BDCP 1505

From: Daniels, Sharon <sdaniels@ci.antioch.ca.us>
Sent: Wednesday, July 23, 2014 4:32 PM
To: 'BDCP.Comments@noaa.gov'
Subject: City of Antioch Comments on DBCP Draft EIR/EIS

On July 17, 2014 the City of Antioch submitted its Comments on the Draft Bay Delta Conservation Plan and Associated Draft EIR/EIS. The original cover letter and Appendices A-D were sent to you via regular mail. To view the letter and Appendices, please click the link below:

http://www.ci.antioch.ca.us/CityGov/PublicWorks/Delta-Issues.htm

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BDCP1505

APPENDICES A, B, C & D

to the

City of Antioch Comments on the Draft Bay Delta Conservation Plan (BDCP) and Associated Draft Environmental Impact Report and Environmental Impact Statement (EIR/EIS)

July 17, 2014

BDCP1505

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APPENDIX A

Technical Comments on the BDCP and Associated EIR/EIS Letter Prepared by Flow Science Incorporated

BDCP1505

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July 17, 2014

BDCP Comments
Ryan Wulff, NMFS
650 Capitol Mall, Suite 5-100
Sacramento, CA 95814

Via email: BDCP.Comments@noaa.gov

Subject: Appendix A to the City of Antioch Comment Letter
Technical comments on the Draft Bay Delta Conservation Plan (BDCP) and associated Draft Environmental Impact Report and Environmental Impact Statement (EIR/EIS)

Dear Mr. Wulff:

On behalf of the City of Antioch (the City), Flow Science is pleased to submit comments on the Bay-Delta Conservation Plan (BDCP) and Associated Environmental Impact Report/Environmental Impact Statement (EIR/EIS) during the public review period. These technical comments constitute **Appendix A** to the City's comment letter.

SUMMARY OF TECHNICAL COMMENTS

Flow Science has reviewed the BDCP Plan and EIR/EIS, and has evaluated the impacts that are likely to occur at the City of Antioch. Flow Science's key findings regarding the technical analysis presented in the EIR/EIS can be summarized as follows:

- The baseline condition ("Existing Conditions") scenario used to evaluate project impacts is flawed and inappropriate, and does not accurately represent current salinity conditions at Antioch. Use of an incorrect baseline conditions results in an understatement of the impacts of the BDCP Proposed Project.
- The BDCP Proposed Project will cause salinity at Antioch to increase significantly, and will significantly reduce the City's ability to use its intake to supply water within its service area. Contrary to assertions in the EIR/EIS, these impacts will result from the Proposed Project and not from sea level rise.

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- The BDCP Proposed Project assumes a change in water quality standards that has not yet happened and that would require State Water Board action. Given that historical, natural salinity in the western Delta was far lower than current levels, Antioch believes that changes in water quality standards would be inappropriate and detrimental to the health of the Delta.
- Because project operations have not been clearly defined, it is not possible to determine with any certainty the impacts of the Proposed Project.
- Mitigation for the significant impacts that are expected to occur at Antioch is not detailed within the EIR/EIS. The EIR/EIS finds that water quality impacts are "considered to remain significant and unavoidable." Despite statements in the EIR/EIS that the assistance provided by BDCP proponents is intended to "fully offset" increased treatment or delivery costs, the BDCP and EIR/EIS suggest no concrete measures that will be implemented to accomplish this.

Additional detail is provided below and in **Appendix C** to the City's comment letter.

BACKGROUND

As detailed in the City's comment letter, the City is located along the San Joaquin River in the western portion of the Sacramento and San Joaquin River Delta (Delta). Since the 1860s, Antioch has obtained all or part of its freshwater supply directly from its intake on the San Joaquin River[1] pursuant to a pre-1914 appropriative water right with a priority of 1867.[2]

Contrary to incorrect statements contained in the EIR/EIS, Antioch continues to obtain much of its water supply from its own diversion facility.[3] Antioch has a substitute

[1] Much of the water in the western Delta (including the City's water supply) comes from the Sacramento River. Historically, significant amounts of Sacramento River water flowed into the San Joaquin River east of Antioch at Three Mile and Georgiana Sloughs. Sacramento River water also reaches Antioch where the river merges with the San Joaquin River just west of the City.

[2] Antioch has vested pre-1914 water rights to water from the San Joaquin River as well as to the tributary flow of the Sacramento River via Georgiana and Three Mile Sloughs. This was determined as a matter of law by the California Supreme Court in the case of Town of Antioch v. Williams Irrigation District et al. (1922) 188 Cal. 451,455.

[3] The City of Antioch uses water from its intake as its main source of supply when salinity at the intake is below specified thresholds. Although the EIR/EIS states that Antioch's intake is "seasonal" and used "infrequently" (EIR/EIS Chapter 8 at p.8-185, lines 13-14), this is not true.

water agreement with the Department of Water Resources (DWR) that partially compensates the City for water purchases from Contra Costa Water District (CCWD). That agreement presently has a 15-year term, which will end at approximately the same time the BDCP is anticipated to begin operations.[4]

Because of its position in the western Delta and its legacy as a fresh water Delta town, the City is also particularly concerned with the ecological health of the Delta, the City's long-term viability as a recreational destination, and the potential significant adverse impacts of urban decay resulting from the BDCP.

DETAILED TECHNICAL COMMENTS RELATED TO WATER QUALITY IMPACTS

The baseline condition used to evaluate the BDCP Proposed Project is flawed and inappropriate. A modeling study was used to delineate the potential effects of the proposed BDCP project on salinity at locations throughout the Delta, including at Antioch's drinking water intake in the western Delta. Our review of the impacts to water quality (Chapter 8 of the EIR/EIS) indicates that two different baseline scenarios were used—the "Existing Conditions" scenario was used to represent baseline for the CEQA evaluation, and the "No Action Alternative" (NAA) was used to represent baseline for the NEPA evaluation. The main differences between these two scenarios appear to be (a) whether Delta outflows are managed to achieve the Fall X2 provision (hereafter referred to as "Fall X2") of the 2008 US Fish and Wildlife Service Biological Opinion (the "2008 BiOp"); and (b) whether the impacts of sea level rise are included. The Existing Conditions scenario does not include Fall X2 or sea level rise, while the No Action Alternative includes both. As detailed below, failing to include Fall X2 in the Existing Conditions scenario makes the baseline condition appear to be more saline than it actually is, so that the potential impacts of the BDCP appear to be significantly smaller than they would with an appropriate baseline.

As noted in prior comments submitted by the City and its consultants to the BDCP and to the State Water Resources Control Board (SWRCB)[5], the western Delta historically exhibited freshwater conditions. In 1928, "Carquinez Strait marked

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[4] On October 29, 2013, the term of the agreement between the State of California and the City of Antioch was extended through September 30, 2028.

[5] See **Appendix D** to the City's comment letter.

approximately the boundary between salt and fresh water under natural conditions," and "[p]rior to diversions for irrigation, Suisun Bay was brackish in the late summer and salt water may have penetrated as far as Antioch, but only for a few days at a time in years of lowest run-off"[6]. Such conditions no longer exist, as saline water is now common at Antioch. However, historic salinity conditions should be considered when assessing the impacts of proposed actions on the fish and wildlife that live in the Delta and that were historically adapted to fresher conditions.

The City asserts that Fall X2 should be included in both baseline conditions, including the Existing Conditions. Legally, the 2008 BiOp represents the requirement to operate to achieve Fall X2, and predates the NOP for the BDCP. Technically, and as discussed further below and in **Appendix C** to the City's comments, simulated water quality is more representative of measured (historic) data with the inclusion of Fall X2.

Antioch and its consultants have received from DWR modeling results[7] obtained from the Delta Simulation Model II (DSM2) model, which was used to simulate hydrodynamics and water quality throughout the Delta for a range of model scenarios. These model runs included two scenarios that were representative of "existing conditions." The "existing biological conditions 1" (EBC1) scenario included current sea levels but not Fall X2, while the "existing biological conditions 2" (EBC2) scenario included current sea levels and Fall X2. The March 2013 Revised Administrative Draft made use of both EBC1 and EBC2, while the current BDCP EIR/EIS utilizes only EBC1, which is renamed as the "Existing Conditions" scenario. Model results for the EBC2 scenario agree well with salinity measurements made near Antioch (see **Figure 1, Appendix C**), while the EBC1 scenario showed poor agreement, particularly in the fall of 1974, 1975, 1978, 1980, 1984, and 1986, or 6 out of the 17 years modeled. The plots of EBC1 shown in **Appendix C** are consistent with Figures 5C.A-104 through 5C.A.-107 of Attachment 5C.A to Appendix 5C of the Draft BDCP (confirming that EBC1 is the "Existing Conditions" scenario defined in the EIR/EIS), which show substantial increases in salinity in the western Delta in the fall of 1978, 1980, 1984, and 1986. These periods

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[6] Means, Thomas. "Salt Water Problem: San Francisco Bay and Delta of Sacramento and San Joaquin Rivers. San Francisco, CA: Thos. H. Means, Consulting Engineer - 1928. p. 57.

See also CCWD, 2010, 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; Technical Report WR10-001, available at http://www.ccwater.com/salinity/HistoricalSalinityReport-2010Feb.pdf.

[7] Flow Science Incorporated received modeling results from DWR via mailed hard-drives in January 2012, April 2013, and May 2013.

of higher salinity are not consistent with field measurements, further confirming that the omission of Fall X2 from the Existing Conditions scenario is not technically appropriate to represent the existing water quality in the Delta.

The data contained in Appendix 8G of the EIR/EIS show a significant difference in chloride concentrations in the San Joaquin River at Antioch between the Existing Conditions and the No Action Alternative (NAA) scenarios. Specifically, the average chloride concentrations are higher under the Existing Conditions, particularly in the late summer and fall. Table C1-1 shows that the mean chloride concentration is higher under the Existing Conditions scenario than under the NAA scenario by 447 mg/l and 382 mg/l in October and November, respectively. Because there are two significant differences between these scenarios—i.e., Fall X2 and sea level rise—the data do not indicate which of these factors is responsible for the differences in simulated salinity levels.

Generally, the impact of a project is determined by comparing the Proposed Project scenario and the Existing Conditions scenario, and the impacts of non-project factors are determined by comparing the NAA scenario and the Existing Condition scenario. Here, we cannot make the latter comparison, as the Existing Conditions and No Action Alternative scenarios are not on common ground regarding Fall X2. In order to determine the impacts of sea level rise alone, the NAA scenario must be compared to the EBC2 scenario, since both the NAA scenario and the EBC2 scenario include operations to meet Fall X2. Once the impact of sea level rise has been determined, the impacts of BDCP could be more accurately delineated.

While the EBC2 scenario was not provided in the December 9, 2013 DRAFT BDCP and EIR/EIS, it was previously provided to Flow Science by DWR. **Figure 3** of **Appendix C** shows that, from September through November of above normal, below normal, and wet years, the availability of usable water at Antioch is higher under the EBC2 scenario than under the Existing Conditions (EBC1) and NAA scenarios; this is expected, as EBC2 includes Fall X2. These same plots also show that usability is greater under the NAA than under Existing Conditions (EBC1). Thus, the exclusion of Fall X2 (Existing Conditions) decreases usability more than sea level rise (captured in the NAA) during the fall of above normal, below normal, and wet years. This comparison highlights the importance of Fall X2, and further supports that it should be included in the CEQA baseline scenario.

As the City has noted in prior comments on the BDCP process and in testimony to the SWRCB, salinity levels in the western Delta, including at Antioch's intake, will be

substantially higher if Fall X2 is not included in the Existing Conditions model runs. (See **Appendix D** to the City's comments.) The exclusion of Fall X2 from the Existing Conditions will increase the salinity simulated under this condition and thus downplay the impacts of the BDCP Proposed Project on salinity in the western Delta; in fact Table Cl-28 in Appendix 8G of the EIR/EIS shows that annual mean chloride concentrations decrease relative to Existing Conditions (i.e., EBC1) for all Operational Scenarios, which is misleading—relative to EBC2, mean annual usability decreases at Antioch for all year types under Scenarios Alt4-H1 and Alt4-H2. Ultimately, the use of the Existing Conditions scenario without Fall X2 would be neither legally nor technically appropriate, and misrepresents the anticipated impacts of the BDCP project.

In summary, Flow Science's analysis shows that the "Existing Conditions" scenario used to represent baseline conditions in the EIR/EIS does not accurately represent current conditions because it does not include Fall X2. Even though model scenario EBC2, which does include Fall X2, was used in prior drafts of the EIR/EIS and was made available to Flow Science and others as early as 2012, it was not used in the CEQA analysis. Because the incorrect existing conditions baseline scenario was used in the CEQA analysis, impacts to the City of Antioch have been underestimated significantly.

Thus, Antioch requests that Fall X2 be included in all modeling scenarios used to describe baseline conditions.

Please note that, because the City asserts that the Existing Conditions scenario is an inappropriate baseline, the impacts of BDCP in this comment letter will be assessed compared to the EBC2 and the No Action Alternative scenarios.

The BDCP will cause salinity at Antioch to increase and will reduce the City's ability to use its intake significantly. Appendix 8G of the EIR/EIS shows the predicted impact to chloride concentrations in the San Joaquin River at Antioch, both in terms of the monthly and daily mean concentration and in terms of compliance with the Bay-Delta Water Quality Objective (250 mg/l as a daily average). However, these metrics do not describe Antioch's ability to use the water[8], as its ability depends only on the instantaneous chloride concentration and not on daily or monthly averages. Thus, the

[8] The 1968 Agreement defines "usable river water" as occurring when the "chloride ion content in the surface zone at slack current after daily higher high tide (HHT) is 250 parts per million [ppm] or less." Throughout these comments, "usable water" is the term applied to water with a chloride content of 250 ppm or less.

potential impacts described in Appendix 8G significantly underestimate the impacts to Antioch.

To determine the actual impacts to the City's municipal water supply, Antioch and its consultants evaluated salinity impacts using DSM2 model results obtained from DWR. Specifically, Flow Science assessed the instantaneous salinity concentration (i.e., model results at 15-minute intervals) to determine how the BDCP Proposed Project is predicted to impact the usability of water at the City's intake. Flow Science compared the percent of time that water can be diverted under the worst-case project conditions (Scenario Alt4-H1) to the EBC2 scenario and to the No Action Alternative. (As noted above, the EBC2 scenario is most representative of existing conditions and should be used as the baseline for CEQA analysis of the BDCP project.)

The increased salinity in the western Delta that is predicted to occur due to the BDCP Proposed Project will significantly impact Antioch's ability to use water. However, the severity of this impact is concealed in the EIR/EIS because model results are presented in the form of annual, monthly and daily averages. For example, Table Cl-28 of the EIR/EIS shows that, under worst-case operations and evaluated as a long-term average, compliance with the chloride objective will decrease by only 2% (the difference between Scenario Alt4-H1 and the No Action Alternative). However, as demonstrated below and in **Appendix C** to the City's comments, the decrease in usable water will be far more severe. On an annual basis, the impacts to usability at Antioch are significant. Over the 17 years modeled, the availability of usable water decreased by 6%, or 9.2 days per year on average as a result of BDCP Proposed Project Scenario Alt4-H1. The availability of usable water is expected to decrease even more during wet years; in these years, usability could decrease by 12%, or over 28 days per year. Importantly, and as detailed in **Appendix C**, these changes result from the BDCP Proposed Project alone, not from sea level rise.

The BDCP Proposed Project is simulated to have the most significant impacts during the fall months, where on average the availability of usable water at Antioch may decrease by up to 64% (**Appendix C**) with Operational Scenario Alt4-H1 relative to the No Action Alternative (i.e., without the impacts of non-project factors such as sea level rise). Evaluating results by month indicates potentially even greater effects. Under all year types, usability during September is simulated to decrease from 5.3 days to 0.8 days, an 85% decrease. The largest loss of usable days is predicted to occur in October, and totals 6.6 days on average.

Breaking the results down by year type also shows significant impacts during the fall months. For example, excluding wet years, the availability of usable water under Operational Scenario H1 from September through November is predicted to decrease from 13.1 to 1.7 days[9], a loss of 11.4 days relative to the NAA; in non-wet years, there are only 0.3 to 3 days of usability in the fall under Proposed Operational Scenario Alt4-H1. The percent difference is most significant during critical and dry years, at 97% and 93% of usable days lost, respectively, in the September through November time period (**Table 4, Appendix C**). The most significant losses are simulated to occur during dry and wet years, when 23.0 and 22.7 days of usable water, respectively, are anticipated to be lost over this three-month period. Thus, the impacts of the BDCP Proposed Project to the City of Antioch, especially during the fall, are much greater than reported in the EIR/EIS.

The modeling performed to assess the water quality impacts of BDCP assumes full implementation of restoration measures—that is, 65,000 acres of tidal marsh restoration. This amount of tidal restoration is expected to occur in year 2060 and beyond, if at all. None of the model results characterizes the potential impacts of restoration on salinity in the years prior to 2060. Because the tidal marsh restoration will be phased, there will be several intermediate conditions during which the hydrodynamics may differ significantly from both the current conditions and the conditions under full tidal marsh restoration. Depending on the design and location of restoration efforts, and the sequence in which restoration is conducted, the volume of water that "sloshes" into and out of the Delta on every tidal cycle may be increased, thus increasing salinity in the western Delta.

Although the City's primary concern is with salinity at its intake, the City would like to incorporate by reference the comments of others that suggest that concentrations of other water quality constituents (e.g., bromide, mercury) may increase as a result of implementation of the Proposed Project. The City is concerned with any degradation of water quality at its intake. In addition, changes in water quality may affect the treatment options available to the City.

[9] These numbers are the arithmetic averages of the non-wet years (i.e., critical, dry, above and below normal years) from **Table 4, Appendix C**

The BDCP Proposed Project assumes a change in water quality standards that has not yet happened and that would require State Water Board action. One aspect of the Proposed Project (represented by Scenarios H1 through H4) is the proposed change of "water quality requirements criteria" in the Delta. The Draft BDCP document states that the BDCP operations "include water operations in accordance with State Water Board D-1641 related to north Delta and western Delta agricultural and municipal and industrial requirements, except that the Sacramento River compliance point for the agreement with the North Delta Water Agency would be moved from Emmaton to Threemile Slough" (p. 3-188, emphasis added). Moving the compliance point landward by about 2.5 miles (the approximate distance from Emmaton to Threemile Slough), as proposed, would allow salinity in the western Delta to increase and thus would further impair Antioch's ability to use the water for municipal purposes. Further, the 2008 BiOps include requirements to meet Fall X2 under certain conditions, as described above, and two of the operational scenarios (Scenarios Alt4-H1 and Alt4-H2) eliminate the Fall X2 requirement; eliminating the Fall X2 requirement would also allow salinity to increase still farther in the western Delta.

Given the fact that historical, natural salinity in the western Delta has been far lower than current levels, and given the serious impacts that may occur to Antioch's water supply and to the ecosystem if salinity is allowed to increase further, Antioch asserts that such a change in water quality standards would be inappropriate. For this reason, the BDCP EIR/EIS should be amended to include scenarios that do not involve changes in water quality standards.

Because project operations have not been clearly defined, it is not possible to determine the impacts of the Proposed Project. Under the Proposed Project as described in the Plan and EIR/EIS, Delta outflow requirements in the spring and fall would be determined using a decision tree. There are four possible combinations of spring and fall outflow criteria, which define four operational scenarios (H1 through H4). Model runs were performed for each of these scenarios, as any of the four may be used each year. However, the decision tree that describes Operational Scenario H—specifically, what "triggers" each operational scenario—has not been defined in the Draft BDCP nor in the EIR/EIS and is "subject to a new determination by the fish and wildlife agencies" (p 3-207). Regarding spring outflows, the EIR/EIS states that "uncertainty exists regarding the mechanism through which higher Delta outflow improves the production and survival of early life stages of longfin smelt. Results of [future] investigations, including those directly related to the decision-tree process, will continue

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to be revealed and considered in the coming years" (p 3-208). However, neither the future studies nor their potential outcomes are discussed.

Regarding fall outflows, the EIR/EIS presents two hypotheses: first, that the fall habitat objective will be accomplished by providing flows necessary to position X2 in or near Suisun Bay in wet years; alternatively, that the new shallow-water habitat areas created through restoration of tidal communities (CM4) could accomplish this objective with lower outflows during the fall. Additional "scientific research to test each of these hypotheses will be conducted before initial operations of the north Delta facility" (p 3-208). Ultimately, neither the spring nor the fall portions of the outflow decision tree have been determined for the proposed BDCP project; thus, the potential impacts of the project cannot be determined with confidence.

Mitigation for water impacts is not provided. Chapter 8 of the EIR/EIS proposes mitigation measures for each foreseeable impact. For chloride (a surrogate for salinity), however, the proposed mitigation strategy consists entirely of additional study, with actions to be taken if identified. Because salinity in the western Delta originates primarily from the ocean, with salty water brought into the estuary by tidal action, Antioch and its consultants know of no such actions that would directly mitigate the impacts of the project on salinity in the western Delta, and none are identified in the EIR/EIS. In fact, the EIR/EIS states that, "because the effectiveness of [Mitigation Measure WQ-7] to result in feasible measures for reducing water quality effects is uncertain, this impact is considered to remain significant and unavoidable" (p, 8-429, emphasis added).

At the same time, and contrary to assertions that impacts are significant and unavoidable, the EIR/EIS expresses BDCP proponents' commitment to "assisting in-Delta municipal, industrial, and agricultural water purveyors that will be subject to significant water quality effects … The assistance provided by the BDCP proponents is intended to fully offset any increased treatment or delivery costs attributable to CM1" (p. 3B-42, emphasis added). For municipal users, the proposed assistance includes providing funding assistance to acquire alternative in-basin water supplies, storage, conjunctive uses, or develop water transfers; develop water supply connections to SWP facilities or BDCP intertie; or develop demand management and/or conservation/recycling projects to extend available water supplies.

However, the methods to "fully offset" any water quality impacts as a result of CM1 may require changes to contracts already in place between DWR and municipal

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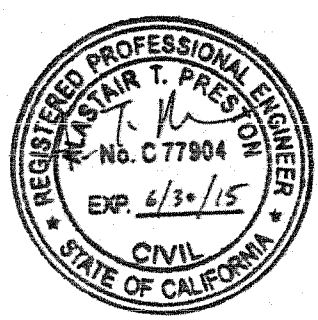
agencies. For example, California Department of Water Resources (DWR) has agreement contract with the City in which it has agreed to reimburse the City for *only* one-third of the cost it incurs to import water when water quality at its diversion point is unusable, as specified by formulae contained in the agreement. The EIR/EIS does not reference this contract, nor how it will distinguish BDCP CM1 impacts to water quality (for which the City should be fully compensated) from other instances of water quality degradation (for which the City should be reimbursed one-third, per the Antioch-DWR contract).

Antioch requests that BDCP proponents specify how they intend to identify and to fully offset the impacts of BDCP CM1 in a manner that is fair and just to all parties.

* * *

Please contact me at (626) 304-1134 or al@flowscience.com if you have any questions regarding these comments. We appreciate the opportunity to submit these comments, and we look forward to seeing these comments addressed in the final EIR/EIS for the BDCP.

Sincerely,



Al Preston, Ph.D., P.E.
Project Engineer

Reviewed by:

E. John List, Ph.D., P.E.
Principal

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APPENDIX B

Legal Comments Letter
Prepared by Matthew Emrick

BDCP1505

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July 14, 2014

BDCP Comments
Ryan Wulff, NMFS
650 Capitol Mall, Suite 5-100
Sacramento, CA 95814

Via email: BDCP.Comments@noaa.gov
Le
Subject: **Appendix B** to the City of Antioch's BDCP comment letter

Dear Mr. Wulff:

I am submitting the following comments on the Bay-Delta Conservation Plan (BDCP), the Implementing Agreement, and Associated Environmental Impact Report/Environmental Impact Statement (EIR/EIS) on behalf of the City of Antioch (the City) to highlight further certain legal issues with the BDCP and its EIR/EIS as well as with the Implementing Agreement (referred to cumulatively as the "BDCP").[1] In reviewing the following comments, it must be considered that Antioch has adjudicated pre-1914 appropriative water rights with a priority from at least 1867. Antioch was able to use its water rights prior to the 1920's year-round and 208 to 225 days or more a year on average since the 1930's.

The BDCP Fails to Adequately Address and Analyze Impacts to Downstream Water Rights Holders Such As Antioch: As discussed in more detail in Antioch's Appendix A of its BDCP Comments, the BDCP will adversely impact the City's water rights and water supply by reducing Delta outflow and increasing salinity to the point that the City's ability to divert water at all will be critically limited. Antioch's water rights are senior in priority to those to be

1 The comments in this letter are based in part on the technical comment on BDCP modeling and water quality impacts set forth in Appendix A to Antioch's BDCP comments.

diverted pursuant to the BDCP. And yet, the EIR/EIS fails to adequately analyze the BDCPs impacts to the City's water rights or to propose any mitigation.

In fact, as noted in Antioch's Appendix A of its BDCP Comments, the EIR/EIS states that Antioch only infrequently uses its water rights, which is an absolutely false statement. As noted above, the City pumps potable water from the Delta every day when it is not too saline to do so, which has been approximately 208 to 225 days a year since the 1930s.[2] The EIR/EIS also fails to properly recognize that the source of Antioch's water supply includes the tributary flow of the Sacramento River via Georgiana and Three Mile Sloughs. Without acknowledging the correct facts and without understanding the nature and scope of the City's water rights, it is simply not possible for the EIR/EIS to have adequately analyzed the impacts of BDCP operations on the City's water rights and water supply.

CEQA (e.g. *San Joaquin Raptor Rescue Center v. County of Merced* (2007) 149 Cal.App.4th 655) and Water Code Section 1702 (as well as the law of water right priority) require that the BDCP properly analyze project impacts (flow, water quality) on water and water rights downstream of the proposed new diversions. Further, the law of water rights priority (*City of Barstow v. Mojave Water Agency* (2000) 23 Cal.4th 1224) and section 1702 specifically require that any adverse impacts on senior water rights be mitigated.[3] The EIR/EIS fails to meet these requirements. As noted, although EIR affects analysis indicates increased salinity and lower outflow downstream of the project, the EIR fails to adequately recognize Antioch's water rights, fails to adequately analyze the impacts to such rights, and as noted above, incorrectly concludes that the City only infrequently uses its rights. Despite potential significant adverse impacts to water quality, the EIR/EIS fails to provide any mitigation measures to protect Antioch's water rights which supply water to over a 100,000 people.

Additionally, neither the BDCP or the BDCP Implementing Agreement ("IA") provide any provisions to ensure that the BDCP and its operations will not adversely impact senior downstream water rights such as Antioch's. The Decision Tree process only requires outflow criteria to satisfy certain biological objectives. While the City acknowledges that a goal of the BDCP and the IA is to protect covered species, this goal does not excuse or immunize the BDCP and its participants and beneficiaries from complying with other provisions of law. As noted, the EIR/EIS needs to properly analyze impacts to in-Delta water rights and propose full mitigation of

2 Prior to the early 1930s and the advent of significant upstream diversions on both the Sacramento and San Joaquin Rivers, the City could pump potable water year around every year except in the most severe drought years.

3 Diverting water out of the Delta for junior water rights used primarily for agricultural purposes in a manner that will adversely impact senior domestic water rights and public trust purposes is unreasonable.

such impacts. The IA should describe the funding and operational requirements to implement such mitigation.

In sum, the EIR/EIS contains incorrect information and fails to properly analyze and mitigate the adverse project impacts to Antioch's senior water rights as required by law.

The BDCP Fails to Meet the Requirements of Delta Protection Act of 1959 and Water Code Section 85320: The EIR/EIS fails to explain how the project meets the requirements of the Delta Protection Act of 1959. In fact, the EIR/EIS indicates that the BDCP will not meet the objectives and requirements of the Act as discussed under the City's Technical Comments. As shown in Appendices A and C to the City's BDCP comment letter, the Proposed BDCP Project will increase salinity levels at Antioch's intake so significantly that the City's water rights and ability to divert its water supply will be substantially impacted – all without any proposed mitigation in the EIR/EIS, BDCP or in the Implementing Agreement.

Water Code sections 12200 et seq. (the Delta Protection Act) were intended in part to ensure that water exports from the Delta do not deprive in-Delta users of water necessary for their beneficial uses and for salinity control. A similar water availability requirement for the BDCP is provided under Water Code section 85320(b)(2)(A). The EIR/EIS as presently proposed, however, fails to adequately analyze the amount water available for export that would not result in adverse impacts to in-Delta uses – especially to in-Delta water rights with higher priority than the State Water Project (SWP) and Central Valley Project (CVP) export projects.

Although Antioch and Department of Water Resources (DWR) have an agreement for impacts to its water quantity and quality from the existing State Water Project, that Agreement has a remaining term of less than 15 years and is not based on the projected additional adverse impacts from the BDCP. Further, the projected impacts from the BDCP will continue for a minimum of 50 years. In addition, the Agreement between Antioch and DWR does not mitigate whatsoever for impacts from CVP operations.

Again, both the BDCP and the IA fail to provide any specific provisions as to how operation of the BDCP will be conducted to comply with the requirements of the Delta Protection Act (or Water Code section 85320(b)(2)(A)). In fact, the IA appears to authorize BDCP operations to violate the provisions of the Delta Protection Act and to immunize BDCP participants from any future regulatory liability by limiting the amount of water required for future mitigation or compliance with the Act. The EIR/EIS should identify all impacted downstream beneficial uses of water and analyze the impacts on such uses and provide specific

mitigations. The IA should describe how the mitigation measures will be properly funded and implemented.[4]

The EIR/EIS Fails to Adequately Address Impacts to Recreation and Public Trust Resources at Antioch: As presently proposed, the BDCP will result in years of construction impacts that will adversely affect in-Delta recreation including preventing and limiting recreational access to certain areas within the Delta. Further, the BDCP will permanently increase salinity (and other water quality related constituents) and reduce outflow in the western Delta and specifically at Antioch.

Antioch's unique historic and cultural legacy within the Delta has been as a freshwater location for well over 150 years. Antioch is known as the gateway to the western Delta for its freshwater location and recreational opportunities. A portion of Antioch's economy is dependent on freshwater boating, recreation, and fishing. The City's operates a municipal marina that is related to certain commercial uses and activities in the City. Many people have chosen to buy or rent homes in Antioch specifically because of the proximity to these freshwater boating, recreation and fishing activities or to simply to enjoy a lifestyle near a freshwater river environment.

While the EIR/EIS recognizes certain potential short-term impacts of construction on recreation and attempts to mitigate such impacts, the EIR/EIS fails to adequately address the *long-term* impacts of the BDCP on recreation, boating, and fishing at Antioch and provides no mitigation for such long-term impacts. In fact, the EIR/EIS indicates that impacts to recreational boating could be non-existent in the long-term. Given that the effects analysis indicates higher salinity and lower outflow in the western Delta, however, such a conclusion would appear contrary to the BDCP's own effects analysis. Increased salinity will impact fish species and fishing opportunities; boating preferences; and recreation (e.g. waterskiing, wakeboarding).

Further, the EIR/EIS fails to address any impacts to public trust resources at Antioch from higher salinity such as impacts to aesthetics (from freshwater river to tidal marsh), aquatic plants and wildlife (Tule islands), and navigation (decreased outflow, increased salinity). Without acknowledging such potential impacts, it is not possible to adequately analyze and potentially mitigate any impacts

Finally, the IA fails to provide any operating procedures or obligations to specifically

4 It is significant to note that earlier versions of the BDCP had mitigation built into the project in the form of relocating impacted downstream diversions at sole cost to the BDCP.

protect or mitigate in-delta recreational and cultural resources or non-covered public trust uses (e.g. navigation, fishing, boating) from projected operational impacts – either short term or long term. Since the IA is the primary operational document, it appears that the BDCP does not intend to mitigate either the long-term adverse impacts to in-Delta recreation and non BDCP-covered public trust resources.

In sum, the EIR/EIS and its associated effects analysis indicate increased salinity levels at Antioch, and yet any analysis of the physical impacts of this condition on recreation and public trust resources within the EIR/EIS are inadequate.

The EIR/EIS Fails to Adequately Analyze and Mitigate Potential Urban Decay Impacts: As discussed above, the BDCP will cause significant changes to the physical environment at Antioch – a City of over 100,000 people and the major City downstream of the proposed project in the western Delta. The EIR/EIS acknowledges certain potential impacts to in-Delta communities including but not limited to declining property values, declining economic stability in communities relying on recreation, and potential abandonment of structures and buildings (especially those near proposed construction). As noted above, the EIR/EIS also acknowledges potential short-term impacts to in-Delta recreation. And yet, there is almost no analysis within the EIR/EIS of any potential urban decay impacts within specified in-Delta communities and none with respect to Antioch.

When there is evidence that adverse effects caused by a project could result in a reasonably foreseeable indirect environmental impacts such as urban decay or deterioration (as here), then the CEQA lead agency is obligated to analyze these indirect environmental impacts. (*Anderson First Coalition v. City of Anderson* (2005) 130 Cal.App.4th 1173, 1182). In the present case, the EIR/EIS indicates potential significant changes in the environment within the western Delta, significant changes to the City's water supply, and acknowledges further potential physical impacts to local communities as noted above. The EIR/EIS, however, fails to analyze the potential for urban decay impacts within Delta communities including Antioch. And since protection and preservation of in-delta cultural resources is a requirement of the Delta Reform Act, the BDCP is legally required to mitigate potential adverse impacts.

The BDCP Fails to Comply with the Co-Equal Goals of the Delta Reform Act of 2009: Public Resource Code section 29702 sets forth the dual/co-equal goals of providing a more reliable water supply and "protecting, restoring, and enhancing the Delta ecosystem." Section 29702 provides further that achieving the co-equal goals shall include protecting and enhancing the "unique cultural, recreational, natural resource" values of the Delta. The BDCP

fails to meet the co-equal goals as the requirements of section 29702 are applied to Antioch and the western Delta. As Antioch's comments indicate throughout this letter, the physical environment, the reliability of Antioch's water supply, and the unique cultural heritage of Antioch will all be adversely impacted by the BDCP. The Delta Reform Act's co-equal goals are legal requirements on the BDCP that, put simply, require the BDCP to improve water quality and supply reliability within the Delta – or at a minimum to not further degrade water quality and the physical environment at Antioch.

The EIR/EIS fails to provide any adequate mitigation measures to ensure the co-equal goals will be met at Antioch or the western Delta other than vague allusions and references to future undefined mitigation at some future underdetermined time. Without full mitigation, the BDCP does not meet the specific requirements of the Delta Reform Act and is therefore invalid.

Further, the IA fails to provide any operational provisions or obligations to ensure that the co-equal goals are met during the course of the 50 year BDCP project term. In fact, the IA appears to assume that the co-equal goals will be met via the operation and implementation of the BDCP alone providing no assurances for in-delta water supply reliability. However, the Delta Reform Act does not limit water supply reliability to the BDCP alone and protection of in-delta water supply reliability is a critical component of complying with the co-equal goals. As noted throughout the City's comments, the BDCP effects analysis shows adverse impacts on downstream water supply reliability including Antioch's.

The EIR/EIS Fails to Adequately Address Mitigation of Impacts to Water Quality: As discussed above and throughout the accompanying documents, the BDCP is subject to certain legal requirements regarding the adverse impacts of water quality in the Delta. An EIR is inadequate if '[t]he success or failure of mitigation efforts . . . may largely depend upon management plans that have not yet been formulated, and have not been subject to analysis and review within the EIR.' (*San Joaquin Raptor Rescue Center v. County of Merced* (2007) 149 Cal.App.4th 645, 670.) 'A study conducted after approval of a project will inevitably have a diminished influence on decision making. Even if the study is subject to administrative approval, it is analogous to the sort of post hoc rationalization of agency actions that has been repeatedly condemned in decisions construing CEQA.' (*Communities for a Better Environment v. City of Richmond* (2010) 184 Cal.App.4th 70.)

In the present case, the BDCP is compelled to meet specific requirements of law, including but not limited to the Delta Reform Act, the Delta Protection Act, and Water Code section 1702. Because these are legal requirements, the BDCP must meet their requirements and this requires mitigation in cases where the project cannot comply with such legal requirements. The BDCP and the EIR/EIS fail to mitigate certain adverse impacts that result in the BDCP violating applicable law. As noted, the EIR/EIS instead attempts to propose future mitigation via consultation with impacted parties without setting forth any specifics, any standards, any time frame, any commitment of funds, or any performance criteria. This violates CEQA, and because the BDCP cannot override legal requirements, the failure to fully mitigate the adverse impacts to Antioch renders the entire project and the EIR/EIS invalid.

The EIR/EIS should analyze how water quality for downstream beneficial uses (including superior water rights such as Antioch's) will be protected and how the BDCP operating criteria will be able to meet both the water quality requirements for covered species and the legal requirements of downstream beneficial uses. The IA should describe how water quality requirements will be met by project operations and provide specific funding and operational criteria to adequately mitigate impacts to downstream beneficial uses. As presently written, the IA fails to do this and provides operational constrictions that could in fact potentially prevent or hinder any future mitigation after project approval (e.g. regulatory assurances; limitations on operational modifications; restrictions on dedication of future water for outflow; lack of input to governance structure from adversely impact non-BDCP parties, etc.).

The City appreciates the opportunity to submit these comments, and we look forward to seeing these comments addressed in the final EIR/EIS for the BDCP.

Sincerely,

Matthew Emrick
Special Counsel for the City of Antioch

BDCP1505

FLOW SCIENCE®

APPENDIX C

Analysis of Water Quality Impacts to Antioch – Evaluation of DSM2 modeling performed in support of the BDCP Proposed Project

FLOW SCIENCE®

As detailed in **Appendix A** to the City of Antioch's comments on the BDCP and associated EIR/EIS, Flow Science has conducted a detailed review of hydrodynamic and water quality modeling performed by DWR to characterize the potential impacts of the BDCP Proposed Project on water quality at the City of Antioch's drinking water intake. This document (**Appendix C** to the City's comments) provides additional detail regarding Flow Science's technical analysis.

DSM2 model results were provided by DWR to Flow Science via hard drive in January 2012, April 2013, and May 2013. Flow Science analyzed these model results in order to assess the effects of the proposed BDCP project on salinity and usability of water at Antioch. The following analyses indicate that a technically inappropriate simulation was used for the baseline condition in the ADEIR, and that the proposed BDCP project is simulated to have significant impacts on the ability of Antioch to draw and use water from the San Joaquin River.

DATA SOURCES

The DSM2 simulation results used in the analyses are listed in **Table 1**. Each simulation used hydrology from WY1975-WY1991. Results for electrical conductivity (EC) at Antioch (RSAN007) were extracted on a 15-minute basis and used for Flow Science's evaluation. In addition to the model results, measured conductivity data[1] were obtained for RSAN008, located approximately one mile from the Antioch intake.

Table 1: DSM2 Simulations

Name	Scenario	Sea Level Rise (SLR) (cm)	Fall X2	Notes
Existing Condition (EBC1)[1]	baseline	0	No	Referred to as EBC1 in April 2013 EIR/EIS.
EBC2[2]	baseline	0	Yes	Not used in December 2013 EIR/EIS.
NAA[2]	No Action	15[4], 45	Yes	
Alt4-H1[3]	Low Outflow	15[4], 45	No	Proposed project can operate within (and beyond) the space defined by these four scenarios.
Alt4-H2[3]	Spring High Outflow	15[4], 45	No	
Alt4-H3[3]	Evaluated Starting Ops.	15[4], 45	Yes	
Alt4-H4[3]	High Outflow	15[4], 45	Yes	

1. Received from DWR on May 6, 2013.

[1] http://www.water.ca.gov/iep/products/data/dssnotice.cfm (accessed 3/7/2012).

2. Received from DWR in January 2012.
3. Received from DWR in April 2013.
4. Results for SLR = 15 cm are not presented here.

ANALYSES

Baseline in EIR/EIS should incorporate Fall X2 provisions

The December 2013 EIR/EIS uses the "Existing Conditions" simulation for baseline purposes. As indicated in **Table 1,** the "Existing Conditions" simulation does not include Fall X2 provisions. By contrast, the "EBC2" simulation (a simulation used in the March 2013 Draft BDCP document, and received by Flow Science from DWR in January 2012) does include Fall X2.

The DSM2 modeling performed to evaluate water quality impacts of the proposed project simulated electrical conductivity (EC), which is a measure of salinity. **Figure 1** presents daily average simulated EC at Antioch for both Existing Conditions (Ex. Cond./EBC1) and EBC2, along with historical measured EC data. Simulation results were compared with historical measured EC. As shown in **Figure 1**, the exclusion of Fall X2 (i.e., the Ex. Cond./EBC1 simulation) results in EC at Antioch that is not representative of historical conditions. Specifically, salinity in the fall of 1974, 1975, 1978, 1980, 1984, and 1986 is substantially overestimated in simulation EBC1, when Fall X2 is excluded.

By contrast, the EBC2 simulation shows good agreement with measured EC at Antioch, indicating that the inclusion of Fall X2 into any baseline scenario is necessary in order to accurately represent current (pre-project) conditions at Antioch. In summary, the EBC2 scenario is the appropriate baseline model simulation for CEQA purposes, and EBC1 does not accurately represent current conditions and should not be used as the CEQA baseline for the BDCP project.

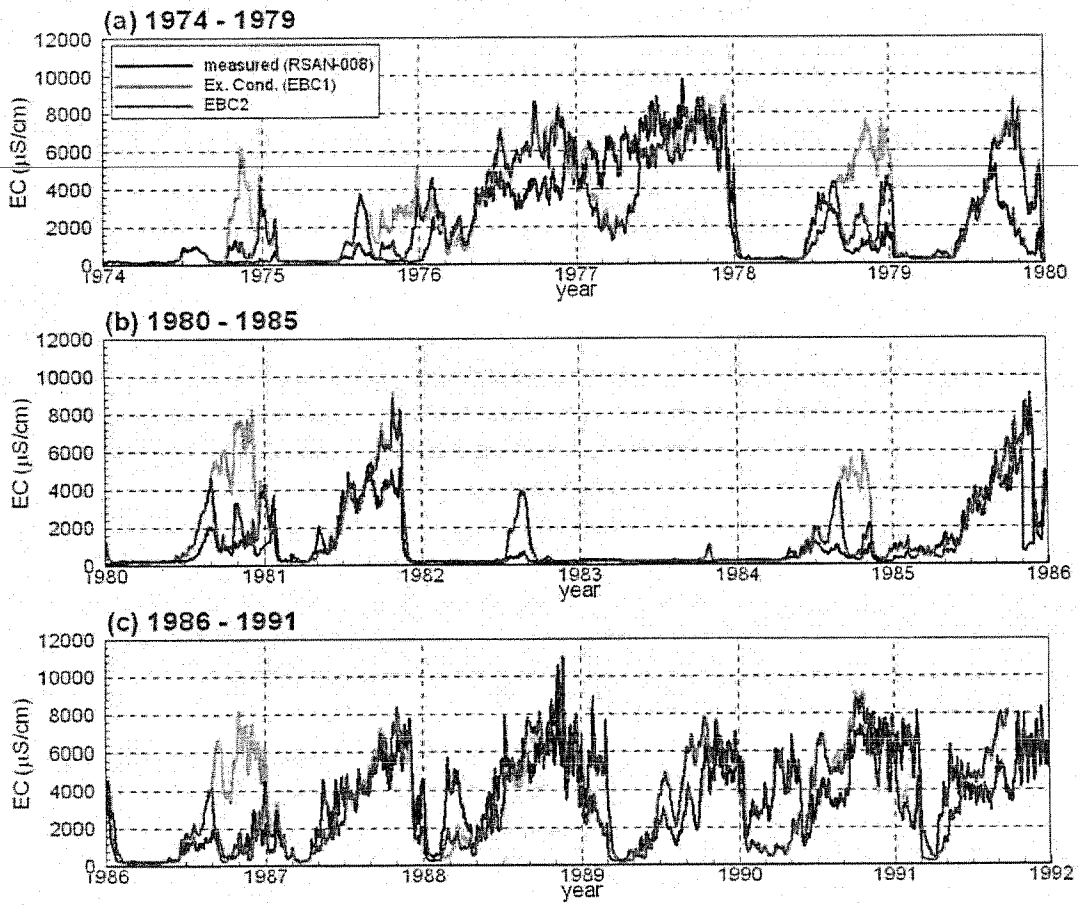

Figure 1. Measured and simulated daily average electrical conductivity (EC) at Antioch. Measured data are from station RSAN-008, located approximately one mile upstream from Antioch's intake. DSM2 simulations (EBC1 and EBC2) were provided by DWR.

BDCP Salinity Impacts at Antioch

In the December 2013 EIR/EIS, the preferred project is represented by the four Alt4 simulation scenarios listed in **Table 1**, with each scenario representing different operating regimes as determined by a "decision-tree" process that has yet to be explicitly defined. The H1 and H2 scenarios do not include Fall X2, whereas the H3 and H4 scenarios do include Fall X2 (**Table 1**).

To evaluate the anticipated impacts of the Proposed Project on salinity at Antioch, Flow Science plotted model results for salinity at Antioch using the EBC2 scenario, the NAA scenario, and the four Alternative 4 (Alt4) scenarios that represent the BDCP Proposed Project. Flow Science's evaluation focused on the EBC2 scenario (the most accurate representation of current conditions because it includes Fall X2), the NAA scenario (which includes both Fall X2 and anticipated sea level rise), and the Alt4 scenarios. The NAA scenario can be compared to the EBC2 scenario to examine the impact of sea level rise (SLR) alone on salinity at Antioch (i.e., without the BDCP Proposed Project). The BDCP Alt4 scenarios can then be compared to the NAA scenario to tease out the difference between increased salinity due to SLR and increased salinity due to the BDCP Proposed Project.

As shown below, the inclusion or exclusion of Fall X2 in the operating rules to be followed by the Proposed Project will have a substantial impact on the salinity at Antioch. DWR's model results indicate that the BDCP project may result in a substantially lower usability of water at Antioch, particularly in the fall months.

Figure 2 plots the percent of time that the salinity at Antioch is less than the usable threshold[2] in each month as computed from the DSM2 simulations for the simulation period 1975-1991[3]. Since the Ex. Cond. (EBC1) simulation is not an appropriate baseline (see above), the effect of sea level rise (SLR) was assessed by comparing the EBC2 and NAA simulations, and the effect of the proposed BDCP project (independent of SLR) was assessed by comparing the NAA and the four Alt4 scenario simulations.

Impact of Sea Level Rise. Comparison of the EBC2 simulation to the NAA simulation indicates that a SLR of 45 cm results in decreased usability in all months except July and October, when the usability under the NAA scenario is slightly higher than under the EBC2 scenario. As a long-term average over the simulation period, a SLR of 45 cm is predicted to result in a 15-day-per-year decrease in usability (i.e., Antioch

[2] Consistent with Antioch's agreement with DWR (first signed in 1968 and extended on October 29, 2013,), the usable threshold is 250 ppm as chloride (Cl^-), which corresponds to an EC of 976 µS/cm. This conversion was made using the relationship between chloride concentration and EC for "normal" years in Guivetchi (1986).

[3] Computed using the 15-minute DSM2 output at Antioch (RSAN007).

will be able to use their intakes 15 days less on average each year, see **Table 2**); as **Figure 2** shows, the decrease in usability is spread relatively uniformly over the year. The impact of sea level rise is most significant during dry years, when it accounts for over 26 days of usability lost, or a 19% decrease in usability.

Table 2. Annual usability at Antioch under EBC2 and the No Action Alternative for the entire simulation period and for different year types within the simulation period

Year Type	# of Usable Days Per Year Under EBC2	# of Usable Days Per Year Under NAA	Usable Days Lost Per Year	Percent Decrease
All Years	163.7	148.5	15.2	9%
Critical Years	63.1	55.6	7.5	12%
Dry Years	144.6	117.9	26.7	19%
Above & Below Normal Years	188.1	177.7	10.4	6%
Wet Years	264.8	248.5	16.3	6%

Impact of BDCP. Figure 2 also shows that, relative to both EBC2 and NAA, BDCP Scenario Alt4-H1 is predicted to result in a significant decrease in usability, particularly during the fall months. The average decrease in usability during the fall months, relative to the NAA, for the entire 17-year simulation period is presented in **Table 3**. On average during the September-November timeframe, simulation results anticipate that usability will decrease by 15.3 days. Simulated usability is almost completely lost during September, which corresponds to an 85% decrease. The largest predicted number of days lost (6.6 days) in one month occurs in October. Note that these impacts of the proposed BDCP project are due entirely to the project, as the effect of SLR has been accounted for by comparing results from Scenario Alt4-H1 to the NAA scenario, which incorporates SLR.

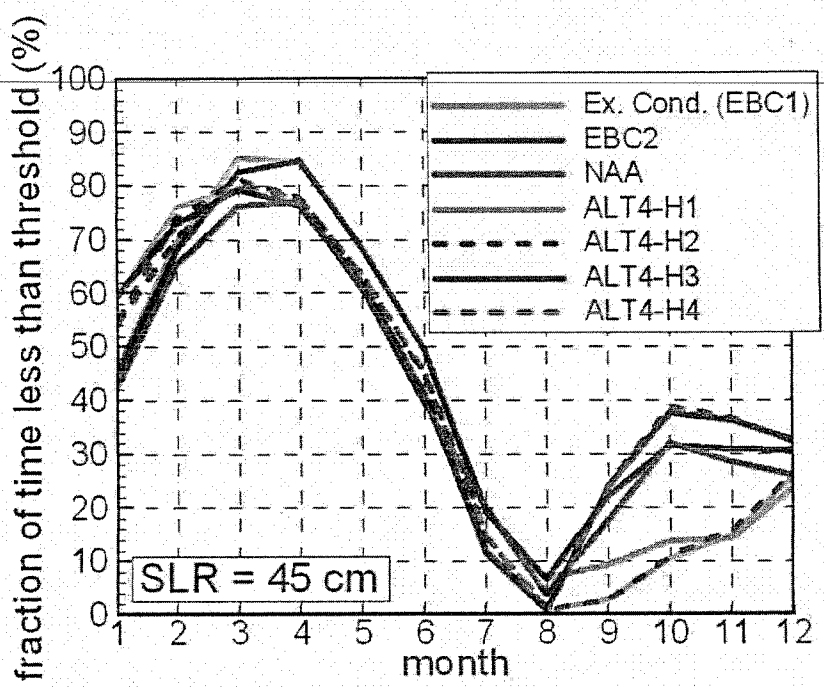

Figure 2. Percent of time water at Antioch's intake can be used for supply (i.e., when the simulated salinity is less than usable threshold at Antioch) by month as computed from DSM2 model results for the simulation period 1975-1991. SLR is zero for Ex. Cond. (EBC1) and EBC2, and 45 cm for all other simulations. Note that Fall X2 provisions are included in EBC2, NAA, Alt4-H3, and Alt4-H4.

Table 3. Decrease in usability at Antioch during the fall months simulated to occur as a result of implementation of the BDCP project (Scenario Alt4-H1)

Month	# of Usable Days/Year Under NAA	# of Usable Days/Year Under Alt4 (Operational Scenario H1)	Usable Days Lost/Year[1]	Percent Decrease[1]
September	5.3	0.8	4.5	85%
October	9.9	3.3	6.6	67%
November	8.5	4.4	4.1	48%
Sept-Nov	23.8	8.5	15.3	64%

[1]Results reflect changes resulting from BDCP project only, and not changes due to SLR. That is, BDCP project simulations with SLR = 45 cm were compared with NAA simulation, which also includes SLR = 45 cm.

Breaking the results down by year type (instead of presenting results in aggregated fashion) reveals that usability is almost completely lost during fall months of all year types except wet years. Also, the predicted salinity impacts, as expressed in terms of the number of days lost, are greatest during dry and wet years. These results are presented graphically in **Figure 3** and numerically in **Table 4**.

Figure 3 shows that usability under scenarios Alt4-H1 and Alt4-H2 during September through November is always less than 10%, and generally less than 5%, for all year types except for wet years. The number of usable days during the September-November simulation period (excluding wet years) ranges from 0.3 to 3 under Scenario Alt4-H1.

Figure 3 shows that the number of usable days during the fall months decreases significantly under Scenario Alt4-H1 compared the NAA, especially in dry and wet years. During dry and wet years, simulated usability decreases by 23 and 22.7 days in the fall, respectively. The largest percent decrease in usability occurs in critical and dry years, when usability decreases by 97% and 93%, respectively. These model results indicate that, in wet and dry year types, the City of Antioch would need to find alternative water supplies (because water at its intake would be unusable) for an additional 23 days in the fall months of each year, likely at significant cost.

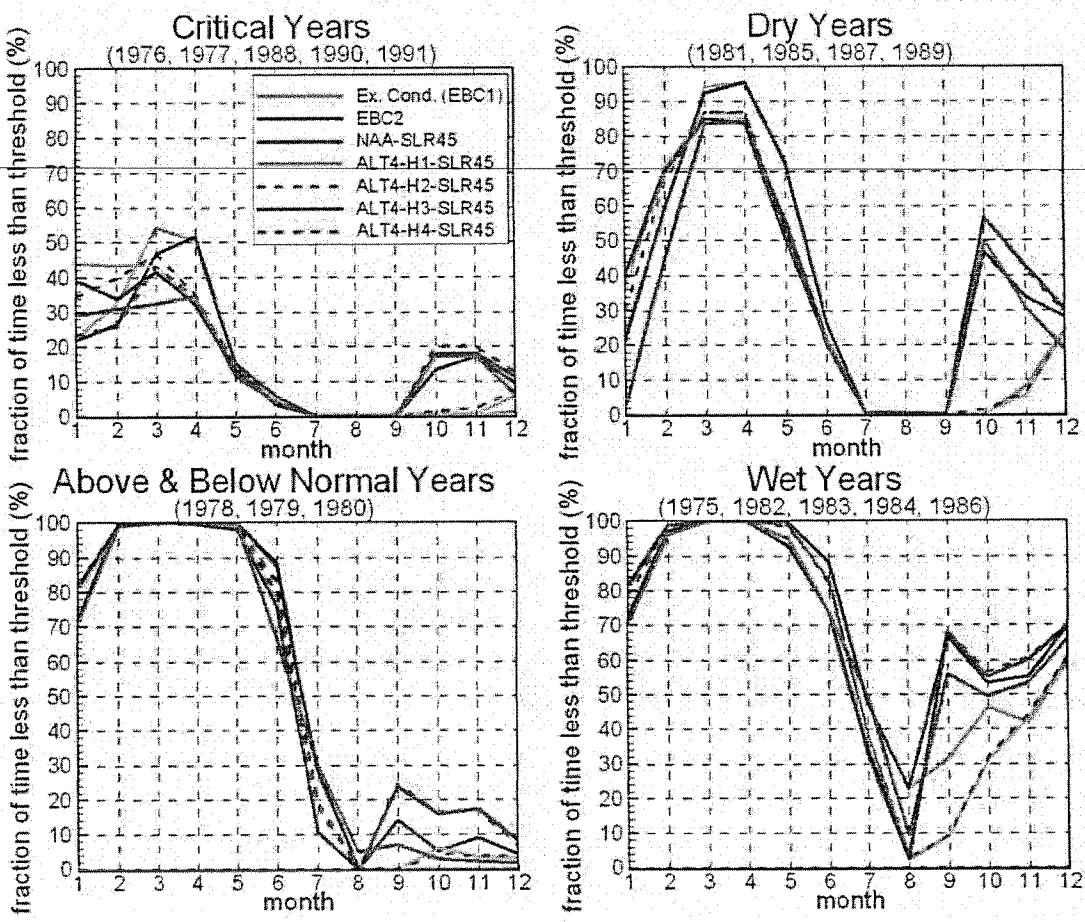

Figure 3. Percent of time water at Antioch's intake can be used for supply (i.e., when the simulated salinity is less than usable threshold at Antioch) by month and by year type as computed from DSM2 model results. SLR is zero for Ex. Cond. (EBC1) and EBC2, and 45 cm for all other simulations.

Table 4. Decrease in usability at Antioch in the Fall (September – November) predicted to occur as a result of the BDCP project scenario Alt4-H1 by year type

Year Type	# of Usable Days/Year Under NAA	# of Usable Days/Year Under Alt4 (Operational Scenario H1)	Usable Days Lost/Year[1]	Percent Decrease[1]
All Years	23.8	8.5	15.3	64%
Critical Years	10.6	0.3	10.3	97%
Dry Years	24.8	1.8	23.0	93%
Above & Below Normal Years	3.8	3.0	0.8	23%
Wet Years	48.1	25.4	22.7	47%

[1]Results reflect changes resulting from BDCP project only, and not changes due to SLR. That is, BDCP project simulations with SLR = 45 cm were compared with NAA simulation, which also has SLR = 45 cm.

Finally, the model results were used to compute the number of days of usable water over the entire simulation period, as an annual average. As **Table 5** indicates, model results show that the BDCP Proposed Project is simulated to cause a significant decrease in annual usability – 9.2 days per year – over all years. The loss is most significant during wet years, when more than 28 days of usability are lost; the highest percent decrease also occurs during wet years.

Table 5. Annual usability at Antioch under EBC2, No Action Alternative, and BDCP project scenario Alt4-H1 by year type

Year Type	# of Usable Days/Year Under NAA	# of Usable Days/Year Under Alt4 (Operational Scenario H1)	Usable Days Lost	Percent Decrease
All Years	148.5	139.3	9.2	6%
Critical Years	55.6	56.4	-0.8	-1%
Dry Years	117.9	115.6	2.2	2%
Above & Below Normal Years	177.7	175.0	2.7	2%
Wet Years	248.5	219.7	28.8	12%

[1]Results reflect changes resulting from BDCP project only, and not changes due to SLR. That is, BDCP project simulations with SLR = 45 cm were compared with NAA simulation, which also has SLR = 45 cm.

BDCP1505

APPENDIX D

Supplemental Information

Appendix D – Supplemental Information

The City of Antioch respectfully requests that the information and reports listed below and attached to these comments be included in the Administrative Record for this matter.

Bernal, Ron, P.E. 2013. "Preliminary review of BDCP model scenarios and concern about definition of "existing condition"." Letter to Jerry Meral and Dale Hoffman-Floerke. Antioch, California: Department of Public Works. April 29, 2013.

CCWD, 2010, 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; Technical Report WR10-001, available at http://www.ccwater.com/salinity/HistoricalSalinityReport-2010Feb.pdf.

City of Antioch 2010. "Summary of Historical Freshwater Availability at Antioch." SWRCB Delta Flow Criteria Informational Proceeding. March 22, 2010.

Harrington, Phil 2010. "Antioch's Concerns regarding the Bay Delta Conservation Plan (BDCP)." Letter to Phil Isenberg, Joe Grindstaff, Lester Snow, David Hayes, and Karen Scarborough. Antioch, CA: City of Antioch. November 15, 2010. Accessible at <http://archive.deltacouncil.ca.gov/docs/correspondence/11_2010/City_of_Antioch_111510.pdf>

Harrington, Phil. "Delta Flow Criteria Informational Proceeding." Letter to Phillip Crader. Antioch, CA: City of Antioch. February 16, 2010. Accessible at <http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/docs/exhibits/antioch/coa_exh1_coverletter.pdf>

Harrington, Phil 2011. Letter to Jerry Meral. Antioch, CA: City of Antioch. May 19, 2011.

Means, Thomas. "Salt Water Problem: San Francisco Bay and Delta of Sacramento and San Joaquin Rivers. San Francisco, CA: Thos. H. Means, Consulting Engineer - 1928. p. 57.

Paulsen, Susan C., Ph.D. P.E. 2012. "Bay-Delta Workshop 1 – Ecosystem Changes and LSZ." Letter to the State Water Resources Control Board. Pasadena, CA: Flow Science Incorporated, Project 064136. August 7, 2012. Accessible at <http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/comm082712/susan_paulsen.pdf>

Paulsen, Susan C., Ph.D., P.E. 2012. "Bay-Delta Workshop 3 – Analytical Tools for Evaluating the Water Supply, Hydrodynamic, and Hydropower Effects of the Bay-Delta Plan." Letter to the State Water Resources Control Board. Pasadena, CA: Flow Science Incorporated, Project 064136. November 11, 2012.

Paulsen, Susan C., Ph.D., P.E. 2010. "Delta Flow Criteria Closing Comments." Letter to the State Water Resources Control Board. Pasadena, CA: Flow Science Incorporated, Project 064136. April 14, 2010. Accessible at <http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/docs/closing_comments/cts_antioch_closing.pdf>

Preston, Al, Ph.D., P.E. 2012 "Addendum to City of Antioch submittal for the Bay-Delta Workshop 1 – Ecosystem Changes and LSZ / Excerpts from Three Relevant Historical Documents." Letter to the State Water Resources Control Board. Pasadena, CA: Flow Science Incorporated, Project 064136. August 16, 2012. Accessible at <http://www.swrcb.ca.gov/waterrights/water_issues/programs/bay_delta/docs/comm081712/al_preston.pdf>

April 29, 2013

Sent by email and regular mail

Jerry Meral
Deputy Secretary, California Natural Resources Agency
1416 Ninth Street, Suite 1311
Sacramento, CA 95814

Dale Hoffman-Floerke
Chief Deputy Director, California Department of Water Resources
1416 Ninth Street, Room 115-2
Sacramento, CA 95814

Subject: Preliminary review of BDCP model scenarios and concern about definition of "existing condition"

Dear Mr. Meral and Ms. Hoffman-Floerke:

The City of Antioch and its consultants are currently in the process of reviewing the potential effects of the proposed BDCP project on salinity at Antioch's drinking water intake in the western Delta. Our review of the Effects Analysis (Chapter 5 of the BDCP Draft, released in March 2013) indicates that there appear to be two different scenarios (EBC1 and EBC2) that have been modeled to represent "existing biological conditions."The main difference between these two scenarios appears to be whether the Delta outflows are managed to achieve the Fall X2 provision (hereafter referred to as "Fall X2") of the 2008 US Fish and Wildlife Service Biological Opinion (the "2008 BiOp"). It appears that EBC1 does not include Fall X2, whereas EBC2 does include Fall X2. Because the 2008 BiOp represents the current legal requirement to operate to achieve Fall X2, the existing or baseline condition should include Fall X2 (i.e., EBC2 is the legally required baseline condition).

Furthermore, Antioch and its consultants have received from DWR modeling results obtained using the DSM2 model. Comparison of the EBC2 scenario with historical field data measured at Antioch indicated good agreement between model results and measured historic salinity; our analysis indicates that EBC2 is an appropriate scenario to use for an "existing condition." The modeling results obtained to date from DWR do not include the EBC1 scenario (we understand that these will be sent to us shortly), and as such no direct comparison has yet been made. However, the results provided in the Effects Analysis (e.g., Figures 5C.A-104 through 5C.A-107 of Attachment 5C.A) indicate that the exclusion of Fall X2 in the EBC1 scenario results in substantial increases in electrical conductivity (EC, a measure of salinity) in the western Delta in the fall of 1978, 1980, 1984, and 1986. These periods of higher EC are not consistent with field measurements, thereby indicating that EBC1 is not a technically appropriate scenario to use for an "existing condition."

As we have noted in prior comments on the BDCP process and in testimony to the State Water Resources Control Board (SWRCB), salinity levels in the western Delta, including at Antioch's intake, will be substantially higher if Fall X2 is not included in project operations. Impacts to water quality at Antioch's intake are particularly severe in the summer and fall months of above-normal and wet years, and model results indicate these impacts are the result of the BDCP project (and not sea level rise).

In summary, Antioch is concerned that two "existing condition" scenarios (EBC1 and EBC2) appear to have been modeled, and in particular that EBC1 (which excludes Fall X2 requirements) does not accurately represent existing or baseline conditions. Our analysis at this point indicates that EBC2 (which includes Fall X2 requirements) is both legally and technically appropriate to use to describe existing or baseline conditions in the forthcoming EIR/S and in other discussions and analyses of the proposed BDCP project. Use of EBC1 (without Fall X2) would be neither legally nor technically appropriate, and could result in artificially misstating the anticipated impacts of the BDCP project. Thus, Antioch requests that Fall X2 be included in the model runs performed to describe both the existing/baseline and project conditions.

Please contact me at (925) 779-6820 or rbernal@ci.antioch.ca.us if you have any questions or would like to discuss these comments.

Sincerely,

Ron Bernal

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BDCP 1505

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

Acknowledgements

CCWD would like to thank the City of Antioch for their contribution towards funding a technical review of CCWD's draft report "Trends in Hydrology and Salinity in Suisun Bay and the Western Delta" (June 2007); their review substantially improved the work and led to the final report "Historical Fresh Water and Salinity Conditions in the Western Sacramento-San Joaquin Delta and Suisun Bay". CCWD is grateful to the many reviewers including Richard Denton, Matthew Emrick, Gopi Goteti, Phil Harrington, E. John List, Susan Paulsen, David Pene, Mat Rogers, and Peter Vorster. We also thank the following for sharing their data and analyses: Roger Byrne, Chris Enright, Spreck Rosekrans, and Scott Starratt, and we thank Ann Spaulding for her contributions.

BNP1505

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.

BDCP 1505

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.

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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.

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Historical Fresh Water and Salinity Conditions in the Western Sacramento-San Joaquin Delta and Suisun Bay

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Acronyms

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

BDO 1505

1. Introduction

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.

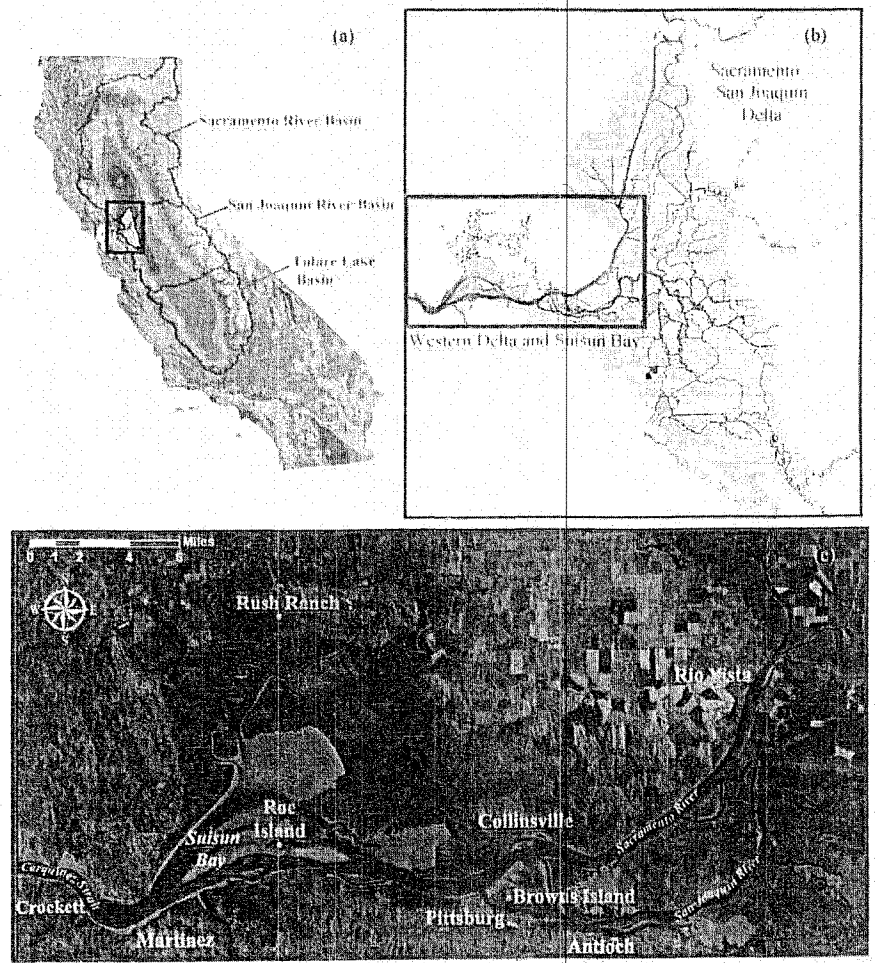

Figure 1-1 – Map

(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.

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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.

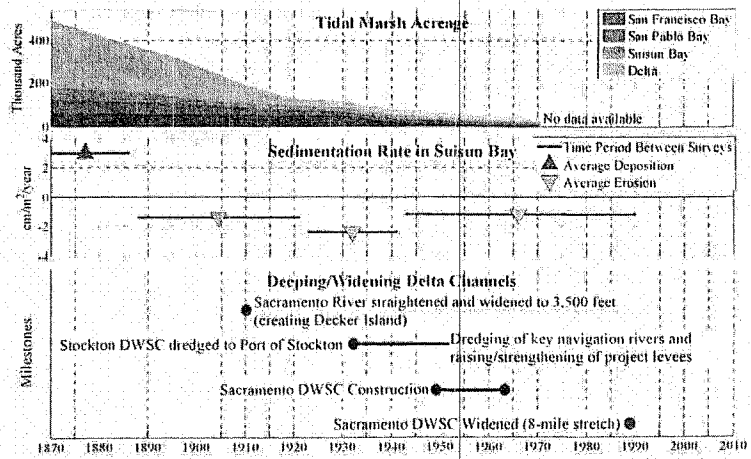

Figure 1-2 – Chronology of anthropogenic modifications to the Bay-Delta landscape

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.

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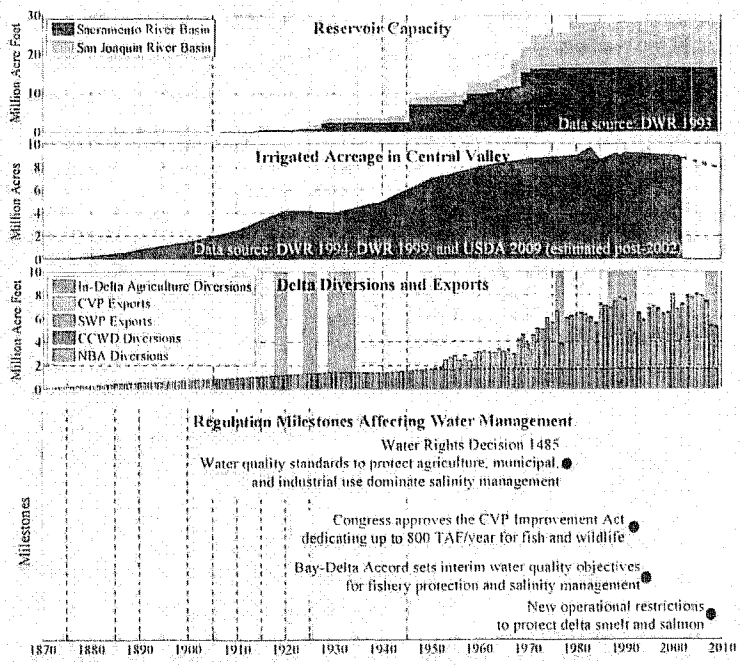

Figure 1-3 – Chronology of anthropogenic activities that affect water management

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.

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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[3] 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).

[3] 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).

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.

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2. Paleoclimatic Evidence of the Last 10,000 Years

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, as 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).

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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.

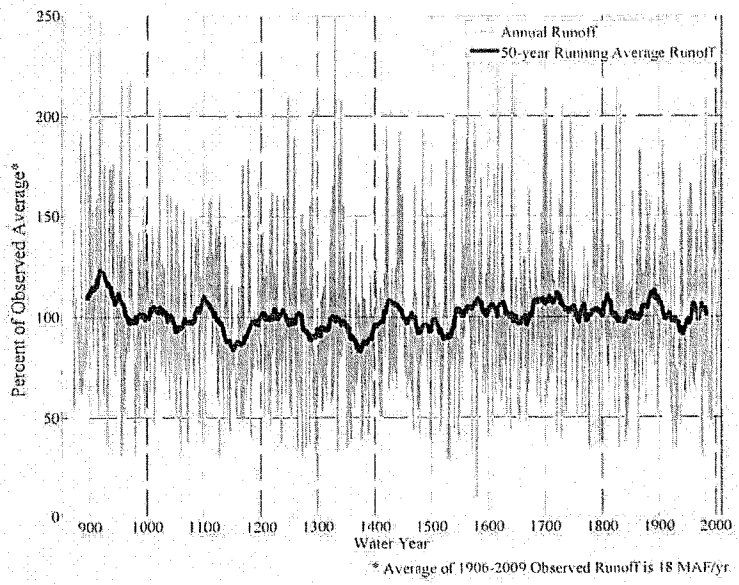

Figure 2-1 – Reconstructed annual unimpaired Sacramento River flow 869 CE to 2009 CE

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).

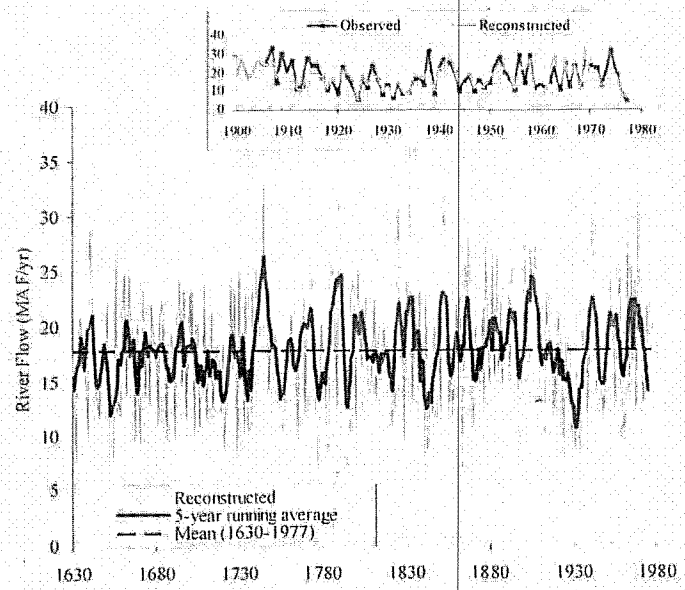

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Figure 2-2 – Reconstructed annual unimpaired Sacramento River flow from 1630-1977.

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.

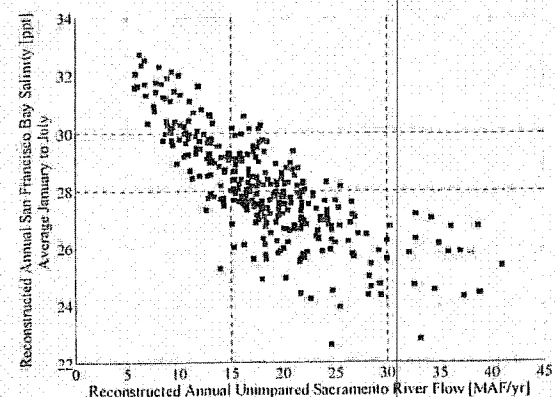

Figure 2-3 – Reconstructed salinity near the mouth of San Francisco Bay compares well with reconstructed unimpaired Sacramento River flow in the upper watershed

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

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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.

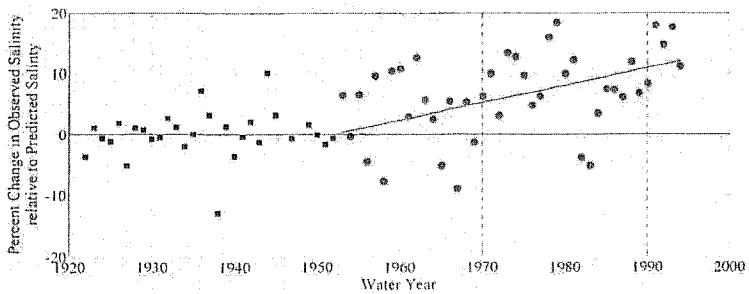

Figure 2-4 – Percent change in observed salinity relative to predicted (reconstructed) salinity for the period 1922 to 1994

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.

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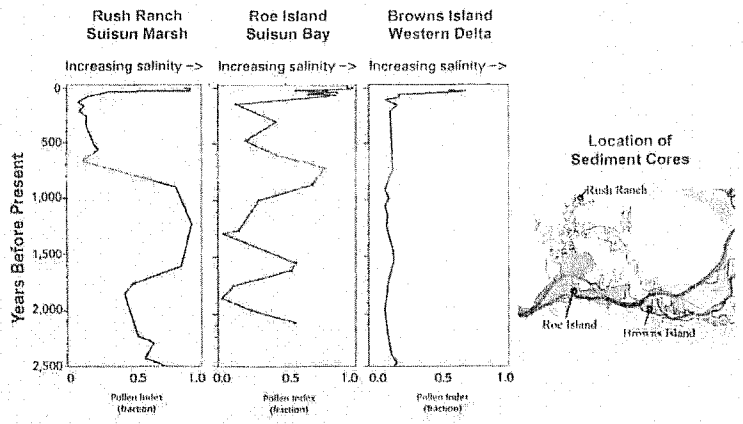

Figure 2-5 – Paleosalinity evidence derived from pollen data

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.

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3. Instrumental Observations of the Last 140 Years

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.

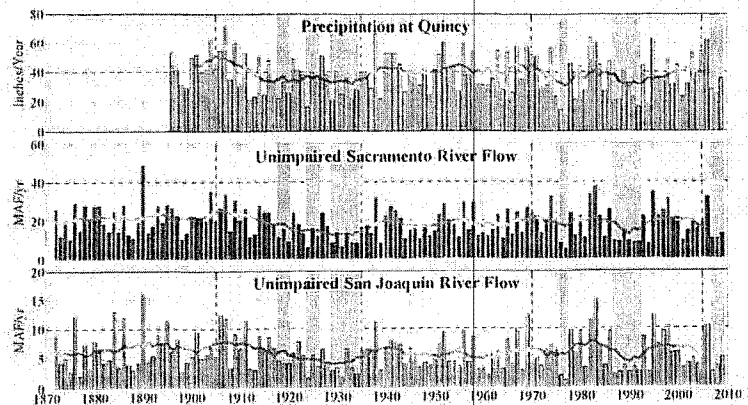

Figure 3-1 – Total annual precipitation and unimpaired flow in the upper Sacramento and San Joaquin River basins (1872-2009)

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.

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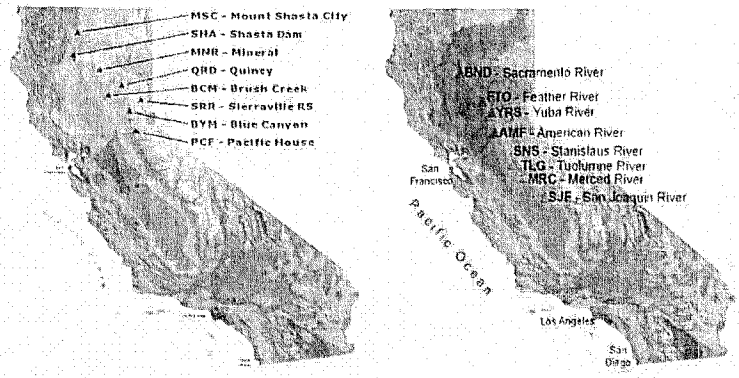

Figure 3-2 – Locations of Precipitation and Runoff Measurements

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

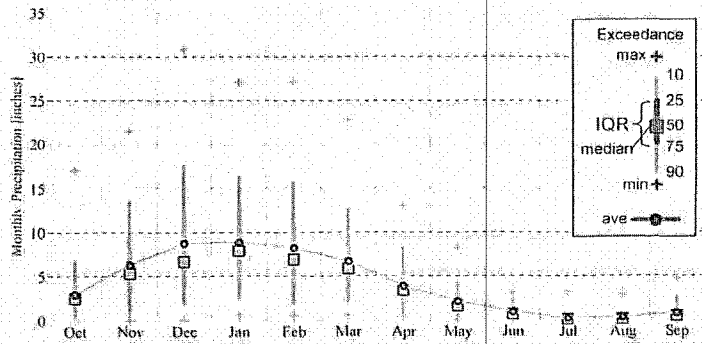

Figure 3-3 – Monthly Distribution of Precipitation in the Sacramento River Basin

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.

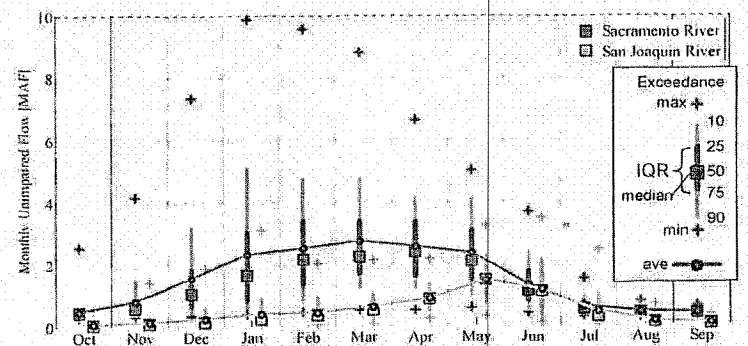

Figure 3-4 – Monthly distribution of unimpaired flow in the Sacramento and San Joaquin River basins

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.

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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

[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.

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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.

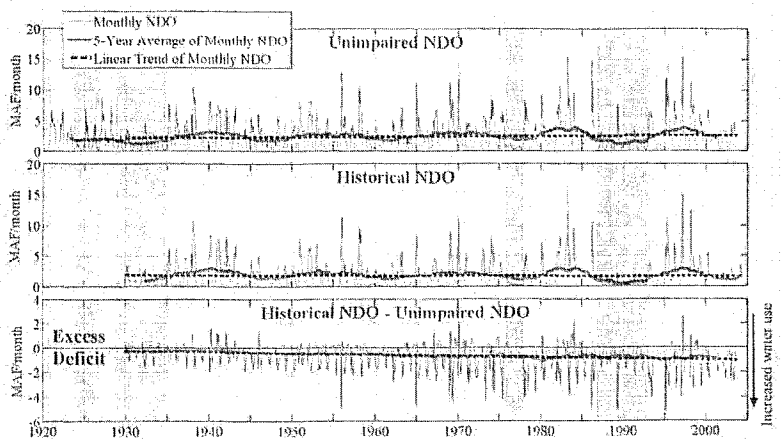

Figure 3-5 – Time series of Monthly Net Delta Outflow under unimpaired conditions and historical (actual) conditions

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.

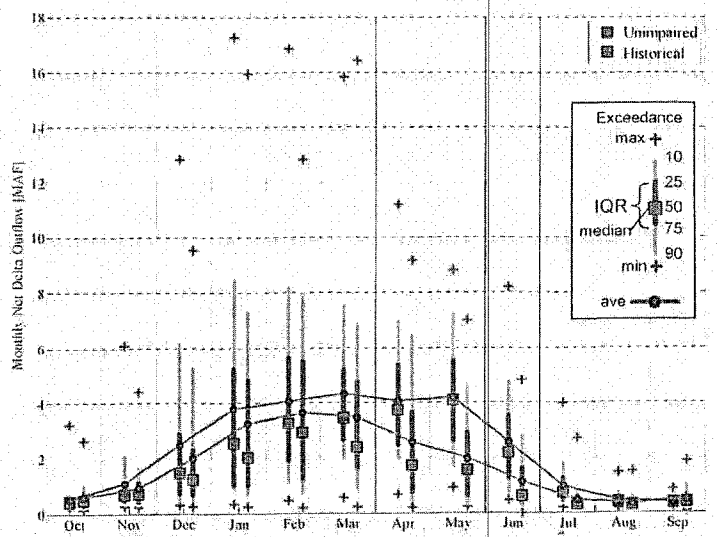

Figure 3-6 – Monthly distribution of Net Delta Outflow

Distribution of monthly NDO for water years 1930 through 2003. 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.

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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.

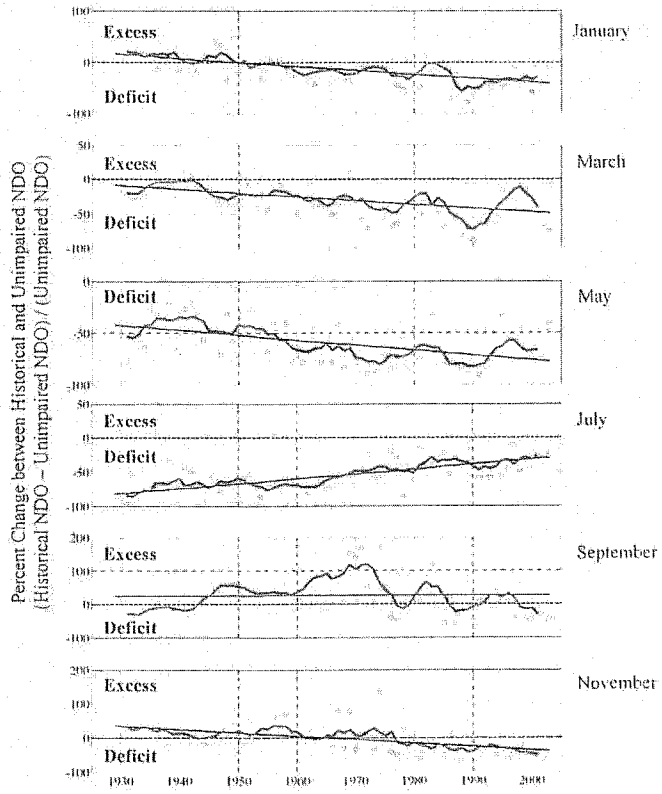

Figure 3-7 – Long-term trends in monthly NDO

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.

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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.

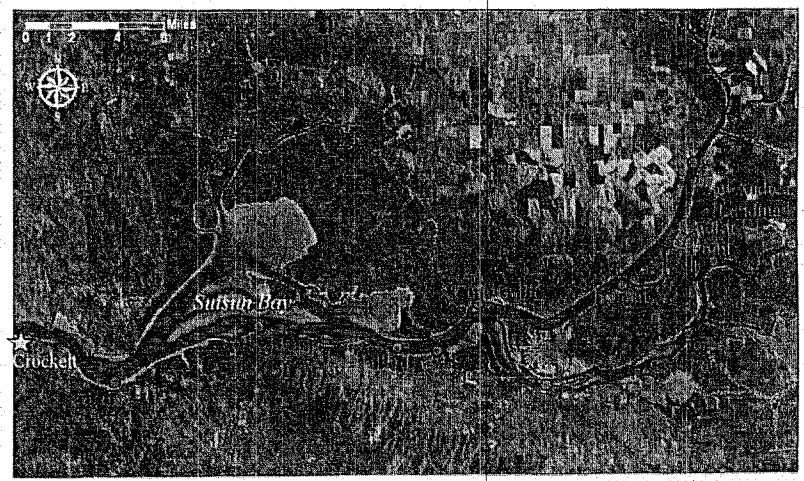

Figure 3-8 – Map of Suisun Bay and Western Delta with locations of continuous monitoring stations

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.

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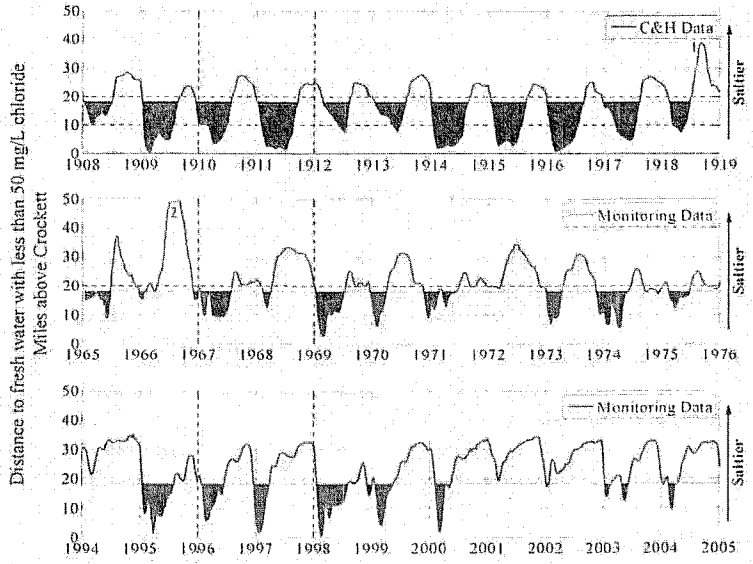

Figure 3-9 – Distance to fresh water from Crockett

"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 (38 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).

[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).

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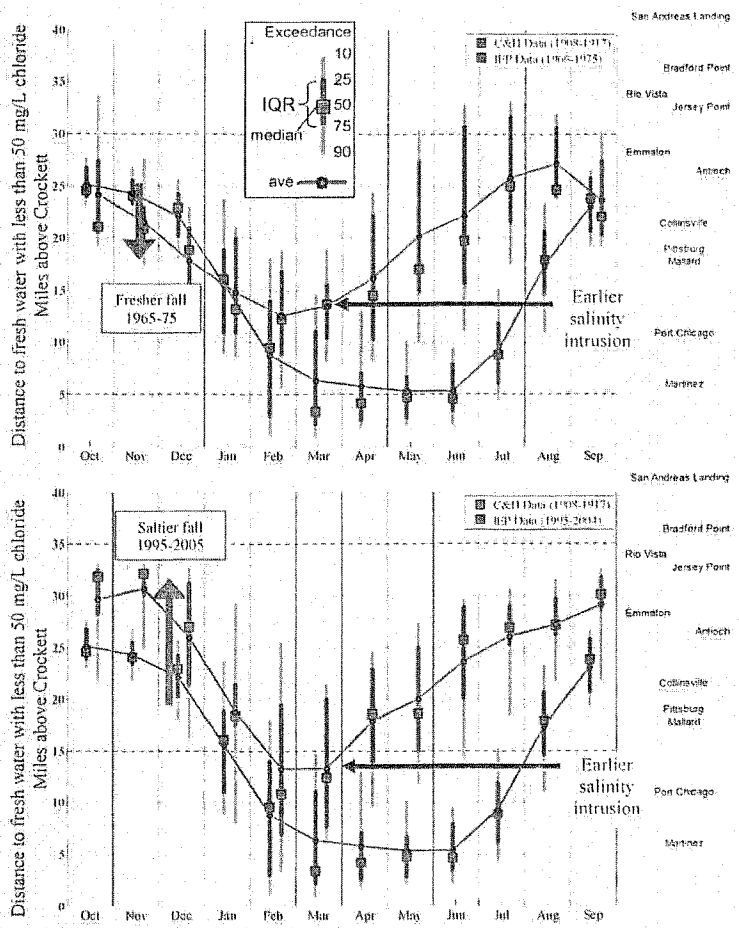

Figure 3-10 – Monthly distribution of distance to fresh water from Crockett

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.

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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).

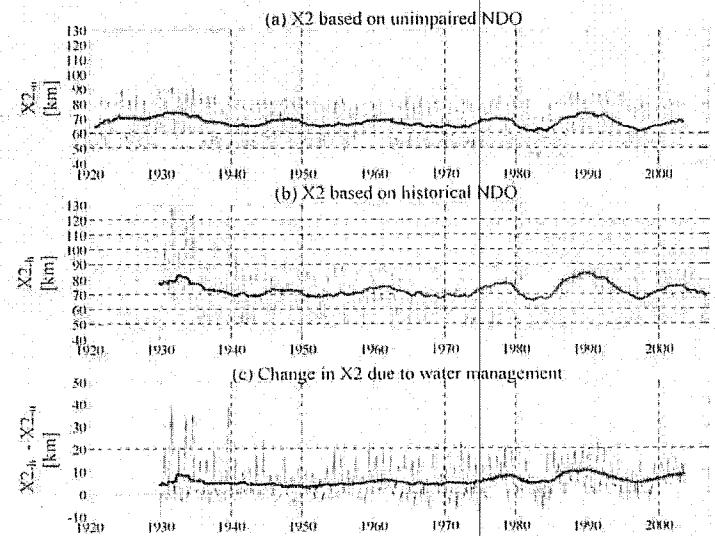

Figure 3-11 – Location of X2 under unimpaired and historical conditions
X2 has a strong seasonal and decadal variability under both unimpaired (top panel) and historical (middle panel) flow conditions reflecting the strong seasonal and decadal variability of NDO. The difference between historical and unimpaired conditions (bottom panel) illustrates the net effect of water management activities.

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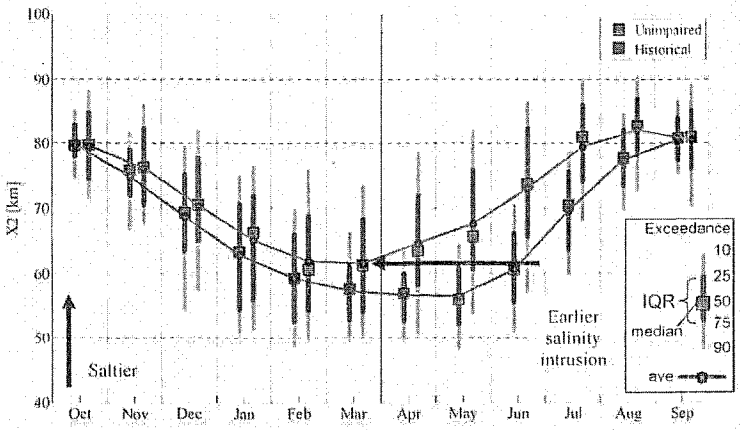

Figure 3-12 – Monthly distribution of X2 from 1945 through 2003

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.

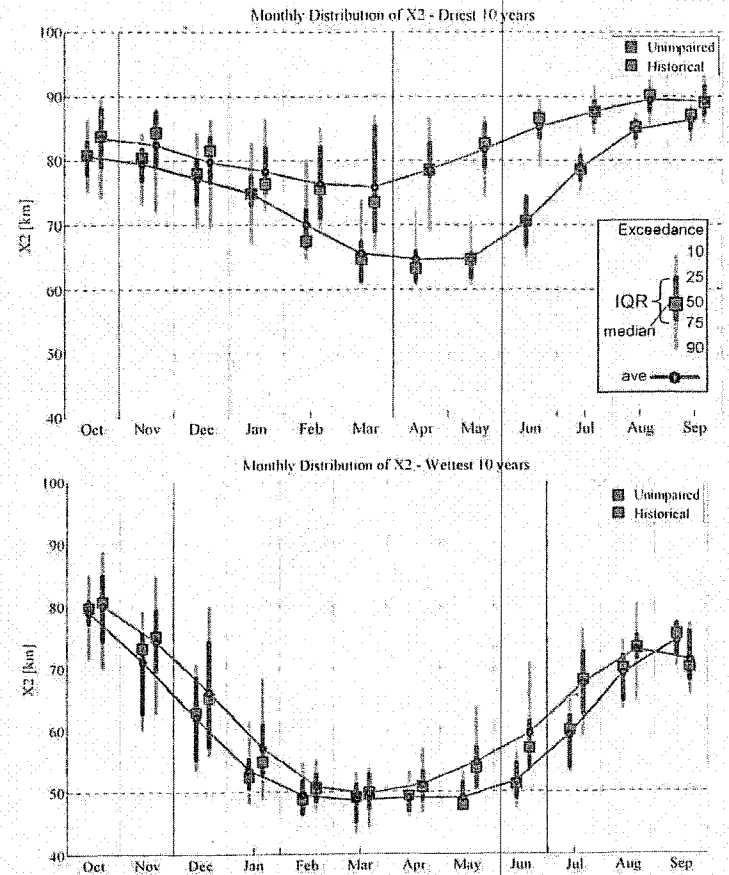

Figure 3-13 – Monthly X2 variability during wet and dry years (1945-2003)
Determination of the ten wettest and driest years is based on the total annual unimpaired Net Delta Outflow. The ten wettest years are 1952, 1956, 1958, 1969, 1974, 1982, 1983, 1986, 1995, and 1998. The ten driest years are 1947, 1976, 1977, 1987, 1988, 1990, 1991, 1992, 1994, and 2001.

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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[39] 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.

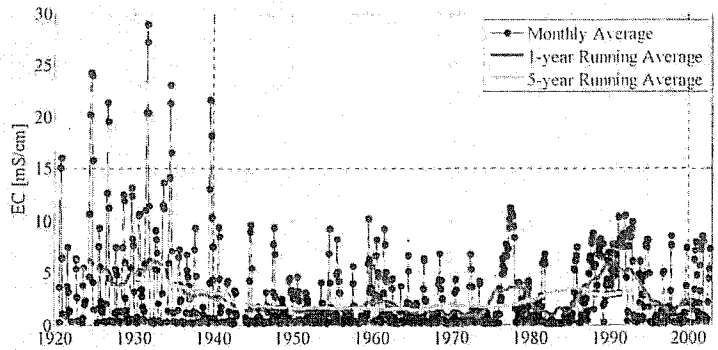

Figure 3-14 – Observed salinity at Collinsville
Monthly average salinity at Collinsville (black dots and black line), with the 12-month running average (red line) and 5-year running average (blue line).

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.

[39] Data provided by Chris Enright (DWR), personal communication, 2007.

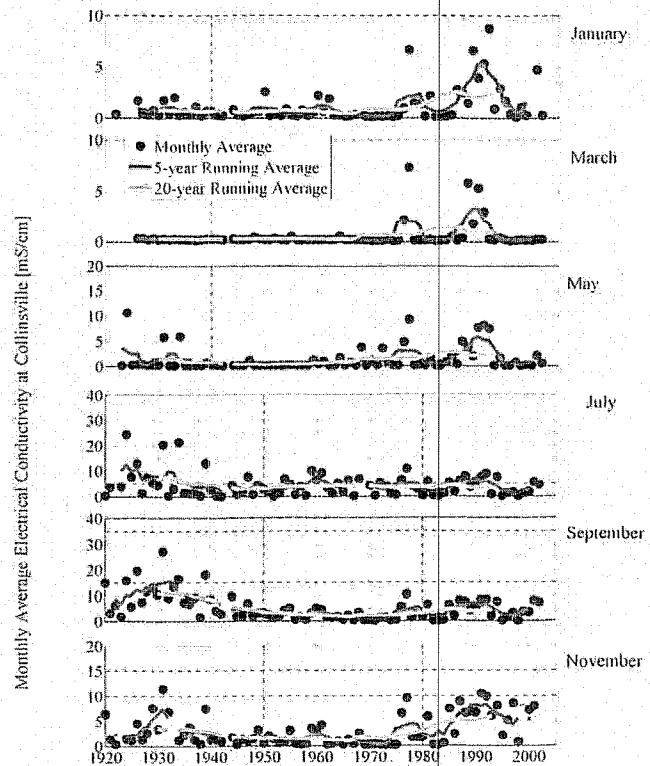

Figure 3-15 – Year-to-year trends in monthly-average salinity at Collinsville, 1920-2002
Monthly average salinity at Collinsville (black dots), with the 12-month running average (red line) and 5-year running average (blue line) for individual months.

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

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attributed it to water operations. In seven months (January-May, September-October) the increasing trend was significant ($p \leq 0.05$).

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.

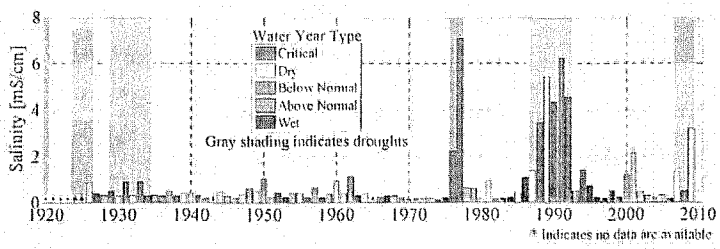

Figure 3-16 – Average Winter salinity at Collinsville

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.

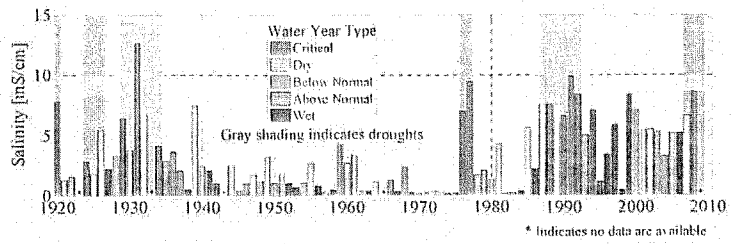

Figure 3-17 – Average Fall salinity at Collinsville

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.

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4. Qualitative Observations of Historical 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.

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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.

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5. 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

BDCP1503

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.

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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.1.1. Regional Precipitation and Runoff

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).

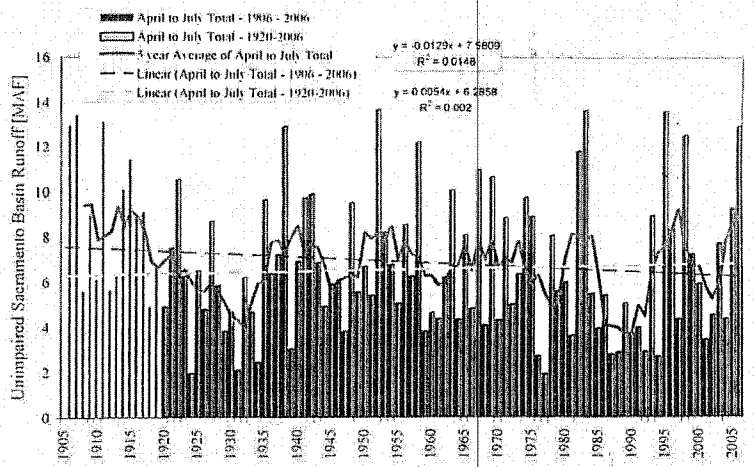

Figure A-1 – Unimpaired runoff from the Sacramento River basins from April to July
Data source: http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST.

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).

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A.1.2. Sea Level Rise

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.2.1. Deepening, Widening, and Straightening Channels (early 1900'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.2.2. Reclamation of Marshland (1850-1920)

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.2.3. Mining 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.

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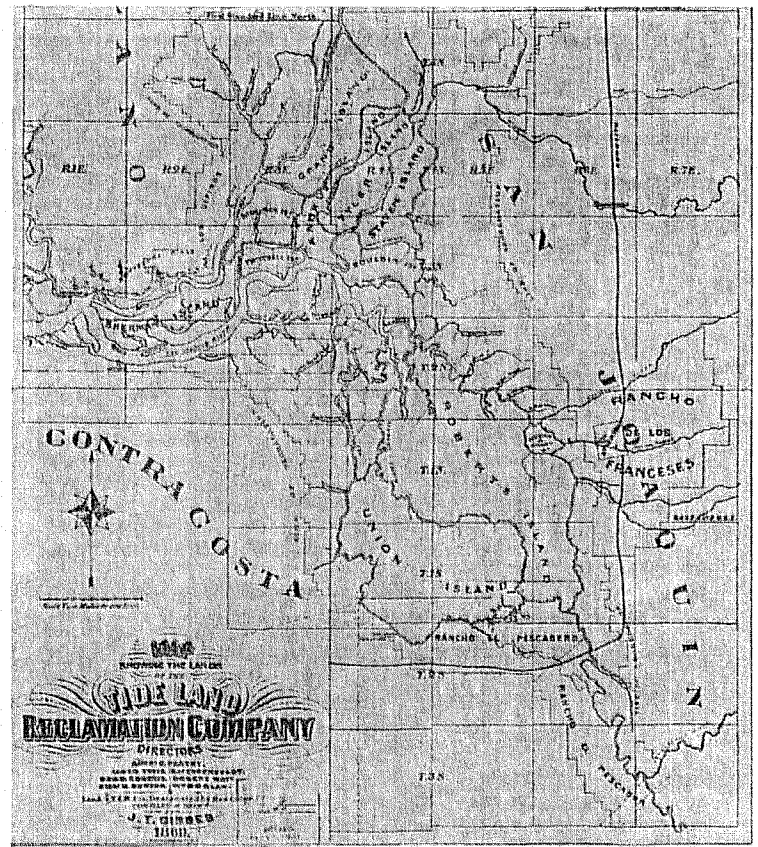

Figure A-2 - Map of the Delta in 1869

Channels of the western, central, and southern Delta in 1869, prior to extensive reclamation efforts (Gibbes, 1869)

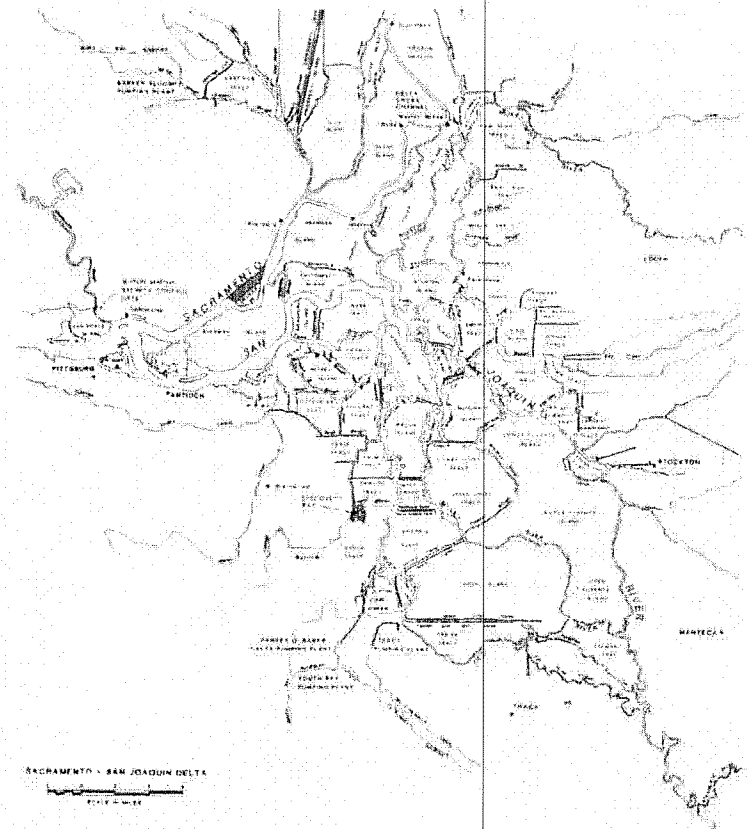

Figure A-3 – Map of the Delta in 1992

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.

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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.)

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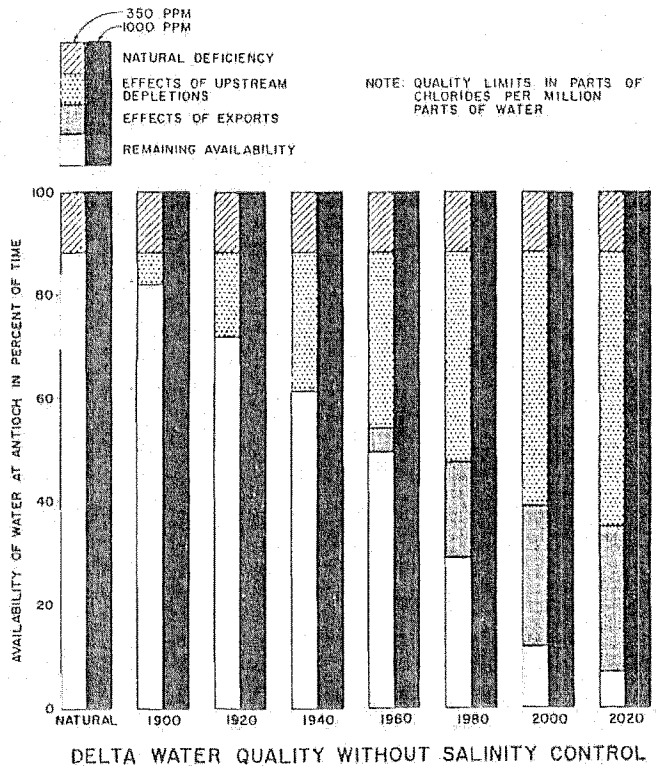

Figure A-4 - Salinity on the San Joaquin River at Antioch (DWR, 1960)

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.

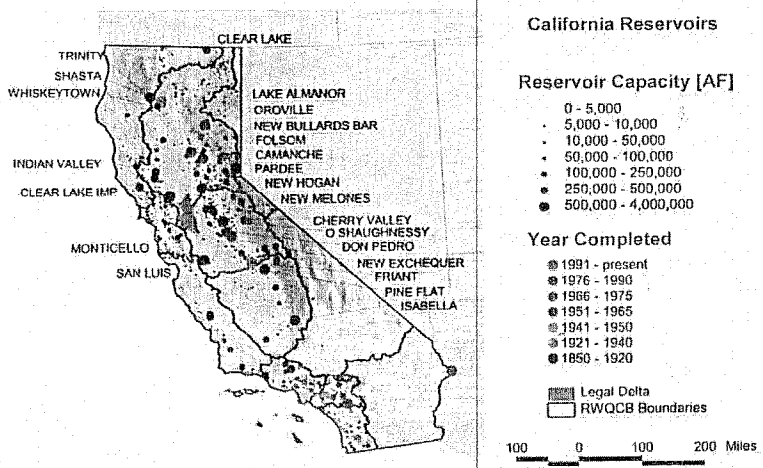

Figure A-5 – Storage reservoirs in California

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.

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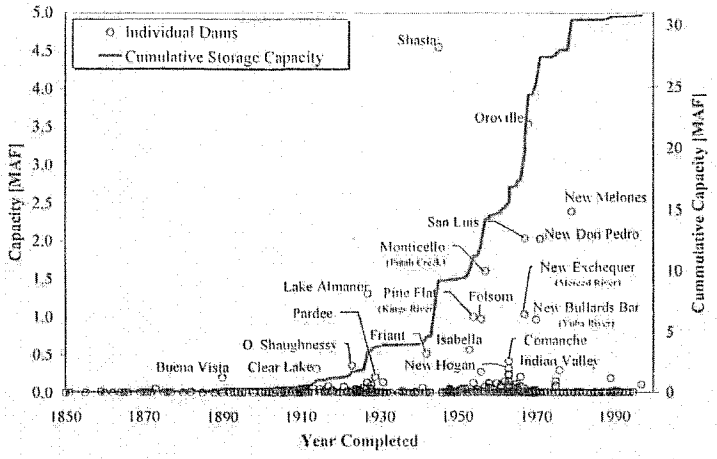

Figure A-6 – Surface Reservoir Capacity

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.

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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

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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

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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.

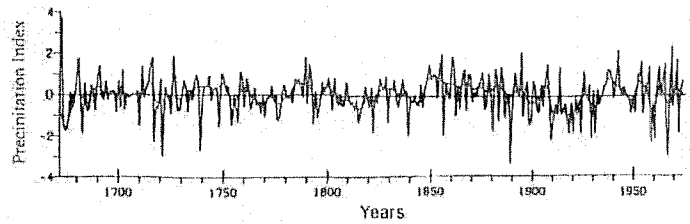

Figure B-1 – Reconstructed annual precipitation, 1675-1975
Data from Graumlich (1987). Precipitation index is presented in units of standard deviation from the 1899-1975 observed mean value.

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.

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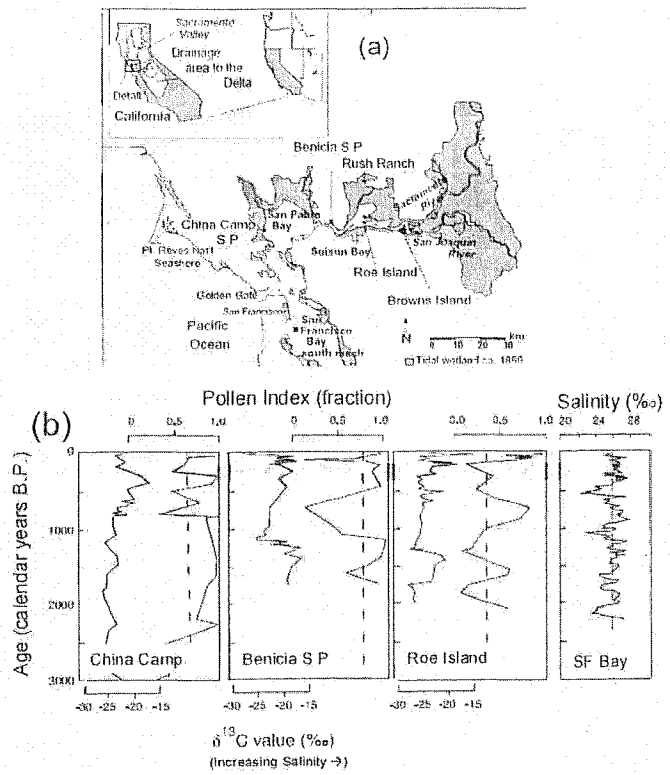

Figure B-2 – Paleosalinity records at selected sites in the San Francisco Estuary

(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 δ13C 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))

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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	4,310,000	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	3,633,400	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

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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

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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		

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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.1.1. Salinity Units

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.1.2. Temporal and Spatial Variability 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).

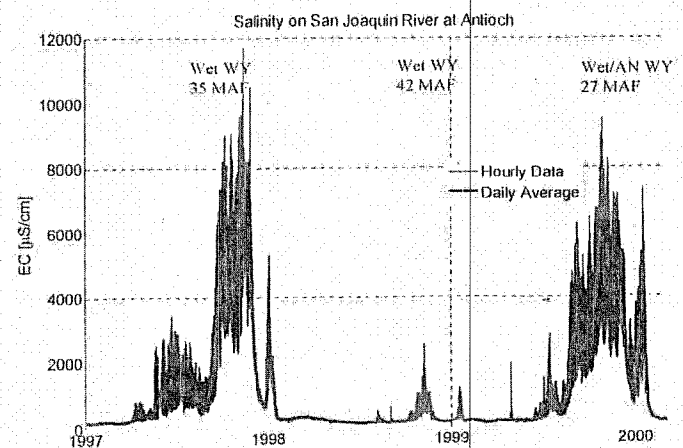

Figure D-1 – Hourly and daily salinity variability in the San Joaquin River at Antioch
Total annual unimpaired Sacramento River flow and water year type is indicated for each water year. Data Source: IEP Data Vaults (http: www.iep.ca.gov.dss)

[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.

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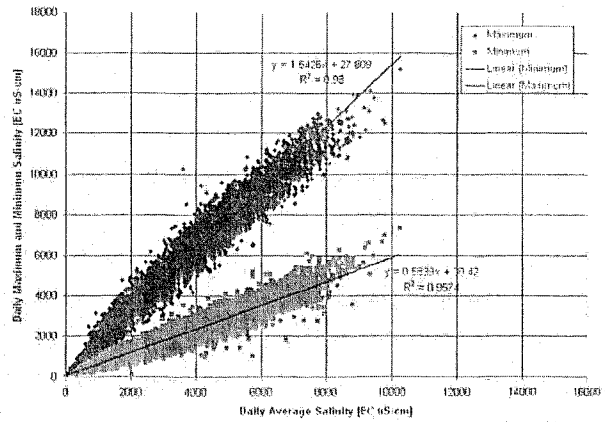

Figure D-2 – Tidal Variability in Salinity at Antioch (1967 to 1992)
Data Source: IEP Data Vaults (http: www.iep.ca.gov/dss)

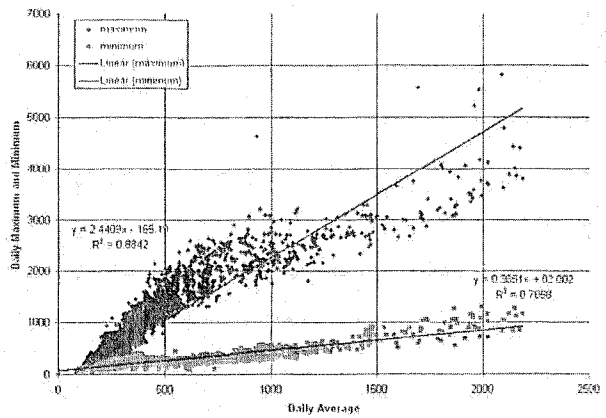

Figure D-3 – Tidal Variability in Salinity at Rio Vista (1967 to 1992)
Data Source: IEP Data Vaults (http: www.iep.ca.gov/dss)

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.2.1. Distance to Freshwater from 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).

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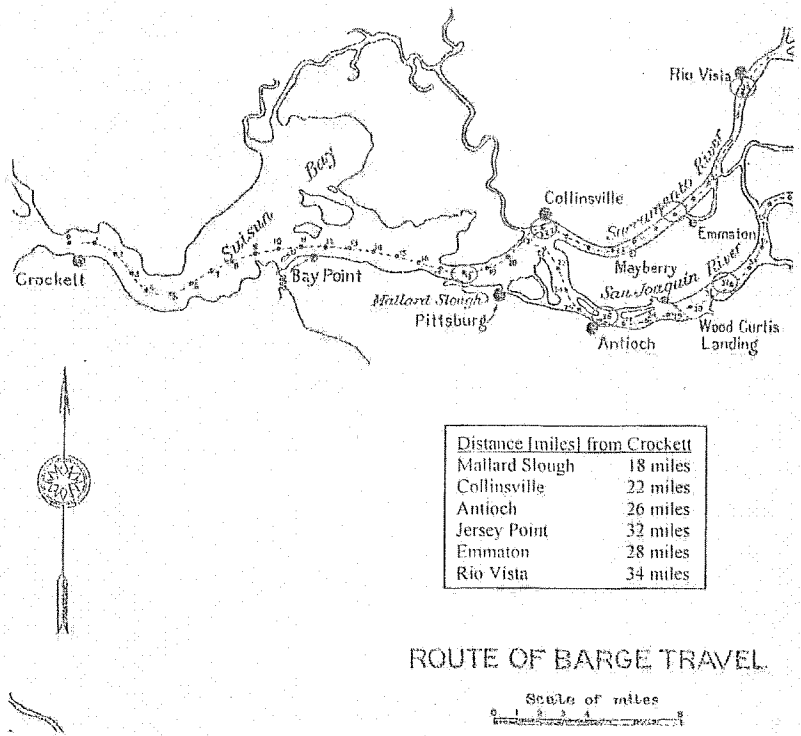

Figure D-4 – C&H Barge Travel Routes

Map adapted from DPW (1931). Red circles indicate locations of landmarks, with distance from Crockett listed in the inset box.

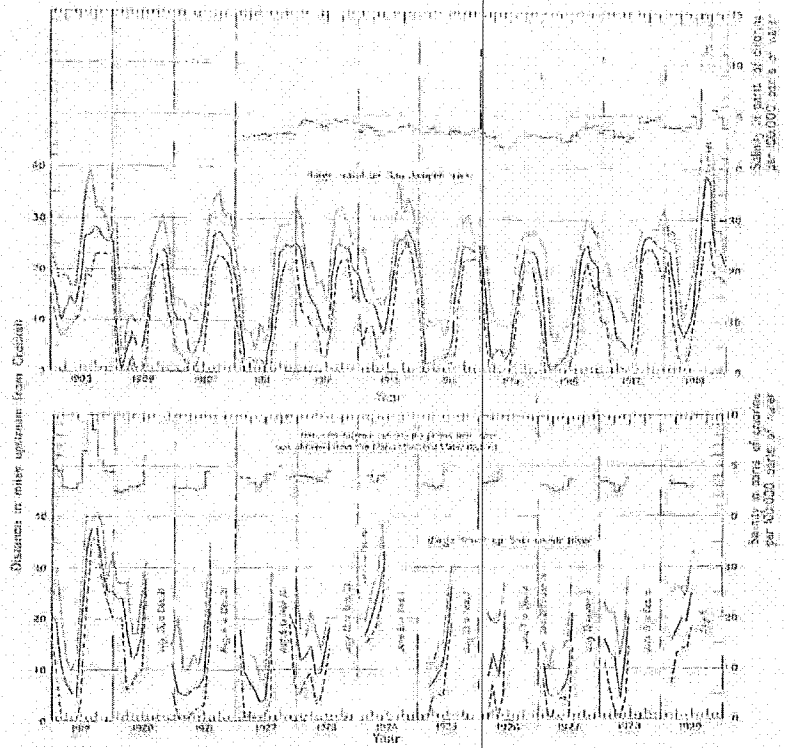

Figure D-5 – C&H Barge Travel and Quality of Water obtained

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.

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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.

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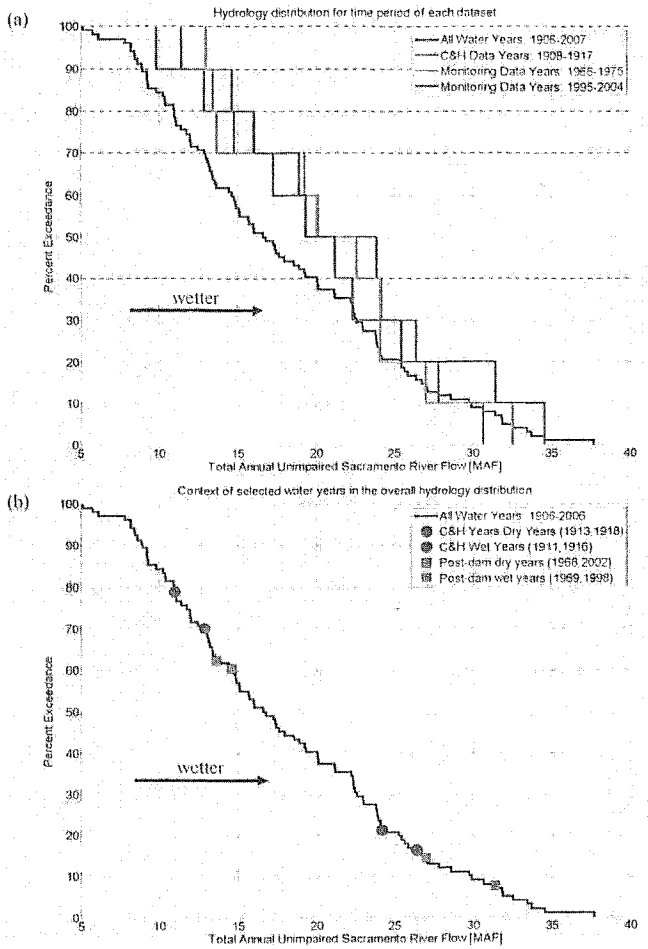

Figure D-6 – Hydrologic Context for Analysis of Distance to Fresh Water

(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.

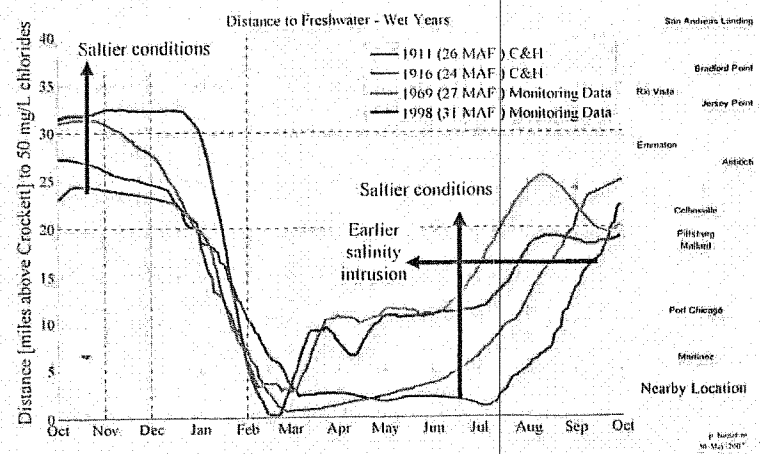

Figure D-7 – Distance to Fresh Water in Select Wet Years

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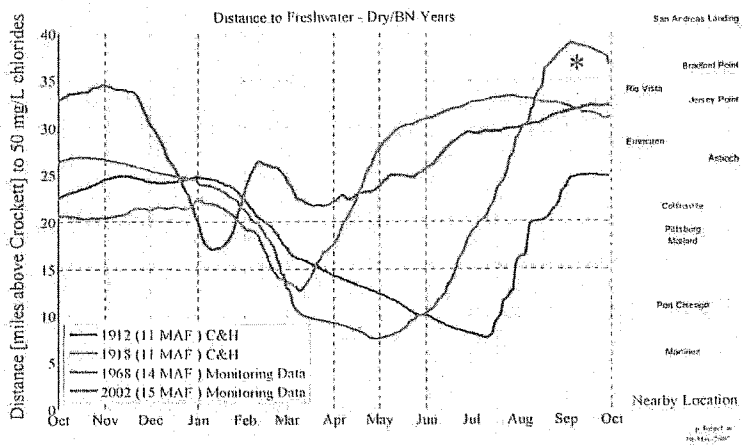
Selected Dry Years

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.

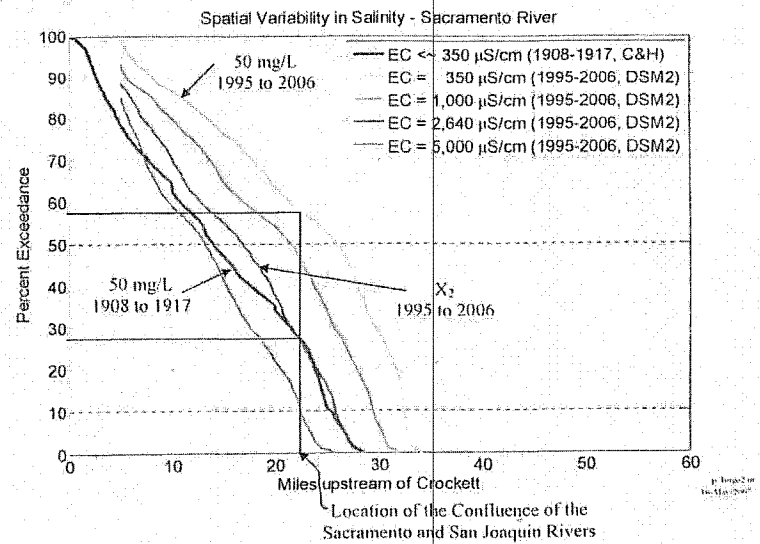


Figure D-9 – Distance along the Sacramento River to Specific Salinity Values

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D.2.2. Maximum Annual Salinity Intrusion Before and After Large-scale Reservoir 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.

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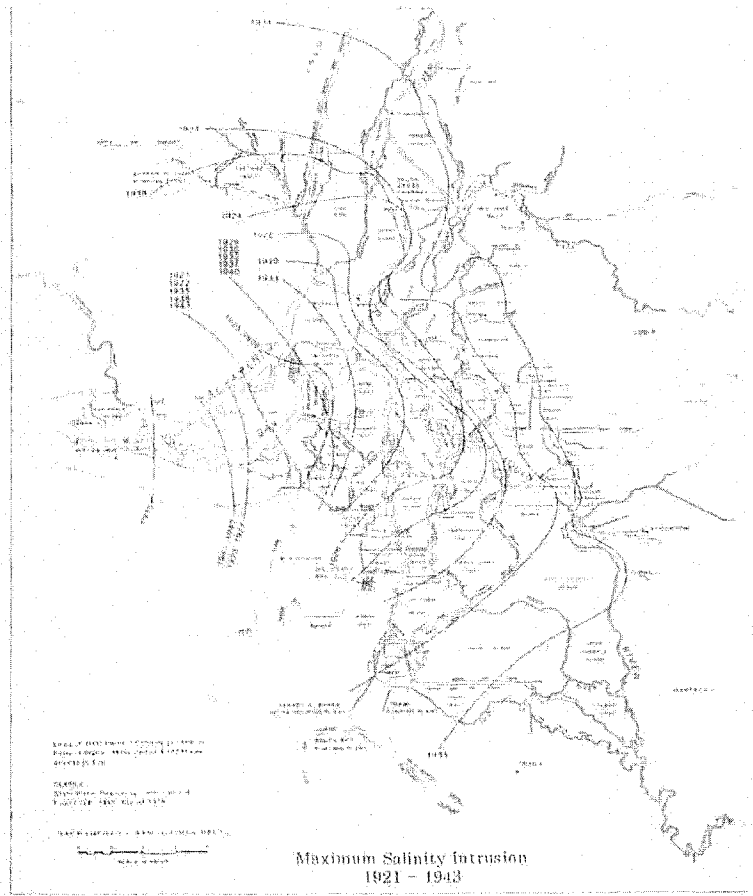

Figure D-10 – Salinity intrusion during pre-CVP period, 1921-1943 (DWR, 1995)

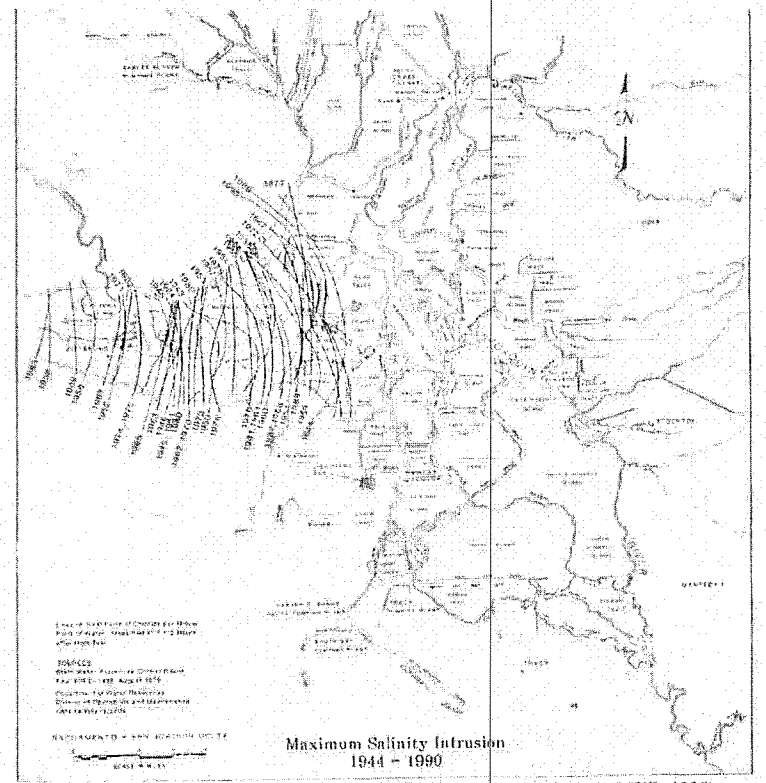

Figure D-11 – Salinity intrusion during post-CVP period, 1944-1990 (DWR, 1995)

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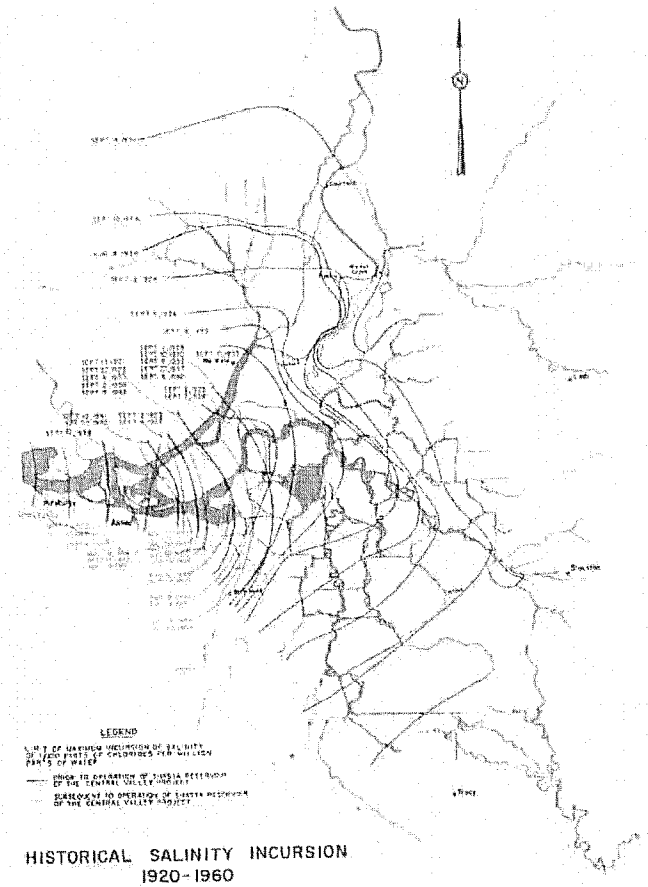

Figure D-12 – Salinity intrusion during 1920-1960 (DWR, 1960)

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.

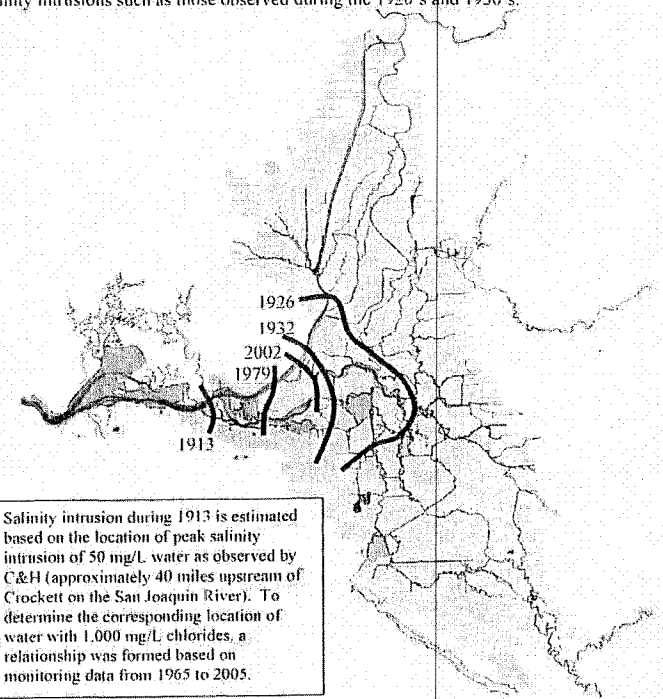

Figure D-13 – Annual Maximum Salinity Intrusion for relatively dry years
Salinity intrusion for relatively dry water years with similar total annual unimpaired runoff, using 1,000 mg/L chloride concentration to distinguish the extent of intrusion.

[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.

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D.3. *Temporal Variability of Salinity in the Western Delta*

D.3.1. 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.

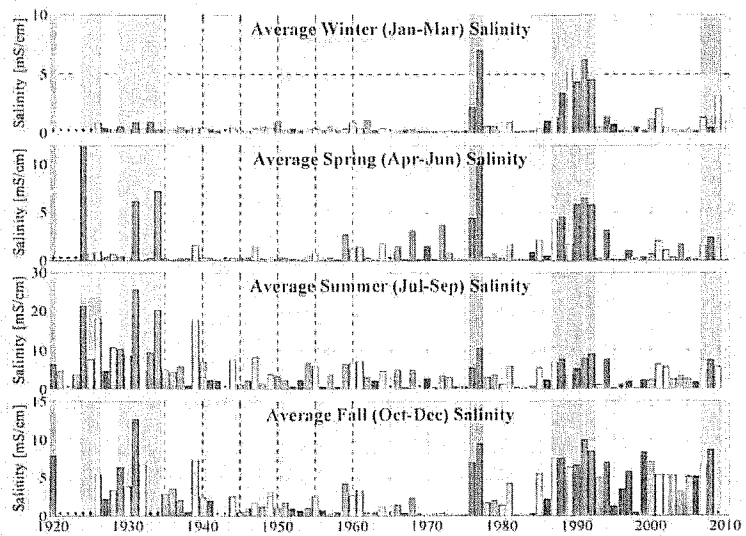

Figure D-14 – Average Seasonal Salinity at Collinsville

[7] Data provided by Chris Enright (DWR), personal communication, 2007

D.3.2. Effects of Water Management 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.

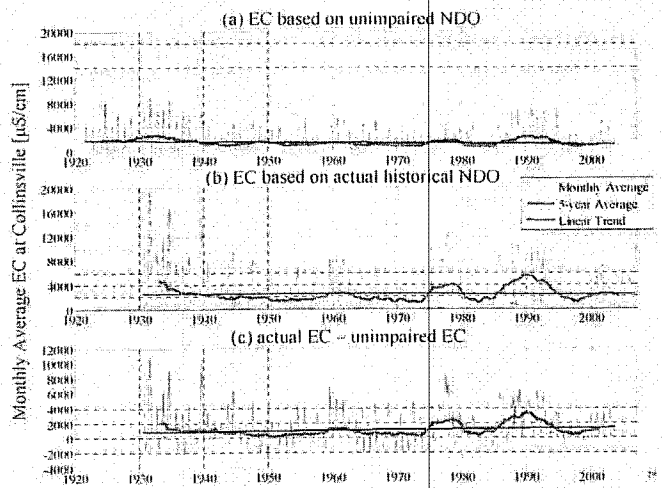

Figure D-15 – Estimates of Collinsville salinity using the G-model for unimpaired and actual historical flow conditions

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.

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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.

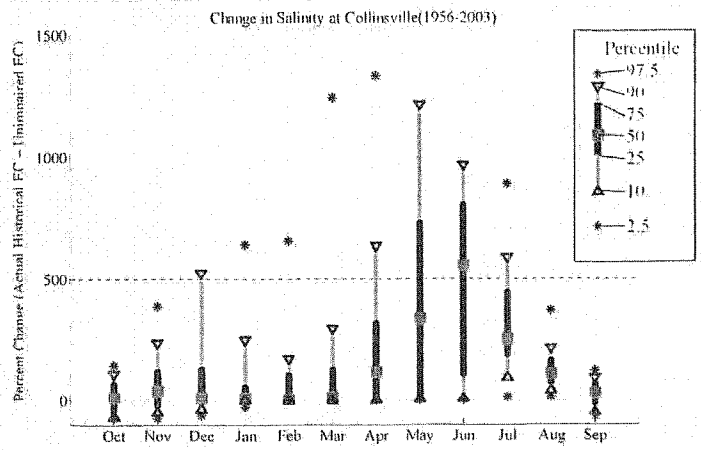

Figure D-16 – Estimated change in salinity at Collinsville under actual historical conditions, as a percent change from unimpaired conditions, 1956-2003

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.

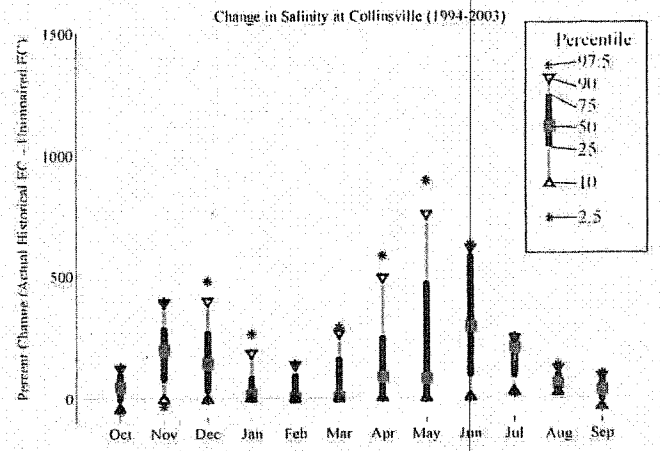

Figure D-17 – Estimated change in salinity at Collinsville under actual historical conditions, as a percent change from unimpaired conditions, 1994-2003

D.3.3. 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.

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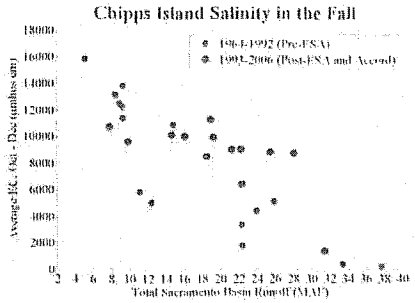

Figure D-18 -- Post-ESA salinity in the Suisun Bay and western Delta

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.

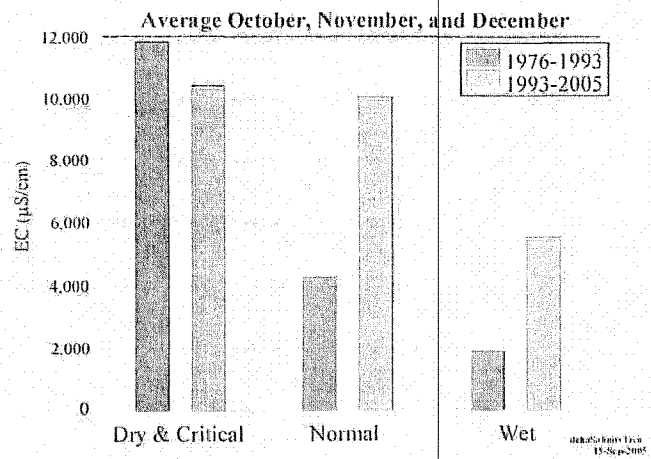

Figure D-19 – Increase in Fall Salinity at Chipps Island

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

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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.

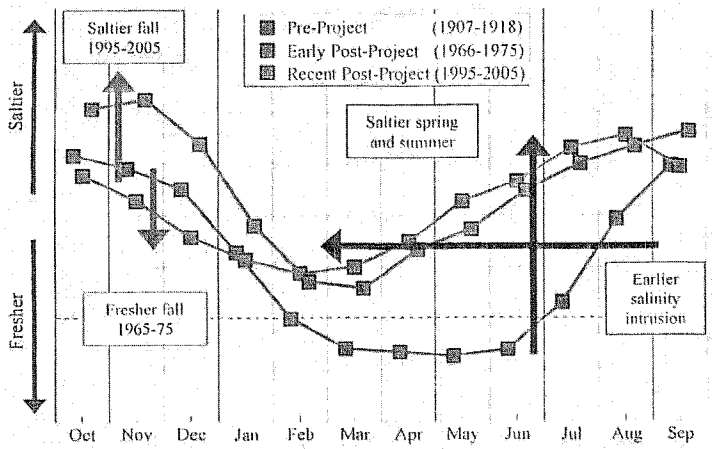

Figure D-20 – Conceptual plot of seasonal variability of salinity in Suisun Bay and the western Delta during different water management eras

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.

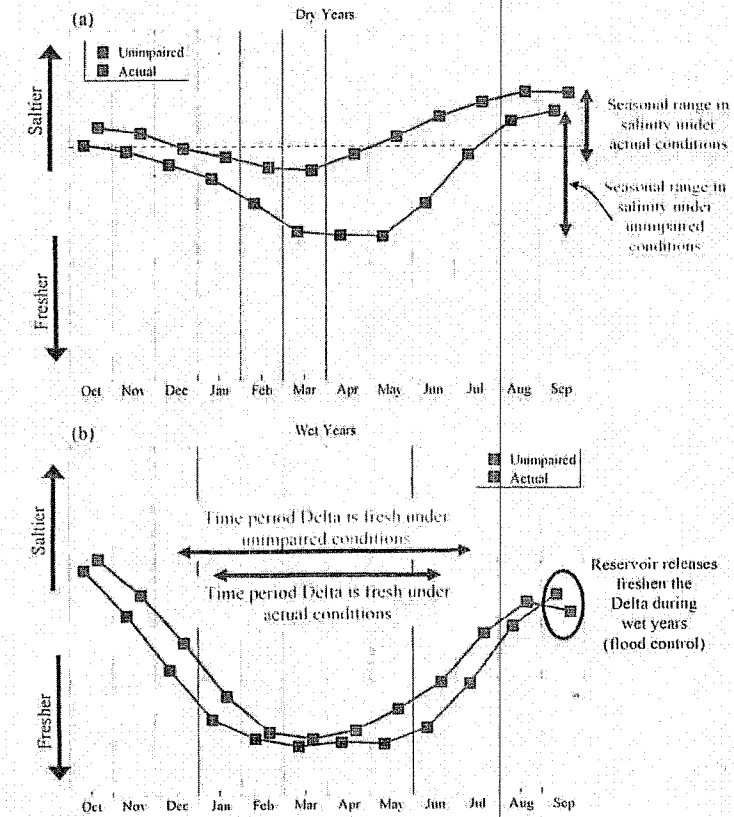

Figure D-21 – Conceptual plot of seasonal salinity variations in the Delta under actual historical conditions compared to unimpaired conditions in (a) dry years and (b) wet years

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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
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

[9] Supplement to Respondent's Answering Brief, p. 10.

E.1.1. 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.

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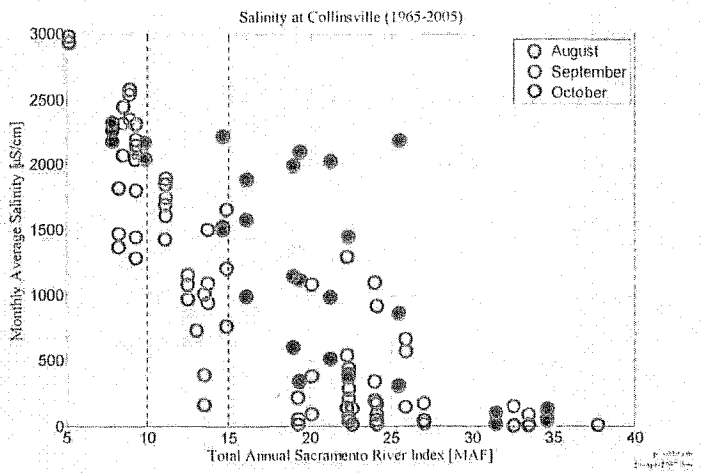

Figure E-1 – Observed salinity at Collinsville, 1965-2005

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.1.2. 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.2.1. Town of Antioch Injunction on Upstream 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).

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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.2.2. 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.

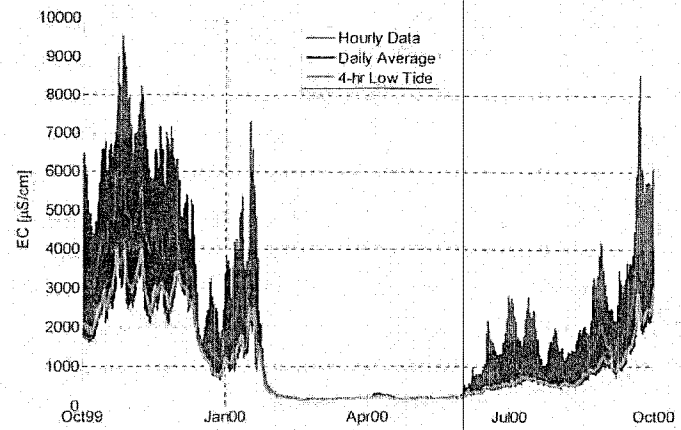

Figure E-2 – Salinity variations in the San Joaquin River at Antioch, water year 2000

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.

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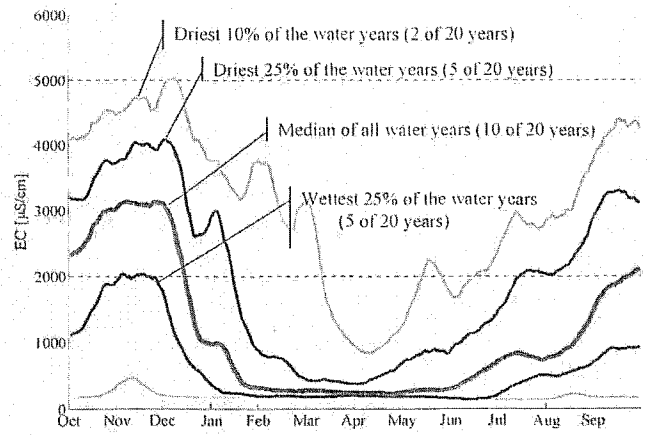

Figure E-3 – Seasonal Distribution of low-tide salinity at Antioch, 1983-2002

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.2.3. Salinity at Kentucky Point on Twitchell Island – 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.

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State Water Resources Control Board
Delta Flow Criteria Informational Proceeding
March 22, 2010

Exhibit by City of Antioch
Summary of Historical Freshwater Availability at Antioch

Summary

The historic (pre-1918) Delta was significantly fresher than the current Delta. The characterization of the Delta as "historically saline" is false and is not based on scientific evidence. Historical salinity and flow conditions must be considered when: (i) establishing Delta outflows and inflows to protect public trust values which adapted to these conditions, (ii) establishing the criteria (volume, timing and quality) required by Senate Bill 7X 1, and (iii) establishing drinking water quality standards for the Delta.

1. Introduction

The City of Antioch (Antioch), located along the San Joaquin River in the western portion of the Sacramento and San Joaquin River Delta (Delta), is one of the oldest towns in California. Since the 1860s, Antioch has obtained all or part of its freshwater supply directly from the San Joaquin River.[1] The City, because of its position in the western Delta, is also concerned with the ecological health of the Delta and its long-term viability as a recreational destination.

As part of the informational proceeding on establishing flow criteria in the Delta, this document summarizes the historical salinity and flow conditions near Antioch and contrasts them with the largely saline conditions prevailing today. The supporting document to this summary is a "powerpoint style" document containing text and figures relevant to the material presented in this summary.

2. Systemic changes have reduced freshwater flows and increased salinity in the western Delta, including at Antioch

Salinity in the western Delta (including at Antioch) is influenced both by natural factors, including ocean tides and hydrology of the upstream watersheds, and by artificial factors, including channelization of the Delta, elimination of tidal marsh, reservoir storage and release operations, and water diversions.

Major anthropogenic modifications to the Delta that affect salinity intrusion began with the European settlement of the region around 1850. Tidal marsh acreage in the Delta decreased from over 250,000 acres in the 1870s to less than 30,000 acres in the 1920s and

[1] Much of the water in the western Delta (including the City's water supply) comes from the Sacramento River. Historically, significant amounts of Sacramento River water flowed into the San Joaquin River east of Antioch at Three Mile and Georgiana Sloughs. Sacramento River water also reaches Antioch where the river merges with the San Joaquin River just west of the City. Town of Antioch v. Williams Irrigation District et al. (1922) 188 Cal. 451, 455

has since continued to decrease (CCWD 2010), producing significant changes in the Delta landscape (Att. at pg. 7). For example, dredging of the Delta river channels to create the Stockton and Sacramento Deep Water Ship Channels affected the salt transport and distribution in the Delta (CCWD 2010). Construction of reservoirs for storage purposes started in the early 1900s and the largest reservoirs of the Central Valley Project (CVP, Lake Shasta) and the State Water Project (SWP, Lake Oroville) were completed in 1945 and 1968, respectively (CCWD 2010). Total upstream reservoir storage capacity increased from 1 million acre-feet (MAF) in 1920 to more than 30 MAF by 1979 (CCWD 2010). Water exports from the Delta have been steadily increasing since the 1950s, and the combined annual exports from CVP and SWP have increased, on average, from about 0.5 MAF/yr in the late 1950s to about 5 MAF/yr during the recent period (Att. at pg. 8).

3. Historical extent of freshwater

Testimony from the lawsuit filed by the Town of Antioch in 1920 and from various literature reports demonstrates that freshwater (low salinity conditions) prevailed in the western Delta in the late 1800s and early 1900s.

3.1 Testimony from Antioch's lawsuit in 1920

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 (Town of Antioch [plaintiff] v. Williams Irrigation District et al. [defendants] (1922, 188 Cal. 451)). The testimony from the Antioch lawsuit provides a perspective of the salinity conditions prevailing in the early 1900s.

3.1.1 Pre-1918: Freshwater was available at Antioch year-round

Testimony from the defendants in the Antioch lawsuit indicated that in the late 1800s, water at Antioch was known to be brackish at high tide during certain time periods, but Antioch was able to pump freshwater at low tide throughout the year, with the possible exception of the fall season during one or two dry years. Water at Antioch was fresh at low tide at least until around 1915 (when the pumping plants started pumping continuously, regardless of tidal stage) (Att. at pg. 11).

Testimony from the plaintiff in the Antioch lawsuit indicated that Antioch's freshwater supply was obtained directly from the San Joaquin River (see footnote 1 above) from about 1866 to 1918, first by private water companies and then by the municipality after 1903 (when the City acquired pre-existing water rights) (Att. at pg. 12). Plaintiff's testimony included salinity measurements taken at Antioch (1913-1917) that indicated that prior to 1918, freshwater was available at Antioch even during dry years and in the fall (Att. at pg. 12).

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3.1.2 Post-1918: Increased upstream diversions drastically increased salinity intrusion

Testimony and measurements from the Delta (1918-1920) presented by the plaintiff in the Antioch lawsuit indicated that after 1918, salinity abruptly increased during the irrigation (rice cultivation) season, but returned to a potable level after irrigation ceased (Att. at pg. 13). The effect of upstream diversions was also confirmed by records in the plaintiff's testimony from California & Hawaiian Sugar Refining Corporation (C&H) (CCWD 2010). Plaintiff's testimony indicated that although Antioch is located along the San Joaquin River, the source of much of the water at Antioch was the Sacramento River, which flowed to Antioch via Georgiana and Three Mile Sloughs (Att. at pg. 14-15); this was confirmed by the California Supreme Court (Att. at p. 15).

Information from the Antioch lawsuit is consistent with literature reports (see the following discussion) and with paleo records of salinity and river flow obtained from tree rings and sediment cores (CCWD 2010).

3.2 Literature reports

Several literature reports confirm that freshwater was available year-round in the western Delta (including Antioch) and Suisun Bay during the late 1800s and early 1900s. For instance, DPW (1931), the precursor to the Department of Water Resources, indicated that the City of Antioch obtained all or most of its freshwater supplies directly from the San Joaquin River until 1917, and that salinity intrusion prevented domestic use of water at the Antioch intake in summer and fall after 1917 (Att. at pg. 9). DPW (1931) and Tolman and Poland (1935) indicated that prior to the 1920s, water near the City of Pittsburg was sufficiently fresh for that City to directly obtain all or most of its freshwater (Att. at pg. 10). Dillon (1980) and Cowell (1963) indicated that prior to the 1920s, freshwater was available in the Suisun Bay and Carquinez Straits for use by the City of Benicia (Att. at pg. 10). Means (1928) indicated that Carquinez Strait (near Martinez in the western Delta) is the approximate boundary between salt water and freshwater under natural conditions. Moreover, Means (1928) also indicated that during the wet season freshwater extended up to the Golden Gate (Att. at pg. 9).

The California Department of Water Resources (DWR, 1960) estimated that water with a chloride concentration of 350 mg/L or less would be available at San Joaquin at Antioch about 85% of the time under "natural" conditions (Att. at pg. 16). DWR (1960) also 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, with decreasing freshwater availability due to upstream diversions; DWR also projected further deterioration of water quality in 1960 and later, but did not include the effects of reservoir releases for salinity control (Att. at pg. 16).

4. Current Salinity Conditions at Antioch

Salinity data compiled by the Interagency Ecological Program (IEP) and California Data Exchange Center (CDEC) were used to analyze the present availability of freshwater at Antioch. These quantitative measurements from the present were compared to the

testimony from the Antioch lawsuit and to observation recorded by C&H to establish how salinity at Antioch and in the western Delta has increased over time compared to historical conditions.

4.1 Freshwater availability continues to decline

Availability of freshwater at Antioch continues to decline. Antioch may take water at its intake when salinity is less than 250 mg/L chlorides (equivalent to about 1000 µS/cm EC)[2]. The number of days per year, expressed as a percentage, when daily average salinity at Antioch was below 1000 µS/cm EC declined from about 70% in the late 1960s to about 40% during the recent period (Att. at pg. 19).

Even in years with above normal runoff in the Sacramento River watershed, freshwater at Antioch is less available than historically (Att. at pg. 20). For instance, during the above normal water year 2000, water at the City of Antioch's intake was below 1000 µS/cm EC for the entire day for about four-and-a-half months (early February through mid-June) and for a portion of the day at low tide for another three-and-a-half months (mid-June through September). For the remaining four months (October-January), water at the City's intakes exceeded 1,000 µS/cm EC for the entire day, regardless of tidal stage. Testimony from the Antioch lawsuit indicates that prior to 1918, water at the City of Antioch's intake was below 1000 µS/cm EC for the entire day during above-normal years and in all but dry fall months.

Salinity at low tide at Antioch during the present is higher than historical conditions (Att. pg. 21). For instance, during the period 1985 to 2009, the tenth percentile low tide daily salinity was below 1,000 µS/cm EC for about one-and-a-half months, and the 25th percentile low tide daily salinity was below 1,000 µS/cm EC for about nine months. However, testimony from the Antioch lawsuit indicates that during the driest years prior to 1918, low tide salinity at the City of Antioch's intake was below 1000 µS/cm EC for about nine months; for all but the driest years, salinity at low tide was below 1,000 µS/cm EC throughout the year. These data establish that salinity is higher at Antioch for a wider range of hydrologic conditions and for a longer duration of the year than under historic conditions.

4.2 Salinity intrusion occurs earlier and extends farther

Since the early 1900s the California & Hawaiian Sugar Refining Corporation (C&H), located in Crockett near the western edge of Suisun Bay, obtained its freshwater supply in Crockett. When freshwater was not available at Crockett, C&H used barges that traveled upstream on the Sacramento and San Joaquin Rivers to procure freshwater. The measurements of distance to freshwater from Crockett, recorded during these barge operations, serve as a surrogate for the historical extent of freshwater in the western

[2] The freshwater salinity threshold of 250 mg/L chlorides at the San Joaquin River at Antioch is based on the 1968 agreement between the City of Antioch and DWR. This threshold is approximately equivalent to 1000 µS/cm EC, based on the site-specific empirical relationships between chloride concentration and EC (K. Guivetchi, DWR Memorandum dated June 24, 1986).

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Delta. A comparison of C&H data during 1908-1917 and estimates[3] of distance to freshwater from Crockett during the post-SWP construction period (1966-1975) indicates that salinity intrusion into the Delta occurs on average about 4 months earlier (in March instead of July) during the post-SWP construction period of 1966-1975 (Att. at pg. 17). Comparison of C&H data from 1908-1917 to estimates of distance to freshwater from Crockett during the period 1995-2004 indicates that salinity intrusion during the recent period not only occurs earlier (by 4 months) but also extends farther in to the Delta (by about 5 to 20 miles) (Att. at pg. 18).

5. Conclusions

- Prior to 1918, freshwater was almost always available at Antioch at least at low tide. Only during dry years and during high tide conditions did salinity at Antioch become brackish.
- Between 1918 and the late 1930s, drought conditions, upstream water diversions, and channelization increased the salinity of water at Antioch.
- By 1940 the drought receded, but salinity at Antioch remained elevated.
- Salinity has continued to increase in recent years at Antioch.
- The fraction of time that water at Antioch is suitable for use (when salinity is < 250 mg/L chlorides or 1000 µS/cm EC) has declined significantly.
- "Historic" Delta was significantly fresher than the current Delta.

6. Request

The City of Antioch requests that the State Water Resources Control Board review and incorporate historic salinity data into its analyses when considering Delta outflow requirements to protect public trust resources in the Western Delta and the flow requirements of SB X7 1 (e. g., volume, timing and quality), and that the Board use historic data to establish and to adjust its "baseline" of water quality for both fisheries health and drinking water quality standards. In fact, the City asks the SWRCB to establish flow and salinity standards in line with the Delta's historic fresh condition. The City also requests that the SWRCB consider using the gauging station at Antioch as a point of interest to ensure that flow criteria and salinity objectives are met.

References

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Means, T. 1928. Salt Water Problem: San Francisco Bay and Delta of Sacramento and San Joaquin Rivers, San Francisco, California, April 1928. Report prepared for the Association of Industrial Water Users of Contra Costa and Solano Counties.
Tolman, C. F. and J. E. Poland. 1935. *Investigation of the Ground Water Supply of the Columbia Steel Company, Pittsburg, California*. Stanford University, California, May 30, 1935.
Town of Antioch v. Williams Irrigation District (1922) 188 Cal. 451.

[3] These estimates were made using IEP data in CCWD (2010), which will be presented by the Contra Costa Water District during this informational proceeding.

November 15, 2010

Sent via email to:

Phil Isenberg, Chair, and Members of the Delta Stewardship Council
Joe Grindstaff, Acting Executive Director, Delta Stewardship Council
Lester Snow, Director, California Resources Agency
David Hayes, Deputy Secretary of the Interior
Karen Scarborough, Undersecretary, California Resources Agency; for distribution to BDCP Steering Committee members

Re: Antioch's Concerns regarding the Bay Delta Conservation Plan (BDCP)

Introduction

The City of Antioch believes it is important to provide comments regarding the potential adverse effects of the Bay Delta Conservation Plan (BDCP) on the Delta, particularly the impacts that may conflict with the goals and policies of the Delta Reform Act.

Antioch's major concerns with the BDCP process and proposed project are summarized as follows:

1. The proposed BDCP proposed project will not comply with the Delta Reform Act, nor meet the co-equal goals in the Western Delta. The BDCP proposed project will:
   - Reduce Delta outflow
   - Increase reliance on the Delta for water supply by increasing exports over current levels
   - Increase salinity in the Western Delta (and other portions of the Delta)
   - Move X2 upstream from its present location.
2. The effects of the BDCP would likely continue the 150-year trend of degradation of the Delta, which was summarized in the draft *Delta Ecosystem White Paper*, presented to DSC on October 28, 2010.
3. The BDCP has not analyzed the impacts of increased Western Delta salinity on the Western Delta ecosystem.

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4. The BDCP has to date not made any proposals to mitigate or pay for potential adverse impacts to Western Delta stakeholders.

Addressing these concerns is not only important for the health of the Delta, it is critical to the success of the BDCP. These concerns are discussed in more detail below.

The BDCP as Presently Proposed is not Consistent with the Co-Equal Goals

During the October 28, 2010, Delta Stewardship Council (DSC) meeting, Antioch was pleased to hear that it appears to be the DSC's position that the BDCP must be consistent with the co-equal goals. Unfortunately, based on recent modeling and *Effects Analysis* by the BDCP, the BDCP project as presently proposed is predicted to:

- Increase diversions and decrease Delta outflow. The BDCP is projected to increase diversions from the Delta above the amounts that have been exported to date by up to 1 million acre feet per year. These projected additional diversions will reduce Delta outflow.[1]

- Degrade water quality significantly in the Western Delta and at Antioch's Intake. BDCP modeling results and *Effects Analysis* indicate an increase in salinity in the Western Delta as a result of the export of Sacramento River water from the northern Delta and reductions in net Delta outflow. The proposed BDCP project is expected to increase average seasonal salinity in the Western Delta, at Antioch, and in portions of the Central Delta by 5 to 30% in spring, summer, and fall.[2] Daily increases in salinity within each of these periods, and in different year types, are expected to range to significantly higher values.

- Relocate X2 in the summer and fall in wet and above normal years well upstream (eastward) of its present location.[3]

[1] The most recent BDCP Effects Analysis (October 21, 2010) is attached to this letter as Attachment A.

[2] Modeling results from the BDCP presented at the June 17, 2010 BDCP Steering Committee meeting, "BDCP Physical Modeling Update: Summary of Delta Hydrodynamic & Water Quality Results" are attached to this letter as **Attachment B**.

[3] Increases in salinity (although less than in the western Delta) are also predicted to occur as a result of the BDCP project in portions of the Central Delta and in Old and Middle River. See **Attachment B**.

Western Delta Impacts

Reducing outflow and increasing salinity would adversely impact the Western Delta ecosystem, which has evolved as a primarily freshwater environment. Further, it appears that the BDCP project as presently proposed would neither protect nor enhance the cultural, recreational, public trust resources or agricultural values in the Western Delta.[4] All of these values in the Western Delta are historically based on a Delta with lower salinity and greater outflow than the projected conditions following the implementation of the BDCP project.[5]

The BDCP's proposed project will also have impacts on Western Delta water supply reliability, water rights and economy. For example, potential costs to the City of Antioch as a result of the salinity increases projected by BDCP effects analyses are estimated to be **$24,000 per day (up to $720,000 per month)**, when water is too saline for diversion at the City's freshwater intake location.[6] Given Antioch's current budget of approximately **$20 million per year**, the impacts of the proposed project will be significant.

The BDCP as presently proposed will continue the 150-year trend of Delta Degradation

The historic decline of outflow and increase in salinity clearly indicates that the Delta ecosystem has to date been given far lower priority than water exports. Although

[4] Water Code section 85022(c) provides that the Delta is a distinct and valuable resource of "vital and enduring interest to all the people" and exists as a "delicately balanced estuary and wetland ecosystem of hemispheric importance."

[5] It is State policy to achieve the co-equal goals of providing a more reliable water supply for California and protecting, restoring and enhancing the Delta ecosystem. These goals are to be achieved in a "manner that protects and enhances the unique cultural, recreational, natural resource, and agricultural values of the Delta as an evolving place." The goal of water supply reliability is not limited to Delta exports and includes in-Delta water supply reliability. Inherent in the co-equal goals are the following objectives set forth in Water Code section 85020:

> (c) Restore the Delta ecosystem, including its fisheries and wildlife as the heart of a healthy estuary and wetland system
> (e) Improve water quality to protect human health and the environment consistent with achieving water quality objectives in the Delta.

[6] Balanced with achieving the co-equal goals is requirement that the Delta Plan and the actions of the Delta Stewardship Council not "diminish, impair, or otherwise affect in any manner whatsoever" water rights including pre-1914 water rights. Water Code Section 85031. The City of Antioch has an adjudicated pre-1914 water right. The City of Antioch is located in the Western Delta just to the east of Suisun Bay at the confluence of the Sacramento and San Joaquin Rivers. The City was founded in the 1850s and was incorporated as a City in 1872. The City has diverted its water supply from the Delta for well over 100 years and has some of the oldest and highest priority water rights in the Delta. Although the City's diversion point is near the mouth of the San Joaquin River, the primary source of the City's water supply is actually the Sacramento River via Three Mile and Georgiana Sloughs as well as from the confluence.

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legislatively declared "equal," export water supply reliability and ecosystem restoration are not equal – not yet. Significant restoration and enhancement of the Delta ecosystem will need to be performed before the Delta ecosystem could ever be declared "co-equal" with export water supply reliability.

As outlined in the DSC White Paper on the *Delta Ecosystem*, the Delta environment has been substantially degraded by systematic alterations that have occurred over the past 150 years, including historic anthropogenic alterations that occurred prior to 1920 and that resulted in significant decreases in outflow and increases in salinity. The State and Federal Water projects (the Projects) resulted in additional, substantial impacts to the Delta following this time period. The BDCP proposed project will compound these historic injuries and will further degrade the Delta environment and the fisheries it supports. The US EPA, State Water Resources Control Board, California Department of Fish and Game, and most recently, Department of Interior biologists[7] have all called for increased Delta outflow and reduced diversions, not the opposite, as BDCP is proposing.

Attached to this letter as **Attachment C** are portions of testimony submitted by Antioch outlining the historic alteration of the Delta. This testimony was submitted to the State Water Resources Control Board during the Delta Flow Criteria proceedings. Antioch's testimony (as well as testimony submitted by Contra Costa Water District[8]) shows that the Delta was historically fresher than today's Delta and that the availability of freshwater in the Delta and at Antioch's intake has declined as the result of historic anthropogenic alterations.[9] This testimony also shows that while salinity historically varied more than today's Delta, the variability occurred in a much fresher Delta with fresh water extending well into Suisun Bay in most years.

No Proposals to Mitigate BDCP's Potential Impacts

Antioch has been actively engaged in the BDCP planning process, regularly attends the BDCP Steering Committee and DSC meetings, and makes and submits comments on issues as they arise. Antioch has sought to collaborate with the BDCP project proponents

[7] See Department of Interior biologists *BDCP Effects Issue Brief*, dated September 27, 2010.

[8] Contra Costa Water District also submitted a comprehensive historic salinity study to the SWRCB during the Delta Flow Criteria proceedings. This study can be found at: http://www.ccwater.com/salinity/HistoricalSalinityReport-2010Feb.pdf

[9] As set forth in more detail in **Attachment C**: Tidal marsh acreage in the Delta decreased from over 250,000 acres in the 1870s to less than 30,000 acres in the 1920s and has since continued to decrease. Total upstream reservoir storage capacity increased from 1 million acre-feet (MAF) in 1920 to more than 30 MAF by 1979. Water exports from the Delta have been steadily increasing since the 1950s, and the combined annual exports from CVP and SWP have increased, on average, from about 0.5 MAF/yr in the late 1950s to about 5 MAF/yr during the recent period.

and agencies in the interest of protecting Antioch's water supply and the western Delta ecosystem and the public trust resources. However, to date there have been no fruitful discussions between Antioch and BDCP proponents or agencies to mitigate the impacts of the BDCP, through either regional solutions or other measures.

Antioch has raised its concerns about the impacts to its water quality and water rights both in writing and verbally at numerous BDCP Steering Committee meetings. Comment letters on record from Steering Committee members and other stakeholders raise similar concerns and make requests that have not been addressed to date, some from more than a year ago.[10] Antioch, CCWD, and North Delta Water Agency submitted a joint letter in December 2009 to request both information on specific model parameters and input/output data from the BDCP modeling analysis, to confirm the accuracy and adequacy of the models and to begin to estimate impacts.[11] To date, Antioch has received only very limited information, such that it cannot fully evaluate the expected impacts to its water supply.

BDCP, the Delta Reform Act, and the Delta Plan - Getting It Right

Antioch strongly supports the DSC taking a more active role in reviewing the BDCP documents to ensure compliance with the Delta Reform Act, as was discussed at the DSC meeting on October 28, 2010. While the BDCP has analyzed and publicized certain environmental benefits of the project, it has done almost nothing to analyze potential mitigation approaches to address adverse impacts of the project.

The BDCP Steering Committee has deferred the discussion of mitigating adverse impacts, saying that these impacts will be "addressed" during the EIR/EIS process. Steering Committee members and stakeholders have stated that engaging the impacted parties proactively will yield a more effective plan and reduce the current lack of trust in the process. To date, discussion of mitigation has been done selectively, or behind closed doors. Given the significance of the adverse impacts, addressing mitigation issues now could reduce mitigation costs and ensure the BDCP complies with the co-equal goals and the principles of reasonable use and the public trust.

Antioch does not oppose the principles and objectives of the BDCP. However, the City believes that the project as presently proposed would violate the co-equal goals and continue to degrade the Delta environment—this is clearly not in the public interest.

[10] See public comments posted on the BDCP website http://baydeltaconservationplan.com/BDCPPlanningProcess/HowToParticipateBDCPPublicComments.aspx.

[11] See http://www.baydeltaconservationplan.com/BDCPEIRComment Archive/LetterBDCPpreceding2009-12-10.pdf

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Proposed Solutions

Antioch believes that potential solutions may exist that could allow the BDCP to meet the co-equal goals. These potential solutions include:

- Commit to the goals of restoring substantial areas of the Delta ecosystem and take measures to enhance Delta outflow prior to the construction of any new export conveyance facilities.
- Establish effective and comprehensive restoration and enhancement goals and objectives for the Delta that are quantifiable, achievable, binding, and fully funded.
- Establish a "Do No Harm" policy: The SWRCB, Department of Fish and Game, Department of the Interior biologists and US EPA have recommended increased Delta outflows and reduced diversions. The BDCP needs to adopt a policy not to reduce outflow or increase salinity beyond existing levels.
- Incorporate mitigation for impacts into the BDCP planning and project design, rather than as an after-the-fact approach within the EIR/EIS process. Modeling has identified significant potential impacts of the BDCP project that can and should be addressed as part of the project design.
- Consider physical and regional in-Delta options to mitigate potential impacts of the BDCP, such as: regional consolidation of intakes and desalination.
- Include reduced diversion and increased Delta outflow alternatives for the EIR/EIS.
- Provide stakeholder engagement and comment disposition as part of the development of the BDCP and NCCP/EIR/EIS process. To date, stakeholder concerns have generally not been addressed, nor solutions discussed, with the exception of a few off-site meetings.

Antioch is ready to engage in discussing and developing these potential solutions. The City looks forward to working with all parties to achieve potential solutions that improve and restore the California Delta. Please contact me if you have any questions, or to discuss how Antioch's concerns may be addressed at this stage.

Sincerely,

Phil Harrington
Director of Capital Improvements/Water Rights
City of Antioch
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cc: Congressman George Miller
Congressman John Garamendi
U.S. Senator Dianne Feinstein
U.S. Senator Barbara Boxer
Senator Lois Wolk
Senator Mark De Saulnier
Assembly Member Jared Huffman
Assembly Member Joan Buchanan
City of Antioch City Manager Jim Jakel
City of Antioch City Attorney Lynn Tracy Nerland
City of Antioch Mayor and City Council Members

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