3. Tools to Assess the Effect of Changes on Water Supply and Hydrodynamics

3.1 Modeling of trends in outflow and salinity

A hypothesis for the decline of several Bay-Delta fishes is changes to through-Delta flows and the location of the low-salinity-zone. Enright and Culberson (2010) did an extensive review of trends in Delta outflow and salinity. They examined precipitation, outflow, and salinity trends before and after 1968 to discern outflow and salinity response to Central Valley Project (CVP)/State Water Project (SWP) operations (they also include analysis of pre- and post-Suisun Marsh salinity control gate operations, which began in 1988). They conclude that the data do not verify variability reduction; rather, annual and by-month salinity variability is generally greater in the post-project period; and that coefficients of variability for precipitation, outflow, and salinity increased after the projects were initiated. These increases in variability suggests that more powerful mechanisms are at play including land-use changes and climate, which overpower the homogenizing influence of appropriations of water, including those by the CVP/SWP, when considering long-term trends.

This section of the report (1) describes historical outflow, including outflow as measured by the location of X2 over the period of record 1922–2011 and (2) describes some, but not all, causes of identified changes in outflow over time. The period of record is evaluated annually as well as by decade.

The analysis of outflow over time is limited to the seasons that the state and federal fisheries agencies have identified as being potentially important to various aquatic species: fall (September through November) and winter-spring (January through June). The 2008 USFWS Biological Opinion (BiOp) for coordinated operation of the SWP/CVP (OCAP) included a fall outflow experiment (Fall X2 experiment) covering the months September through November (USFWS 2008, pp. 282-283). While acknowledging the uncertainty of benefit, the 2010 Flow Criteria Report also proposed a fall outflow requirement for the months September through November (State Water Board 2010, p. 98). For these reasons, fall outflow (September-November) is analyzed in this report.

The 2010 Flow Criteria Report further proposed a percent of unimpaired flows approach for the winter-spring months, covering January through June (State Water Board 2010, p. 98). They are the same months Jassby *et al.* (1995) used in their statistical analysis of the relationship between winter-spring outflows and longfin smelt abundance. For these reasons, Winter-Spring outflow (January through June) is also analyzed here.

3.1.1 Outflow and Calculated X2 Location (1922-2010)

The 2010 Flow Criteria Report suggests that the magnitude and timing of outflow and the location of the low-salinity zone have changed significantly over time, as evidenced by the difference between calculated unimpaired outflows and actual outflows (State Water Board 2010, pp. 28-33). The analysis contained in the 2010 Flow Criteria Report concludes the difference between unimpaired outflow and actual outflow is a result of increased appropriation of water from the Bay-Delta estuary and the Sacramento/San Joaquin River watershed. (State Water Board 2010, p. 28). That analysis is not appropriate and the conclusion is not accurate.

Unimpaired flow calculations are informative illustrations of precipitation, and they are used in this report for that purpose. However, as explained in detail below, unimpaired flow calculations are not appropriate estimations of natural outflow. The 2010 Flow Criteria Report fails to account for that fact or the fact that unimpaired flow is a calculation of a hypothetical environment. Unimpaired flow has never existed in our system and cannot be used as a surrogate measure for natural outflows. (DWR 1987, p. 10; *see also*, DWR presentation to State Water Board available on the State Water Board website and incorporated herein by this reference.) To do so would be counter to accepted scientific principles.

Further, it was and would continue to be an error to assume appropriation of water is the sole driver of outflow. As concluded by Enright and Culberson (2010), "seasonal outflow and salinity variability is primarily climate driven." Enright and Culberson demonstrated that consecutive month outflow differences are consistent with watershed precipitation, suggesting that climate is a more powerful mechanism controlling seasonal variability than water project operations on seasonal and decadal scales.

A further concern with the data cited to support the 2010 Flow Criteria Report is that the grouping of years averaged and used for comparative purposes does not avoid the potential for upstream hydrology to bias the results (State Water Board 2010, pp. 28-32). The analysis presented below evaluates the historical period of record (Water Years 1922 to 2010) and compares this period to the predevelopment era, providing a factual and scientifically sound basis for discussion.

3.1.1.1 Data and Methods

Table 1 summarizes the data used for this trends analysis. The analysis uses monthly flow time series in units of cubic feet per second (cfs.) for the available period of record from October 1921 through September 2010 (Water Years 1922 to 2010). All references to years in this study are to water years (October 1 through September 30 of the calendar year in which it ends) unless otherwise noted. These time series were used to compute annual time series in units of thousand acre-feet (TAF) per year or million acre-feet (MAF) per year. These time series were also used to create 12 monthly data series (*e.g.*, a January series, a February series, etc.) where successive values are 1 year apart.

Table 1Data Utilized in Trends Analysis

Data Record	Period of Record	Source
Net Delta Outflow	October 1921 – September 1929 October 1929 – September 2010	DWR BDO DAYFLOW
Sacramento River at Freeport	October 1990 – September 2010	DAYFLOW
Yolo Bypass	October 1990 – September 2010	DAYFLOW
San Joaquin River at Vernalis	October 1990 – September 2010	DAYFLOW
Mokelumne River below Woodbridge	October 1990 – September 2010	DAYFLOW
Cosumnes River at Michigan Bar	October 1990 – September 2010	DAYFLOW
Miscellaneous Stream Flow	October 1990 – September 2010	DAYFLOW
Delta Net Consumptive Use	October 1990 – September 2010	DAYFLOW
Delta Exports	October 1990 – September 2010	DAYFLOW
Unimpaired Flows	October 1990 – September 2010	DWR BDO
Sacramento River @ Shasta	October 1990 – September 2010	CDEC
American River @ Nimbus	October 1990 – September 2010	CDEC
Feather River @ Thermalito	October 1990 – September 2010	CDEC
Yuba River @ Marysville	October 1990 – September 2010	CDEC
Sacramento Accretions	October 1990 – September 2010	Calculated
Unimpaired Sacramento Accretions	October 1990 – September 2010	Calculated
X2 Location	October 1921 – September 2010	Calculated

BDO- Bay-Delta Office

CDEC – California Data Exchange Center (DWR 2011)

Calculated unimpaired flows include: Sacramento Valley, Sacramento River @ Red Bluff, Feather River, Yuba River, American River, San Joaquin Valley, East Side Streams, and In-Delta Consumptive Use

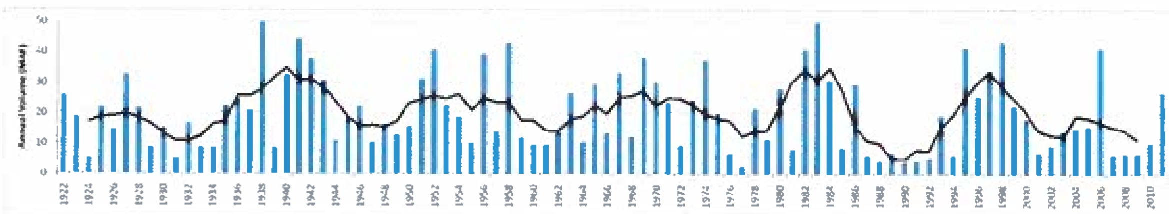
The primary source of historical Delta inflow and outflow data is the DAYFLOW database (DWR 2012). Monthly averages are computed from daily values provided in the database. Historical flows prior to October 1929 are based on a joint DWR-Bureau of Reclamation (1958) hydrology study and provided as monthly averages by the staff of DWR's Bay-Delta Office. Historical Eastside inflow is computed as the sum of historical river flows from the Mokelumne, Cosumnes, and miscellaneous streams. Historical Delta outflow, as reported in the DAYFLOW database, is a computed value based on water balance. In reality, Delta outflow is tidally influenced and fluctuates over daily diurnal flood-ebb cycles and over bimonthly spring-neap cycles. For example, outflow during summer tidal cycle can vary in direction and amount from 330,000 cfs. upstream to 340,000 cfs. downstream (Delta Atlas, 1993).

3.1.2 Annual Delta Outflow (1922–2010)

Annual Delta outflow shows no clear long-term time trend. Fox *et al.* (1990) found no statistically significant trend in annual Delta outflow between 1922 and 1986. The investigators concluded that precipitation had increased faster than water use within the watersheds. They noted that other factors, including imports, the redistribution of groundwater, and changes in runoff patterns, may have balanced the increase in water use within the watersheds.

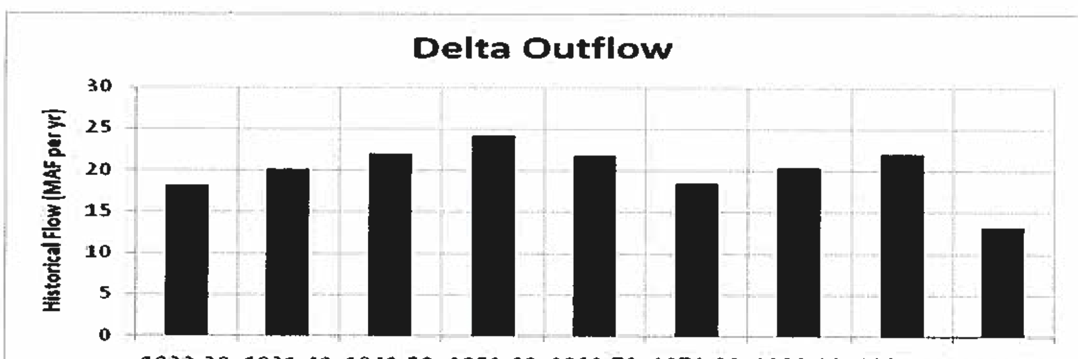
As shown on Figure 1, visual inspection suggests no statistically significant long-term trend in Delta outflow (shown as the blue bars) from 1922 and 2010. The black line shows a 5-year center-weighted average outflow. A Sen's nonparametric estimate of the long-term trend was conducted. A Mann-Kendall test, a two-sided test performed at the 95 percent confidence level, confirms that no statistically significant time trend exists.

Figure 1 Annual Variation in Outflow (TAF) showing no statistically significant trend over time.



To further characterize the outflow time series, Delta outflow is shown as decadal averages on Figure 2. The figure shows that decadal average outflows have varied, following no particular trend. However, outflow decreased in the most recent decade (2001–2010), the decade often described as the Pelagic Organism Decline (POD) period, compared to the previous decade (1991–2000), the pre-POD period and the second wettest period of record.[2]

Figure 2 Delta outflow by decade (1922–2010) showing no particular long term trend and a decrease in outflow in the most recent decade (the POD period) compared to the previous decade (the pre-POD period).

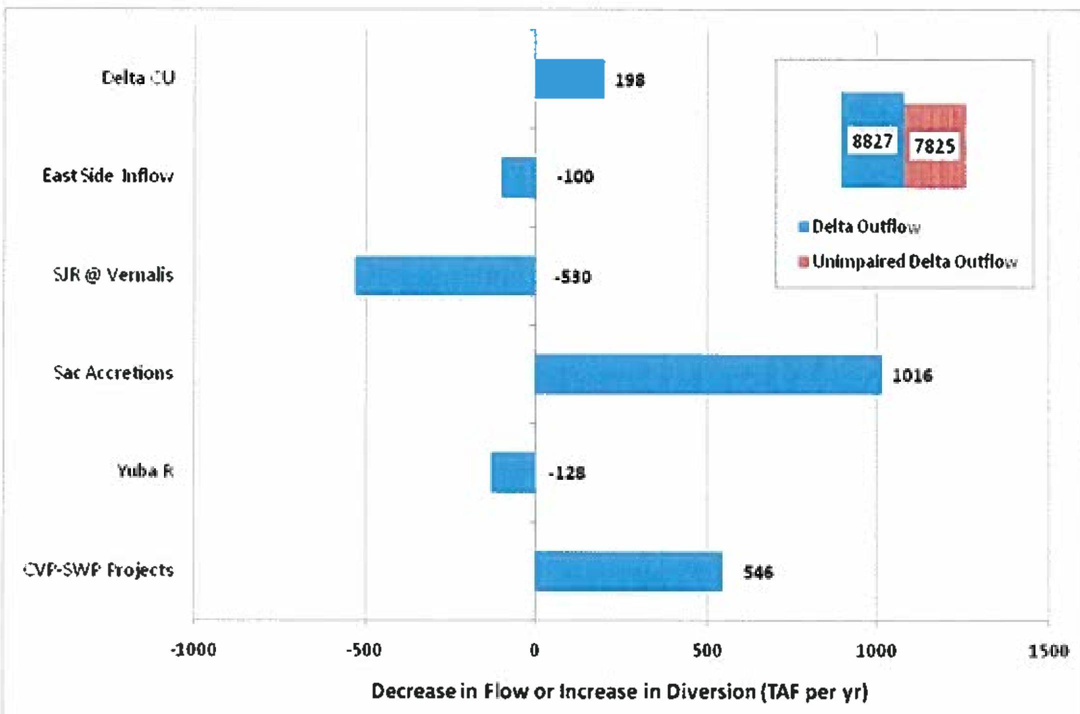


In an effort to understand the reasons for the decrease in outflow from the prior decade (1991–2000) to the recent decade (2001–2010), this analysis evaluates changes in inflows to the Delta and increases in water diversions, by source, both upstream and in-Delta.

[2] The 1991-2000 is the second wettest period of record based on the 8-River index.

Figure 3 demonstrates that annual outflow reduction is primarily the result of dryer hydrologic conditions between the prior decade (1991–2000) to the most recent decade (2001–2010). The vertical bar chart inset in the top right-hand corner of the figure demonstrates that the difference in outflow is explained in large part by the difference in unimpaired outflow (i.e. the unimpaired outflow reduction [red bar at 7,825 TAF/year] accounts for a majority of the outflow reduction [blue bar at 8,827 TAF/year]). In other words, the outflow reduction between decades is primarily the result of dryer hydrologic conditions; however, water management also contributed to the outflow reduction. The horizontal blue bars in the main body of the figure represent normalized contributions by individual hydrologic drivers towards the decrease in annual outflow between decades. The blue bars in the main body of the figure represent the changes in outflow other than hydrology, which is the largest driver of changes in outflow. These horizontal blue bars sum to the difference between the vertical bars. The figure shows that, after the reduction in unimpaired outflow, the reduction in Sacramento Valley accretions (1,016 TAF/year) is the most significant hydrologic factor explaining the decrease in outflow between the 2 decades. In-Delta appropriations by the CVP and SWP have a much smaller contribution to the outflow reduction (546 TAF/year); this contribution aggregates effects of in-Delta appropriations by the CVP and SWP and inflows from the Sacramento River (below Shasta), the Feather River, and the American River.

Figure 3 Contributions to decrease in annual outflow. Horizontal bars indicate sources of the change in outflow between decades. The majority of the difference in outflow between these two decades is due to differences in natural hydrology as measures by unimpaired outflow. Reductions in Sacramento accretions are the next largest contributor, followed by increases in CVP/SWP appropriations.



3.1.3 Calculated X2 Location (1922–2010)

The 2010 Flow Criteria Report focuses on fall (September through November) and winter-spring (January through June). As a result, this analysis of X2 location focuses on the data from these two seasons over the historical period (1922-2010).

The location of X2[3] is determined by a variety of factors. Freshwater from the upstream watersheds mixes with salty ocean water in the Delta. This freshwater flow (*i.e.,* Delta outflow) pushes the freshwater- seawater interface downstream; therefore, changes in Delta outflow (annual volumes as well as seasonal timing) affect the location of X2. Long-term changes in tidal energy, including sea level rise, influences how effectively freshwater flow pushes seawater downstream. Geometry of the land-water interface plays a key role in determining the tidal prism, amplitude, and excursion. Therefore, historical changes, including, but not limited to, changes in floodplains, channel configuration, bathymetry, and depth, affect long-term trends in the position of X2. Operation of water facilities such as the Suisun Marsh salinity gates and the Delta Cross Channel influence the flow paths within the Bay-Delta, therefore, also affect X2 positions.

The analysis presented in this paper is limited in its ability to evaluate the multiple factors that affect long-term X2 trends. As described in the following section, the X2 locations described in this study were estimated from flow data and therefore capture the influence of Delta outflow only. Therefore, the trend analysis does not reflect possible changes associated with sea-level rise, Delta island flooding, etc. It is anticipated that further analysis will be undertaken that will utilize measured salinity data to evaluate long-term X2 trends and, therefore, will reflect changes associated with other factors.

3.1.3.1 Data and Methods

The metric used in this study to evaluate long-term X2 trends is the calculated monthly average X2 location. The Delta outflow data described in Table 1 were used to estimate time series of the monthly average X2 location. These time series were also used to create 12 monthly data series (*e.g.,* a January series, a February series, etc.) where successive values are 1 year apart. A time series of the historical monthly average X2 location was developed for this trend analysis using the Kimmerer-Monismith (K-M) equation (Jassby *et al.* 1995). The K-M equation predicts average X2 location as a function of current month Delta outflow and previous month X2 location. The early historical Delta outflow time series includes several months when the value was negative. Since the K-M equation is a function of the common log of Delta outflow,

[3] The authors of this paper are not aware of any studies that conclude that the two part per thousand isohaline location (X2) is preferred by native fish over, for example, the one part per thousand or three parts per thousand isohaline positions. The resident native fish are largely adapted to a wide range of salinities (euryhaline). Instead, management of the X2 location was believed to create hydrodynamic conditions that maintain the "entrapment zone" in a location that is conducive to successful fish rearing (Jassby *et al.* 1995). References in this paper to shifts in the X2 location, therefore, should be understood to refer to shifts in hydrodynamic conditions and are not intended to suggest that any absolute salinity level has been found to be a central driver to fishery success.

the equation is not defined when outflow is less than 1 cfs. Therefore, an alternate approach was developed and utilized to estimate the X2 location when the K-M equation is not valid (Hutton 2011). As the X2 location used in the comparison and trend analysis reported below is a calculated location, differences may occur between the calculated X2 locations and the actual location, particularly in low outflow years after 1990.

3.1.4 Fall X2

The 2010 Flow Criteria Report cited Feyrer *et al.* (2007, 2011), (the latter of which was still in review at the time), for the conclusion that the average X2 location during fall has moved upstream, resulting in a corresponding reduction in the amount and location of suitable delta smelt abiotic habitat, as estimated by the X2 location (State Water Board 2010, p. 108). The Public Water Agencies reviewed these analyses and concluded that:

- Fall outflows were higher than unimpaired flows during the period 1956 to 1987 because the reservoirs were operating and making releases to reach mandatory reduced storage levels before the next rainy season. During this period, water demand throughout the watershed and in the Delta was developing so reservoir releases to create flood control space kept the Delta artificially fresh.
- The relevance of the time periods used in the 2010 Flow Criteria Report and in Feyrer *et al.* (2007, 2011) is not clearly articulated nor justified. The hydrological conditions that existed in the 1950s thru 1980s were highly altered, as further evidenced by the artificially fresh Delta in the fall, which to a certain extent flattened the hydrograph rather than supported variability.
- The actual trends in the location of X2 in fall are different than those presented in the 2010 Flow Criteria Report. The X2 location is, in fact, further downstream in the Delta (the Delta is fresher) in September, and about the same in October, compared to conditions before Shasta Dam was constructed.

The historical data indicate that the calculated X2 location early in the fall has been moving west (Delta becoming fresher) over time, with a flattening of that trend in more recent decades. The X2 data for the months August and September show the location of X2 trending closer to the San Francisco Bay, a downward trend (Figures 4 through 7). The month of August is added to this analysis because X2 in August affects X2 in September. A Sen's nonparametric estimate of the long-term trend was conducted, showing downward trends in August and September of 1.2 and 0.7 kilometers per decade, respectively. A Mann-Kendall test confirms the statistical significance of these trends.

Figure 4 Calculated X2 location in August 1922–2010, showing a statistically significant downward trend of 1.2 kilometers per decade over the time period.

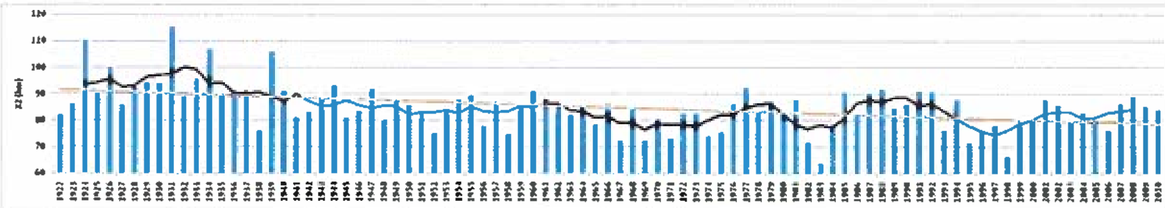


Figure 5 Calculated X2 location in August by decade (1922–2010).

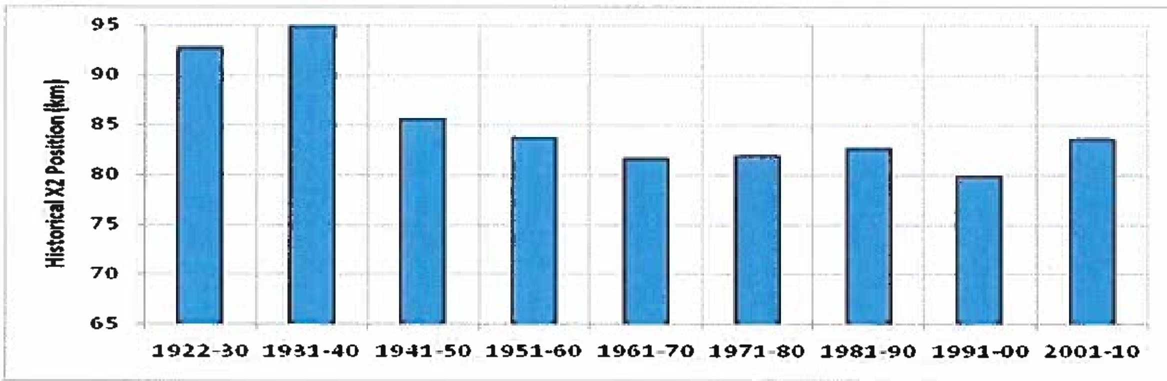


Figure 6 Calculated X2 location in September 1922–2010, showing a statistically significant downward trend or 0.7 kilometers per decade over the time period.

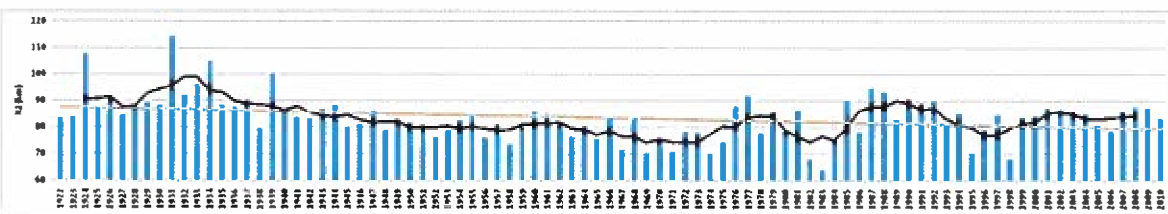
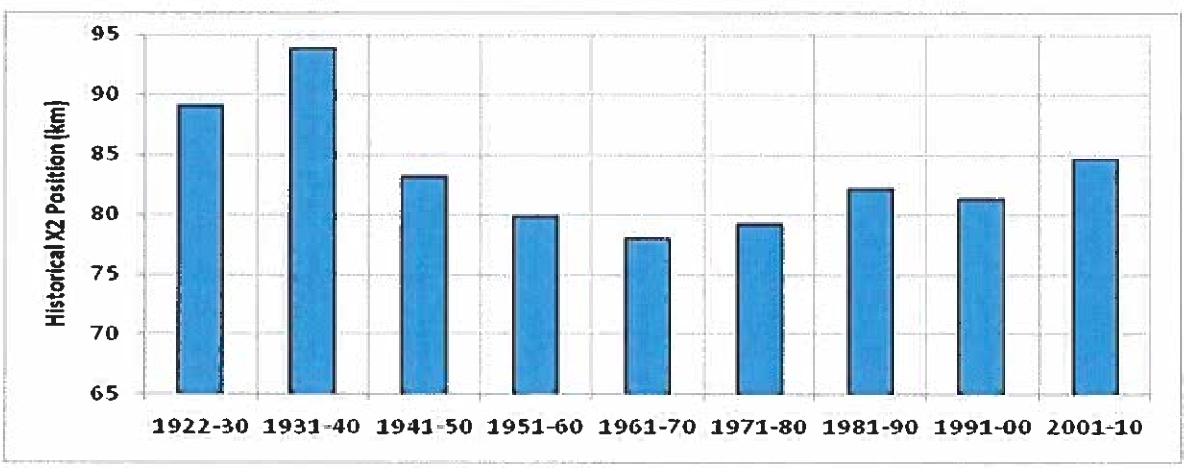


Figure 7 Calculated X2 location in September by decade (1922–2010).



Figures 8 and 9, upon visual inspection, indicate no long-term trend in the position of X2 in Octobers. A Mann-Kendall test confirms that no significant long-term trend exists. Figures 10 and 11 for the month of November show a different trend, with increasing X2 over time. A Sen's nonparametric estimate of the long-term trend was conducted, resulting in an increasing trend of 0.5 kilometer per decade. A Mann-Kendall test confirms the statistical significance of this trend.

Figure 8 Calculated X2 location in October 1922–2010, showing no significantly significant trend in salinity over the time period.

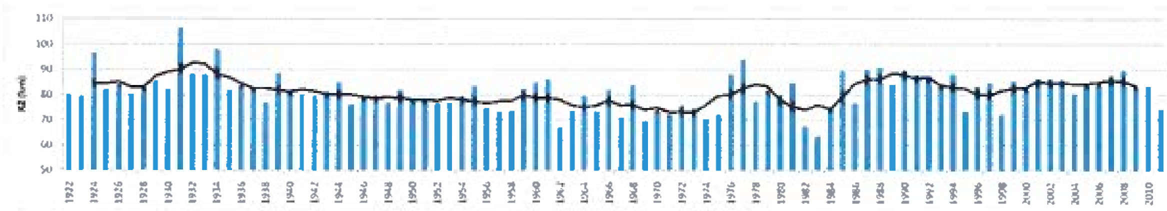


Figure 9 Calculated X2 location in October by decade (1922–2010).

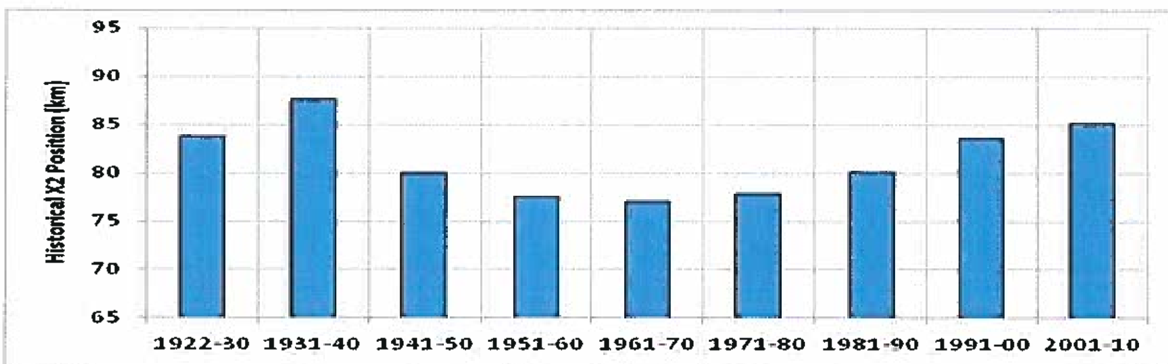


Figure 10 Calculated X2 location in November 1922–2010, showing a statistically significant increasing trend of 0.5 kilometers per decade over the time period.

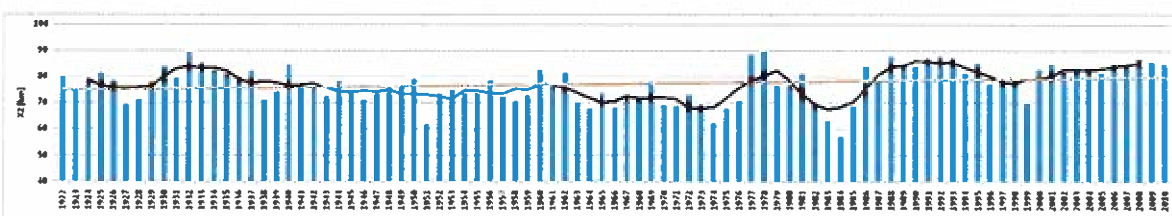


Figure 11 Calculated X2 location in November by decade (1922–2010).

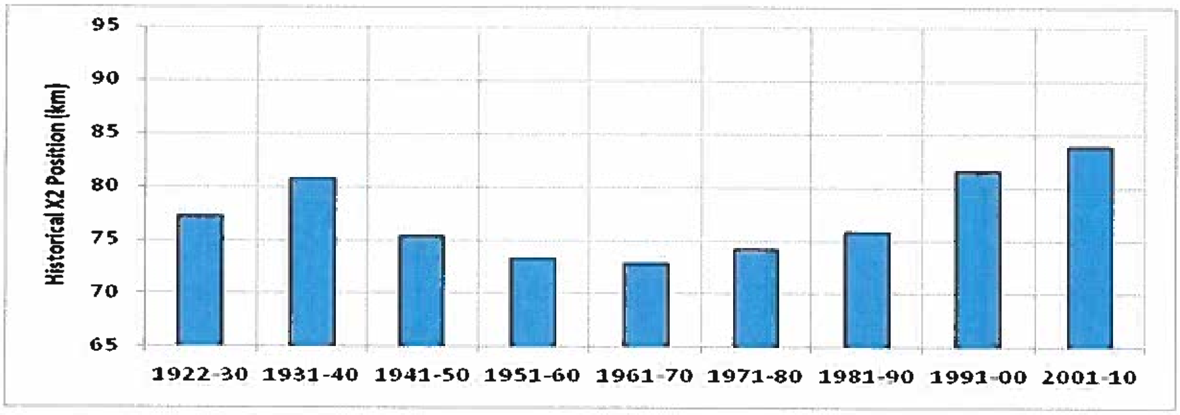
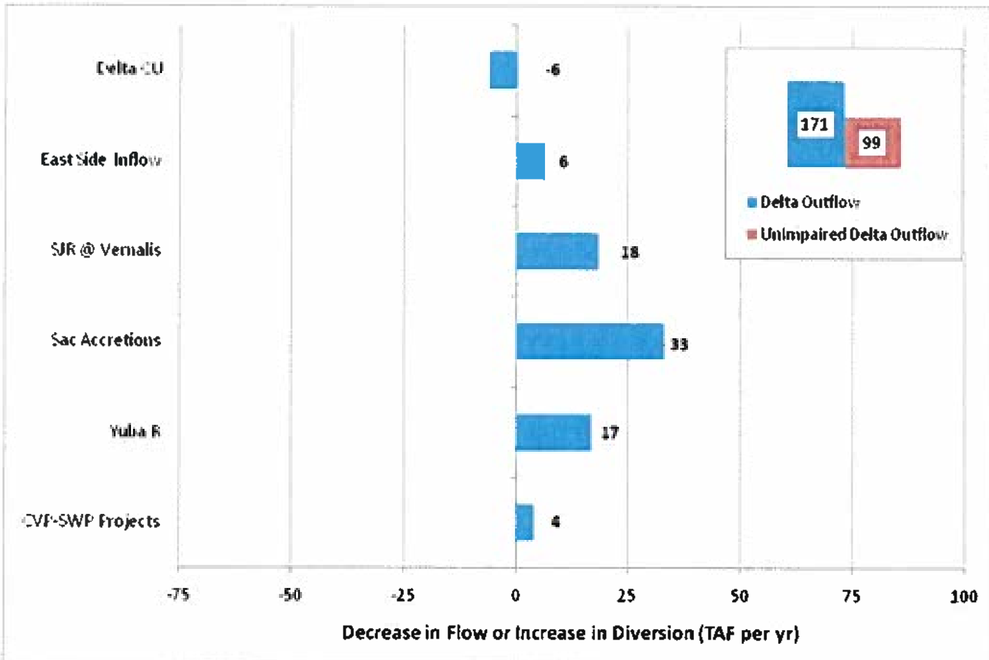


Figure 12 demonstrates that the September outflow reduction is primarily the result of dryer hydrologic conditions that have occurred between decades, from the prior decade (1991–2000) to the most recent decade (2001–2010). The vertical bar chart inset in the top right-hand corner of the figure demonstrates that the difference in outflow is explained in large part by the difference in unimpaired outflow (i.e., the reduction in unimpaired outflow [red bar at 99 TAF/year] accounts for a majority of the reduction in outflow [blue bar at 171 TAF/year]). However, water management also contributed to the outflow reduction. The horizontal blue bars in the main body of the figure represent normalized contributions by individual hydrologic drivers towards the decrease in annual outflow between decades. These horizontal blue bars sum to the difference between the vertical bars. These horizontal blue bars in the main body of the document represent changes in outflow other than hydrology. The figure shows that, after reduction in unimpaired outflow, the reduction in Sacramento Valley accretions (33 TAF/year) is the next most significant hydrologic factor explaining the decrease in September outflow between the 2 decades. The CVP/SWP Projects appear to have had minimal (4 TAF/year) contribution to reductions in outflow. Increased exports are nearly balanced by increased upstream project reservoir releases.

Figure 12 Contributions to decrease in September Delta outflow (1991-2000 compared to 2001-2010). The majority of the difference in outflow between these two decades is due to differences in natural hydrology as measured by unimpaired outflow. Reductions in Sacramento accretions are the next largest contributor.



Similar to Figure 12, Figures 13 and 14 identify the hydrologic factors that drive the decrease in October and November outflow from the prior decade (1991–2000) to the most recent decade (2001—2010), respectively. The vertical bars on Figure 13 show that unimpaired flow was higher in 2001–2010 than in 1991–2000 (red bar at -14 TAF/year). The figure shows that the reduction in Sacramento Valley accretions (93 TAF/yr) and San Joaquin River inflow at Vernalis (40 TAF/year) were the most significant factors in explaining the decrease in October outflow between the 2 decades. The CVP/SWP Projects actually contributed to higher outflow in 2001–2010 (-57 TAF/year), i.e., increased exports were more than fully balanced by increased upstream project reservoir releases. The vertical bar chart inset in the top right-hand corner of Figure 14 demonstrates that the difference in November outflow is explained in large part by the difference in unimpaired outflow; that is, the reduction in unimpaired outflow [red bar at 107 TAF/year] accounts for a majority of the reduction in outflow [blue bar at 136 TAF/year]. The horizontal blue bars in the main body of the figure represent normalized contributions by individual hydrologic drivers towards the decrease in annual outflow between decades. These horizontal blue bars sum to the difference between the vertical bars. These horizontal blue bars in the main body of the document represent changes in outflow other than hydrology. The figure shows that, after reduction in unimpaired outflow, no single hydrologic factor stands out in explaining the decrease in November outflow between the 2 decades. In other words, while water management also contributed to the outflow reduction between decades that reduction is primarily the result of dryer hydrologic conditions.

Figure 13 **Contributions to decrease in October Delta outflow (1991-2000 compared to 2001-2010). Unimpaired flow was higher in the most recent decade. Reduction in Sacramento Valley accretions and San Joaquin River inflow at Vernalis were the most significant factors in explaining the decrease in October outflow between the two decades. CVP/SWP Projects contributed to higher outflow in 2001-2010.**

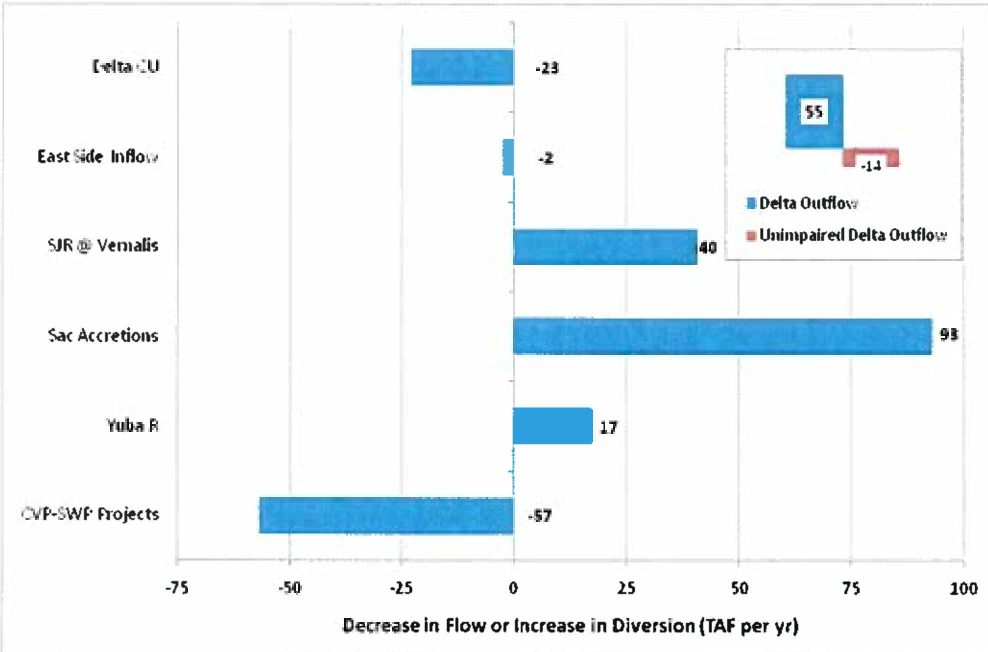
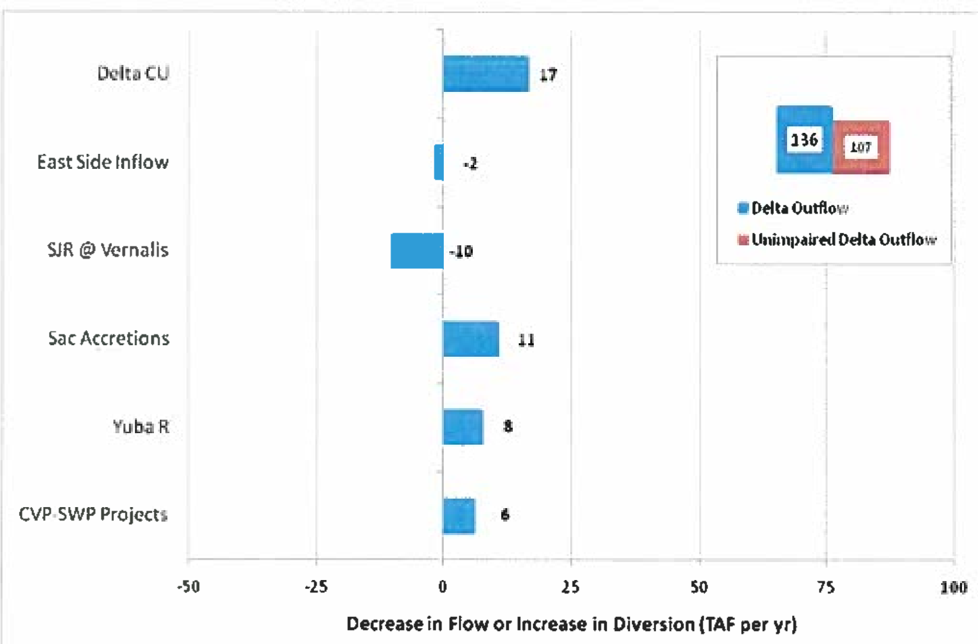


Figure 14 **Contributions to decrease in November Delta outflow (1991-2000 compared to 2001-2010). The difference in November outflow is explained in large part by the reduction in unimpaired outflow. After reduction in unimpaired outflow, no single hydrologic factor stands out in explaining the decrease in November outflow between the two decades.**



3.1.5 Winter-Spring X2

The 2010 Flow Criteria Report proposed a percent of unimpaired flow approach to managing outflow from January through June (State Water Board 2010, p. 98). The primary justification for this recommendation was the statistical correlation between winter-spring (January-June) outflow (X2) and longfin smelt abundance (State Water Board 2010, pp. 100-108). A secondary rationale was the existence of various other statistical correlations between abundance of several non-Endangered Species Act listed species and outflow (X2) during various months within the January-June (winter-spring) timeframe (State Water Board 2010, pp.100-108). A third rationale was a citation to Bunn and Arthington (2002) and their four principles that generally describe how flow affects aquatic biodiversity, although the 2010 Flow Criteria Report did not explain the potential applicability of those principles to the Bay-Delta estuary (State Water Board 2010, p. 100). To support the conclusion that outflow (X2) has changed over time, creating an increasingly unnatural flow pattern, the 2010 Flow Criteria Report made several comparisons between actual outflow and unimpaired outflow over various time periods: 1956–1987, 1988–2009, and 2000–2009 (State Water Board 2010, p. 104).

There are several observations in the 2010 Flow Criteria Report regarding the analysis of Winter-Spring X2 patterns that are particularly relevant and worth reconsidering.

- It is not appropriate or meaningful to average the winter months (January-March) and the spring months (April-June) together for the purpose of identifying trends in outflow. The hydrology between winter and spring is in stark contrast, as are the life stages and biological requirements of the fishes in the two seasons. The inflow and diversion patterns are also quite different in winter compared to spring.

- The time periods selected (1956–1987, 1988–2009, and 2000–2009) for comparative purposes in the 2010 Flow Criteria Report raise a number of concerns. It is unclear how natural hydrology was accounted for in the selection of averaging periods. This lack of clarity is a concern as natural hydrology can skew the results of a data analysis, thereby suggesting changes in water consumption that may not exist. The biological relevance of the time periods selected (1956 and later) is also questionable because these periods represent highly altered physical conditions in the Delta and are, therefore, not related to "natural" or undeveloped conditions. It is also unclear why the entire hydrologic record was not used in the analysis.

- As mentioned previously and as discussed in more detail below, unimpaired flows are a calculation of artificial conditions. The Delta and the fishes within the Delta have never experienced unimpaired outflow. It is, therefore, inappropriate to compare the artificial unimpaired flow calculation to actual historical outflow conditions and conclude that a change has occurred.

- By averaging two entirely different seasons over several decades, the trends in the position of X2 are obscured. The analysis considers data at several different scales and then asserts that differences in the calculated X2 locations are the proximate cause.

When January-June data are considered over the entire hydrologic record, an eastward movement of the X2 line does appear to have occurred through time (Figure 15). This outcome is expected because one of the historic purposes of the reservoirs was to capture and store water in the winter and spring (thereby reducing outflow) and to facilitate releases of freshwater in the summer and fall.

Figure 15 Calculated X2 location in January through June 1922–2010 showing X2 trending eastward over time due to construction and operation of reservoirs designed to capture winter and spring flows to reduce flooding and to store water for release later in the year.

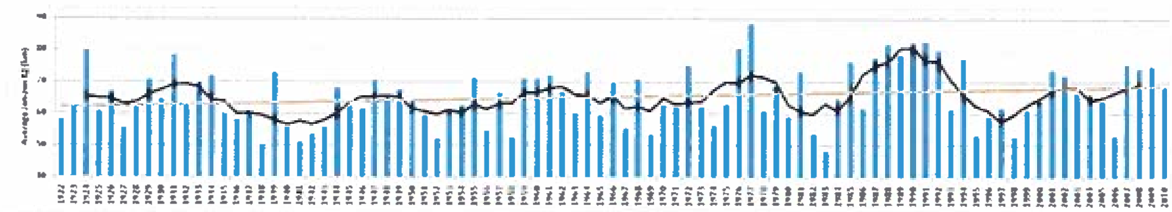
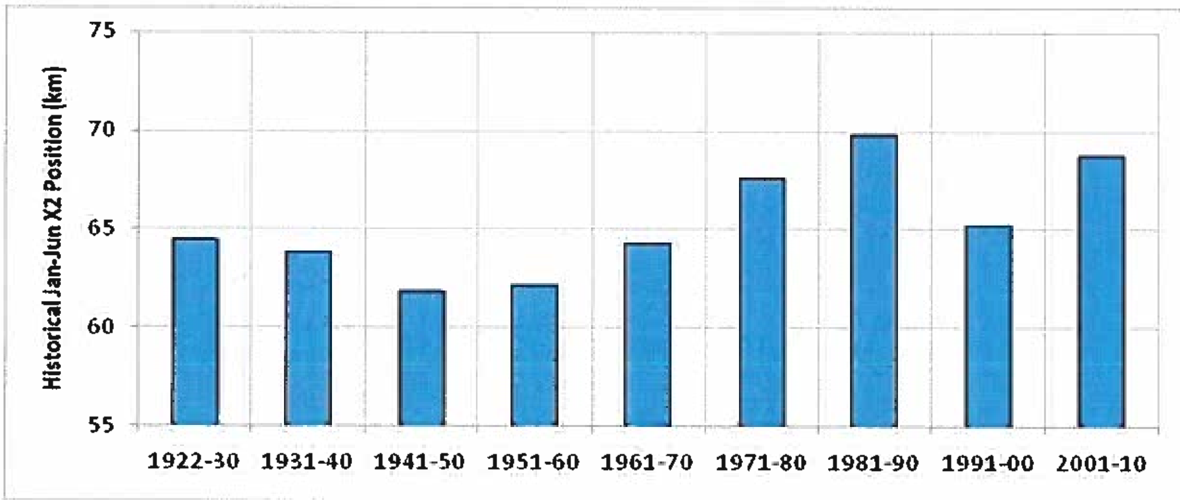


Figure 16 Calculated X2 location in January through June by decade (1922–2010). Calculated X2 location moved eastward after major reservoirs were constructed in the 1940s and 1950s; however, the increase has not been steady over time.



Figures 15 and 16 are mirroring the gross scale of the 2010 Flow Criteria Report, which makes identifying seasonal trends difficult. Therefore, this analysis also considers changes in the calculated X2 location by month. As spring is generally considered the most biologically important season for fishes, Figures 17 through 19 show the monthly X2 location for April, May, and June. The April data show that the calculated X2 location in 2001–2010 was comparable to the decades 1971–1990, but more easterly than 1991–2000. Data from the more recent two decades shows May and June to be fresher than they were in the immediately prior three decades (1971–1990) and are comparable to the decade 1961–1970.

Figure 17 **Calculated X2 location in April 1922–2010. Calculated X2 location in 2001-2010 was comparable to the decades 1971-1990, but more easterly than 1991-2000.**

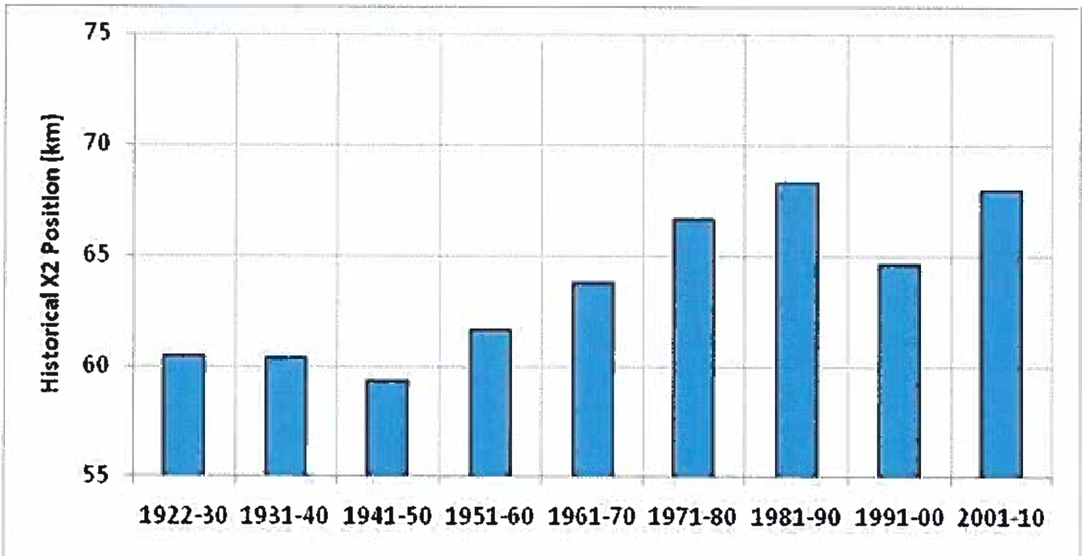


Figure 18 **Calculated X2 location in May 1922–2010. The most recent two decades (1991-2010) were fresher than the immediately prior three decades (1971-1990) and were comparable to the decade 1961—1970.**

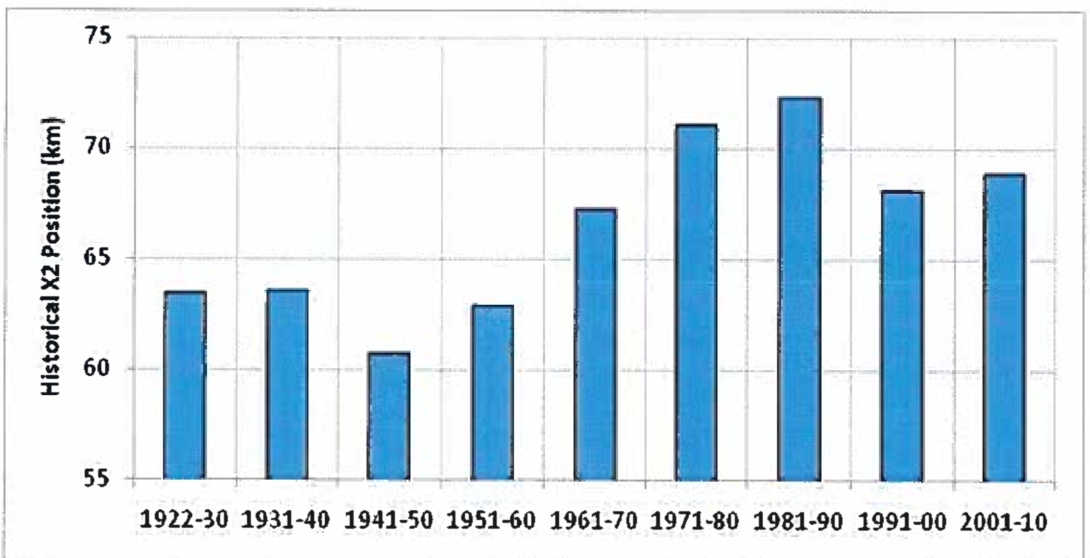
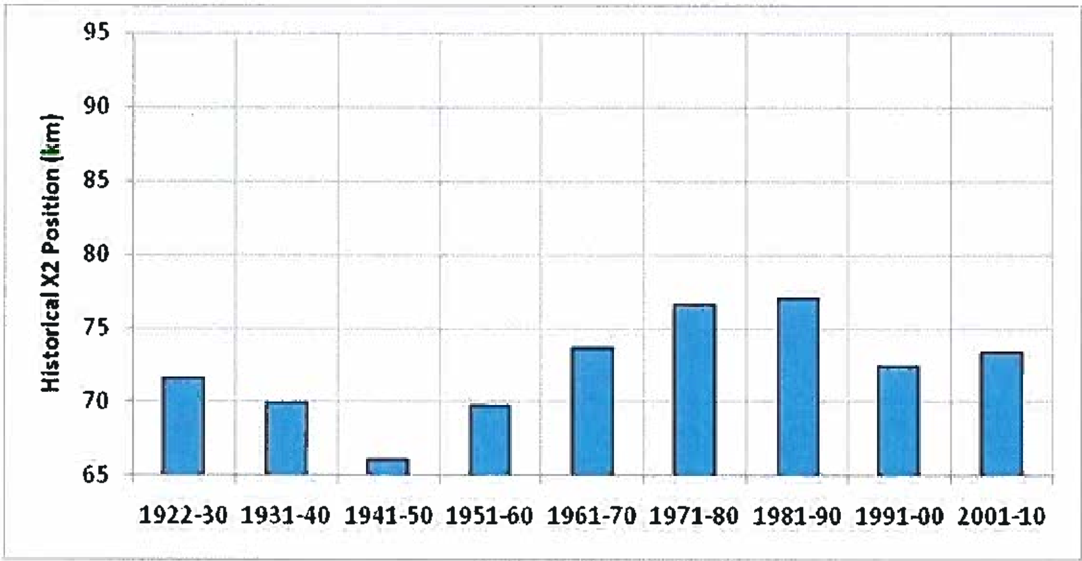


Figure 19 Calculated X2 location in June 1922–2010. The most recent two decades (1991-2010) were fresher than the immediately prior three decades (1971-1990) and were comparable to the decade 1961-1970.



Figures 20 through 22 show the monthly X2 location for January, February, and March. In these months, the most recent decade (2001–2010) is most comparable to the decade 1981–1990. In the most recent decade (2001–2010) X2 has on average been further upstream than in the prior decade (1991–2000).

Figure 20 Calculated X2 location in January 1922–2010. The most recent decade (2001-2010) is most comparable to the decade 1981-1990. In the most recent decade (2001-2010) X2 was further upstream on average than in the prior decade (1991-2000).

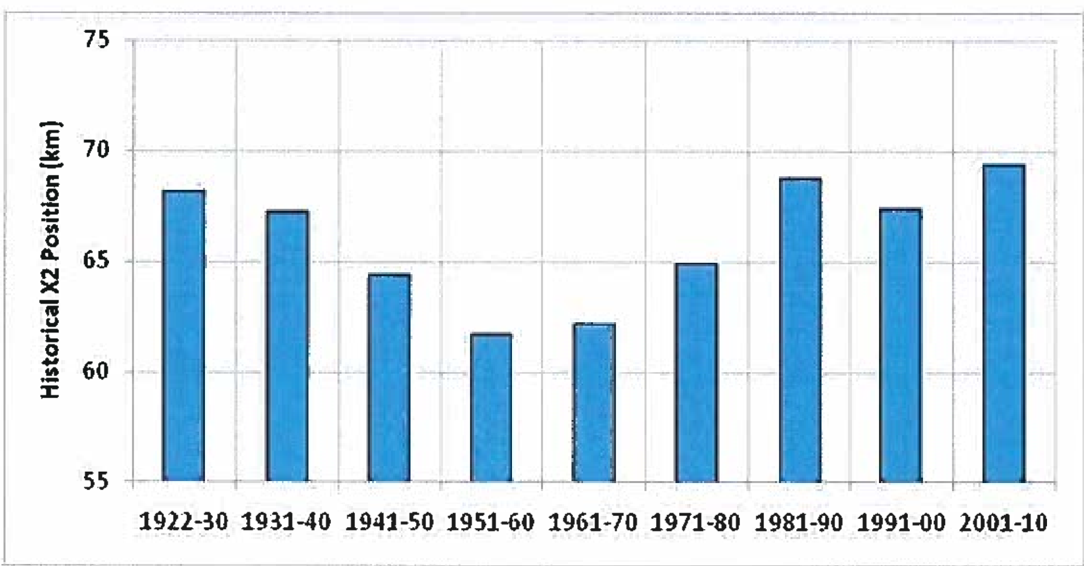


Figure 21 Calculated X2 location in February 1922–2010. The most recent decade (2001-2010) is most comparable to the decade 1981-1990. In the most recent decade (2001-2010) X2 was further upstream on average than in the prior decade (1991-2000).

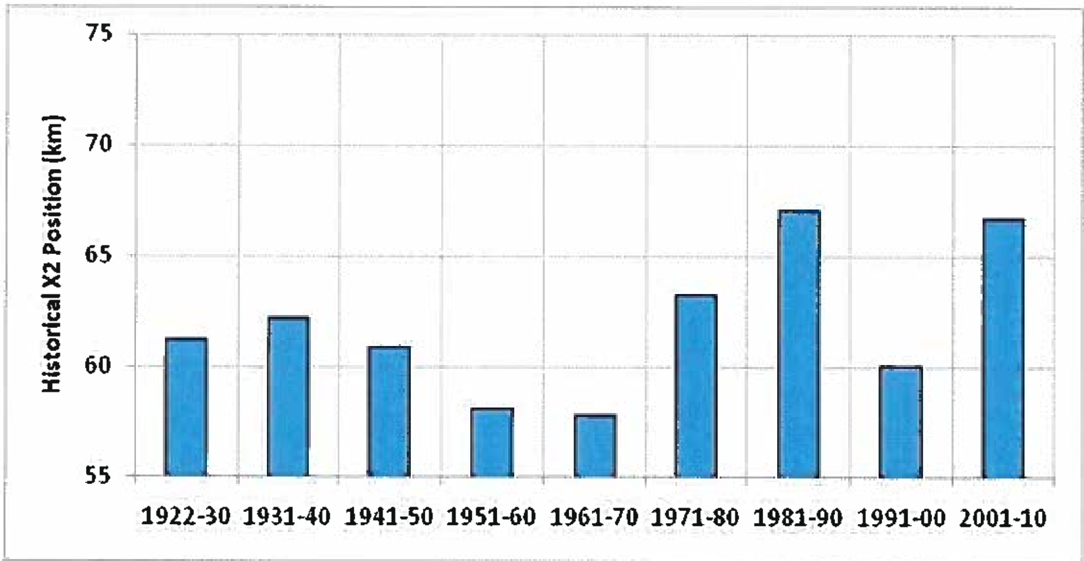
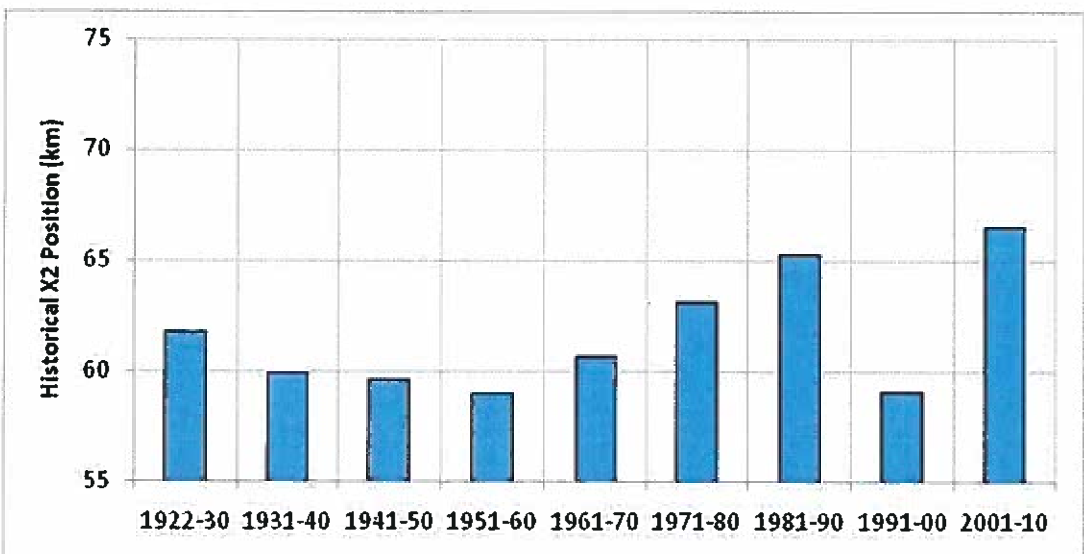


Figure 22 Calculated X2 location in March 1922–2010. The most recent decade (2001-2010) is most comparable to the decade 1981-1990. In the most recent decade (2001-2010) X2 was further upstream on average than in the prior decade (1991-2000).



Figures 16 through 22 show that the calculated X2 has been greater each month (January -June) in the decade 2001–2010 than it was in the prior decade 1991–2000. To understand the reason for this difference in the X2 location, Figures 23 and 24 compare changes in inflows and water diversions between the decades 1991–2000 and 2001–2010. These figures show that the increase in X2 is due primarily to dryer hydrology. As hydrologic and diversion patterns are different in winter compared to spring, the changes are identified by season winter (January - March) and spring (April-June).

Figure 23 identifies the hydrologic factors that drive the decrease in winter (January-March) outflow from the prior decade (1991–2000) to the most recent decade (2001–2010). The vertical bar chart inset in the top right-hand corner of the figure demonstrates that the difference in outflow is explained in large part by the difference in unimpaired outflow (*i.e.*, the reduction in unimpaired outflow [red bar at 6,273 TAF/year] accounts for the majority of the reduction in outflow (blue bar at 6,745 TAF/year]). Thus, the outflow reduction between decades is primarily the result of dryer hydrologic conditions. Water management also contributed to the outflow reduction. The horizontal blue bars in the main body of the figure represent normalized contributions by individual hydrologic drivers towards the decrease in annual outflow between decades. These horizontal blue bars sum to the difference between the vertical bars. The horizontal blue bars in the main body of the document represent changes in outflow other than hydrology. The figure shows that, after reduction in unimpaired outflow, CVP/SWP operation (434 TAF/year) is the next most significant hydrologic factor in explaining the decrease in winter outflow between the 2 decades. In other words, Figure 23 shows that 93% of the outflow difference (6273 TAF v. 6745 TAF) is due to changes in unimpaired flow (drier hydrologic conditions) and that CVP/SWP operations comprise only 6% of the difference (434 TAF v. 6745 TAF).

Figure 23 Contribution to decrease in January- March Delta outflow (1991–2000 compared to 2001–2010). Changes in unimpaired flow (drier hydrologic conditions) explain 93% of the difference in outflow between these decades. CVP/SWP operations explain only 6% of the difference.

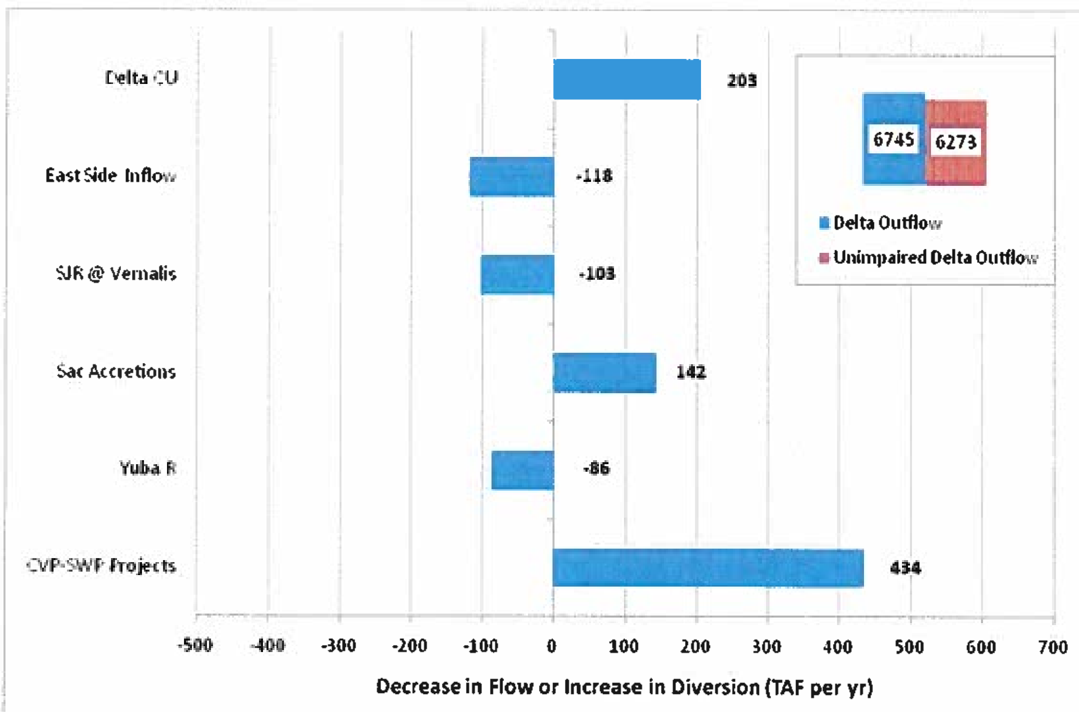
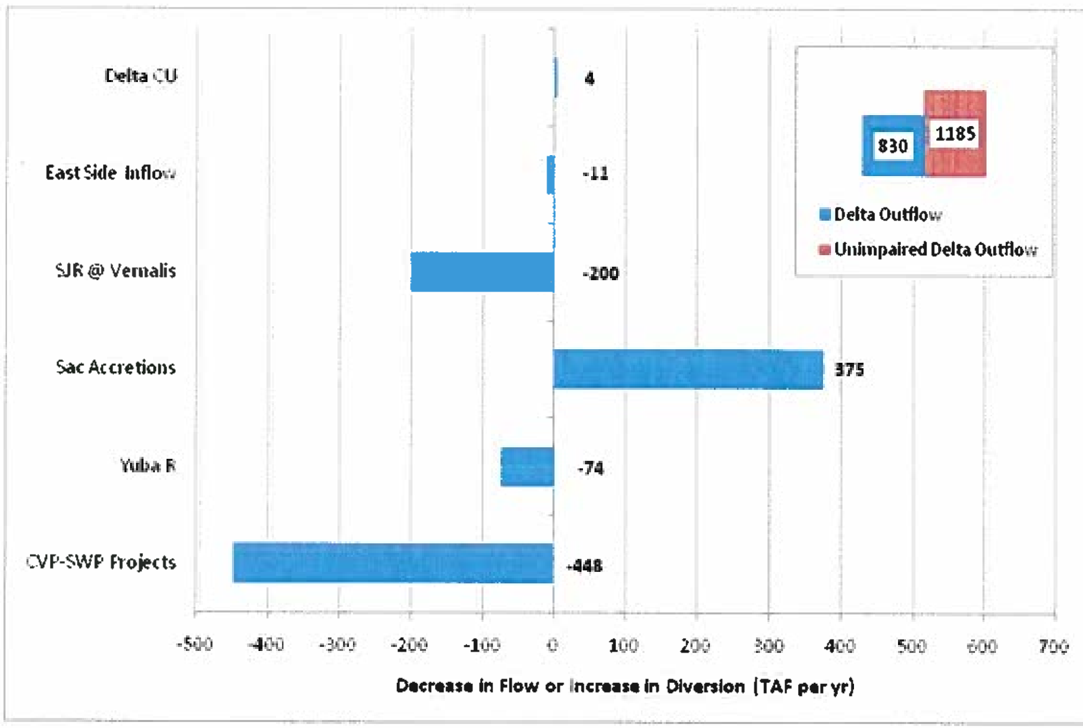


Figure 24 identifies the hydrologic factors that drive the decrease in spring (April-June) outflow from the prior decade (1991–2000) to the most recent decade (2001–2010). The vertical bar chart inset in the top right-hand corner of the figure demonstrates that the difference in outflow is less than is explained by the difference in unimpaired outflow (*i.e.*, the reduction in unimpaired outflow [red bar at 1,185 TAF/year] is larger than the reduction in outflow [blue bar at 830 TAF/year]). In other words, drier hydrologic conditions can explain all of the reduction in outflow between decades. The horizontal blue bars in the main body of the figure represent normalized contributions by individual hydrologic drivers towards the decrease in annual outflow between decades. These horizontal blue bars sum to the difference between the vertical bars. The horizontal blue bars in the main body of the document represent changes in outflow other than hydrology. The figure shows that, after reduction in unimpaired outflow, reduction in Sacramento Valley accretions (375 TAF/year) is the next most significant hydrologic factor contributing to decrease in winter outflow between the 2 decades. The CVP-SWP Projects (-448 TAF/year) and San Joaquin River flows at Vernalis (-200 TAF/year) actually contributed to higher outflow.

Figure 24 Contribution to decrease in April-June Delta outflow (1991–2000 compared to 2001–2010). The difference in outflow between the decades is less than the difference in unimpaired outflow; therefore drier hydrologic conditions can explain all of the reduction in outflow. The CVP/SWP Projects and San Joaquin River flows at Vernalis actually contributed to higher outflow.



3.1.6 Calculation of predevelopment outflow

In the 2010 Flow Criteria Report, and in presentations by certain stakeholders in the ongoing Delta Plan review workshops, a percent of the unimpaired hydrograph approach has been proposed as a method of regulating future Delta inflows and outflow. The fundamental assumption underlying the percent of the unimpaired hydrograph approach is that the unimpaired flow is a valid or otherwise useful estimator of predevelopment or "natural" flows. It is not. The term "unimpaired" outflow leads many to wrongly believe it means "natural" or pristine.

Unimpaired inflows is a calculation intended to represent flow entering the Delta through existing leveed river channels absent storage operations and downstream uses. These flows are assumed to be routed through the existing system of channels and bypasses into the Delta and the Bay, without any losses or modifications on the way and with no recognition of the natural interaction of water with the land, the original incubator of native species (DWR, 2007).

If restoring a more "natural" flow patterns is the goal, regulations based on unimpaired outflow are not going to be effective. The obvious question therefore is what is a valid approach to estimate natural or predevelopment outflow? The Public Water Agencies have been considering that question. They have explored ways to estimate the variability in natural flow, and those next step modeling efforts are described below.

3.1.6.1 Natural flows

The physical structures of the historic Delta (land covers and channel configurations) were very different than exist today. As the physical aspects of the Delta changed over time, local hydrodynamics, hydraulics and flow changed as well. In large portions of the existing Delta, the land and the water are disconnected from each other by levees, native vegetation has been replaced by agriculture, and the once meandering rivers have been channelized. Any estimate of natural flows, including outflows, must account for the fact that the physical environment was dramatically different under natural conditions because those historic structures heavily influenced outflow patterns.

Under natural conditions, the Central Valley functioned as a series of side-stream reservoirs, located alongside the major streams, rather than at the headwaters of the streams. These stream-side reservoirs filled and drained every year. Thus, the natural rim inflows did not flow unimpeded through river channels into the Delta and the Bay. Rather, they spilled over elevated natural levees into side-stream reservoirs, where they were retained, diminished and ultimately returned to the channel.

Under natural conditions, the channels of the major rivers were not adequate to carry normal winter rainfall runoff and spring snowmelt (Grunsky, 1929). They overflowed their banks into vast natural flood basins flanking both sides of the Sacramento and San Joaquin Rivers (Hall, 1880). Water flowed over the levees in thin sheets, until the water level on the non-river side of the levees rose and joined with the water surface in the channel. When this happened, all visible trace of a channel was lost and the area took on the appearance of a large inland sea (Grunsky, 1929, p. 796). In the San Joaquin Valley in July 1853, for example, engineers surveying a route for a railroad, reported:

> The river [San Joaquin] had overflowed its banks, and the valley was one vast sheet of water, from 25 to 30 miles broad, and approaching within four to five miles of the hills.

(Williamson, 1853, p. 12). The filling and emptying of these flood basins had the effect of delaying the transmission of flood flows down the major rivers, reducing peak flows and velocities (TBI, sec. IV.B.1 and Grunsky, 1929). Some of the water in these flood basins gradually drained back into the main river channels after the floods subsided, through a complex network of sloughs. Some basins drained relatively rapidly while others retained flood waters through the summer or year round (Grunsky, 1929, p. 793 and 796; McGowan, 1961; Thompson, 1961, Olmstead and Davis, 1961, pp. 25-27). These flood basins also contained vast tracts of tule marsh, which retarded the drainage of the basins and evapotranspired residual flood waters (Babtist *et al.*, 2007). The resulting delayed transmission and reduced volume of flood and other natural flows is not reflected in unimpaired flows. Thus, setting monthly flow standards based on a percentage of monthly unimpaired flows is not relevant to the original landscape that nurtured the species the State Water Board seeks to protect.

The main river channels were lined by wide levees that were built up over time from sediment deposited as rivers spread out over the floodplain. These levees were much larger and more developed along the Sacramento River than along the San Joaquin River (Hall, 1880, part II, p. 51). Along the Sacramento, the natural levees rose from 5 to 20 feet above the flood basins and ranged in overall width from about 1 to 10 miles, averaging 3 miles (Thompson, 1961, p. 297). The southern reaches of the San Joaquin River developed natural levees only poorly due to low sediment loads (Hall, 1880, part II, p. 51), and only as the river entered the valley floor (Warner and Hendrix, 1985, pp. 5.15-5.16), sustaining large freshwater marshes still found there today (Katibah, 1984 and Garone, 2011, p. 79). However, natural levees did form along the major northern San Joaquin River tributaries -- the Tuolumne, Stanislaus, Merced, Mokelumne, Cosumnes, and northern San Joaquin (Warner and Hendrix, 1985, p. 5.15). Lush riparian forests occupied these levees.

The flood basins also received flow from sources other than flood flows spilling over the natural levees. These included upland runoff and west- and east-side streams, e.g., Stony, Cache, Putah. These were blocked from reaching the main river channels by the natural levees. They spread out over the valley floor, pooling in expansive sinks of tule marsh and connecting to the main rivers only by subsurface flow (Garone, 2011, p. 23; Thompson, 1961, p. 299). Further, breaches or "crevasses" in the natural levees and percolation of water through the relatively coarse, porous levees permitted excess waters to escape the main streams and spread over the low flood plains (Thompson, 1960, pp. 352-353).

This highly productive system was completely replumbed to control floods, facilitate the irrigation of the valley, and for navigation. The channels were dredged and rip-rapped, the levees were raised, the flood basins were drained, bypasses installed, and head-stream reservoirs were built to replace the side-stream storage and generate electricity.

The Sacramento and San Joaquin Rivers discharged into the Delta, which is a product of its topography. As the rivers descended from the mountains toward sea level near their confluence, their gradients decrease dramatically, reducing their velocity and ability to incise their channels. Thus, they distributed their flow into numerous sloughs that meandered across the landscape (Garone, 2011, p. 27) to a common mouth into Suisun Bay. Shoals were present at the mouth of the rivers, one notably opposite Collinsville, which was an obstruction to the escape of flood waters from the Sacramento River (Hall, 1880, part II, p. 23). An appreciable amount of Sacramento River water below Sacramento was originally (and continues to be) routed through the Georgiana and Three-Mile sloughs into the San Joaquin River (Hall, 1880, p. 47).

Under natural conditions, these rivers were braided together in the Delta in a complex arrangement of channels weaving through flat, low-lying islands with elevations at or below sea level. These islands were submerged for much of the year, with water levels fluctuating with the tides and river flood stages. The islands' outer margins had small natural levees while the interior sections were marsh. When river flows were high in spring, the historical Delta was a morass of flooded island and marshes. In late summer, when river flows were low, the islands and marshes, protected by low natural levees, were often surrounded by saline water pushed upstream by tides. Nearly 50% of the Delta was originally submerged by daily tides (Thompson 1957, p. 21; Thompson 1961, p. 299). Dominant vegetation in the saucer-shaped islands included tules and on higher levee ground, coarse grasses, alder, walnut, and cottonwood (Thompson, 1957, chapters 1-2, pp.135-136; Thompson, 1961, p. 299; Hall 1880, part II, Moyle, 2002, p. 32). By the 1930s, these vast areas of Delta tidal wetlands and riparian vegetation were diked, drained, and converted into islands of farmland surrounded by high levees, now highly subsided; the sloughs were replumbed and deepened; and sand bars were removed, completely altering the natural hydrodynamics and its rich and diverse habitat for native species (Thompson, 1957, Lund *et al.*, 2010, Ch. 2, 3, and 5).

Finally, under natural conditions, groundwater moved generally from recharge areas along the sides of the valley towards topographically lower areas in the central part of the valley, where it discharged primarily as evapotranspiration from marshes and riparian forests (TBI, Sec. IV.B.2; Bertoldi *et al.*, 1991, pp. A17, A23, Fig. 14A; Williams, 1989, p. D33; Davis, 1959, p. 86). Groundwater was near the surface in much of the Valley (Bryan, 1915, p. 19 and plate 11; Kooser *et al.,* 1961, pp. 265 and 278). The U. S. Geological Survey estimated that under natural conditions, the groundwater table was less than 10 feet below the surface over about 62% or 8,000 square miles of the Central Valley (Williamson *et al.*, 1989, P. D40). The groundwater system was in a state of dynamic equilibrium. Natural recharge was balanced by natural discharge. This has been recently confirmed for the San Joaquin Valley (excluding the Tulare Basin) using a physically based, surface-subsurface numerical model (HydroGeoSphere) (Bolger *et al.,* 2011, pp. 322-330). The natural groundwater system has been extensively altered by pumping for irrigation and other uses, resulting in widespread overdraft and land subsidence.

3.1.6.2 Estimation of pre-development land cover

There is general agreement within the scientific community regarding the nature of the physical environment that existed in the pre-development era. A recent San Francisco Estuary Institute ("SFEI") study further collaborates the natural flow description provided above (see SFEI Report at http://www.sfei.org/news_items/press-delta-historical-ecology-report). However, there is yet to be general agreement on how many acres of each land cover type existed and the land cover's cumulative consumptive water use.

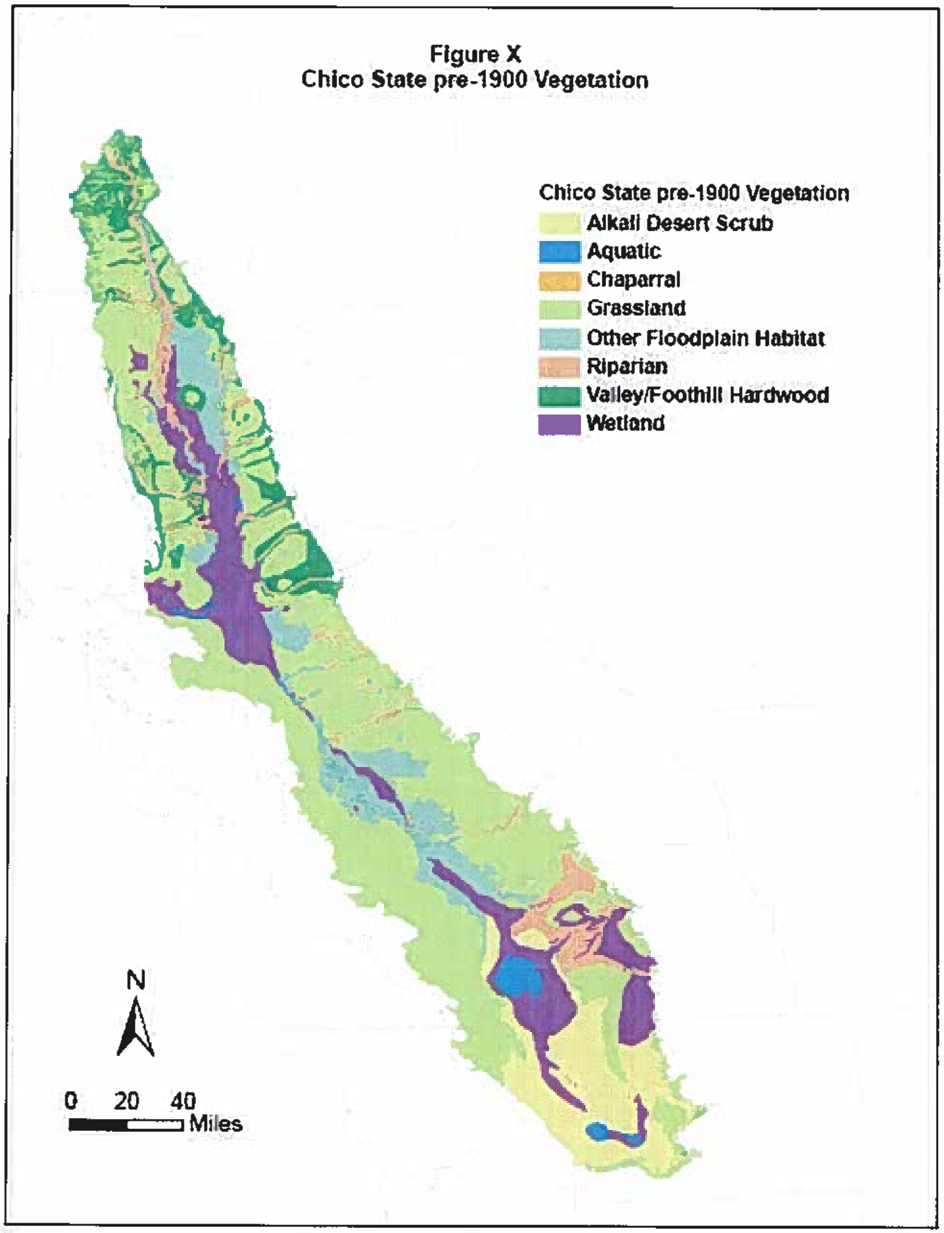
In 2003, California State University-Chico ("Chico") completed a historic mapping effort to determine the acreages of the various types of native vegetation that once covered the Delta and its watershed. The Chico effort mapped four different time periods, with the "pre-1900" map being of particular interest for purposes of calculating predevelopment (pre-1900) outflow.[4] To

[4] Chico (2003) has been referenced in at least two published works: Bolger et al. 20011 and Barbour *et al.* 2007.

create its maps, Chico reviewed and digitized approximately 700 historic maps, searching numerous collections of historic maps in public libraries. For this report, Dr. Phyllis Fox confirmed the accuracy of the Chico State pre-1900 map using several sources, including: Hall (1887); Küchler (1977); Roberts *et al.* (1977); Dutzi (1978); and Fox (1987). These archival maps and others were scanned (400-dpi full color scanner), the scanned versions were georeferenced[5] using various data layers (e.g., county, township), and the map features were digitized by hand using editing features in ArcMap. ArcMap's geoprocessing tools were used to determine areas of the various types of vegetation.

[5] Transforming scanned images into maps with reference coordinates.

Figure 25 Chico (2003) pre-1900 map.

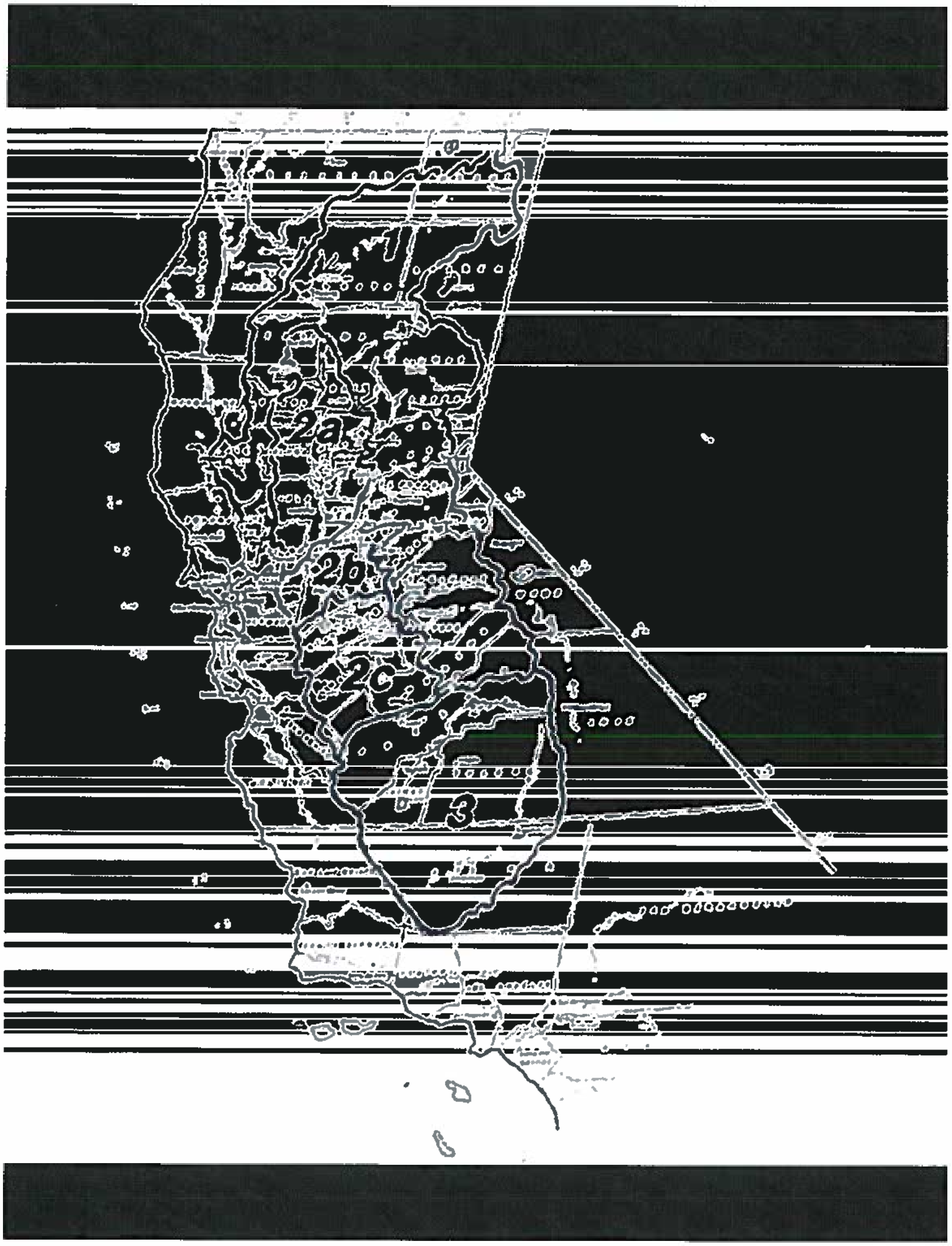


Chico (2003) estimated land cover throughout the Central Valley. We divided the area that drains into the Bay into upper, middle and lower region to correspond with DWR's hydrologic units, as defined by DWR in California Central Valley Unimpaired Flow Data, Second Edition, February 1987.[6] The DWR drainage area encompasses the Sacramento Valley (Area 2a), the Delta and upslope areas (Area 2b), and the San Joaquin Valley Area (Area 2c). These three

[6] DWR has updated its designation of basins and boundaries since the 2nd edition, and future estimates will reflect that new information.

areas define the rim of the valley where the unimpaired flows are gauged. See Figure 26, DWR hydrologic units.

Figure 26 Hydrologic Units Used in Calculating Freshwater Inflow to San Francisco Bay Under Natural Conditions, DWR 1987.



We estimated acreages of each type of vegetation by drainage basin based on Chico pre-1900 map using ArcMap's "Calculate Geometry" feature. The results of this analysis, by drainage basin, are summarized in Table 2 discussed below for each vegetation type.[7]

Table 2 Natural Vegetation Land Area (acres), Chico (2003)

Vegetation	Sacramento Basin (2a) (Acres)	Delta (2b) (Acres)	San Joaquin Basin (2c) (Acres)	Totals (Acres)
Aquatic	32,616	18,319	9,242	60,177
Grassland	1,591,415	615,799	2,263,714	4,470,928
Other Flood Plain Habitat	474,743	117,101	572,291	1,164,135
Riparian	443,852	54,930	72,192	570,974
Valley/Foothill Hardwood	639,650	197,656	9,268	846,574
Wetland	529,814	395,354	86,497	1,011,665
Total	3,712,090	1,399,159	3,013,204	**8,124,453**

It is unknown if Chico's estimates accurately depict "pre-development" conditions as significant modifications to the physical environment and large scale farming had already began by the turn of the 20th century. The earliest resource map used by Chico is 1874 (Chico, 2003, Table 1). To the extent Chico's estimates reflect early development, Chico underestimates natural land cover, and as a result, underestimates natural evapotranspiration.

There is some uncertainty regarding Chico's land cover estimates, primarily because of the various assumptions associated with using numerous archival resources, with varying degrees of accuracy, that cover a range of years. Nevertheless, it appears that the Chico estimates are consistent with findings of other similar research efforts, as discussed below.

3.1.6.2.1 Description of historic grasslands

The plains were smooth and nearly level lands that were formed as flood waters spread over them, leaving behind thick deposits of silt. The vegetation in the grasslands was prairie, as variously defined by Heady (1988), Küchler (1977), and Bartolome et al (2007). The original grassland no longer exists. What it once looked like and contained can never be known with certainty as early eye witness accounts are vague. The best guess by experts is that it was dominated by two species of needlegrass (*Stipa cernua* and *S. pulchra*).

Vernal pools (or "hog wallows") were present within the grasslands but were not separately mapped by Chico. These are seasonal ephemeral wetlands that fill and dry out each year. They

[7] "Chaparral" was removed from the land cover estimates as it was insignificant, totaling a few hundred acres.

are shallow depressions underlain with an impermeable layer of soil. In winter, the hardpan soils underlying these pools prevent water from penetrating, saturating the upper soil and filling the basin with water, thus forming pools and small lakes. Rainfall collects in the depression, stands through early spring, then evaporates as temperatures rise and rainfall declines. The soil remains moist through April and May and then desiccates (Solomeshch, 2007). However, this does not imply they do not contribute to water losses.

The Central Valley vernal pools appear to be supported by perched aquifers. Seasonal surface water and perched groundwater connect uplands, vernal pools and streams (Rain *et al.*, 2006). Thus, these aquifers may contribute significantly to evapotranspiration. These vernal pools have not been mapped and evapotranspiration from this vegetation type has been treated by Chico (2003) as standard grassland, a likely underestimate.

Most vernal pools are densely vegetated seasonally, primarily with native annual grasses, forbs, and pool-bed algae. They support a rich variety of plants including annual forbs, grasses, rushes, and succulents; cryptophytic perennial herbs, perennial grass and forb halophytes, perennial rushes, cryptophytic perennial forbs, and small subshrubs (Solomeshch *et al.*, 2007, p. 398). Rings of vegetation form as the rainfall stops and temperatures rise in late spring. These vernal pools were present throughout the Central Valley under natural conditions, but were most abundant in Fresno, Madera, Merced, Placer, Sacramento, Tehama, and Yuba counties (Solomeshch *et al.*, 2007, p. 398). Most pools are less than 0.02 acres (100 m^2) in area, but a few covered tens of acres up to 300 acres and were temporary lakes (Solomeshch *et al.* 2007, p. 398; Barbour *et al.*, p. 83). Under natural conditions, vernal pools may have covered 1 percent of the State's area (Barbour *et al.*, pp. 81-83; Crampton, 1974, p. 30), but they were not separately mapped by Chico.

3.1.6.2.2 Description of wetlands

Chico (2003) described its wetland category as, "Wetland (perennial) – Also considered Freshwater Marsh." Wetlands are among the most productive wildlife habitats in California. They occur on virtually all exposures and slopes provided the depression or basin is periodically flooded. Characteristic species include various species of Cattails (*Typha spp.*), Bullrushes or Tules (*Scirpus spp.*), Rushes (*Juncus spp.*), and Sedges (*Carex spp.*).

The Chico map describes about 1 million acres of perennial wetland. This estimate is confirmed by a number of primary sources, including the federal surveys done pursuant to the Arkansas Swamp Act of 1850, comparable California surveys, independent surveys by the California State Engineer, and technical summaries based upon surveys. One of the most significant of these reports confirming the extent of the tule marshes was prepared by Professor Hilgard, generally regarded as the father of modern soil science and the first director of the Agricultural Experiment Station at the University of California, Berkeley. His report was prepared for the 1880 U.S. Census. It separately listed the area of tule lands in each county, showing a total of 1.2 million acres tributary to the Bay. Another authoritative source, Marsden Manson, assistant to California's first State Engineer, published an estimate of about 1.0 million acres tributary to the Bay in a refereed and archival journal, based on State Engineer surveys. Thus, the value returned by the Chico pre-1900 map is consistent with historical surveys.

3.1.6.2.3 Description of floodplain habitat

This is the second largest category of native land areas, comprising 1.2 million acres, or slightly more than perennial wetlands. "Other Floodplain Habitat" is a category used by Chico to designate areas that are a mixture of wetlands, grasslands, and riparian forest that have not been previously differentiated on historic maps. Our analysis indicates some of the area classified by Chico as "other floodplain habitat" was classified by Dutzi as oak woodlands and savanna. Further, a comparison of the Chico pre-1900 map with early maps based on surveys indicates that much of this land has been mapped as tule marsh by others.

3.1.6.2.4 Description of valley/ foothill hardwood

In the Central Valley, "valley/foothill hardwood" vegetation as mapped by Chico primarily consists of three hardwood areas dominated by oaks: (1) the open woodland around the rim of the Central Valley; (2) savannas with trees widely spaced and scattered over grasslands, and (3) the densely wooded, thickly canopied oak riparian areas on the upper edge of levees along rivers (valley oak riparian forest) (Barbour and Major, 1988, pp. 387-405, 425-55; Allen-Diaz *et al.* 2007; Shelton 1987; Dutzi 1978; Pavlik *et al.* 1991, p. 9 and 63-64; Anderson 2006, pp. 30-32). The divisions between these three categories are somewhat arbitrary; gradations of communities exist between the savanna and riparian types.

The Chico map returned 847,000 acres of this vegetation type in the study area. Of this, 640,000 acres was in the Sacramento basin (basin 2a); 198,000 acres in the Delta (basin 2b); and 9,000 acres in the San Joaquin basin (basin 2c). This estimate is within the range of estimates by others. Shelton (1987) estimated 494,000 acres of "valley oak savanna," a subset of valley/foothill hardwood area mapped by Chico, reporting none in either the Delta or San Joaquin. Dutzi (1978) estimated 1.5 million acres of "valley oak woodland and savanna" in the Sacramento Valley, which includes all three categories mapped by Chico.

3.1.6.2.5 Description of riparian

Riparian vegetation was found along all of the low-velocity waterways in the Central Valley, but the largest areas occurred on the rivers with the largest natural levees. The riparian forest extended from the banks to the edge of the moist soil zone, and, in many cases, as far as the hundred-year flood line, up to 4 to 5 miles on each side on the lower Sacramento River, where natural levees were widest (Garone 2011, pp. 24-25; Katibah 1984, p. 24). They were also present along tributaries of the main rivers and the upper San Joaquin River (Roberts *et al.* 1977, Figure 2; Warner and Hendrix 1985, pp. 5.10 - 5.11; Williamson 1853, p. 12).

The Chico map describes 571,000 acres, of which 444,000 acres are in the Sacramento Valley (basin 2a); 55,000 in the Delta (basin 5b); and 72,000 acres in the San Joaquin Valley (basin 2c). Chico's estimate for the Sacramento Valley (444,000 acres) is about equal to Dutzi's (1979) estimate for this area (438,000 acres), which is not surprising as Chico relied on Dutzi for its pre-1900 mapping. The difference is primarily due to differences in the boundary of the Sacramento Valley.

However, Chico's estimate for the study area (571,000 acres) is low compared to estimates by others including Küchler 1977 (874,000)[8]; Roberts *et al.* 1977 (937,900 acres)[9]; Katibah 1984 (921,000 acres); and Warner and Hendrix (1985). Warner and Hendix comprehensively reviewed estimates available through 1985 and concluded that "the present 'best estimate' of pre-settlement riparian wetlands vegetation in the Central Valley is at least 1,600,000 acres...". Chico mapped areas shown by others as riparian forest as grasslands or other floodplain habitat, which use less water. Further, Chico separated out the riparian oak fringe of the riparian zone in some areas, which is generally included in most estimates of riparian acreage. Barbour *et al.* (1993), for example, estimated 900,000 acres of riparian forest, which they described as including the fourth zone, or the valley oak forest (Barbour *et al.* 1993, pp. 74-75).

3.1.6.2.6 Description of aquatic

Chico defined "aquatic" as including major water bodies, including lakes, reservoirs, and estuaries. Under natural conditions, the Central Valley contained open water surfaces, including lakes, sloughs, and overflow basins. The open water surface area was determined from historic sources to be about 68,000 acres (SWC, 1979). This compares favorably with the Chico (2003) estimate of aquatic areas of 60,000 acres. Water surface evaporation was calculated using the historic area and annual average pan evaporation data (5.6 ft/yr). The pan data was measured at Gerber. It was supplied by DWR and is used in their CalSim 3.0 model (Cheng, 2012).

3.1.6.3 Estimation of evapotranspiration of natural vegetation

To estimate consumptive use of native vegetation in the pre-development era, the evapotranspiration ("ET") rate (acre-feet per year) for each vegetation type must be identified and calculated (acre-feet per year).

ET is the sum of water lost by evaporation from the soil and open water surface plus loss from interception by vegetative cover and transpiration from plants. Transpiration is the loss of water from plants in the form of vapor that occurs primarily through stomates, microscopic holes in the leaves through which water is lost and carbon dioxide enters for growth. Lesser amounts are lost through the cuticle and lenticels in the bark (Kramer and Boyer, 1995). A leaf that facilitates the uptake of carbon dioxide (CO_2) and thus growth is also favorable for the loss of water. Thus, transpiration is related to canopy size, plant size, density, leaf area, etc. (Cowan, 1982, pp. 535-562; Devitt *et al.* 1994, pp. 452-457). These are important considerations here as the native vegetation was consistently described in eye witness accounts as large, immense, and lush. The evaporation component, on the other hand, is controlled by climatic conditions.

Generally, there are several methods to determine evapotranspiration. These include lysimeters, soil water balance, bowen ratio, eddy covariance, remote sensing energy balance, and sap flow measurements, among others. All of these methods contain degrees of error. We have used two methods in this report to estimate the ET rate of native vegetation: literature review of field

---

[8] As reported by Shelton 1987.

[9] The Roberts et al. 1977 map was digitized and the area determined using the "Calculate Geometry" feature in ArcMap returning 638,451 acres in the Sacramento Valley (basin 2a), 131,931 acres in the Delta (basin 2b), and 114,862 acres in the San Joaquin Valley (basin 2c).

experiments and climate based assessment calculations. This analysis provides preliminary estimates based on both methods.

3.1.6.3.1 Results of evapotranspiration field experiment literature review

Research on the rate of vegetative evapotranspiration has been going on for decades. The calculated ET values from the literature review provided in Table 10 are used as comparison against the values measured by researchers. The reasons for providing a comparative range is that the science of measuring ET is evolving and many of the published field studies were conducted in locations outside of the Central Valley so the actual vegetation evapotranspiration (ET_c) values may not be accurately represent the pre-development conditions in the Central Valley. However, the purpose of this literature review is to show the variable magnitude f field study measurements.[10] Results of this literature review are presented in Tables 3 through 5, below.

Table 3 Water Use by Tules and Cattails

Locations	Type of Marsh	Annual Water Use (ft/yr)[d]	Reference
King Island, Delta	Freshwater tidal marsh	7.4 – 13.0[a]	Stout (1929-35)
Victorville, CA (Mojave River)	Desert inland marsh	6.5 – 7.0	Young and Blaney (1942)
Mesilla Valley, NM (Rio Grande River)	Freshwater marsh	10.1	Young and Blaney (1942)
Bonner's Ferry, ID	Inland marsh	5.1	Robinson (1952)
Antioch, Delta	Freshwater tidal marsh	5.8[b]	Blaney and Muckel (1955)
Clarksburg, Delta	Freshwater tidal marsh	9.6[c]	DPW (1931b)

a. Value for third year of growth. Range corresponds to two different tank configurations.
b. Calculated based on limited experiments at Joice Island in Suisun Marsh.
c. Experiments conducted in isolated tanks and values adjusted by multiplying by a factor of about 0.5.
d. All values measured in tank experiments in which tanks were set in natural environment unless otherwise stated.

[10] As some early ET studies had various methodical limitations, the American Society of Civil Engineers (ASCE) convened a task force to review the early literature. The 1989 ASCE report identified certain studies as "outstanding research" and contains a complete bibliography of ET studies widely considered reliable. Many of the citations presented herein were characterized by the ASCE as "outstanding," particularly those conducted by Blaney and Young in the Delta and elsewhere in California.

Table 4 Water Use by Native Grassland Vegetation

Vegetation	Annual Water Use (ft/yr)	Location	Reference
Field Studies			
Native brush	1.4 – 1.8	San Bernadino, CA	Young and Blaney (1942)
Native brush	1.5	Muscoy, CA	Young and Blaney (1942)
Native brush	1.2	Claremont, CA	Young and Blaney (1942)
Native brush	1.6	Palmer Canyon, CA	Young and Blaney (1942)
Native grass and weeds	0.8	San Bernadino, CA	Young and Blaney (1942)
Native grass and weeds	1.1-1.25	Cucamonga, CA	Young and Blaney (1942)
Native grass and weeds	1.0	Anaheim , CA	Young and Blaney (1942)
Native grass and weeds	1.1	Ontario, CA	Young and Blaney (1942)
Native grass and weeds	1.1	Wineville, CA	Young and Blaney (1942)
Annual grasses, forbes, and legumes	1.2	Placer County, CA	Lewis (1968)
Grasslands	0.8-1.3 (7/01-6/07)	Lower Sierra Nevada Foothills, Vaira Ranch	Ryu et al (2008) Baldocchi et al. 2004
Tank Studies			
Annual grasses	0.8 - 1.2	Placer County, CA	Lewis (1968)
Grass	1.2	San Luis Rey, CA	Blaney (1957)
Grasslands Grasses	0.9 – 2.9 2.2	Sierra Ancha, AZ Sierra Ancha, AZ	Rich(1951) Rich (1951)

Table 5 Water Use by Common Riparian Vegetation

Vegetation	Annual Water Use (ft/yr)	Location	Reference
Field Studies			
Canyon-bottom, Lower Reach: 82% alder, 8% sycamore, 4% Bay, 3% willow, some maple, oak. Understory grapevine & blackberry.	6.9[a]	Coldwater Canyon, CA	Blaney (1933)
Canyon-Bottom, Upper Reach: 48% alder, 26% Bay, 9% maple, 7% willow, 6% sycamore, some oak, cedar, spruce, etc. Same understory.	5.4[a]	Coldwater Canyon, CA	Blaney (1933)
Moist-land vegetation, including willows, tules and other unspecified vegetation	9.5[b]	Temescal Canyon, CA	Blaney et al. (1933)
River-bottom brush comprising 38% heavy tree cover of willows, alders, cottonwood, sycamore; 19% grass, 20% brush, 6% tule swamp	4.2	Santa Ana River, CA	Troxell (1933)
Tank Studies			
Isolated clump of 7 ft tall red willows	4.4	Santa Ana, CA	Blaney et al. (1933)
Mixture of cottonwoods and willows	5.2 – 7.6[c]	San Luis Rey, CA	Blaney (1957, 1961)
Alders	5.0	Santa Ana, CA	Muckel (1966)
Cottonwoods and willows	7.6, 6.0[c]	Safford Valley, AZ	Gatewood et al. (1950)

a. Reported for the 4-month period May-October 1932 and converted to a 12-month basis using the monthly distribution of water use for willows, by dividing 0.77 [DPW 1931b].

b. Reported for the month of May 1929 and converted to a 12-month basis using the monthly distribution of water use for willows by dividing by 0.11 [DPW 1931b].

c. Range depends on depth to groundwater, which varied from 3 to 4 feet at San Luis Rey and 7 ft at Safford Valley. Variously reported as 7.6 ft/yr in Table 29 for cottonwood and willow and 6.0 ft/yr for cottonwood at 195 and 203.

In the first oak woodland study, Lewis (1968) measured consumptive use for three oak woodland watersheds (12-47 acres) in the Sierra-Nevada Foothills in Placer county. The predominant hardwood was interior live oak (*Quercus wislizenii*) associated with varying amounts of blue oak (*Quercus douglasii*) and black oak (*Quercus morehus*) with some digger pine (*Pinus sabiniana*) and poison oak, annual grasses, legumes and forbes as ground cover. The measure evapotranspiration averaged 1.7 ft/yr and ranged from 1.4 to 2.0 ft/yr over a 10 year period, from 1956-1966.

In 2000, Lewis et al. published another similar study on another similar watershed, in the Sierra-Nevada Foothills in Yuba County. The woodland was dominated by blue oaks (*Quercus douglasii*) and intermixed with interior live oaks (*Q. wislizenii*) and foothills pine (*Pinus sabiniana*); annual grasses and legumes dominated the ground cover. The 17- year average consumptive use for the period 1981-1997 in the Yuba County study was 1.2 ft/yr, with a range of 0.9 to 1.8 ft/yr.

The results of the initial review of ET field studies are summarized in Table 6 as a range of possible ET_c rates.

Table 6 Summary table, evapotranspiration of native vegetation based on field studies

Land Cover	Minimum ET_c (ft. / yr.)	Maximum ET_c (ft. / yr.)
Riparian Forest	4.2	9.5
Wetland	5.1	13
Grassland	0.8	2.9
Valley/Foothill Hardwood	0.9	4

3.1.6.3.2 Climate based assessment (ET rates)

To provide a comparison on the ET rates measured in published field experiments, Dr. Daniel J. Howes from the Irrigation Training and Research Center (ITRC) at California Polytechnic State University, San Luis Obispo calculated upper limit (or potential) of ET_c rates for Riparian Forest, Wetland, Other Floodplain Habitat, and Open Water. A simplified soil water balance was used to estimate ET_c for Grassland habitat. Dr. Howes' initial ET calculation is as follows:

The potential evapotranspiration rate is limited based on available energy in a natural system and the availability of water to the vegetation. Energy exchange at the vegetative surface governs evapotranspiration and is limited by the amount of available energy (Allen *et al.*, 1998, Allen *et al* 2011). The equation for the energy fluxes of an evaporating surface with a large extensive vegetative surface is $\lambda ET = Rn - G - H$ where:

λET is the latent heat flux (representing evapotranspiration)

Rn is the net radiation

H is the sensible heat flux

G is the soil heat flux.

While the different fluxes can be positive or negative, a positive Rn supplies energy in the form of radiation to the system and positive ET, G, and H remove energy from the system.

A convenient way to examine vegetative water use is to measure local weather parameters and compute a reference evapotranspiration, then to use a vegetation specific coefficient to adjust the reference evapotranspiration to the actual vegetation evapotranspiration. In California, a well watered grass reference surface is used as the basis for the reference evapotranspiration (grass reference evapotranspiration, ETo). Alfalfa is used as a reference in other parts of the U.S. The actual vegetation evapotranspiration (ETc) will differ from ETo depending on available water supply, albedo (reflectance of incoming solar radiation), vegetative cover density, vegetative health, growth stage, aerodynamic properties, and leaf and stomata properties (e.g. canopy resistance) (Allen *et al.* 1998). The coefficient to adjust ETo to ETc is termed a crop coefficient in agriculture but the term ETo Fraction (EToF with "o" denoting a grass reference crop) is used here to limit confusion since natural vegetation is being examined not agricultural crops. ETc can be estimated from ETo and EToF as:

$$ETc = EToF \times ETo \qquad \text{Eq. 1}$$

ETo is computed based on local weather parameters from a specialized weather station that is specifically located in a setting without obstructions from wind surrounded by healthy, well watered vegetation. ETo is computed using the 2005 Standardized ASCE Penman-Monteith equation (PM-ETo) (Allen *et al.,* 2005). Using a clipped grass as the reference, specific known properties of grass, including albedo, aerodynamic resistance, and bulk surface resistance, are used in the PM-ETo equation.

EToF is an adjustment factor based on the vegetation and soil properties to be examined. There are many types of vegetation that have higher potential to evapotranspire water compared to grass, therefore EToF can be greater than 1.0. The limitation of available energy means that EToF has limitation as well. For natural vegetation, that has sufficient available water, with full ground cover, the maximum EToF can be computed as (Allen *et al.*, 1998):

$$EToF_{max} = EToF_h + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3} \qquad \text{Eq. 2}$$

Where $EToF_h$ = 1.0+0.1*h for vegetation heights less than or equal to 2 meters (~6.5 feet) and equal to 1.2 with vegetation heights greater than 2 meters. RHmin is the minimum relative humidity during the day, u_2 is the wind speed measured at 2 meter above the ground surface, and h is the vegetation height. Where there is standing water with the vegetation (*i.e.* wetlands), a value of 0.05 is added to the $EToF_{max}$ computed with the previous equation to account for additional evaporative losses (Allen *et al.*, 1998).

Daily weather data was obtained from five CIMIS weather station (Durham and Gerber in the Sacramento Valley, Twitchell Island in the Delta, and Modesto and Firebaugh in the San Joaquin Valley) to evaluate the $EToF_{max}$ for applicable habitat in the evaluated in the water balance. The $EToF_{max}$ values were weighted based on daily ETo values over the timeframe analyzed which was 25 years for some station to 13 years for another depending on data availability. The EToF for the Aquatic category was not computed using the previous equation, instead taken directly from Allen *et al.* (1998) for shallow water bodies, because open water does not have the same properties as vegetation. Descriptions of each type of habitat are discussed above.

Table 7 shows the ET_oF_{max} computed from Eq. 2. These values are in agreement with Allen *et al.* (2011) which states that ET_oF should not exceed 1.3- 1.4 in semi-arid climates.

Table 7 Estimated EToFmax based shallow water for aquatic and on Equation 2 for the other categories.

Vegetation	Assumed Maximum Height (ft)	Weighted Annual $ETоF_{max}$*		
		Sacramento Valley	Delta	Northern San Joaquin
Aquatic		1.05	1.05	1.05
Other Flood Plain Habitat	6	1.22	1.26	1.22
Riparian	35	1.27	1.35	1.27
Wetland	25	1.30	1.36	1.30

* The $ETоF_{max}$ assumes expansive vegetation. In cases where there are small stands of vegetation surrounded by sparse vegetation or dry land, the EToF can be significantly higher (oasis and close line effects). The Chico State pre-1900 vegetation map shows large expanses of these vegetation types so these values should be reasonable.

Grassland ET is highly dependent on available soil moisture. As will be discussed, in some areas the grasses could have access to groundwater. In many grassland habitats, these grasses will be dependent on rainfall to meet their evapotranspiration demands. An initial analysis was conducted to examine a daily soil water balance of rain fed grasslands in each of the three regions. Weather data including ETo and precipitation was obtained from one CIMIS weather station in each region (Gerber in the Sacramento Valley (2006), Twitchell Island in the Delta (2004), and Modesto in the San Joaquin Valley (2001)). Years were selected which had similar precipitation totals as shown in Table 2. Soil type information was estimated for the grassland habitat using NRCS soils map of California.

For the Sacramento Valley, Delta, and San Joaquin Valley north of Fresno the soils were classified on average as silty loam, loam, and loam, respectively. The San Joaquin Valley generally has sandy to fine sandy loam on the east side of the San Joaquin River, and clay loam on the west side. The available water holding capacity for an "average" soil was used which is based on a loam soil. A conservative root zone depth of 3 feet was assumed. The initial analysis resulted in an estimated annual EToF value for grasslands in the Sacramento, Delta, and San Joaquin of 0.3, 0.25, and 0.21, respectively.

No attempt was made to quantify the $ETоF_{max}$ for Valley/Foothill Hardwood habitat. It is expected that the ETc within this habitat will be between Other Flood Plain Habitat and grasslands.

The ETo values used were obtained for this preliminary evaluation from the California Department of Water Resources ETo Zone Map. ETo Zones 12 and 14 are within the Sacramento Valley, Zone 14 covers the Delta, and Zones 12, 14, and 15 cover the San Joaquin Valley north of Fresno. The following table shows the long-term average ETo, precipitation, $ETоF_{max}$, and the maximum likely ETc for each vegetative habitat within each region.

Table 8 Estimated upper crop evapotranspiration (ETc)

Sacramento Basin Vegetation	Long-Term Average ETo	Precipitation	$EToF_{max}$	Upper Est. ETc
	ft/yr	ft/yr	ft/ft	ft/yr
Aquatic	4.6	1.8	1.05	4.8
Grassland	4.6	1.8	0.3	1.4
Other Flood Plain Habitat	4.6	1.8	1.22	5.6
Riparian	4.6	1.8	1.26	5.8
Valley/Foothill Hardwood	4.6	1.8	0.80	3.7
Wetland	4.6	1.8	1.30	6.0
Delta Vegetation	**Long-Term Average ETo**	**Precipitation**	**$EToF_{max}$**	**Upper Est. ETc**
	ft/yr	ft/yr	ft/ft	ft/yr
Aquatic	4.8	1.2	1.05	5.0
Grassland	4.8	1.2	0.25	1.2
Other Flood Plain Habitat	4.8	1.2	1.27	6.0
Riparian	4.8	1.2	1.35	6.4
Valley/Foothill Hardwood	4.8	1.2	0.80	3.8
Wetland	4.8	1.2	1.36	6.5
San Joaquin Basin Vegetation	**Long-Term Average ETo**	**Precipitation**	**$EToF_{max}$**	**Upper Est. ETc**
	ft/yr	ft/yr	ft/ft	ft/yr
Aquatic	4.7	1.0	1.05	4.9
Grassland	4.7	1.0	0.21	1.0
Other Flood Plain Habitat	4.7	1.0	1.22	5.7
Riparian	4.7	1.0	1.27	5.9
Valley/Foothill Hardwood	4.7	1.0	0.80	3.7
Wetland	4.7	1.0	1.30	6.1

The upper ETc estimates shown in Table 8 are based on annual computations for average ETo within each basin. A more detailed evaluation is planned in the near future to examine long-term average weather parameters for multiple weather stations within each basin to refine these estimates. Additional refinements include possibly subdividing each basin by localized weather conditions (precipitation and ETo) and using remote sensing of actual evapotranspiration to examine the relative ETc rates for vegetative habitat that might be similar to what would have been found in pre-development. Through these refinements the Upper and Lower ETc estimates in the following section could change especially the Lower ETc estimates which are conservatively low for some vegetation such as grasslands.

3.1.6.4 Calculation of natural outflow

Natural flows are those that would have occurred before the Central Valley was altered by colonial and American development. The primary reason natural flows are lower than unimpaired flows is water use by natural vegetation is not accounted for in the unimpaired flow calculation. To get a truer estimate of natural flows, an estimate may be calculated by subtracting natural vegetation water use from the total supply using a simple water balance around the portion of the Central Valley that drains to the Bay:

Delta Outflow = Water Supply – Water Use by Native Vegetation

The water balance was calculated for the portion of the Central Valley that drains to the Bay as defined by DWR's unimpaired flow calculations. The results of the natural outflow calculation are summarized in Table 10. This calculation adjusts DWR's estimate of unimpaired Delta outflow to account for consumptive use by native vegetation to provide a more accurate estimate of natural annual Delta outflow assuming average climatic conditions over water years 1922-2010.

Water supply was set equal to the sum of DWR's unimpaired Delta inflow and DWR's estimate of precipitation on the valley floor. Natural inflow to the Delta watersheds is assumed to be equal to DWR's unimpaired rim inflow, reported as "Delta Unimpaired Total Inflow" for the period 1922-2010 from the most recent version of DWR's impaired flow calculations. The annual average is 29.2 MAF/yr. Precipitation on the Valley floor estimated using the most recent long-term, annual average (1922-2008) calculated by DWR for use in their C2VSIM groundwater model based on PRISM data (Kadir, 2012). The results of this analysis are summarized in Table 9.

Vegetation water use was determined by multiplying ET_c for each vegetation type by the number of acres in each region. Because of the uncertainties described previously in determining the actual ET_c values from predevelopment vegetation, an upper and lower estimate of ET_c was used to calculate a range of vegetation water use. The lower end of the ET range for riparian forest, wetland, and grassland is as described in Table 6, and is based on reports from field studies.

Other Floodplain Habitat as described by Chico 2003 is a mix of grassland, wetland and riparian land cover. The lower end of the range was determined using best professional judgment. The lower end ET of grassland is 0.8 ft/yr, wetlands is 5.1 ft/yr, and riparian forest is 4.2 ft/yr and so a ET for Other Floodplain Habitat should fall within the above stated range. Historical references indicate that land cover was predominantly dense riparian forest rather than grassland, and therefore it is appropriate to select an ET similar to Valley/Foothill Hardwood (4.0). Using best professional judgment the lower end ET for Valley/Foothill Hardwood is 3.5 ft/yr.

The lower end of the range for Valley/Foothill Hardwood was increased from 0.9 to 2 in order to reflect the historical studies indicating dense riparian forest. The 0.9 field study was based on areas with large grasslands and few trees.

The natural flow calculation presented here is not an estimate of a realized annual Delta outflow, i.e., it is not an estimate of actual flow in an individual year such as 1900 or 1850. Rather, the natural flow calculation is a long-term annual average, presented to demonstrate that unimpaired flows are natural flows and are an improper basis from which to establish objectives intended to restore the health of the estuary, which evolved in an entirely different flow environment.

Table 9 Valley Floor Precipitation (1922-2008)

Region	ValleyFloor Area (Acres)	Long-Term Average Precipitation (in/yr)	Precipitation (ac-ft/yr)
Sacramento Basin	3,712,090	21.3	6,588,960
Delta	1,399,159	14.5	1,690,650
San Joaquin Basin	3,013,204	11.7	2,937,874
Total			**11,217,484**

Table 10 Estimated Delta Outflow Under Predevelopment Conditions

Water Supply				**Long-Term Average Annual Water Supply (MAF/Yr)**	
Unimpaired Rim Inflow				29.20	
Precipitation on the Valley Floor				11.22	
Total Water Supply				**40.42**	
ETc Outflow					
Sacramento Basin	**Lower ETc**	**Upper ETc**	**Area**	**Lower ETc**	**Upper ETc**
Vegetation	**ft/yr**	**ft/yr**	**1,000 Acres**	**MAF/yr**	**MAF/yr**
Aquatic	4.4	4.8	33	0.14	0.16
Grassland	0.8	1.4	1,591	1.32	2.19
Other Flood Plain Habitat	3.5	5.6	475	1.66	2.66
Riparian	4.2	5.8	444	1.86	2.57
Valley/Foothill Hardwood	2.0	3.7	640	1.28	2.35
Wetland	5.1	6.0	530	2.7	3.17
Delta Basin	**Lower ETc**	**Upper ETc**	**Area**	**Lower ETc**	**Upper ETc**
Vegetation	**ft/yr**	**ft/yr**	**1,000 Acres**	**MAF/yr**	**MAF/yr**
Aquatic	4.5	5.0	18	0.08	0.09
Grassland	0.8	1.2	616	0.50	0.73
Other Flood Plain Habitat	3.5	6.0	117	0.41	0.71
Riparian	4.2	6.4	55	0.23	0.35
Valley/Foothill Hardwood	2.0	3.8	198	0.4	0.75

Wetland	5.1	6.5	395	2.02	2.55
San Joaquin Basin	**Lower ETc**	**Upper ETc**	**Area**	**Lower ETc**	**Upper ETc**
Vegetation	**ft/yr**	**ft/yr**	**1,000 Acres**	**MAF/yr**	**MAF/yr**
Aquatic	4.4	4.9	9	0.04	0.05
Grassland	0.8	1.0	2,264	1.80	2.22
Other Flood Plain Habitat	3.5	5.7	572	2.00	3.26
Riparian	4.2	5.9	72	0.3	0.43
Valley/Foothill Hardwood	2.0	3.7	9	0.02	0.03
Wetland	5.1	6.1	86	0.44	0.53
Total Vegetation Water Use				**17.20**	**24.80**
				Upper Bound	**Lower Bound**
				MAF/yr	**MAF/yr**
		Natural Flow Condition		**23.21**	**15.61**

The current outflow based on 2011 level of development as reported by DWR in its SWP Delivery Reliability Report is 16 MAF/yr. The result of this analysis is that current outflow is within this initial estimate of predevelopment annual average outflow. In addition, unimpaired outflow, based on SOURCE, is 28 MAF. The unimpaired outflow estimate is nearly 80% higher than the low estimate of natural outflow and 17% higher than the high estimate. The most important conclusion to be gleaned from this analysis is that unimpaired outflow is not an accurate or meaningful estimate of natural outflow.

3.1.6.5 Description of analysis to refine predevelopment outflow calculation

The Public Water Agencies are developing a simple spreadsheet model that estimates natural Delta inflows and outflows that would have occurred prior to colonial and American settlement (*i.e.*, pre-development conditions). The purpose of this further analysis is to estimate inter- and intra- annual variability in predevelopment or "natural" outflow that was not included in the initial analysis contained above.

Pre-development Delta inflows and outflows will be developed for an 88-year hydrologic period (1922-2009) assuming a monthly time step. The spreadsheet model will allow the user to easily perform sensitivity analysis by changing key input assumptions.

Calculations of pre-development Delta inflows and outflow will modify unimpaired flow calculations undertaken and published by DWR. Specifically, DWR's estimates of unimpaired flows will be modified to account for: (1) valley floor depletion of water supplies through evapotranspiration of native vegetation and riparian lands; (2) bank overflow and detention storage in low-lying areas within the Valley floor; and (3) seasonal variation in groundwater storage. In contrast to DWR's unimpaired flow estimates, pre-development accretions within the valley floor will be calculated using a land use based approach. Valley floor depletions will be calculated using estimates of pre-development land use and a simple one-dimensional root zone soil moisture model. Bank overflows and detention storage will be estimated using a hydraulic model of the Sacramento and San Joaquin river system and hydrologic routing of overflows through detention basins. Seasonal variation in groundwater storage will be estimated based on a review of historical literature and depletion by natural vegetation.

Development of Delta inflows and outflows under natural conditions will be undertaken in a series of steps as follows:

- Obtain unimpaired outflows from the mountain and foothill watersheds from published DWR reports and data
- Determine historical accretions within the valley floor
- Adjust historical accretions to account for land use change within the floor of the Central Valley.
- Route unimpaired flows through the stream system, accounting for bank overflow and detention storage
- Determine Delta outflow from Delta inflows and in-Delta depletions

It is anticipated that this model will be completed in early 2013. The Public Water Agencies anticipate having further discussions with State Water Board as the model is finalized and vetted with the scientific community.