
Critically dry	1
Dry	2
Below normal	3
Above normal	4
Wet	5

Exception procedure for Health and Safety: If, by February 28 of a given year, Reclamation and DWR predict that they will not be able to achieve these ratios and make deliveries required for human health and safety, even after pursuing all options to augment inflow while preserving the ability to meet fish flow needs in all seasons, the agencies may submit a plan to NMFS to maximize anadromous fish benefits while meeting health and safety needs. The project agencies' current estimate of health and safety needs is a combined CVP/SWP export rate of 1,500 cfs. The plan must demonstrate that all opportunities for purchasing water in the San Joaquin Basin have been or will be exhausted, using b(3) or other water purchasing authority.

Meeting the long-term biological requirements of listed species and providing adequate water deliveries for these needs under the current system configuration may not be compatible, particularly considering anticipated hydrologic patterns associated with climate change. For this reason, Reclamation and DWR may propose a reconfiguration of the water conveyance system to allow diversion from the Sacramento River. Such an alteration of the conveyance system is being considered in the BDCP planning process. The operation of a conveyance structure that diverts water directly from the Sacramento River carries additional risk for listed species that migrate, spawn, or rear in the Sacramento River or North Delta. As detailed in this Opinion, the status of those species is precarious. Any new conveyance will be subject to section 7 consultation, and issues of injury or mortality of juvenile fish associated with all diversion facilities, reduction of flow variability for fish life history functions, reduction of Shasta Reservoir storage necessary for mainstem temperature control, and other potential adverse effects must be adequately addressed in any conveyance proposal.

Rationale: VAMP studies of CWT Chinook salmon smolts indicate that in general, fish released downstream of the zone of entrainment created by the export pumps (*e.g.*, Jersey Point)

have higher survival indices to Chipps Island than fish released higher up in the system (*e.g.*, Durham Ferry, Mossdale, or Dos Reis). Studies identify increased flows as a factor that increases survival of tagged Chinook salmon smolts. To date, most VAMP experiments have utilized San Joaquin River flows to export pumping ratios of approximately 2:1. Survival to Chipps Island of smolts released upstream has been relatively low under these conditions. (Kjelson *et al.* 1981, Kjelson and Brandes 1989, SJRGA 2007). Historical data indicates that high San Joaquin River flows in the spring result in higher survival of outmigrating Chinook salmon smolts and greater adult returns 2.5 years later (Kjelson *et al.* 1981, Kjelson and Brandes 1989, USFWS 1995) and that when the ratio between spring flows and exports increase, Chinook salmon production increases (CDFG 2005, SJRGA 2007). NMFS, therefore, concludes that San Joaquin River Basin and Calaveras River steelhead would likewise benefit under higher spring flows in the San Joaquin River in much the same way as fall-run do. For a full explanation of data and analysis supporting this action, see appendix 5.

Increased flows within the San Joaquin River portion of the Delta will also enhance the survival of Sacramento River salmonids. Those fish from the Sacramento River which have been diverted through the interior Delta to the San Joaquin River will benefit by the increased net flow towards the ocean caused by the higher flows in the San Joaquin River from upstream and the reduced influence of the export pumps. Such flows will reduce the proportion of Sacramento River fish that continue southwards toward the pumps and increase the percentage that move westwards toward Chipps Island and the ocean. Although the real environment is much more complex than this generality, in theory, increasing the speed of migration through a particular reach of river, or shortening the length of the migratory route decrease the extent of exposure to factors causing loss (Anderson *et al.* 2005)

Action IV.2.2 Six-Year Acoustic Tag Experiment

Objective: To confirm proportional causes of mortality due to flows, exports and other project and non-project adverse effects on steelhead smolts out-migrating from the San Joaquin basin and through the southern Delta.

Action: Reclamation and DWR shall fund a 6-year research-oriented action concurrent with Action IV.2.1.

The research shall be composed of studies utilizing acoustically-tagged salmonids, and will be implemented to assess the behavior and movement of the outmigrating fish in the lower San Joaquin River. The studies will include three releases of acoustic tagged fish, timed to coincide with different periods and operations: March 1 through March 31, April 1 through May 31, and June 1 through June 15. NMFS anticipates that studies will utilize clipped hatchery steelhead and hatchery fall-run as test fish.

During the period from March 1 through March 30, the exports will be operated in accordance with the requirements dictated by action IV.2.3. During the 60-day period between April 1 and May 30, exports will be dictated by the requirements of action IV.2.1. Reclamation shall operate to a minimum 1:1 inflow to export ratio during the period between

June 1 and June 15, allowing exports to vary in relation to inflows from the San Joaquin to test varying flow to export ratios during this period. If daily water temperatures at Mossdale exceed 72°F for seven consecutive days during the period between June 1 and June 15, then the inflow to export ratio may be relaxed. NMFS anticipates that warm water conditions in the lower San Joaquin River will not be suitable for steelhead under these conditions.

Implementation procedures:

1) By September 1, 2009, Reclamation/DWR shall convene DOSS for the purpose of refining the study design for this experiment. The experiments shall be developed to ensure that results are statistically robust and uncertainties due to experimental design have been minimized to the fullest extent possible. Additional expertise may be included in the workgroup, at the discretion of the agencies.

2) Issues relevant to listed anadromous fish species that shall be addressed include, but are not limited to:
   a) Increasing survival of emigrating smolts from the tributaries into the main stem of the San Joaquin River.
   b) Increasing survival of emigrating smolts through the main stem of the San Joaquin River downstream into the Delta.
   c) Increasing survival of emigrating smolts through the Delta to Chipps Island.
   d) The role and influence of flow and exports on survival in these migratory reaches.
   e) Selection of routes under the influence of flows and exports.
   f) Identifying reach-specific mortality and or loss.
   g) The effectiveness of experimental technologies, if any, *e.g.*, non-physical barrier ("bubble curtain.")

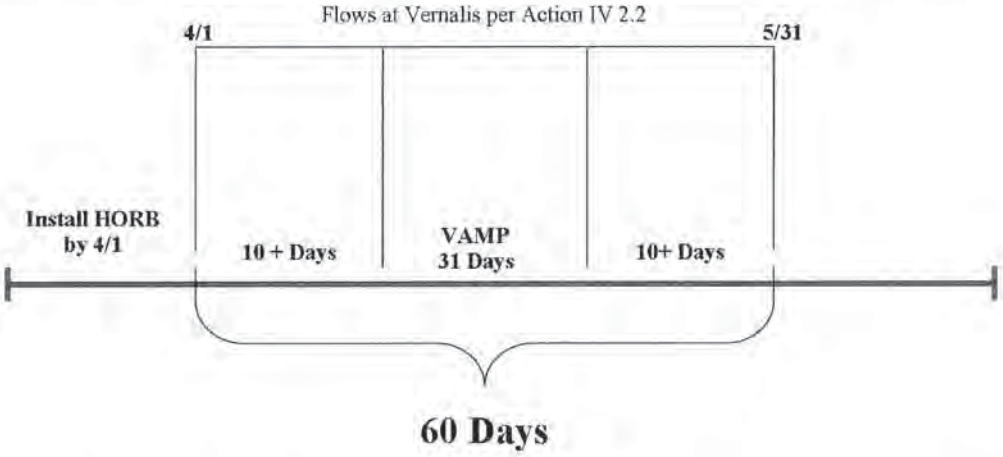
3) Annual reviews of the study results shall be conducted by the DOSS group. At the end of the 6-year period, a status review of Action IV.2.1 shall be prepared by the DOSS group. The status review shall be used to assess the success of Action IV.2.1 in increasing survival through the Delta for San Joaquin River basin salmonids, but in particular, steelhead. Based on the findings of the status review, the DOSS group will make recommendations to NMFS, Reclamation, CDFG, DWR, and USFWS on future actions to be undertaken in the San Joaquin River basin as part of an adaptive management approach to the basin's salmonid stocks.

4) Complementary studies to achieve performance goals: At its discretion, Reclamation and DWR also may develop and propose complementary studies to examine alternative actions that would accomplish the targeted survival performance goals. A primary effort of these studies will be to establish an appropriate survival goal for out-migrating steelhead smolts from Vernalis to Chipps Island in all water year types. Reclamation and DWR may propose studies which test actions that incorporate non-flow or non-export related actions. The studies shall contain specific actions within the authority and discretion of Reclamation and/or DWR, an evaluation of the projected benefits of each action with respect to increasing survival to the performance goal, evidence used to

support this evaluation including literature citations, particle tracking modeling and other predictive tools, to demonstrate that the survival will be achieved, and a demonstration that the actions are reasonably certain to occur within the term of the study period. Any complementary study proposal shall be peer reviewed by the Calfed Science Program (or other comparable science group) and by the DOSS workgroup prior to being submitted to NMFS.

Upon receipt of the complementary study proposal, NMFS will review the draft proposal for sufficiency of information, experimental design, and likelihood to meet performance goals and provide comments back to Reclamation and DWR within 30 days of receipt. If NMFS concurs with the complementary study proposal, and finds the studies do not conflict with the actions implemented under the RPA, then the study may be conducted concurrently with the actions set forth above (Action IV.2.1 and IV.2.2). Throughout the six years of study, all new data will be annually evaluated by the proposed DOSS group, which will then provide recommendations through a written report to the management of NMFS and Reclamation for continuing actions in the San Joaquin River basin in support of CV steelhead.

Exception: If, despite Reclamation and DWR's best efforts, the new experiment is not ready for implementation in 2010, then VAMP study design may continue for 1 year, upon written concurrence of NMFS. A generalized representation of the design is provided, as follows:



Rationale: This experiment will provide important information about the response of fish migration to flows, exports, and other stressors in the San Joaquin River corridor. Flows and exports will be varied according to time period. From March 1 through March 31, the studies will assess the relationship of the Vernalis flow-to-export ratio under the OMR flow restriction (see Action IV.2.3) to route selection at channel bifurcations in the South Delta and mainstem San Joaquin River, survival in the different channels reaches of the South Delta, and ultimately through the Delta to Chipps Island as a whole.

From April 1 through May 30, the studies will assess the effectiveness of varying ratios by water year type (see Action IV.2.1) by comparing channel selection, route survival, and

overall through-Delta survival during this period of stabilized conditions to the other two periods.

From June 1 to June 15, the studies will focus on the relative importance of exports, as compared to flows, by deliberately varying exports under similar flow conditions. Acoustic tagging studies have the potential to provide this level of resolution. Results from these studies may be able to indicate, at a fine temporal and spatial scale, how exports and flow influence route selection of migrating fish and their survival probabilities in the different channel reaches. Knowledge of these factors should aid in the management decision process and reduce project impacts to listed salmonids based on findings with strong scientific foundations.

Action IV.2.3 Old and Middle River Flow Management

Objective: Reduce the vulnerability of emigrating juvenile winter-run, yearling spring-run, and CV steelhead within the lower Sacramento and San Joaquin rivers to entrainment into the channels of the South Delta and at the pumps due to the diversion of water by the export facilities in the South Delta. Enhance the likelihood of salmonids successfully exiting the Delta at Chipps Island by creating more suitable hydraulic conditions in the mainstem of the San Joaquin River for emigrating fish, including greater net downstream flows.

Action: From January 1 through June 15, reduce exports, as necessary, to limit negative flows to -2,500 to -5,000 cfs in Old and Middle Rivers, depending on the presence of salmonids. The reverse flow will be managed within this range to reduce flows toward the pumps during periods of increased salmonid presence. The negative flow objective within the range shall be determine based on the following decision tree:

Date	Action Triggers	Action Responses
January 1 – June 15	January 1 – June 15	Exports are managed to a level that produces a 14-day running average of the tidally filtered flow of (minus) -5,000 cfs in Old and Middle River (OMR). A five-day running average flow shall be calculated from the daily tidally filtered values and be no more than 25 percent more negative than the targeted requirement flow for the 14-day average flow.[36]

[36] Daily OMR flows used to compute the 14-day and 5-day averages shall be tidally filtered values reported by the USGS for the Old River at Bacon Island and Middle River at Middle River monitoring stations. The 14-day running average shall be no more negative than the targeted flow requirement. The 5-day running average shall be no more than 25 percent more negative than the targeted flow requirement. (Transition explanations below are based on personal communication Ryan Olah, USFWS, to ensure consistency of OMR measurements and averaging periods with implementation of OMR in Smelt Biological Opinion).

January 1 – June 15 First Stage Trigger (increasing level of concern)	Daily SWP/CVP older juvenile loss density (fish per taf) 1) is greater than incidental take limit divided by 2000 (2 percent WR JPE ÷ 2000), with a minimum value of 2.5 fish per taf, or 2) daily loss is greater than daily measured fish density divided by 12 taf (daily measured fish density ÷ 12 taf) or 3) CNFH CWT LFR or LSNFH CWT WR cumulative loss greater than 0.5%, or 4) daily loss of wild steelhead (intact adipose fin) is greater than the daily measured fish density divided by 12 taf (daily measured fish density ÷ 12 taf)[37]	Reduce exports to achieve an average net OMR flow of (minus) -3,500 cfs for a minimum of 5 consecutive days. The five day running average OMR flows shall be no more than 25 percent more negative than the targeted flow level at any time during the 5-day running average period (*e.g.*, -4,375 cfs average over five days). Resumption of (minus) -5,000 cfs flows is allowed when average daily fish density is less than trigger density for 3 consecutive days following the 5 consecutive days of export reduction[38]. Reductions are required when any one criterion is

Transition to more restrictive (less negative) OMR limit

When a more restrictive Old and Middle River flow (OMR) limit is decided upon, the water projects may continue to operate to the old limit for up to two additional days, with both 5-day and 14-day averaging periods in effect. On the third day, the moving daily OMR will be no more negative than the new limit, and no moving averages will apply. New moving averages will be calculated from the third day forward. On the fourth day, OMR can be no more than 25% more negative than the daily OMR on the third day; On the fifth day, OMR can be no more than 25% more negative than the midpoint between the daily OMRs on the third day and the fourth day; on the sixth day, OMR can be no more than 25% more negative than the average of the OMRs on the third, fourth, and fifth day; and so on. From the 8th day forward, if OMR restrictions due to triggers are still be implemented, a full 5-day moving average will exist, and daily OMR on any day cannot be more than 25% more negative than the 5-day moving average. On the 17th day, a 14-day moving average will be available. Consequently, from the 17th day forward, the 14-day moving average cannot be more negative than the OMR limit.

Transition to less restrictive (more negative) OMR limit

When a less restrictive OMR limit is decided upon, the water projects may begin to operate to that limit on the same day. The 5-day and 14-day averaging periods will continue to be computed through the transition. However, the 5-day averaging period will not provide 25% flexibility from the day the new OMR is imposed through the 7th day after the new limit is adopted. Through the 7th day after imposition, daily OMR may not be more negative than the new limit.

[37] NMFS assumes that the loss of winter-run Chinook salmon and steelhead are similar in nature based on annual loss estimates. As an initial trigger, the density of steelhead, which includes smolts and adults, will be used in the same equation as the older juvenile salmon trigger to change OMR flows. This will be reviewed by the DOSS group annually and recommendations to the trigger criteria made based on an assessment of the results.

[38] Three consecutive days in which the loss numbers are below the action triggers are required before the OMR flow reductions can be relaxed to -5,000 cfs. A minimum of 5 consecutive days of export reduction are required for the protection of listed salmonids under the action. Starting on day three of the export curtailment, the level of fish loss must be below the action triggers for the remainder of the 5-day export reduction to relax the OMR requirements on day 6. Any exceedances of the triggers restarts the 5-day OMR actions with the three day loss monitoring criteria.

		met.
January 1 - June 15 Second Stage Trigger (analogous to high concern level)	Daily SWP/CVP older juvenile loss density (fish per taf) is 1) greater than incidental take limit (2 percent of WR JPE) divided by 1000 (2 percent of WR JPE ÷ 1000), with a minimum value of 2.5 fish per taf, or 2) daily loss is greater than daily fish density divided by 8 taf (daily fish density ÷8 taf), or 3) CNFH CWT LFR or LSNFH CWT WR cumulative loss greater than 0.5%, or 4) daily loss of wild steelhead (intact adipose fin) is greater than the daily measured fish density divided by 8 taf (daily measured fish density ÷ 8 taf)	Reduce exports to achieve an average net OMR flow of (minus) -2,500 cfs for a minimum 5 consecutive days. Resumption of (minus) -5,000 cfs flows is allowed when average daily fish density is less than trigger density for 3 consecutive days following the 5 consecutive days of export reduction. Reductions are required when any one criterion is met.
End of Triggers	Continue action until June 15 or until average daily water temperature at Mossdale is greater than 72°F (22°C) for 7 consecutive days (1 week), whichever is earlier.	If trigger for end of OMR regulation is met, then the restrictions on OMR are lifted.

Implementation procedures: Combined exports will be managed to provide for an OMR flow of -5,000 cfs, tidally filtered over 14-days during the period between January 1 and June 15. The 5-day running average shall be no more than 25 percent more negative than the targeted flow requirement. Further reductions in exports will occur in a tiered fashion depending on the magnitude of Chinook salmon and steelhead salvage at the CVP and SWP fish salvage facilities. There are two export reductions triggered by increases in fish salvage rates at the fish collection. The first reduction decreases exports to achieve a net average

OMR flow of -3,500 cfs over a minimum of 5 consecutive days. The second reduction, based on higher salvage numbers, further reduces exports to achieve a net average OMR flow of -2,500 cfs over a minimum of 5 days.

These actions will be taken in coordination with USFWS RPA for Delta smelt and State-listed longfin smelt 2081 incidental take permit. During the January 1 through June 15 period, the most restrictive export reduction shall be implemented. If the USFWS Delta smelt RPA requires greater reductions in exports than those required by NMFS for salmonids, to achieve a more positive OMR flow, then the smelt action will be implemented, since it also will increase survival of listed salmonids. Likewise, if the NMFS RPA criteria are more restrictive than those called for under the Delta smelt RPA, then NMFS RPA criteria will prevail and will increase survival of Delta smelt as well as salmonids.

Rationale: Juvenile listed salmonids emigrate downstream in the main channel of the San Joaquin River during the winter and spring period. Juvenile listed steelhead from the San Joaquin River basin, the Calaveras River basin, and the Mokelumne River basin also utilize the lower reaches of the San Joaquin River as a migration corridor to the ocean. The river reach between the Port of Stockton and Jersey Point has many side channels leading south toward the export facilities. High export levels draw water through these channels toward the pumps, as these channels are the conduits that supply water to the pumps from the north. Outputs from PTM simulations, as well as data from acoustic tagging studies (Vogel 2004, SJRGA 2006, 2007), show that migrating fish are vulnerable to diversion into these channels and respond to flow within the channels, including the net migration speed downstream (SJRGA 2008).

The acoustic tagging studies also indicate that fish behavior is complex, with fish exhibiting behavior that is not captured by the "tidal surfing' model utilized as one of the options in the PTM simulations. Fish made their way downstream in a way that was more complicated than simply riding the tide, and no discernable phase of the tide had greater net downstream movement than another. Furthermore, tagged fish chose channels leading south more frequently when exports were elevated, than when exports were lower (Vogel 2004). Fish that moved into channels leading south may eventually find their way back to the main channel of the San Joaquin, but this roundabout migratory path exposes fish to higher predation risks as well as the potential to become lost within the Delta interior, increasing migration route length and duration of the outmigration. Increased time in the channels of the Central and South Delta exposes fish to unscreened agricultural diversions, discharges of agricultural irrigation return water to the Delta, increased water temperature later in the season, and the risk of predation from pelagic predators such as striped bass and localized ambush predators such as largemouth bass. In order to increase the likelihood of survival, emigrating steelhead from the San Joaquin Basin and the east-side tributaries should remain in the mainstem of the San Joaquin River to the greatest extent possible and reduce their exposure to the adverse effects that are present in the channels leading south toward the export facilities.

Reducing the risk of diversion into the central and southern Delta waterways also will increase survival of listed salmonids and green sturgeon entering the San Joaquin River via Georgiana Slough and the lower Mokelumne River. As described in the effects section of the Opinion, these fish also are vulnerable to entrainment by the far-field effects of the exports. The data output for the PTM simulation of particles injected at the confluence of the Mokelumne River and the San Joaquin River (Station 815) indicate that as net OMR flow increases southwards from -2,500 to -3,500 cfs, the risk of particle entrainment nearly doubles from 10 percent to 20 percent, and quadruples to 40 percent at -5,000 cfs. At flows more negative than -5,000 cfs, the risk of entrainment increases at an even greater rate, reaching approximately 90 percent at -7,000 cfs. Even if salmonids do not behave exactly as neutrally buoyant particles, the risk of entrainment escalates considerably with increasing exports, as represented by the net OMR flows. The logical conclusion is that as OMR reverse flows increase, risk of entrainment into the channels of the South Delta is increased. Conversely, the risk of entrainment into the channels of the South delta is reduced when exports are lower and the net flow in the OMR channels is more positive -- that is, in the direction of the natural flow toward the ocean.

Action IV.3 Reduce Likelihood of Entrainment or Salvage at the Export Facilities

Objective: Reduce losses of winter-run, spring-run, CV steelhead, and Southern DPS of green sturgeon by reducing exports when large numbers of juvenile Chinook salmon are migrating into the upper Delta region, at risk of entrainment into the central and south Delta and then to the export pumps in the following weeks.

Action: From November 1 through April 30, operations of the Tracy and Skinner Fish Collection Facilities shall be modified according to monitoring data from upstream of the Delta. In conjunction with the two alerts for closure of the DCC (Action IV.1.1), the Third Alert shall be used to signal that export operations may need to be altered in the near future due to large numbers of juvenile Chinook salmon migrating into the upper Delta region, increasing their risk of entrainment into the central and south Delta and then to the export pumps.

Third Alert: The catch index is greater than 10 fish captured per day from November 1 to February 28, or greater than 15 fish captured per day from March 1 to April 30, from either the Knights Landing catch index or the Sacramento catch index.

Response: From November 1 through December 31, when salvage numbers reach the action triggers, exports shall be reduced as follows:

Date	Action Triggers	**Action Responses**

November 1 – December 31	Daily SWP/CVP older juvenile loss density greater than 8 fish/thousand acre feet (taf), or daily loss is greater than 95 fish per day, or Coleman National Fish Hatchery coded wire tagged late fall-run Chinook salmon (CNFH CWT LFR) or Livingston Stone National Fish Hatchery coded wire tagged winter-run (LSNFH CWT WNT) cumulative loss is greater than 0.5%.	Reduce exports to a combined 6,000 cfs for 3 days or until CVP/SWP daily density is less than 8 fish/taf. Export reductions are required when any one of the four criteria is met.
	Daily SWP/CVP older juvenile loss density greater than 15 fish/taf, or daily loss is greater 120 fish per day, or CNFH CWT LFR or LSNFH CWT WNT cumulative loss greater than 0.5%.	Reduce exports to a combined 4,000 cfs for 3 days or until CVP/SWP daily density is less than 8 fish/taf. Export reductions are required when any one of the four criteria is met.

From January 1 through April 30, implement Action IV.2.3 which include restrictions on OMR flows rather than set levels of combined export pumping. Alert triggers will remain in effect to notify the operators of the CVP and SWP that large numbers of juvenile Chinook salmon are entering the Delta system.

Rationale: As explained previously, juvenile salmonids and green sturgeon have a lower chance of survival to the ocean if they are diverted from their migratory routes on the main Sacramento and San Joaquin Rivers into the central and south Delta. Export pumping changes flow patterns and increases residence time of these diverted fish in the central Delta, which increases the risk of mortality from predation, water diversions, poor water quality, and contaminant exposure, as well as the likelihood of entrainment at the pumps. When more fish are present, more fish are at risk of diversion and losses will be higher. The Third Alert is important for real-time operation of the export facilities because the collection and dissemination of field data to the resource agencies and coordination of response actions may take several days. This action is designed to work in concert with the OMR action in IV.2.3.

Action Suite IV.4 Modifications of the Operations and Infrastructure of the CVP and SWP Fish Collection Facilities

Objective: Achieve 75 percent performance goal for whole facility salvage at both state and Federal facilities. Increase the efficiency of the Tracy and Skinner Fish Collection Facilities to improve the overall salvage survival of winter-run, spring-run, CV steelhead, and green sturgeon.

Action: Reclamation and DWR shall each achieve a whole facility salvage efficiency of 75 percent at their respective fish collection facilities. Reclamation and DWR shall implement the following actions to reduce losses associated with the salvage process, including: (1) conduct studies to evaluate current operations and salvage criteria to reduce take associated with salvage,

(2) develop new procedures and modifications to improve the current operations, and (3) implement changes to the physical infrastructure of the facilities where information indicates such changes need to be made. Reclamation shall continue to fund and implement the CVPIA Tracy Fish Facility Program. In addition, Reclamation and DWR shall fund quality control and quality assurance programs, genetic analysis, louver cleaning loss studies, release site studies and predation studies. Funding shall also include new studies to estimate green sturgeon screening efficiency at both facilities and survival through the trucking and handling process.

By January 31 of each year, Reclamation and DWR shall submit to NMFS an annual progress report summarizing progress of the studies, recommendations made and/or implemented, and whole facility salvage efficiency. These reports shall be considered in the Annual Program Review.

Action IV.4.1 Tracy Fish Collection Facility (TFCF) Improvements to Reduce Pre-Screen Loss and Improve Screening Efficiency

Objective: Implement specific measures to reduce pre-screen loss and improve screening efficiency at Federal facilities.

Action: Reclamation shall undertake the following actions at the TFCF to reduce pre-screen loss and improve screening efficiency:

1) By December 31, 2012, improve the whole facility efficiency for the salvage of Chinook salmon, CV steelhead, and Southern DPS of green sturgeon so that overall survival is greater than 75 percent for each species.

    a) By December 31, 2011, Reclamation shall complete studies to determine methods for removal of predators in the primary channel, using physical and non-physical removal methods (*e.g.*, electricity, sound, light, CO_2), leading to the primary louver screens with the goal of reducing predation loss to ten percent or less. Findings shall be reported to NMFS within 90 days of study completion. By December 31, 2012, Reclamation shall implement measures to reduce pre-screen predation in the primary channel to less than ten percent of exposed salmonids.
    b) By March 31, 2011, Reclamation shall complete studies for the re-design of the secondary channel to enhance the efficiency of screening, fish survival, and reduction of predation within the secondary channel structure and report study findings to NMFS. NMFS shall review study findings and if changes are deemed feasible, Reclamation shall initiate the implementation of the study findings by January 31, 2012.
    c) No later than June 2, 2010, Reclamation shall submit to NMFS, one or more potential solutions to the loss of Chinook salmon and green sturgeon associated with the cleaning and maintenance of the primary louver and secondary louver systems at the TFCF. In the event that a solution acceptable to NMFS is not in place by June 2, 2011, pumping at the Tracy Pumping Plant shall cease during louver cleaning and maintenance operations to avoid loss of fish during these actions.

2) By December 31, 2011, Reclamation shall implement operational procedures to optimize the simultaneous salvage of juvenile salmonids and Delta smelt at the facility.

3) Immediately upon issuance of this biological opinion, Reclamation shall begin removing predators in the secondary channel at least once per week. By June 2, 2010, Reclamation shall install equipment to monitor for the presence of predators in secondary channel during operations. This could include an infrared or low light charged coupled device camera or acoustic beam camera mounted within the secondary channel.

4) Reclamation shall operate the facility to meet design criteria for louver bypasses and channel flows at least 75 percent efficiency.

5) Reclamation shall maintain a head differential at the trash rack of less than 1.5 ft. between the ambient Old River water surface elevation and the primary intake channel at all times.

6) By January 2, 2010, Reclamation shall install and maintain flow meters in the primary and secondary channels to continuously monitor and record the flow rates in the channel. Deviations from design flow criteria shall initiate immediate corrective measures to remedy deficiencies and return channel flows to design flow specifications.

7) Reclamation shall change its operations of the TFCF to meet salvage criteria, while emphasizing the following actions: (a) Primary Bypass Ratio; (b) Secondary Bypass Ratio; (c) Primary Average Channel Velocity; and (d) Secondary Average Channel Velocity.

8) Records of all operating actions shall be kept and made available to NMFS engineers upon request. NMFS shall be notified of any major or long-term deviations from normal operating design criteria within 24 hours of occurrence.

Action IV.4.2 Skinner Fish Collection Facility Improvements to Reduce Pre-Screen Loss and Improve Screening Efficiency

Objective: Implement specific measures to reduce pre-screen loss and improve screening efficiency at state facilities.

Action: DWR shall undertake the following actions at the Skinner Fish Collection Facility:

1) By December 31, 2012, operate the whole Skinner Fish Protection Facility to achieve a minimum 75 percent salvage efficiency for CV salmon, steelhead, and Southern DPS of green sturgeon after fish enter the primary channels in front of the louvers.

2) Immediately commence studies to develop predator control methods for Clifton Court Forebay that will reduce salmon and steelhead pre-screen loss in Clifton Court Forebay to no more than 40 percent.

   a) On or before March 31, 2011, improved predator control methods. Full compliance shall be achieved by March 31, 2014. Failure to meet this timeline shall result in the cessation of incidental take exemption at SWP facilities unless NMFS agrees to an extended timeline.
   b) DWR may petition the Fish and Game Commission to increase bag limits on striped bass caught in Clifton Court Forebay.

3) Remove predators in the secondary channel at least once per week.

Action IV.4.3 Tracy Fish Collection Facility and the Skinner Fish Collection Facility Actions to Improve Salvage Monitoring, Reporting and Release Survival Rates

Objective: To improve overall survival of listed species at facilities through accurate, rapid salvage reporting and state-of-the-art salvage release procedures. This reporting is also necessary to provide information needed to trigger OMR actions.

Action: Reclamation and DWR shall undertake the following actions at the TFCF and the Skinner Fish Collection Facility, respectively. Actions shall commence by October 1, 2009, unless stated otherwise.

1) Sampling rates at the facilities for fish salvage counts shall be no less than 30 minutes every 2 hours (25 percent of operational time) year-round to increase the accuracy of salvage estimates used in the determination of trigger levels. Exceptions to the 30-minute count may occur with NMFS' concurrence under unusual situations, such as high fish densities or excessive debris loading.

2) By October 1, 2010, websites shall be created or improved to make salvage count data publicly available within 2 days of observations of the counts. Information available on the website shall include at a minimum:

   a) duration of count in minutes;
   b) species of fish salvaged;
   c) number of fish salvaged including raw counts and expanded counts;
   d) volume of water in acre-feet, and average daily flow in cfs;
   e) daily average channel velocity and bypass ratio in each channel, primary and secondary;
   f) average daily water temperature and electrical conductivity data for each facility; and
   g) periods of non-operation due to cleaning, power outages, or repairs.

3) Release Site Studies shall be conducted to develop methods to reduce predation at the

"end of the pipe" following release of salvaged fish. Studies shall examine but are not limited to:

a) potential use of barges to release the fish in different locations within the western Delta, with slow dispersion of fish from barge holding tanks to Delta waters;
b) multiple release points (up to six) in western Delta with randomized release schedule; and
c) conducting a benefit to cost analysis to maximize this ratio while reducing predation at release site to 50 percent of the current rate.

4) By June 15, 2011, predation reduction methods shall be implemented according to analysis in 3. By June 15, 2014, achieve a predation rate that has been reduced 50 percent from current rate.

5) Add salt to water within the tanker trucks hauling fish to reduce stress of transport. Assess use of other means to reduce stress, protect mucous slime coat on fish, and prevent infections from abrasions (*i.e.*, commercially available products for this purpose).

6) All personnel conducting fish counts must be trained in juvenile fish identification and have working knowledge of fish physiology and biology.

7) Tanker truck runs to release salmonids should be scheduled at least every 12 hours, or more frequently if required by the "Bates Table" calculations (made at each count and recorded on the monthly report).

8) Reclamation and DWR shall use the Bates Table to maintain suitable environmental conditions for fish in hauling trucks. Trucks should never be overcrowded so that the carrying capacity of the tanker truck is exceeded.

Rationale: The process for salvaging listed salmonids and green sturgeon that are drawn into the pumping facilities is not efficient. For salmonids, at the Skinner Fish Protection Facility, loss rates can be as high as five fish lost for every fish salvaged. Most of this loss occurs in the forebay before the fish even encounter the fish screen louvers and the screening process. Conversely, at the Federal TFCF, most loss occurs because of poor screening efficiency in the louver array, although predation also occurs in front of the trash racks and in the primary channel leading to the primary louver array. Louver array cleaning protocols also lead to high loss rates because louvers are removed during cleaning, but pumping continues and fish are drawn directly into the facilities. The efficiency of the salvage process for green sturgeon is unknown, and this is a significant gap in the operational protocol for the facilities. The 2004 CVP/SWP operations Opinion identified terms and conditions to be implemented regarding salvage improvements, including evaluations for operational improvements. Some of those terms and conditions have been implemented but many have not.

Action IV.5 Formation of Delta Operations for Salmon and Sturgeon (DOSS) Technical Working Group

Objective: Create a technical advisory team .that will provide recommendations to WOMT and NMFS on measures to reduce adverse effects of Delta operations of the CVP and SWP to salmonids and green sturgeon and will coordinate the work of the other technical teams.

Action: The DOSS group will be comprised of biologists, hydrologists, and other staff with relevant expertise from Reclamation, DWR, CDFG, USFWS, and NMFS. Invitations to EPA, USGS, and Regional Water Quality Board biologists will be extended to provide expertise on issues pertinent to Delta water quality, hydrology and environmental parameters. By October 1, 2009, Reclamation shall, jointly with NMFS, convene the DOSS working group. The working group will have biweekly phone conferences, or more frequently if necessary for real-time operations, and meet at least quarterly to discuss and review information related to project operations and fisheries issues. Either Reclamation or NMFS may call for a special meeting of the DOSS group if they deem it necessary.

The team will:

1) provide recommendations for real-time management of operations to WOMT and NMFS, consistent with implementation procedures provided in this RPA;
2) review annually project operations in the Delta and the collected data from the different ongoing monitoring programs;

3) track the implementation of Actions IV.1 through IV.4;

4) evaluate the effectiveness of Actions IV.1 through IV.4 in reducing mortality or impairment of essential behaviors of listed species in the Delta;

5) oversee implementation of the acoustic tag experiment for San Joaquin fish provided for in Action IV.2.2;

6) coordinate with the SWG to maximize benefits to all listed species; and

7) coordinate with the other technical teams identified in this RPA to ensure consistent implementation of the RPA.

The DOSS team shall provide annual written reports to Reclamation, DWR, and NMFS, including a summary of major actions taken during the year to implement Action Suite IV of this RPA, an evaluation of their effectiveness, and recommendations for future actions. At the technical staff level, the working group will coordinate with the DAT, the SWG, and other workgroups to ensure coherent and consistent implementation of actions in the Delta. Every five years, the DOSS working group will produce a summary report of the previous five years of operations, actions taken, and the effectiveness of those actions in achieving the objectives of the Delta actions in this RPA. Included in this report will be recommendations

for adaptive management changes consistent with the objectives of this RPA. The report will be provided to NMFS, Reclamation, DWR, CDFG and USFWS.

The DOSS group shall also provide a coordinating function for the other technical working groups, to assure that relevant information from all technical groups is considered in actions to implement this RPA.

Rationale: This RPA contains a series of measures to minimize adverse effects of project operations in the Delta. An interagency technical team is necessary to track implementation of these measures, recommend actions within the boundaries of the implementation procedures in this document, and to build expertise over time to recommend changes to Delta operations. Any significant changes to Operations will trigger re-initiation of this opinion.

Action IV.6 South Delta Improvement Program—Phase I (Permanent Operable Gates)

Action: DWR shall not implement the South Delta Improvement Program, which is a proposal to replace temporary barriers with permanent operable gates.

Rationale: In a separate formal consultation (2009/01239), NMFS issued a 2008 biological opinion on the installation and operation of temporary barriers through 2010 (NMFS 2008). That biological opinion concluded that the temporary barriers would not jeopardize the continued existence of listed species or adversely modify critical habitat. This CVP/SWP operations Opinion concludes that on the basis of the best information available, the proposed replacement of these temporary barriers with permanent operable gates will adversely modify critical habitat. NMFS has not identified an alternative to the proposed permanent gates that meets ESA obligations.

After analyses of the operations of the temporary barriers are completed, as specified in the 2008 biological opinion, DWR may request that Reclamation reinitiate consultation with NMFS on the South Delta Improvement Program or may pursue permitting under ESA section 10. Additionally, DWR may apply information developed from Action IV.1.2 to modify the barrier design.

V. Fish Passage Program

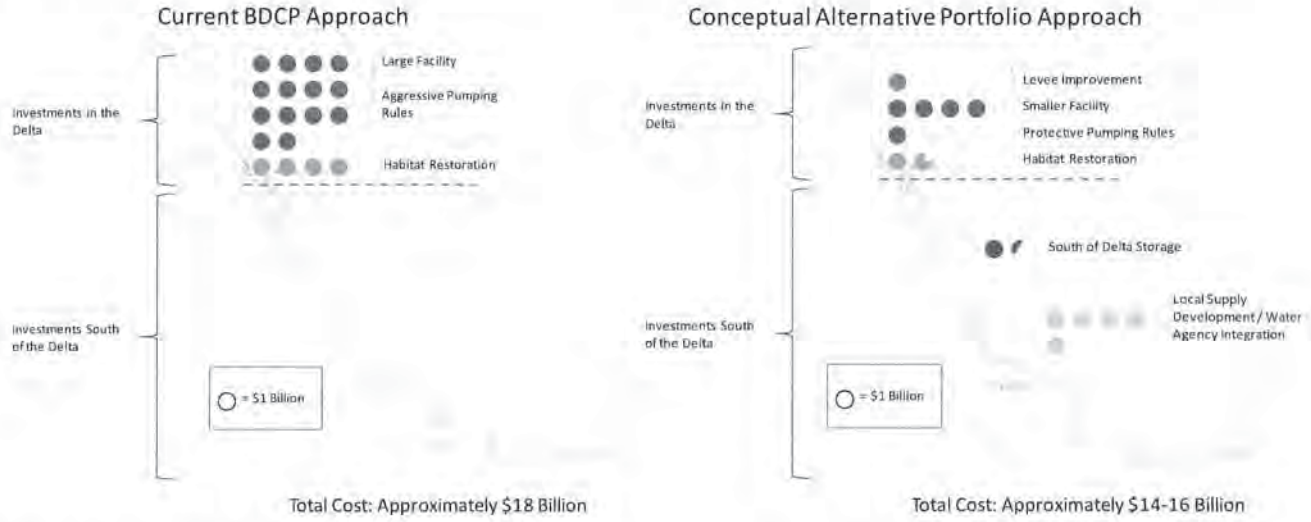
Introduction: The duration of the proposed action is more than two decades. The long time horizon of the consultation requires NMFS to anticipate long-term future events, including increased water demand and climate change. The effects analysis in this Opinion highlights the difficulty of managing cold water aquatic species below impassible barriers, depending entirely on a fluctuating and often inadequate cold water reservoir pool. The analysis shows that even after all discretionary actions are taken to operate Shasta and Folsom reservoirs to reduce adverse effects of water operations on listed anadromous fish, the risk of temperature-related mortality of fish and eggs persists, especially in critically dry years. This mortality can be significant at the population level. The analysis also leads us to conclude that due to climate change, the frequency of these years will increase.

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Benefits of a Diversified Portfolio Approach to the Bay-Delta and Water Supply

A Bay Delta Conservation Plan that includes a balanced portfolio of investments both in and outside of the Delta offers a wide range of potential benefits in comparison with a narrow focus on a large new Delta water conveyance facility and habitat restoration. Given the statewide importance of a Delta solution, we urge BDCP, the Delta Stewardship Council and others to analyze these and other potential benefits from a portfolio approach to restoring the Bay-Delta and improving water supply reliability in export areas.



Cost-Effective Solutions: By considering the benefits of water supply investments that do not depend on increased exports from the Delta, a portfolio approach can help in developing the most cost-effective plan for the Bay-Delta and improved water supply reliability. This approach is similar to integrated planning efforts undertaken by individual water agencies across the state and has the potential to provide superior benefits at a lower overall cost.

More Water for California's Economy: A smaller Delta facility would save billions of dollars in construction, operations and maintenance costs. Some of these savings can be invested in proven water supply tools such as water conservation and recycling, and in South of Delta storage that can provide improved dry year water supply. Considered as a complete portfolio, this approach can produce more water for export water users than would be produced through a narrow focus on a large Delta facility.

Jobs for Southern California, the Bay Area and the Central Valley: Investing billions of dollars in new water sources in export areas will generate thousands of jobs in the communities that will provide the local cost share for these investments. Based on an analysis by the City of Los Angeles, a $3.5 billion investment in local water solutions in the urban sector would generate 10,000 jobs over a five year period. In contrast, a narrow focus on a large Delta facility and habitat restoration would generate few direct jobs in communities south of the Delta.

Science-Based and Permittable: By basing proposed operations in the Delta on the best available science and by investing in alternative water supply sources that reduce reliance on the Delta, a portfolio approach allows BDCP to develop a truly science-based plan that can receive required regulatory permits.

Better Environmental Results: By reducing pressure for Delta exports, a portfolio approach could help implement science-based flow standards in the Bay-Delta to restore the largest estuary on the West Coast, to help recover listed species and to rebuild the California salmon fishery. In addition, investments in local water supplies in the export areas can reduce energy use and greenhouse gas emissions associated with transporting water from northern to southern California. Some of those investments, such as water recycling, groundwater management and urban stormwater capture can also improve Southern California coastal water quality and reduce contamination in groundwater basins.

Faster Water Supply Benefits: The length of time required to provide benefits is a key factor in designing a Delta plan. A large new Delta facility would provide no benefits until construction is complete – perhaps 15-20 years from today. In contrast, investments in local water supplies and stronger Delta levees produce benefits more rapidly, as each project is completed. In addition, a smaller facility could likely be constructed more rapidly. The delay in receiving benefits from a large facility could result in even higher costs for export water users, who could be forced to make major investments in local water supplies during the coming 15-20 years, in addition to the cost of financing a large Delta facility.

More Local Control Over Water Supplies: By increasing investments in local water sources, a portfolio approach would increase local control over water supplies. Communities including Los Angeles, San Diego, Long Beach, Santa Monica and many others are already planning major investments in local water supplies that will reduce their reliance on water imported from the Delta. This approach is also consistent with the state water code requirement to reduce reliance on Delta water supplies.

Greater Reliability, Especially During Dry Years: A portfolio approach would provide multiple water supply benefits during dry years, when water is most precious. First, local water sources such as conservation and water recycling are far less vulnerable to droughts, earthquakes and climate change impacts than are Delta supplies. Second, a portfolio approach would invest in South of Delta water storage to increase water availability in dry years. And third, by investing in Delta levees and a smaller Delta facility, a portfolio approach would provide greater dry year reliability than would a large facility alone. BDCP currently anticipates that more than 75% of Delta exports will come from the existing South Delta pumps in the driest years – even with a large new North Delta intake. Under this approach, investments in Delta levees are needed to decrease the vulnerability of 75% of Delta exports in the driest years. In any "dual conveyance" alternative that would divert from both the North and South Delta, investments in Delta levees would improve the reliability of ongoing exports from the South Delta.

Broader Potential Support: Most of the concepts included in a portfolio approach have been supported by a wide range of stakeholders for many years. This approach could provide broader benefits for the Delta, for the environment and for water users than an approach that is artificially constrained to the Delta alone. This portfolio approach could attract broader support, leading to new potential financing partners and easier implementation.

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Doug Obegi's Blog

Growing Support for Analysis of Bay-Delta Conceptual Alternative



Posted January 31, 2013 in Saving Wildlife and Wild Places, U.S. Law and Policy

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Last month, a coalition of environmental groups, urban water agencies, business groups and local elected officials in California released a new, portfolio based conceptual alternative for the Bay Delta and asked state and federal agencies to analyze this alternative in the Bay Delta Conservation Plan EIS/EIR. We believe that this alternative promises better environmental results and greater and more secure water supplies at less cost than the state's current preferred BDCP project. Since the alternative was released, additional business groups, newspapers, and other interests have expressed support for meaningful analysis of this alternative. Below are links to the letters, editorials, newspaper stories, and other information regarding this alternative.

Water Districts and Municipalities

- 1/16/2013 Alameda County Water District
- 1/16/2013 City of San Diego
- 1/16/2013 Contra Costa Water District
- 1/16/2013 East Bay Municipal Utility District
- 1/16/2013 Otay Water District
- 1/16/2013 San Diego County Water Authority
- 1/16/2013 San Francisco Public Utilities Commission
- 2/26/2013 City of Sacramento

Business Organizations

- 1/16/2013 Contra Costa Council and 2/22/2013 (separate letter)
- 1/16/2013 Environmental Entrepreneurs
- 1/22/2013 San Diego Regional Economic Development Corporation

Environmental Organizations and Independent Bodies:

- 1/16/2013 Defenders of Wildlife
- 1/16/2013 Natural Resources Defense Council
- 1/16/2013 Planning and Conservation League
- 1/16/2013 The Bay Institute
- 2/4/2013 Charles Gardiner, Executive Director of the Delta Vision Foundation

Elected Officials

- 1/16/2013 Congressman George Miller
- 1/17/2013 Contra Costa County Supervisor Mary Piepho
- 1/17/2013 Contra Costa County Supervisor Karen Mitchoff
- 1/18/2013 Congressman John Garamendi

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1/18/2013	Congresswoman Doris Matsui
1/18/2013	Congressman Jerry McNerney
1/18/2013	Congressman Mike Thompson
2/4/2013	Solano County Supervisor Skip Thomson
2/4/2013	Sacramento County Supervisor Don Nottoli
2/4/2013	Yolo County Supervisor Mike McGowan
2/4/2013	San Joaquin County Supervisor Larry Ruhstaller
2/12/2013	Contra Costa County Board of Supervisors (Board of Supervisors Vote 2/12/2013)
2/13/2013	Congressman Ami Bera
2/21/2013	Congressman Jared Huffman
2/21/2013	Congresswoman Jackie Speier
2/22/2013	Assemblywoman Susan Bonilla
3/19/2013	Sacramento County Board of Supervisors
3/21/2013	State Senator Lois Wolk
3/21/2013	State Senator Mark DeSaulnier
3/21/2013	State Senator William Monning
3/21/2013	State Senator Jim Beall
3/21/2013	State Senator Cathleen Galgiani
3/21/2013	State Senator Fran Pavley
3/21/2013	State Senator Ellen Corbett
3/21/2013	State Senator Mark Leno
3/21/2013	State Senator Hannah-Beth Jackson
3/21/2013	State Senator Jerry Hill
3/21/2013	State Senator Marty Block
3/21/2013	Assemblymember Susan Bonilla
3/21/2013	Assemblymember Roger Dickinson
3/21/2013	Assemblymember Susan Talamantes Eggman
3/21/2013	Assemblymember Mariko Yamada
3/21/2013	Assemblymember Joan Buchanan
3/21/2013	Assemblymember Richard Pan
3/21/2013	Assemblymember Tom Ammiano
3/21/2013	Assemblymember Wes Chesbro
3/21/2013	Assemblymember Ken Cooley
3/21/2013	Assemblymember Toni Atkins
3/21/2013	Assemblymember Paul Fong
3/26/2013	Solano County Board of Supervisors
5/29/2013	Congressman Scott Peters
5/29/2013	Congressman Juan Vargas
5/29/2013	Congressman Susan Davis

State Agencies

2/1/2013	Delta Protection Commission

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Newspaper Editorials

1/20/2013 San Diego Union Tribune: "A better idea, and billions cheaper"

1/23/2013 Merced Sun-Star: "Our View: Alternative plan for Delta worth a look"

1/24/2013 Sacramento Bee: "Can governor broker a water peace treaty"

2/7/2013 Chico News Review: "Alternative to the tunnels: There's an easier, cheaper, less destructive way to meet the state's water needs"

3/24/2013 San Diego Untion Tribune: "Progress on the water front"

Media Coverage

1/16/2013 Los Angeles Times: "Groups say smaller tunnel is better"

1/16/2013 San Diego Union-Tribune: "Filner urges Brown to scale back water project"

1/18/2013 Greenwire: "Democrats back alternative to massive delta water tunnels"

1/20/2013 Stockton Record: "Coalition plan urges single, smaller tunnel"

1/26/2013 Associated Press: "Calif. groups want state to study smaller tunnel"

1/26/2013 Sacramento Bee: "Brown's water plan faces mixed reviews"

1/28/2013 Davis Enterprise: "Brown's canal proposal bad plumbing: Garamendi"

2/21/2013 KPBS: "Dueling Proposals are Latest in Plan for Sacramento Delta"

3/13/2013 The California Spigot: "A Cautionary Tale for California: BDCP Fails in Dry and Wet Years"

3/5/2013 Los Angeles Times: "Democrats urge Brown to consider alternative to water project"

3/5/2013 Woodland Daily Democrat: "Lawmakers seek analysis of alternative to Delta tunnel plan"

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Microcystis: Toxic Blue-Green Algae

What are *Microcystis* blooms and why they are a problem?



Figure 1. Mat of *Microcystis* on the surface of a water body.

Microcystis aeruginosa is a single-celled blue green alga, or cyanobacterium, that occurs naturally in surface waters. *Microcystis* can proliferate to form dense blooms and mats under certain conditions (see Figure 1). Many variants of these cyanobacteria produce multiple toxins, including the potent liver toxin, microcystin. When *Microcystis* die, their cells break open, releasing the toxin microcystin into the water. Ingestion of water or algal cells containing microcystin has produced adverse effects in fish, dogs, cats, livestock and humans.

What effects do *Microcystis* blooms have on humans and animals?

People swimming in dense *Microcystis* blooms have experienced irritation such as skin rashes, burns, and blistering of the mouth. Ingestion or inhalation of water containing dense bloom material may cause vomiting, nausea, headaches, diarrhea, pneumonia, and fever. Ingestion of significant levels of the toxin microcystin can cause liver damage and dysfunction in humans and animals. No deaths from ingestion of microcystins have been reported in humans. However, dogs, wildlife and livestock have died following exposure to this toxin.



What causes *Microcystis* blooms?

Microcystis blooms typically thrive in warm, turbid, and slow-moving waters. The blooms with the highest biomass occur in waters that are high in nitrogen or phosphorus (eutrophic waters). *Microcystis* also require sufficient light intensity to conduct photosynthesis, which results in blooms. In California, cyanobacteria proliferate in the early summer through late autumn and may last for two-four months. *Microcystis* may be present in the water in the absence of visible blooms because the mats can sink below the surface.

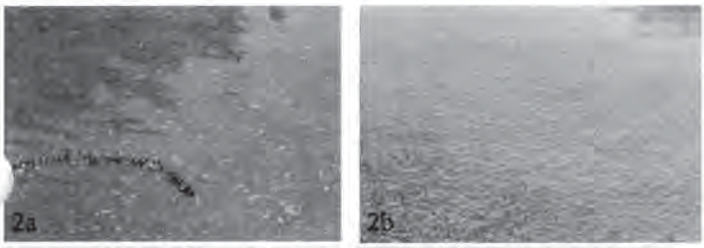


Figure 2. Recent pictures of microcystis blooms in the Delta. Inset 2a, Old River; 2b near Mildred Island

How are humans and animals exposed?

The most common route of exposure to microcystin is drinking water, followed by recreational exposures and food supplements. Typical water treatment processes do not fully remove microcystin that might be present in drinking water supplies stored in reservoirs. Swimming and playing in water that contains, or recently contained, *Microcystis* blooms is another common exposure route. Children have the highest risk of exposure since they tend to unintentionally ingest water while swimming. Microcystin can move through the aquatic food web, exposing fish and shellfish, as well as the people that consume them. Microcystin does not remain in edible fish and shellfish tissues for more than a few weeks. However, people that frequently consume sport fish caught from a water body that supports *Microcystis* blooms have a higher risk of exposure. Dogs can ingest large amounts of *Microcystis* cells when they clean their coats after playing in water. Livestock, wildlife and dogs are exposed through drinking water and containing *Microcystis* or ingesting algal mats.

Where have blue-green algal blooms occurred in California?

Microcystis blooms are occurring with greater frequency in California than in the past. The map below identifies the locations of known recurrent algal blooms in our state. The location of blooms identified in the map reference all strains of blue-green algae, including *Microcystis*. Information on the locations of *Microcystis* blooms exclusively is not available.



Preventing *Microcystis* Blooms

Any efforts to prevent nutrients from running off of lawns, pastures, or agricultural fields will reduce the frequency and severity of toxic blue-green algae blooms as well as other types of nuisance blooms. For the homeowner, this means carefully using fertilizers on lawns as well as preventing run-off when watering. Replacing lawns with native plants will reduce or eliminate the need for fertilizer and will cut water use by 75% (an added benefit). *Microcystis* thrives when the nitrogen:phosphorus ratio is less than 15 parts nitrogen (N) to 1 part phosphorus(P). When the ratio of N:P is greater than 20:1, non-toxic algae predominate. Agriculturalists can play a major role in reducing BGA blooms by also carefully controlling the use of fertilizers. Water agencies can contribute to solving this problem by increasing the flushing of waterways through releases of water from dams. These releases increase mixing of different layers of water downstream and decrease water temperature, both of which are unfavorable for toxic *Microcystis*. In rivers, any actions that increase flow rate will minimize the conditions which foster blooms.

Guidelines for avoiding exposure to *Microcystis* and microcystin



- Never drink from water containing visible blue-green algal blooms.
- Do not allow children or pets to play in water that contain algal blooms.
- Follow the advice on all postings and signs located at waterbodies.
- If you suspect exposure, wash affected area with water and contact a physician.
- If you think a waterway contains microcystin, report it to your local Health Department or Regional Water Quality Control Board.

Sources of Additional Information

Websites with useful information:
General Health: http://ww2.cdph.ca.gov/healthinfo/environhealth/water/Pages/Bluegreenalgae.aspx
Updated information, including newly identified locations, see *Blue Green Algae Voluntary Guidance Document* posted at: http://www.waterboards.ca.gov/water_issues/programs/bluegreen_algae/

Ackowledgements: This factsheet was prepared by T. Le, student intern, Ecotoxicology Program, Office of Environmental Health Hazard Assessment, with support from a Prop. 50 grant from CALFED. For more information, contact Regina Linville at rlinville@oehha.ca.gov or P. Lehman at plehman@water.ca.gov.

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Phycologia (1996) Volume 35 (6 Supplement), 25–35

A comparison of cyanobacterial bloom dynamics in freshwater, estuarine and marine environments

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HANS W. PAERL. 1996. A comparison of cyanobacterial bloom dynamics in freshwater, estuarine and marine environments. *Phycologia* **35** (Supplement): 25–35.

Cyanobacterial blooms are diagnostic of accelerating eutrophication in freshwater (FW) and estuarine (E) ecosystems. In full salinity marine (M) ecosystems blooms are more closely controlled by physical than trophic conditions. FW and E blooms are initiated and exacerbated by (1) excessive nutrient (N and P) loading, (2) high surface water temperatures (> 20°C), (3) persistent water column stratification, (4) long water residence time, and (5) organic matter enrichment. Physical–chemical forcing features can act synergistically to control bloom potential. Factors additionally favouring cyanobacterial blooms include (1) low dissolved inorganic carbon concentrations (especially in FW), (2) low total and dissolved N:P ratios, (3) close metabolic coupling between sediments and water column, and (4) high irradiance, long daylength. FW and E blooms are closely controlled by hydrodynamic and salinity alterations. The ability of nuisance taxa (nuisance characteristics include hypoxia and anoxia, toxicity, odour and taste problems and food web alterations) to dominate these waters can be traced to exploitation of physical–chemical 'extremes' in nutrient loading, stratification and irradiance. In subtropical and tropical oligotrophic, N-deficient oceanic environments, blooms are dominated by N_2-fixing genera (*Trichodesmium*, *Rhizosolenia–Richelia*) that often accumulate as buoyant surface-dwelling 'mats' under low wind stress (i.e. low turbulence and non-mixed) conditions. Nuisance conditions are not encountered in the open ocean, largely because nutrient limitation (Fe, P) and frequent episodes of wind mixing preclude massive accumulations of biomass over time scales exceeding a few days. In all environments, the ability to rapidly (within minutes to hours) migrate to high irradiance near-surface waters by gas vacuolation can confer an advantage over less-motile, non-cyanobacterial taxa. Bloom genera exhibit adaptive biochemical, physical and biotic mechanisms, which promote dominance under anthropogenically-stressed conditions. These include the following: N_2 fixation, cellular nutrient (P, N) storage, metal (Fe, Cu) sequestration by siderophore chelators, mucilage and sheath production to counter desiccation, buoyancy regulation, photoprotection by carotenoid accessory pigments, and consortial associations with other microorganisms and higher plants. Management strategies aimed at arresting problematic blooms should consider and manipulate the linkages and synergistic interplay of physical, chemical and biotic variables favouring nuisance genera.

INTRODUCTION

Blue-green algae or cyanobacteria exhibit remarkable physiological, morphological and ecological adaptations and diversification in response to global evolutionary change, including the development of a modern-day oxic biosphere (Cloud 1976; Stanier & Cohen-Bazire 1977; Schopf & Walter 1982). As opportunistic phototrophs, cyanobacteria have also exploited recent anthropogenic alterations of aquatic environments, most notably nutrient enrichment (Fogg 1969; Paerl 1988b). A striking example of cyanobacterial ecological opportunism is the development and persistence of dense blooms in response to nutrient enrichment in a vast range of lakes, reservoirs and rivers (Fogg 1969; Reynolds & Walsby 1975; Reynolds 1987; Paerl 1988b).

Among the most problematic and notorious cyanobacterial blooms are those of nuisance genera, including *Anabaena*, *Aphanizomenon*, *Microcystis*, *Nodularia* and *Oscillatoria*. Extensive surface blooms pose serious water quality and fisheries resource problems, including deoxigenation of hypolimnetic (non-mixed bottom) waters, leading to toxicity (H_2S buildups) accompanied by foul odours, undesirable tastes and fish kills in affected waters. Nuisance strains can be toxic to algal consumers and animals (including man) utilizing affected waters for drinking purposes (Nizan *et al.* 1986; Carmichael 1991). Freshwater and brackish (i.e. estuarine) food webs can be negatively impacted due to poor edibility and food quality of bloom species (Holm *et al.* 1983; Fulton & Paerl 1988). As nutrient-enriched freshwater and estuarine ecosystems increasingly exhibit nuisance blooms, the need grows for effective mitigation strategies.

In the marine environment, cyanobacterial blooms are confined to pelagic, near-surface blooms of the N_2-fixing genera *Trichodesmium* and the *Richelia* (heterocystous cyanobacterium)–*Rhizosolenia* (diatom) symbiosis in tropical and subtropical N-deplete oceans (Carpenter *et al.* 1992). In contrast to freshwater and estuarine bloom taxa however, marine blooms are not necessarily closely correlated with enhanced anthropogenic nutrient loading. Furthermore, while some selective inhibition of invertebrate grazers (crustacean zooplankton) may be taking place in association with these bloom genera (O'Neil & Roman 1994), no broad-scale toxicity can be attributed to them. Marine bloom-forming genera, while closely controlled by physical factors (i.e. temperature, irradiance and turbulence), appear distinctly different from freshwater and brackish taxa in that they are not strong indicators of nutrient-enhanced eutrophication or of toxicity. It has been suggested that *Trichodesmium* bloom formation may partially be controlled by the availability of iron (Fe) (Rueter *et al.* 1992), which in western Atlantic Ocean waters (e.g. Gulf

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Stream) can mediate N_2 fixation and growth of this genus (Paerl *et al.* 1994). A bulk of the iron entering oceanic environments is of aeolian origin, originating from dust storms (i.e. Sahara Desert) transported over open ocean waters. If aeolian sources are increasing due to human desertification, there may well be a link between anthropogenic nutrient loading and marine cyanobacterial bloom dynamics. Marine blooms will be considered jointly with freshwater and brackish blooms in terms of physical controls but differently in terms of nutritional controls or ecological and environmental manifestations.

Despite the ubiquity and periodic persistence of blooms, there exists preciously little information linking ambient physical, chemical and biotic conditions (and combinations thereof) to bloom dynamics. Equally obscure are cyanobacterial physiological and ecological 'strategies' that have evolved to optimize growth and persistence during physically and chemically favourable bloom periods. Here, I will explore the functional linkage between physical–chemical 'forcing features' (including nutrient loading and utilization dynamics, temperature, turbulence and stratification, water residence and flushing, and irradiance) and biotic factors, including nutrient and energy metabolism, motility and buoyancy regulation and interactions with other micro- and macroorganisms that may be instrumental in promoting and maintaining blooms of nuisance genera. In particular, an improved understanding of synergistic interactions between cyanobacteria and their immediate physical, chemical and biotic environment on relevant microbial scales is aimed at ecologically and environmentally relevant information useful for devising effective bloom control measures.

ENVIRONMENTAL FACTORS CONTROLLING CYANOBACTERIAL BLOOM FORMATION AND PROLIFERATION

Physical–chemical factors controlling cyanobacterial bloom potentials are numerous and complex (Table 1). These factors frequently determine which genera and species become established and dominant in specific ecosystems. Most often mentioned are the size and volume of the system, and its water retention (flushing), vertical mixing and light attenuation characteristics. Cyanobacteria exhibit relatively slow growth rates (< 1 division per day). Therefore, lengthy periods of physical stability (i.e. stable climatic and hydrologic conditions) are a prerequisite for the development of bloom populations (Reynolds & Walsby 1975). In addition, temperature (> 20°C) and nutrient availability (supply) control growth rates (Fogg 1969).

Surface accumulations, as odouriferous, toxic and noxious scums, are a problematic aspect of blooms. Excessive buoyancy is thought to be responsible for surface scum formation (Reynolds & Walsby 1975). Irradiance and nutrient supply are major environmental factors controlling buoyancy (Konopka *et al.* 1978). Reduced irradiance can enhance buoyancy in numerous bloom-forming species (Walsby 1972). Reduced CO_2 availability in low alkalinity freshwater systems (Paerl & Ustach 1982) and high inorganic nitrogen concentrations (Van Rijn & Shilo 1983) also increase buoyancy. Surface accumulation facilitates interception of atmospheric CO_2 (Paerl & Ustach 1982) and inorganic N from dry or wet atmospheric deposition (Lewis 1983), both of which would benefit growth. Buoyancy alteration is ecologically advantageous by allowing cyanobacteria to exploit favourable nutrient gradients throughout the water column and surface sediments (Reynolds & Walsby 1975).

Irradiance regulates buoyancy by controlling photosynthesis. This is accomplished in two ways. (1) High rates of photosynthesis (i.e. high irradiance) increase cellular turgor pressure, thus leading to the collapse of gas-filled cytoplasmic inclusions, or gas vesicles, which provide buoyancy (Walsby 1972). Conversely, low levels of irradiance lead to suboptimal photosynthetic rates, reducing cell turgor pressure and promoting gas vesicle formation and buoyancy. In this manner,

Table 1. Physical–chemical factors potentially controlling blue-green algal blooms

Factors	Effects and impacts
Physical	
Flushing/altered water residence time	Potential removal mechanism for blooms, if flushing exceeds growth rates of bloom taxa
Large-scale vertical mixing	Counteracts near-surface accumulations of buoyant bloom populations. Forces competition for light and nutrients with more desirable, non-buoyant eukaryotic taxa
Small-scale turbulence (shear)	May disrupt blue-green algal filaments, colonies, aggregates and mutualistic associations with other microflora and micro- and macrofauna
Shading (reduced surface irradiance)	Can alter phytoplankton community composition and can negatively affect blue-green algal surface bloom taxa
Temperature	Generally, temperatures in excess of 20°C accompanied by stratification and high nutrient loading can promote blooms
Chemical	
pH modifications	Can alter phytoplankton community composition; low pH (< 6.0) favours eukaryotes, and high pH (> 8.0) favours cyanobacteria
Nutrient (N and P) inputs	Long-term (months/years) reductions in *both* N and P inputs are frequently effective in reducing blue-green algal bloom potentials; low N : P loading ratios (< 20) often caused by excessive P loading can enhance bloom potential
Salinity	Salinity in excess of a few ‰ (as NaCl) can be an effective barrier to development and persistence of many nuisance species
Trace metals	Under high N and P loading conditions, restricted availability of Fe may control phytoplankton growth; cyanobacteria are able to compete effectively for low levels of Fe; no convincing evidence for other trace metal limitations

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cells are capable of regulating their position in the water column in relation to photosynthetic needs. (2) Active photosynthesis can also lead to the production of relatively dense polysaccharides, leading to a loss of buoyancy (Konopka *et al.* 1978). Both mechanisms interact to control buoyancy in natural waters where irradiance, transparency, inorganic carbon (CO_2/HCO_3^-) and nitrogen supplies can vary rapidly in time and space.

Periods of low irradiance are often associated with wind-induced mixing. During such periods, phytoplankton organisms are forced into deeper waters and exposed to reduced levels of irradiance. If calm periods follow periods of vigorous vertical mixing, surface accumulations of highly buoyant cells may occur. The history and degrees of water column stability can dictate surface accumulations of cyanobacteria (Reynolds & Walsby 1975; Konopka 1984).

Temperature regimes play a critical role in cyanobacterial bloom formation. Generally, as temperatures exceed 20°C, the chances for cyanobacterial dominance increase, particularly in nutrient-enriched water bodies. In laboratory chemostat culture studies, Tilman & Kiesling (1984) showed temperature and N : P supply ratio to be the most important variables controlling cyanobacterial dominance.

Low N : P ratios have been implicated as a major factor favouring cyanobacterial dominance in a variety of lakes (V.H. Smith 1983) and in the Baltic Sea (Niemi 1979). V.H. Smith (1983) concluded that cyanobacteria were either rare or absent when total N : P exceeded 29 (by weight). This has fostered interest in manipulating the N : P ratio as a means of controlling cyanobacterial dominance and bloom formation. The hypothesis is consistent with the fact that certain cyanobacterial bloom genera are capable of fixing atmospheric N_2, which would afford a competitive advantage when combined N availability is restricted and P is available (i.e. relatively low available N : P ratios).

CYANOBACTERIAL ECOPHYSIOLOGICAL STRATEGIES INSTRUMENTAL IN BLOOM FORMATION AND PROLIFERATION

A. Nitrogen fixation

A unique (to photosynthetic prokaryotes) and advantageous ecophysiological trait is the ability of certain cyanobacterial taxa to fix atmospheric nitrogen (N_2), thereby circumventing N limitation (Stewart 1973; Fogg 1974). Diazotrophy has allowed these taxa to periodically invade and dominate waters sufficient in phosphorus but deficient in nitrogen supply (Gibson & Smith 1982; Healy 1982). In numerous freshwater ecosystems, tropical reefs, salt marshes, benthic microalgal mats and so forth, cyanobacterial N_2 fixation can constitute a highly significant fraction (10 to nearly 100%) of 'new' nitrogen input supporting primary and secondary production (Wiebe *et al.* 1975; Horne 1977; Lean *et al.* 1978).

The ability to fix N_2, however, is not without environmental constraints. Molecular oxygen (O_2) is a potent inhibitor of nitrogenase, the enzyme mediating this process (Yates 1980). Ironically, as oxygenic phototrophs, cyanobacteria themselves are in large part (during blooms) responsible for creating and maintaining O_2-saturated and supersaturated conditions in N-limited surface waters. To solve this paradoxical problem, dominant freshwater and brackish filamentous bloom genera, including *Anabaena, Aphanizomenon, Gloeotrichia, Nodularia* and *Nostoc*, form biochemically and morphologically distinct, O_2-devoid heterocysts, harbouring the O_2-sensitive N_2-fixing nitrogenase enzyme complex (Donze *et al.* 1972; Fay 1973; Wolk 1982). In oceanic waters, planktic N_2 fixation is largely confined to the non-heterocystous genus *Trichodesmium*, which forms fusiform tuft and spherical puff aggregates (Carpenter *et al.* 1992). The manner by which *Trichodesmium* accomplishes diazotrophy without the aid of heterocysts is the subject of considerable research. Another contributor to marine N_2 fixation dynamics is the *Richella* (heterocystous cyanobacterium)–*Rhizosolenia* symbiosis. Diazotrophy has opened up diverse P-sufficient aquatic ecosystems to exploitation by heterocystous and non-heterocystous bloom-forming taxa (Horne 1977; Healy 1982). In particular, well-stratified eutrophic lakes and ponds are sites of extensive N_2-fixing heterocystous cyanobacterial blooms.

Table 2. Heterocystous N_2-fixing cyanobacterial genera commonly found in aquatic planktic and benthic (including epilithic and epiphytic) habitats. Adapted from Paerl (1988)

Genus	Freshwater/ estuarine/marine	Habitat
Anabaena	Freshwater	Planktic and benthic
	Estuarine/marine	Benthic (mats)
Aphanizomenon	Freshwater	Planktic
Calothrix	Freshwater	Benthic
	Marine	Benthic
Cylindrospermum	Freshwater	Benthic
	Marine	Benthic
Gloeotrichia	Freshwater	Planktic and benthic
Mastigocladus	Freshwater	Benthic
	Marine	Benthic
Nodularia	Freshwater	Planktic
	Estuarine	Planktic
Nostoc	Freshwater	Planktic and benthic
	Estuarine/marine	Benthic
Richelia	Marine	Planktic and endosymbiotic
Rivularia	Freshwater	Benthic
	Marine	Benthic
Scytonema	Freshwater/marine	Planktic and benthic
Tolypothrix	Freshwater	Planktic and benthic
	Estuarine/marine	Benthic

Despite their spectacular success in many N-limited freshwater and some brackish ecosystems, heterocystous cyanobacterial genera (Table 2) are frequently absent as significant contributors of fixed N or C in large N-limited lakes, estuaries and coastal waters exhibiting inorganic and organic nutrient input and concentration ratios (N : P) considered favourable for cyanobacterial dominance (V.H. Smith 1983; Howarth *et al.* 1988). Ironically, P-sufficient, N-limited waters cover vast stretches of the globe, including much of the oceans and estuaries (Dugdale 1967; Ryther & Dunstan 1971); planktic and benthic primary and secondary production could clearly benefit from N_2 fixation via heterocystous cyanobacteria. On the face of it, it would appear that a potential niche for these diazotrophs remains largely unoccupied in such waters.

These aquatic ecosystems are not *a priori* incapable of supporting heterocystous N_2-fixing cyanobacteria. For example, two often cited oligotrophic, N-sensitive large lakes, Tahoe

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(California–Nevada) and Crater (Oregon), contain benthic/periphytic heterocystous N_2-fixing genera, including *Nostoc*, *Calothrix* and *Scytonema* (Reuter *et al.* 1985). Also, chronically N-deficient estuaries and coastal lagoons support benthic heterocystous taxa showing relatively high N_2 fixation rates. Oceanic coral reef, shelf and coastal mangrove habitats are often richly endowed with diverse heterocystous genera, including *Scytonema*, *Nostoc*, *Anabaena*, *Cylindrospermum* and *Calothrix* (Frémy 1933; Whitton & Potts 1982; Table 2). Therefore, it is difficult to invoke salinity or 'unusual' ionic or nutritional inputs and ratios as barriers to the development and proliferation of heterocystous taxa (J. Thomas *et al.* 1988). It is striking, however, that the examples cited above are all benthic or otherwise attached. There are a few examples of brackish and full-salinity systems where planktic heterocystous genera thrive. Most obvious are the invasions of N_2-fixing *Nodularia* and *Aphanizomenon* blooms during vertically stratified summer periods in the Baltic Sea (Grøntved & Steeman Nielsen 1957; Niemi 1979) and massive blooms of *Nodularia* in the stratified Peel-Harvey Estuary in W. Australia (Huber 1986).

Early studies (Fogg 1969) cite dissolved organic matter (DOM) as a factor potentially controlling cyanobacterial blooms. In freshwater and brackish environments, blooms are often associated with organically enriched conditions. However, close scrutiny of the relationship between DOM and such blooms yields no clear cause and effect relationships (Paerl 1988a, 1988b). Fogg (1969) and others have pointed out that it is difficult to functionally distinguish whether elevated DOM is a result or a cause of cyanobacterial blooms. Furthermore, the waters in question are frequently enriched with terrigenously and autochthonously derived DOM.

B. Turbulence as a potential limiting factor

In examining the suite of physical–chemical factors potentially controlling establishment and persistence of planktic cyanobacteria, turbulence plays an eminent role (Table 1). Large-scale wind and tide–induced mixing affects vertical and horizontal distributions and transport of cyanobacterial bloom taxa. Many heterocystous and non-heterocystous genera (*Anabaena*, *Aphanizomenon*, *Nodularia*, *Microcystis*, *Oscillatoria*, *Trichodesmium*) regulate buoyancy (Reynolds & Walsby 1975; Konopka *et al.* 1978; Van Rijn & Shilo 1983). In highly turbulent waters, the ability to maintain optimal vertical positioning can be overcome by mixing (Reynolds 1987), which negatively affects growth and long-term competition (for nutrient and radiant energy resources) with eukaryotic phytoplankton adapted to variable light and nutrient regimes (diatoms, chlorophytes, chrysophytes, etc.). This knowledge has led to the application of artificial mixing strategies aimed at reducing and eliminating cyanobacterial blooms. To be an effective bloom mitigation tool, destratification must operate continually during favourable cyanobacterial growth periods (spring–summer) (D.W. Smith 1988; Shapiro 1990). Even when intermittent weak stratification takes place during these periods, cyanobacterial blooms quickly re-emerge, leading to summer dominance (Paerl 1987). Shallow, periodically mixed lakes such as Clear Lake (California), Klamath Lake (Oregon), Lakes George and Victoria (embayments) (Uganda–Kenya) and brackish segments of the Baltic Sea as well as a wide suite of agricultural and urban impoundments exhibit such conditions (Reynolds 1987; Vincent 1987; Paerl 1988b).

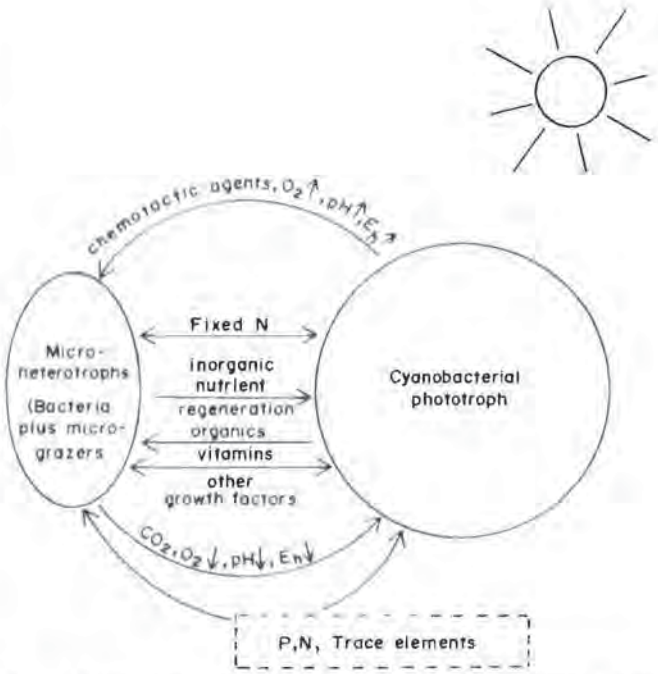


Fig. 1. Conceptual diagram illustrating cyanobacterial–bacterial heterotroph and grazer interactions in the cyanobacterial 'phycosphere'.

Magnitude and duration of small-scale turbulence (shear) are known to alter phytoplankton growth rates and structural integrity (Thomas & Gibson 1990a, 1990b). Non-disruptive (to cell, colonial or filament integrity) low-level turbulence promotes localized 'phycosphere' nutrient cycling, alleviates nutrient limitation (CO_2, PO_4^{3-}, trace metals) and generally promotes cell growth (Rhee *et al.* 1981). It has been our experience that gently stirred cultures of bloom-forming heterocystous genera, including *Anabaena*, *Aphanizomenon*, *Nostoc*, *Nodularia* and *Gloeotrichia*, frequently show better growth than static cultures. Subtle increases in turbulence (as either stirring or shaking) can, however, inhibit growth, with excessive turbulence causing disaggregation and cell and filament damage. Optimal N_2 fixation, photosynthetic rates and growth in these genera have been shown to be strongly reliant on mutually beneficial microbial (heterotrophic–phototrophic) consortial interactions functioning within the phycosphere of filaments and aggregates of colonial genera (Fig. 1; Paerl 1990). Turbulence may disrupt beneficial consortial interactions and thus act as a negative growth factor.

Excessive shear (Hunt 1982) can physically disrupt filaments of heterocystous N_2-fixing cyanobacteria (Kucera & Paerl, in preparation). The junctions between heterocysts and adjacent vegetative cells are narrow, fragile, prone to disruption and sites of filament breakage (Fig. 2; Lang & Fay 1971). It is most evident in bloom-forming species present as solitary filaments, such as *Anabaena cylindrica* Lemmermann, *A. circinalis* Rabenhorst *ex* Bornet *et* Flahault and *A. oscillarioides* Bory *ex* Bornet *et* Flahault, whereas intertwined, aggregated species such as *Anabaena flos-aquae* Brebisson *ex* Bornet *et* Flahault, *Aphanizomenon flos-aquae* Ralfs *ex* Bornet *et* Fla-

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Figs 2, 3. Bacteria–blue-green algae associations.

Fig. 2. Transmission electron micrograph (transverse section) of the heterocyst–vegetative cell junction in the N_2-fixing, bloom-forming filamentous cyanobacterium *Anabaena oscillarioides*. A bacterial epiphyte closely associated with the junction can also be seen. Note that the fragile junction near the polar plug region was severed during sample preparation.

Table 3. Impact of stirring speed and resultant filament breakage on chlorophyll *a*–specific N_2 fixation (nitrogenase activity as acetylene reduction) in *Anabaena oscillarioides*. Filaments were exposed to a range of stirring speeds. Controls are slowly stirred (50 rpm) conditions. When observed, filament breakage is indicated with an asterisk (*). Controls and treatments were grown under N-limited conditions (Chu-10 N-free medium) under continuous illumination (200 μmol m s^{-1}) at 25°C. Standard errors among triplicate samples are shown

Stirring speed (rpm)	Nitrogenase activity (μmol C_2H_4 mg chlorophyll a^{-1} h
50	7.5 ± 0.5
100	7.2 ± 0.7
250	5.8 ± 1.2
400*	3.2 ± 0.5
550*	2.4 ± 0.7
750*	1.2 ± 0.4

hault, *Gloeotrichia* spp. and *Nostoc* spp. may be better protected from shear. When filament breakage involving heterocysts occurs, affected heterocysts lose their ability to fix N_2 (Paerl & Bland 1982) and are shed (Table 3). Heterocysts originate as differentiated vegetative cells; the differentiation process is irreversible and represents a substantial energetic, molecular and morphological investment (Lang & Fay 1971; Wolk 1982; Hazelkorn 1986).

C. Nutrient limitation

Biological N_2 fixation confers a distinct competitive advantage in freshwater, estuarine, coastal and pelagic ocean waters, where N limitation prevails. During periods of N sufficiency, the ability of diazotrophs to compete depends on growth rates, relative to other microorganisms competing for common nutrient resources and losses (e.g. grazing, sinking). In the presence of high ambient levels of combined N, however, nitrogenase activity may be repressed and the success of diazotrophs will be dependent upon their ability to efficiently utilize combined sources of N.

Nutrient loading, ambient concentrations and the types of limiting nutrients in estuaries can change dramatically over seasonal time scales in all aquatic systems. These dynamic aspects should be considered in the greater context of nutrient controls of cyanobacterial growth. The supply rates of N or P are often cited as primary nutritional factors controlling cyanobacterial growth and dominance. Loading ratios and ambient concentrations of soluble and total N:P, relative to cellular requirements, have been related to the occurrence of cyanobacteria in freshwaters (V.H. Smith 1983, 1990), with low N:P ratios favouring N_2 fixers. Surprisingly, however, in estuaries low N:P loading ratios are often not associated with cyanobacterial abundance.

Although the absolute ambient concentrations of N may at times be high, N can still be in short supply relative to P. This

Fig. 3. Scanning electron micrograph showing bacterial attachment specifically near the heterocyst–vegetative cell junction of *Aphanizomenon flos-aquae*. This sample was obtained from a surface-dwelling N_2-fixing bloom in Clear Lake, California. Subsequent work indicated that the attached bacteria were heterotrophs, capable of being chemotactically attracted by amino acids and some sugars.

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is particularly true of anthropogenically impacted estuaries. In these systems N limitation may prevail, but N_2 fixation may be precluded by other physical–chemical constraints.

D. Oxygen inhibition: role of microzones

Molecular oxygen (O_2) is a potent inhibitor of nitrogenase in oxygenic cyanobacteria (Yates 1980). Among bloom-forming genera, the formation of heterocysts is an obvious adaptation to the 'oxygen problem'. Some cyanobacterial genera not endowed with heterocysts, but possessing N_2-fixing potential (nif genes and nitrogenase activity), have evolved additional structural, physiological and ecological strategies facilitating limited exploitation of oxygenated, nutrient-sufficient waters. These include filamentous and coccoid nonheterocystous genera such as *Oscillatoria, Lyngbya, Trichodesmium* and *Synechococcus*. Members of these genera typically occur in colonies, including aggregated bundles, laminar mats and biofilms. In certain freshwater and marine habitats, including sediments, intertidal sand and mudflats, reefs and fouling layers supporting localized O_2 depletion, these genera can be dominant diazotrophs.

Photosynthetic and heterotrophic bacteria can also fix N_2 in various freshwater and marine habitats. In contrast to cyanobacteria, however, heterotrophic bacteria are confined to anoxic waters, sediments, and detrital and surficial habitats having O_2-depleted microzones. Some diazotrophic bacterial and cyanobacterial genera thrive as endosymbionts in microalgae, higher plants and animals, where localized O_2 depletion can be assured.

E. Salinity and ionic composition of waters

Salinity has been mentioned as a potential regulator of N_2 fixation. N_2 fixation appears particularly susceptible to osmotic stress, and organisms unable to adjust by production of compensatory factors exhibit inhibition of activity at increasing salt concentrations (Dubois & Kapustka 1981; Le Rudilier *et al.* 1984). Organisms introduced into an estuarine or marine environment from terrestrial or freshwater realms may not be able to compensate for increasing salinities and osmotic stress. Indigenous populations are often able to adjust to varying salinities by the production of compatable osmolytes (Reed & Steward 1985). Apart from the work of Dicker & Smith (1980), who found relatively wide salt tolerance for an *Azotobacter* sp. isolated from a salt marsh, there has been relatively little consideration of this as a factor in regulating estuarine and marine N_2 fixation.

Certain freshwater bloom-forming cyanobacterial species can be highly sensitive to even a few ‰ salinity (NaCl) when discharged into estuarine waters (Paerl *et al.* 1984). In addition, it has been proposed that relatively high concentrations of the structural analogue of molybdate (MoO_4^{2-}), sulphate (SO_4^{2-}) present in sea water and saline lakes might competitively (via uptake) inhibit N_2 fixation (Howarth & Cole 1985). While some competitive inhibition of MoO_4^{2-} uptake by sea water (and higher) SO_4^{2-} concentrations occurs (Cole *et al.* 1993), N_2-fixing potentials of marine diazotrophs appear unaffected by this competition (ter Steeg *et al.* 1986; Paulsen *et al.* 1991). The small cellular Mo requirements for N_2 fixation are met by sufficient uptake and storage in both fresh and sea water.

F. NH_3 feedback inhibition

Nitrogenase synthesis and, in several photosynthetic diazotrophs, nitrogenase activity are regulated by intracellular N concentrations. For gene expression (most thoroughly studied in *Klebsiella pneumoniae* (Schroeter) Trevisan), there is a complex interaction between several operons (nif, ntr and pln) with several sites of sensitivity to intracellular combined N that combine to provide a mechanism of induction during N deficiency and repression during N sufficiency (Le Rudilier *et al.* 1984). When exposed to as little as 0.14–1.60 μM NO_3^- and 1.4–12.0 μM NH_4^+ for several generations, heterocyst formation may be repressed in cyanobacteria (Howarth *et al.* 1988).

POTENTIAL ROLE OF CYANOBACTERIAL–MICROBIAL CONSORTIAL INTERACTIONS IN BLOOM DYNAMICS

With few exceptions, naturally occurring and cultured cyanobacterial bloom species are commonly found in close association with diverse microorganisms (Guseva 1951; Whitton 1973; Paerl 1982). Microbial associates include heterotrophic eubacteria (Caldwell & Caldwell 1978; Paerl & Kellar 1978; Caldwell 1979), fungi (Whitton 1973), phytoflagellates (Paerl 1982) and ciliated and amoeboid protozoa (Wright *et al.* 1981). Associations occur inside colonies, aggregates of filaments and within sheaths, capsules and slimes located outside cyanobacterial cell walls. Collectively, such regions are referred to as the 'phycosphere' (Whitton 1973; Kessel & Eloff 1975; Caldwell 1977). The functional roles of phycosphere-level microbial associations in the context of cyanobacterial growth, secondary metabolite and toxin production/exchange are discussed in detail in a companion paper by Paerl & Millie (this volume). Here, I will evaluate phycosphere-mediated processes in the context of bloom potentials.

In nature, the diversity of phycosphere-associated microbial associations as well as specificities of microbial attachment sites are striking. Bacterial, flagellate or protozoan species may appear randomly attached to cyanobacterial filaments and colonies or scattered throughout the mucilaginous phycosphere. In contrast, one can encounter highly specific associations, where a single microbial species may exclusively inhabit morphologically and physiologically differentiated cyanobacterial host cells such as akinetes and heterocysts (Figs 2, 3; Paerl & Millie, this volume).

In a study of a specific association between a heterotrophic bacterium (*Pseudomonas aeruginosa* (Schroeter) Migula) and cyanobacterial (*Anabaena oscillarioides*) heterocysts, virtually all *P. aeruginosa* cells were found attached to heterocysts as opposed to vegetative cells (Figs 2, 3; Paerl & Kellar 1978). *Pseudomonas aeruginosa* was chemotactically attracted to *A. oscillarioides* heterocysts and to a variety of organic substrates, including some sugars and amino acids (Paerl & Gallucci 1985). $^{15}N_2$ fixed by host *A. oscillarioides* was transferred to heterocyst-associated *P. aeruginosa* (Paerl 1984),

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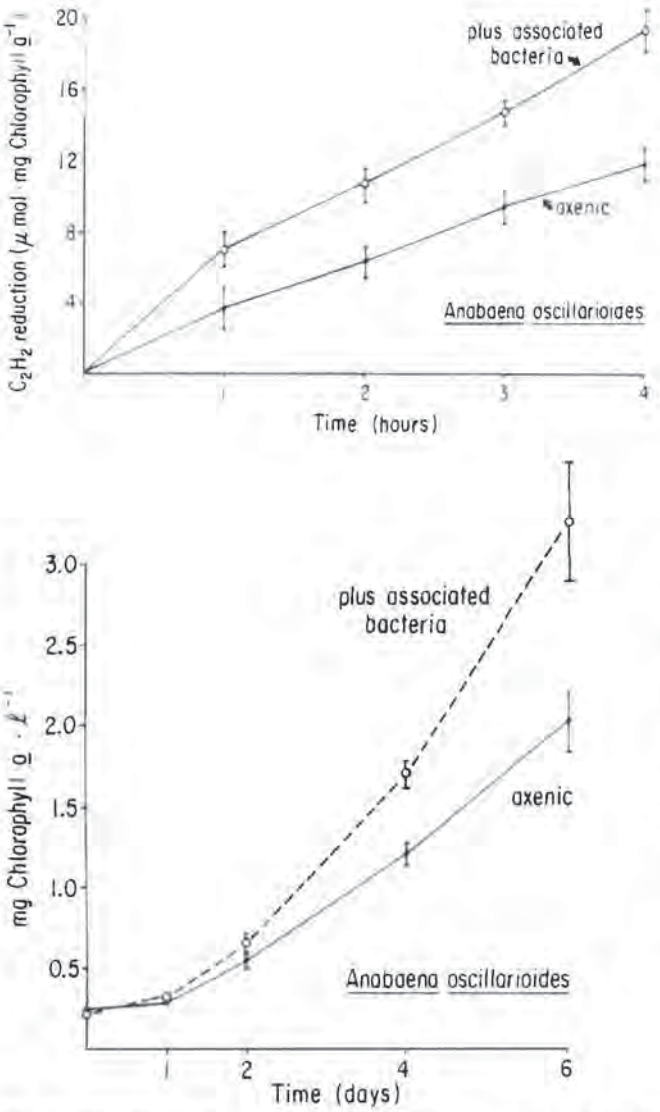


Fig. 4. Stimulatory effects of the heterotrophic bacterium *Pseudomonas aeruginosa* on N_2 fixation (acetylene reduction) and growth (as chlorophyll *a*) of the filamentous, heterocystous cyanobacterium *Anabaena oscillarioides*. This and other heterotrophic bacterial epiphytes were commonly associated with heterocysts of *Anabaena, Aphanizomenon, Nostoc* and *Gloeotrichia* species in various freshwater lakes and rivers (Paerl & Kellar 1978). Axenic (i.e. bacteria-free) *A. oscillarioides* populations were obtained by first fragmenting filaments by sonication, followed by extensive rinsing, and culturing sterile fragments on sterile Chu-10 N-free medium. *Pseudomonas aeruginosa* cells were then introduced to create bacteria-associated conditions.

and axenic isolates of *A. oscillarioides* exhibited optimal cellular growth (based on chlorophyll *a* production) and N_2 fixation rates when reinoculated with *P. aeruginosa* (Paerl 1988a) (Fig. 4). When released into axenic *A. oscillarioides* cultures, *P. aeruginosa* reestablished the heterocyst-specific association.

Among non-N_2-fixing colonial *Microcystis aeruginosa* (Kützing) Lemmermann blooms, bacterial colonization of mucilaginous layers surrounding *M. aeruginosa* colonies and amoeboid protozoan grazers within such colonies are most numerous during periods of optimal chlorophyll *a*–specific CO_2 fixation. Using microautoradiography, it was shown that

Table 4. Microautoradiographic determination of cell-specific rates of photosynthetic CO_2 fixation in colonies of the non-N_2-fixing, bloom-forming cyanobacterium *Microcystis aeruginosa*. Original stocks were derived from a bloom on the Neuse River, North Carolina. They were cultured on ASM + N medium and exposed to 250 μmol m^{-2} s^{-1} PAR at 25°C. Determinations were made on axenic (bacteria and protozoan-free) *Amoeba* spp.- and bacteria-associated (bacteria largely confined to mucilaginous sheaths) populations of *M. aeruginosa*. Results from three independent experiments are shown. Standard errors for determinations are shown

	pgC $cell^{-1}$ h^{-1}		
Date	Axenic	*Amoeba*-associated	Bacteria-associated
10 Oct. 1985	0.11 ± 0.012	0.25 ± 0.015	0.23 ± 0.012
12 Nov. 1985	0.14 ± 0.010	0.31 ± 0.012	0.22 ± 0.014
25 Nov. 1985	0.12 ± 0.008	0.27 ± 0.017	0.31 ± 0.013

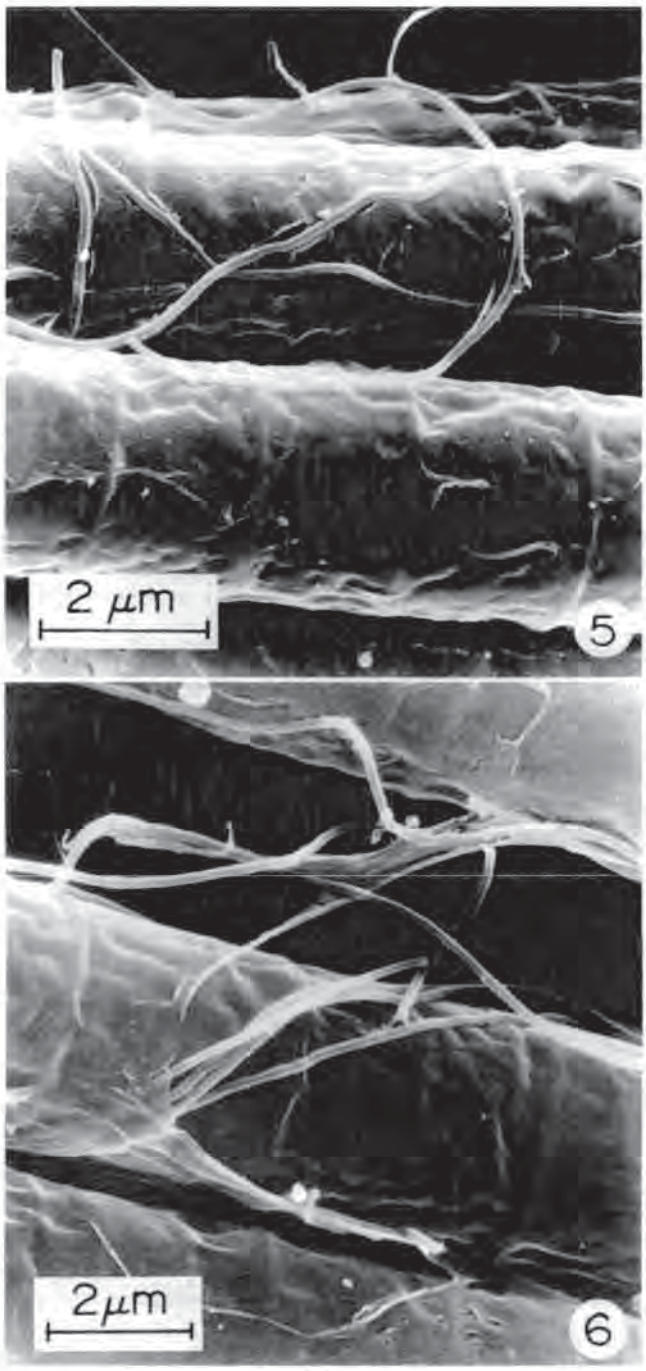
M. aeruginosa cells bordering regions being grazed exhibit higher cell-specific rates of $^{14}CO_2$ fixation than cells more distant from grazers (Table 4). These findings illustrate some of the mutualistic properties of cyanobacterial–microbial interactions.

Examinations of natural and laboratory cyanobacterial–bacterial associations by Lange (1967), Kuentzel (1969), Straskrabova (1974) and others (Caldwell 1977) have implicated phycosphere-associated bacteria as mutualistic cohorts during cyanobacterial bloom development and proliferation. Bacteria were suspected of recycling essential (for photosynthetic growth) CO_2 and PO_4^{3-} supplies during periods of dense bloom formation. In concert, these observations suggest mutually beneficial properties of such associations, which may provide 'host' cyanobacteria with a competitive nutrient cycling and productivity advantage (vs eukaryotic algae) during bloom initiation and maintenance.

It has also been shown that bacterial colonization of heterocysts enhances localized O_2 consumption (Paerl & Kellar 1978; Lupton & Marshall 1981). Because N_2 fixation potentials among various *Anabaena* and *Aphanizomenon* species are to some extent regulated by ambient O_2 tension (despite the presence of heterocysts) (Stewart & Pearson 1970; Paerl & Kellar 1978), it was concluded that respiratory O_2 protection provided by heterocyst-associated bacteria helped optimize N_2 fixation potentials among these genera, especially during O_2 supersaturated bloom conditions.

In marine bloom-forming *Trichodesmium* aggregates, bacterial (as well as protozoan and crustacean) associations are common (Figs 5, 6; Carpenter *et al.* 1992; O'Neil & Roman 1994). Efforts aimed at culturing *Trichodesmium* have shown that this diazotroph grows far better in the presence of bacteria (Paerl *et al.* 1994), suggesting mutualism, if not symbiosis, embodied in such associations. Associations are often most pronounced during maximum bloom phases, when CO_2 and N_2 fixation rates and growth are maximal (Paerl *et al.* 1989, 1994). Paerl *et al.* (1989) showed bacteria associated with *Trichodesmium* to assimilate a variety of organic compounds, especially N-rich amino acids (presumably the products of N_2 fixation). Capone *et al.* (1994) showed significant release of amino acids by *Trichodesmium*. Bacterial associations may therefore be involved in re-assimilating these otherwise 'lost' metabolites, constituting a phycosphere nutrient recycling mechanism for *Trichodesmium* aggregates (Fig. 1). It appears

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Figs 5, 6. Associations between filamentous bacteria and blue-green algae.

Fig. 5. Scanning electron micrograph illustrating close bacterial associations with photosynthetically active, N_2-fixing trichomes of the planktic marine cyanobacterium *Trichodesmium* sp. This sample was obtained from the western north Atlantic Ocean (Gulf Stream) near the North Carolina coast.

Fig. 6. Scanning electron micrograph showing filamentous bacteria both inside and outside of the thin mucilaginous sheath surrounding a *Trichodesmium* trichome. Sample is identical to that shown in Fig. 5.

that such associations are mutually beneficial, possibly mediating exchange and enhancing cycling of essential nutrients (P, Fe, organic and inorganic C, N) and metabolites in the ultraoligotrophic, nutrient-deplete waters that these associations thrive in.

Situations arise where cyanobacteria and bacteria directly compete for similar resources, including growth-limiting nutrients. In particular, limited availability of dissolved inorganic (and organic) phosphorus can lead to direct competition between planktic bacteria and cyanobacteria (as well as other phytoplankton), both under controlled laboratory conditions (Rhee *et al.* 1981) and in nature (Faust & Correll 1976; Paerl & Lean 1976). Furthermore, decreased PO_4^{3-} availability can lead to declines in cyanobacterial bloom (particularly N_2-fixing genera) potentials (Schindler 1975; Healy 1982). The ability of bacteria to outcompete cyanobacteria for this critical nutrient might *a priori* serve as a potential agent modifying magnitudes and duration of blooms. Effective microbial competition for available PO_4^{3-} (or other inorganic nutrients) is, however, reliant on a variety of interacting physical–chemical and biotic factors, including photosynthetically active radiation (PAR) availability, temperature, pH, ionic properties, concentrations and supply rates of growth-limiting nutrients relative to microbial uptake affinities, intracellular storage capabilities, buoyancy alteration, nutrient exchange–recycling characteristics of cyanobacterial–microbial associations and nutrient regeneration by micro- and macrozooplankton and fish communities.

In an autoradiographic study designed to examine potential competitive interactions between planktic bacteria and cyanobacteria (*Anabaena, Microcystis*) for growth-limiting concentrations of PO_4^{3-} in eutrophic Heart Lake, Ontario, Paerl & Lean (1976) showed that bacteria were indeed capable of more effectively utilizing ambient PO_4^{3-} per unit cell biomass. However, when results were normalized for total biomass, cyanobacterial populations clearly dominated with respect to PO_4^{3-} incorporation. Parallel studies of cellular PO_4^{3-} storage (as polyphosphates) capabilities concluded that these cyanobacterial genera exhibited highly effective means of storing PO_4^{3-}. In fact, subsequent P-starvation experiments conducted on similar cyanobacterial blooms (dominated by *Anabaena spiroides* Klebahn var. *crassa* Lemmermann) in Thompson Lake, Ontario (Shindler *et al.* 1981) demonstrated that natural cyanobacterial populations, while undergoing intense competition for PO_4^{3-} uptake with planktic bacteria, were able to maintain active photosynthetic growth and N_2 fixation for up to 10 days following initial PO_4^{3-} starvation.

Periodic vertical migration into phosphorus-rich hypolimnia in eutrophic lakes allows for ready access to this nutrient. Bacteria, which may effectively compete with cyanobacteria in PAR-rich epilimnia, are not capable of extensive short-term vertical migrations into meta- or hypolimnia. As a result, cyanobacteria need not directly compete with bacteria for epilimnetic PO_4^{3-} supplies, because periodic migration into P-rich hypolimnia followed by storage of assimilated PO_4^{3-} (as polyphosphates) assures long-term access to phosphorus.

In conclusion, examinations and evaluations of recent freshwater and marine studies reveal that cyanobacterial–bacterial and cyanobacterial–protozoan associations may yield more mutualistic (as opposed to antagonistic) characteristics than previously assumed. Such associations appear to function in

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a positive synergistic manner throughout various stages of bloom development and proliferation. It is therefore cautioned that bloom eradication and mitigation approaches utilizing biological control measures based on bacterial lysis and protozoan/metazoan grazing of cyanobacteria require careful and critical evaluation prior to deployment on the natural community and ecosystem level. Such measures may in fact yield water quality and trophic results contrary to those desired, in both the short and long term.

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