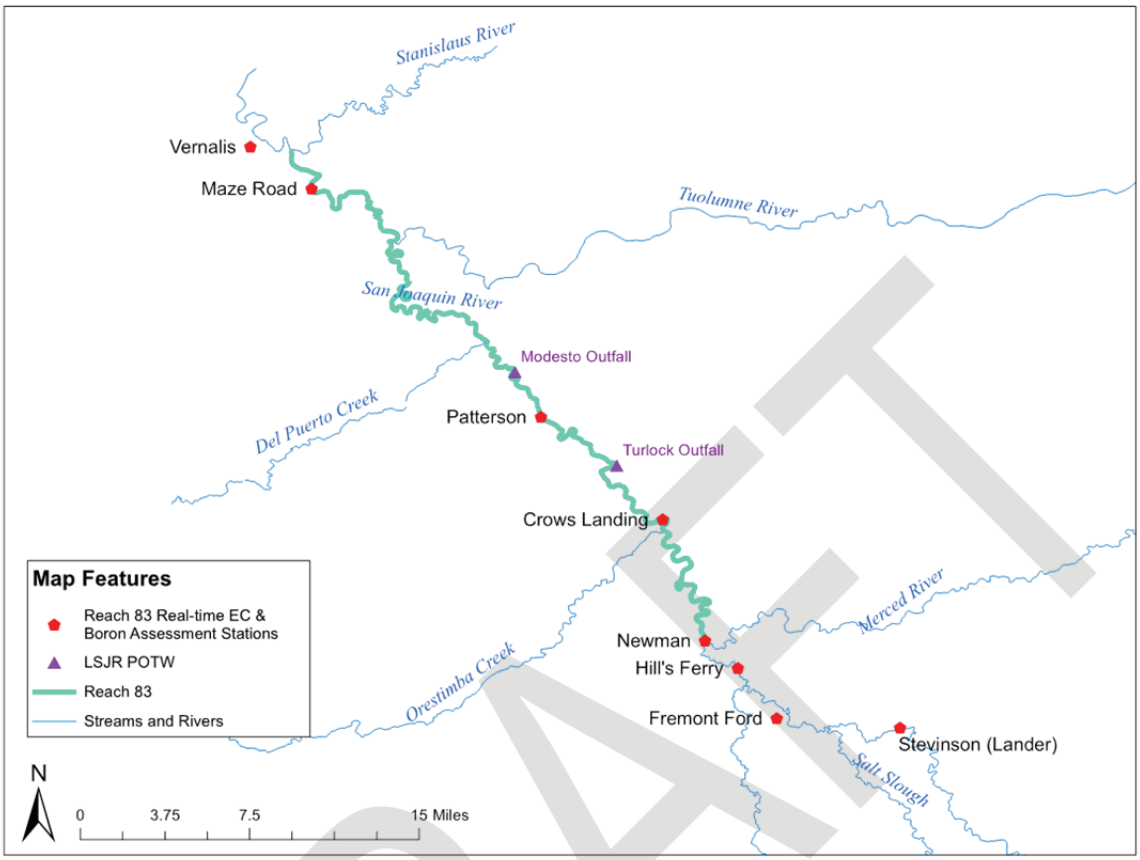
APPENDIX C
TREND ANALYSES OF BORON CONCENTRATION IN THE LSJR AT CROWS LANDING

Introduction

The Central Valley Water Board staff reviewed monitoring station data collected from the Lower San Joaquin River (LSJR) to evaluate the potential for existing boron Water Quality Objectives (WQOs) within the river between the mouth of the Merced River and the Airport Way Bridge near Vernalis (Reach 83) to be exceeded during times when the electrical conductivity (EC) concentration approaches or reaches the proposed Basin Plan Amendment (BPA) EC WQOs. The proposed Monitoring and Surveillance program in the BPA staff report designates the Crows Landing monitoring station as a compliance point for EC and boron WQOs because the highest concentrations of both constituents observed within Reach 83 of the river have been measured there. Crows Landing is upstream of the major agricultural diversion and discharge points on Reach 83 but downstream of the Merced River inflows. The concentration of boron entering Reach 83 is further diluted downstream of Crows Landing by high quality waters of two additional Sierra Nevada east side tributaries—the Tuolumne and Stanislaus Rivers. This dilution is evidenced by the improved water quality in the river farther downstream at the Maze Road monitoring station which is downstream of the Tuolumne River and the Vernalis monitoring station which is downstream of the Stanislaus River (Figure C-1).

Figure C-1 LSJR Study Location and Monitoring Sites



The boron WQOs of concern for the LSJR are listed in Table III-1 of the Water Quality Control Plan for the Sacramento and San Joaquin River Basins (Basin Plan) and presented below in Table C-1.

Table C-1. Numeric Boron Water Quality Objectives in the Lower San Joaquin River

Concentration (mg/L)	Statistical Parameter	Enforcement Period	Water-Year Type
0.8	monthly mean	15 March through 15 September	All, except Critically Dry
1.0	monthly mean	16 September through 14 March	All, except Critically Dry
1.3	monthly mean	1 October through 30 September	Critically Dry
2.0	maximum	15 March through 15 September	All
2.6	maximum	16 September through 14 March	All

Hydrologic and Analytical Considerations

When the Control Program for Salt and Boron Discharges to the LSJR was adopted into the Basin Plan in 2006, a correlation between EC and boron was identified for water samples collected at Vernalis—the furthest downstream point on Reach 83 and boundary to the Sacramento-San Joaquin Delta. The correlation noted that when EC concentrations remained below 1,000 µS/cm, the boron WQOs would be met. EC concentrations in water between Crows Landing and Vernalis are different with Vernalis comprised of all LSJR inflows including the three major eastside tributaries and Crows Landing receiving greater influence from groundwater, wetland discharges and flows from the Grassland Bypass Project (GBP) (San Francisco Estuary Institute, 2016). The GBP was implemented in 1996 and consolidates subsurface agricultural drainage from approximately 90,000 acres into the San Luis Drain (SLD). The drain then discharges into Mud Slough (north) which in turn discharges into the San Joaquin River upstream of the Merced River. The GBP discharge volume has sequentially decreased since 1996 and is scheduled to end in 2019.

To evaluate potential impacts to boron concentrations with the implementation of the Preferred Alternative, which includes completion of the Grasslands Bypass Project and 30-day running average EC concentrations up to 1,550 µS/cm during most time periods and 2,470 µS/cm during Extended Dry Periods[1], the following analyses were conducted:

- Compared historic boron concentrations to existing WQOs;
- Compared historic EC to boron concentrations in the San Joaquin River at Crows Landing; and
- Evaluated historic impact of GBP flows and boron loads on conditions at Crows Landing.

To complete the evaluations, staff utilized flow (daily composite), EC and boron data from the San Joaquin River at Crows Landing and the discharge from the San Luis Drain that had been collected as part of implementing the GBP. Data utilized is compiled in Attachment A of this Appendix.

Since the initiation of the GBP, several distinct hydrologic conditions have occurred which have had an impact on water quality conditions at Crows Landing. The first was the initiation of the GBP itself which consolidated agricultural subsurface drainage from 90,000-acres to a single discharge point in 1996. The second was the initiation of significant discharge reductions from the GBP in 2005. The third was the beginning of the longest Extended Dry Period in the San Joaquin Basin which commenced in 2013.

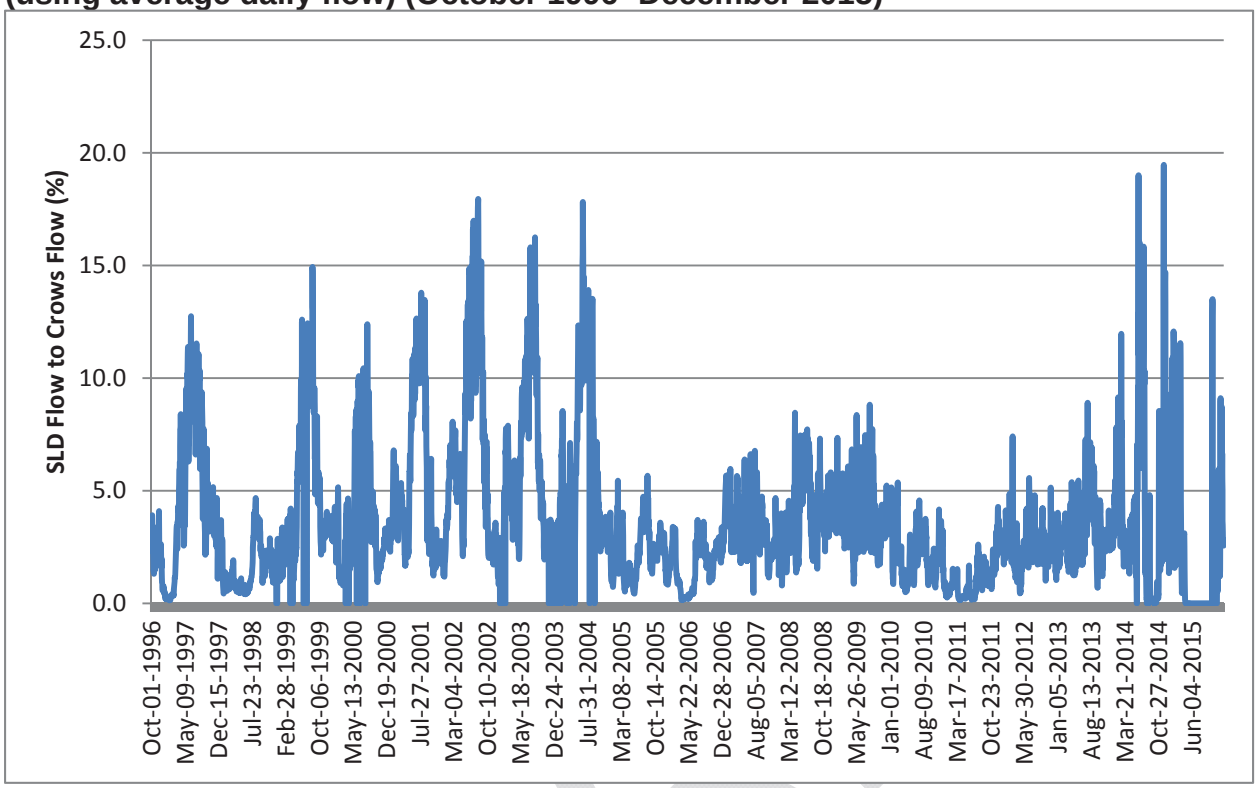
[1] See Chapter 6 for a detailed description and definition of an Extended Dry Period

To determine if these key events impacted water quality conditions, some initial evaluations were conducted comparing overall flow and boron concentration trends.

Comparison of Flow and Boron Concentration Trends

The GBP has been collecting flow and boron data at the San Luis Drain's point of discharge into Mud Slough (north) and at the Crows Landing monitoring station since the project's beginning in 1996. Figure C-2 plots an estimated monthly percentage of flow at Crows Landing originating from the discharge of the San Luis Drain from October 1996 through December 2015. The estimate is conservative as there are approximately 28 discharge points and 12 diversion points between the discharge into Mud Slough (north) and Crows Landing that are not accounted for (Central Valley Water Board, 1989a and 1989b). Figure C-2 shows that the ratio of San Luis Drain to Crows Landing discharge flow ranged from about 1 percent to about 18 percent between 1996 and 2004. Between 2004 and 2015 the discharge flow ratio ranged from about 1 percent to 9 percent. This change corresponds with the second phase of the GBP which reduced discharge. Thre project is expected to cease discharge in 2019. An exception to the reductions occurred in 2014 and 2015 when the GBP at times potentially contributed almost 20 percent of the flow at Crows Landing. This increase occurred during an Extended Dry Period. The data used to generate Figure C-2 are presented in the tables in Attachment A.

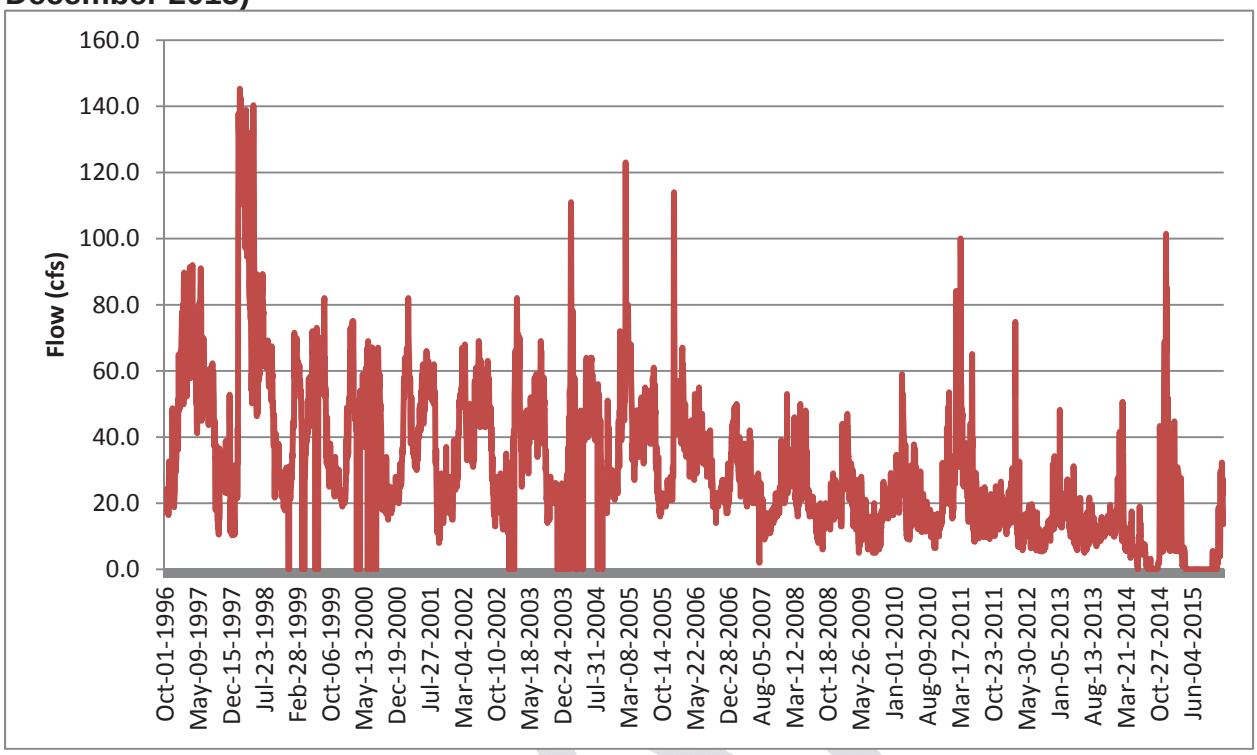
Figure C-2. Crows Landing flow percentage originating from the San Luis Drain (using average daily flow) (October 1996- December 2015)



Beginning with implementation of the GBP in 1996, subsurface agricultural drainage discharges from 90,000 acres of agricultural lands on the west side of the LSJR Basin have been diverted into the San Luis Drain and around managed wetlands into the San Luis Drain which conveys the discharges to Mud Slough. Over time, the discharge has gradually decreased. By the end of 2019, the GBP is scheduled to cease discharge to the San Luis Drain.

Figure C-3 displays the gradual decrease in the volume of discharge water entering the LSJR from the San Luis Drain through Mud Slough from October 1996 through December 2015. The figure plots the average daily flow. A decreasing trend in discharge occurred in 2005. Before then, the discharge volume typically fluctuated between 20 cubic feet per sec (cfs) and 80 cfs, except during the Wet Water Years (WY) of 1996, 1997, and 2005 when the maximum discharge at times was over 100 cfs. After 2005, the minimum and maximum flows gradually decreased, except that the maximum flow was relatively high during the Wet WYs of 2006 and 2011. Of note, the maximum flow in December of the 2015 Critically Dry WY (2014 calendar year) was also relatively high, possibly due to several large winter storms during that month. The data used to generate Figure C-3 are presented in the tables in Attachment A.

Figure C-3. San Luis Drain average daily discharge to Mud Slough (October 1996-December 2015)



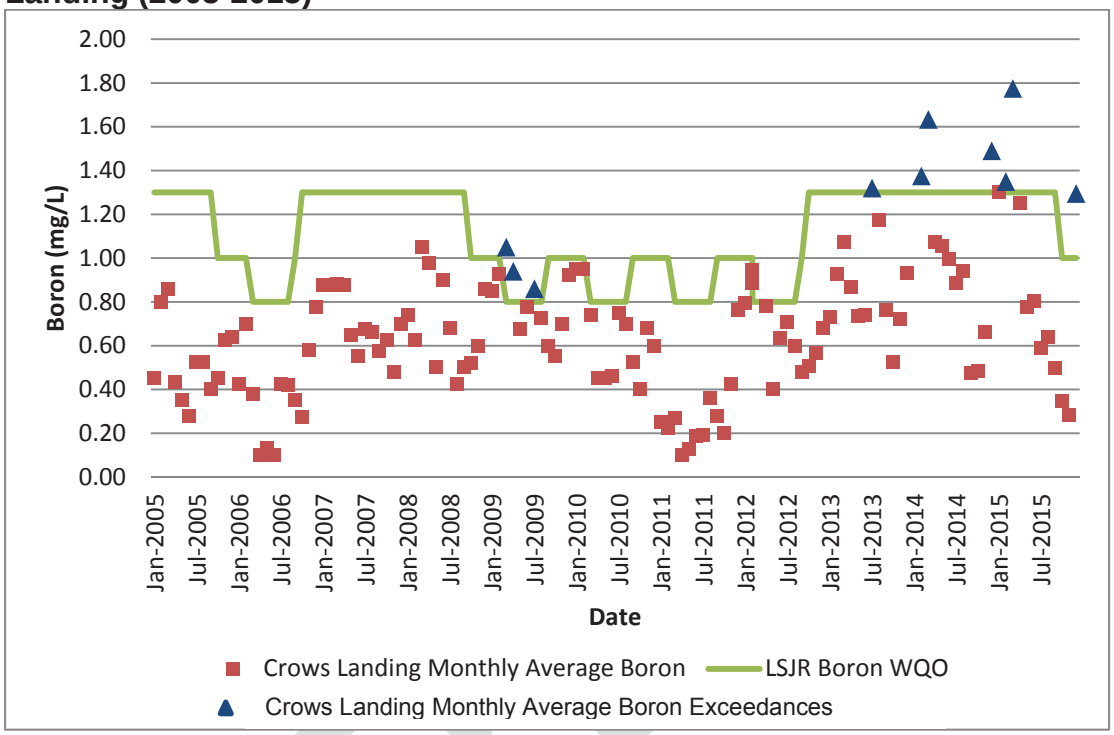
Due to the change in GBP discharge in 2005 and its decreasing influence on the water quality in the LSJR at Crows Landing, evaluations of EC and boron data were limited to the 2005-2015 time period.

Comparison of Historic Boron Concentrations to Existing Water Quality Objectives

Central Valley Water Board staff next evaluated the boron concentration trend in the LSJR at Crows Landing. Figure C-4 presents the monthly average boron concentrations at Crows Landing along with the existing boron WQOs for the LSJR. The figure shows that there were ten exceedances of the monthly average boron WQOs during the period: three occurred during the 2009 Below Normal Water Year (March, April and July), one in July of the 2013 Critically Dry WY, two in the 2014 Critically Dry WY (February and March), three during the 2015 Critically Dry WY (December 2014, and February and March 2015) and one in the 2016 Dry WY (December 2015). With the exception of the three slightly elevated exceedances that occurred in the 2009 Water Year, monthly average boron WQOs were not exceeded after 2005 until the beginning of the drought in the 2012 WY and into the start of the 2016 WY. The maximum boron WQO was also exceeded twice during this period: samples collected on 30 December 2014 and 27 March 2015 had boron concentrations of 2.7 mg/L and

2.1 mg/L, respectively. The data used to generate Figure C-4 are presented in the tables in Attachment A.

Figure C-4. Monthly average boron concentrations in the LSJR River at Crows Landing (2005-2015)



Correlation between EC and Boron in the San Joaquin River at Crows Landing

The correlation between EC and boron data collected at Crows Landing from January 2005 to December 2015 was evaluated to predict if boron concentrations would exceed the boron WQOs after discharge from the San Luis Drain stops at the end of 2019. Figures C-5, C-6 and C-7 compare weekly EC as μS/cm to boron concentrations in mg/L during three separate time periods: January 2005 to December 2015; January 2010 to December 2015; and January 2013 to December 2015, respectively. Correlation between the two constituents decreased as comparisons are weighted toward drought conditions (2013 to 2015), with R^2 decreasing from about 0.72 to 0.41. The correlation coefficient was 0.0006 during all three of the time periods. The data used to generate Figures C-5, C-6 and C-7 are presented in the tables in Attachment A.

Figure C-5. Weekly EC vs. Boron Concentrations in the LSJR at Crows Landing (2005-2015)

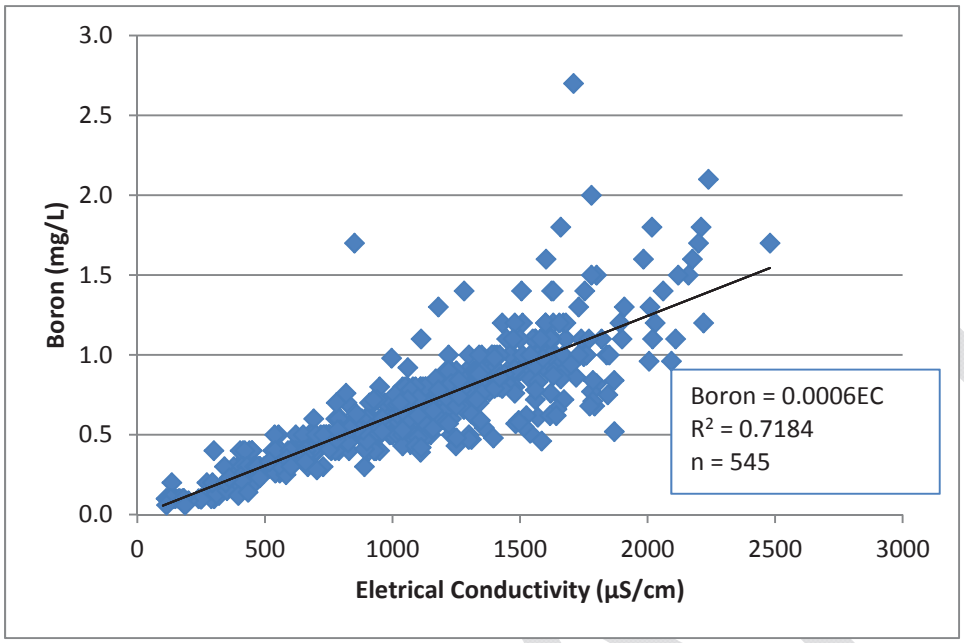


Figure C-6 Weekly EC vs. Boron Concentrations in the LSJR at Crows Landing (2010-2015)

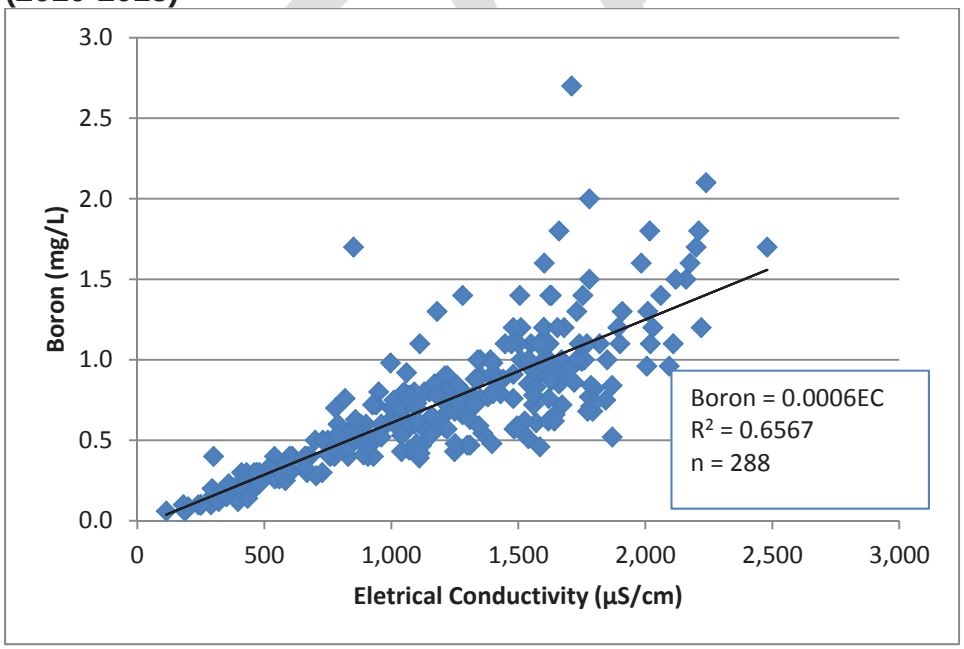
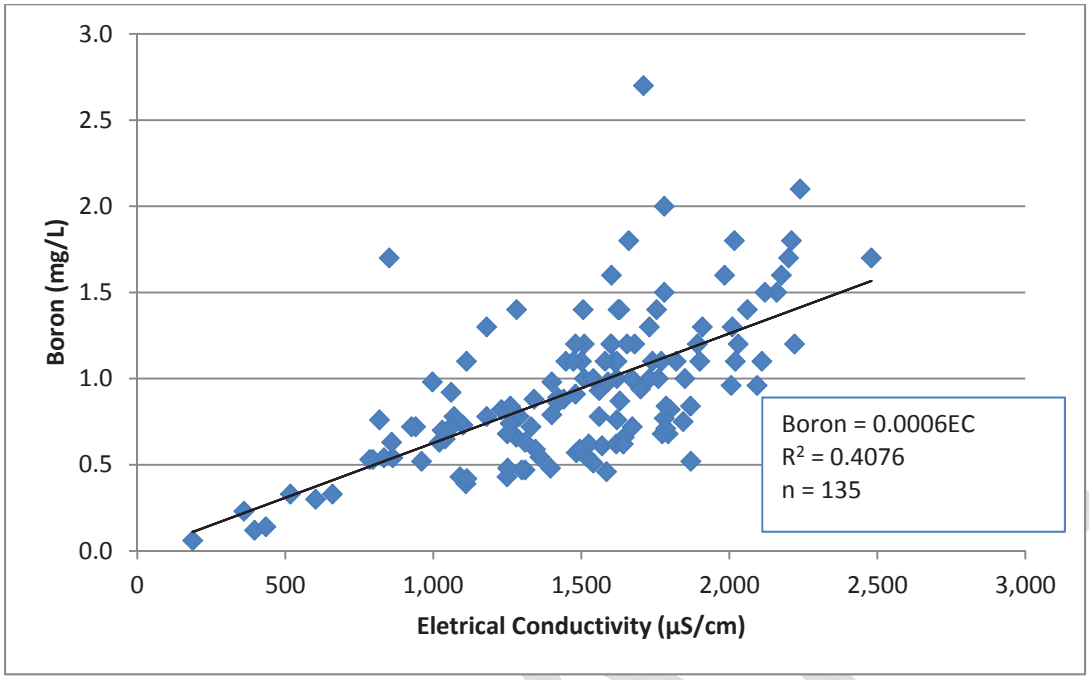


Figure C-7 Weekly EC vs. Boron Concentrations in the LSJR at Crows Landing (2013-2015)



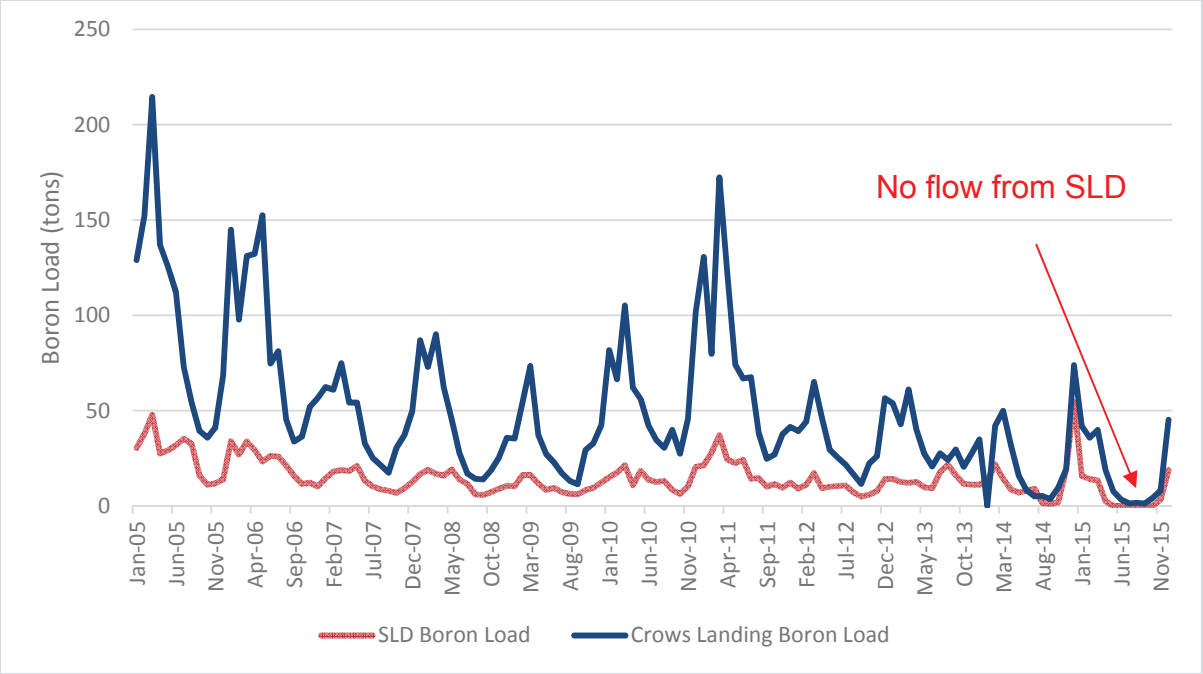
The proposed EC WQO is 1,550 µS/cm as a 30-day running average for all time periods except Extended Dry Periods when the WQO increases to 2,470 µS/cm as a 30-day running average and 2,200 µS/cm as an average of the previous 4 consecutive quarters. Using the correlation coefficient of 0.0006, boron concentration of 0.93 mg/L was calculated when the EC concentration is 1,550 µS/cm, 1.482 mg/L when the EC concentration is 2,470 µS/cm, and 1.32 mg/L when the EC concentration is 2,200 µS/cm.

Based on these calculations, the boron concentration at Crows Landing during the irrigation season of non-Extended Dry Periods would exceed the WQO of 0.8 mg/L when the EC concentration is 1,550 µS/cm. During Extended Dry Periods, the boron critical year WQO of 1.3 mg/L would be exceeded when the EC concentration at Crows Landing is 2,470 µS/cm. However, since there is considerable uncertainty in the precision and accuracy of the correlation factor, especially during the Extended Dry Period, the data was also evaluated by determining the historic impact of boron loading into the river by the GBP and potential concentrations shifts if the GBP goes to zero discharge.

Comparison of Boron Load Trends

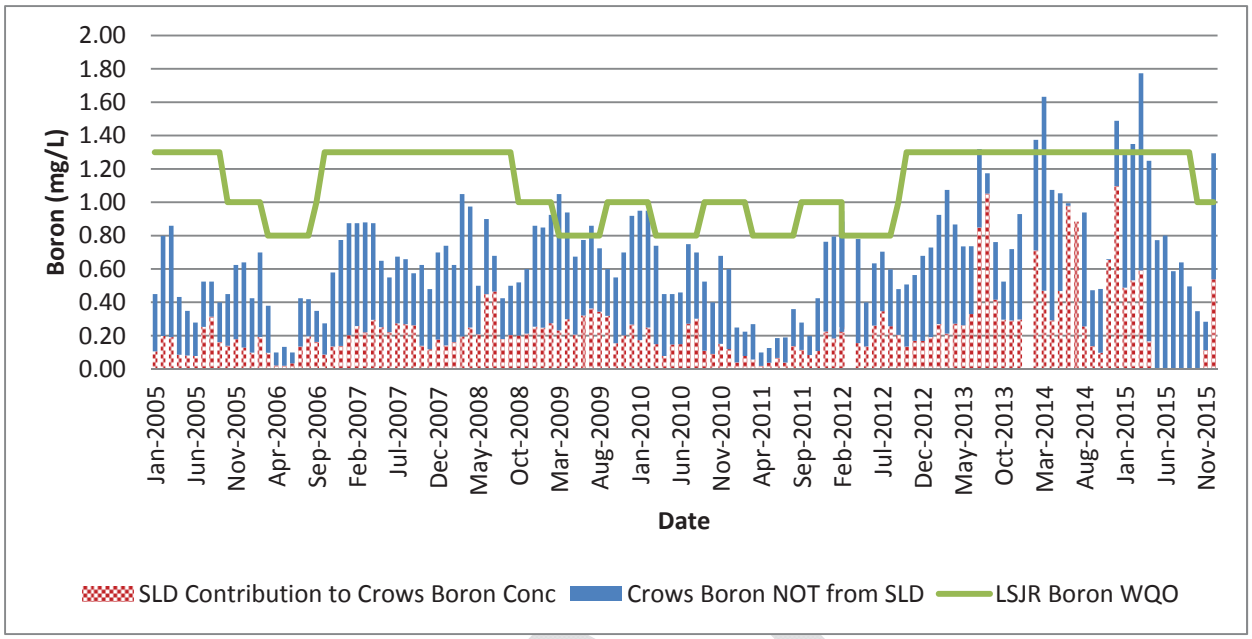
Using daily boron and daily average flow values collected from San Luis Drain for the Grasslands Bypass Project and weekly boron and daily average flow values collected at Crows Landing, the monthly boron discharge loads (in tons) were calculated for the period of 2005-2015 and presented in Figure C-8. Of note is the period from May 2015 through October 2015 when there were no monthly boron loads coming from SLD, due to a lack of flows. Implementation of the proposed EC WQOs rely on the completion of the GBP and the termination of such flows from the San Luis Drain. This graph shows that a decrease in flow from the SLD resulted in a substantial decrease of boron loads in the SJR River during 2015. The data used to generate Figure C-8 are presented in the tables in Attachment A.

Figure C-8 Monthly Boron loads from San Luis Drain and LSJR Crows Landing (in tons)



Using the ratio of San Luis Drain boron load to Crows Landing boron load, a conservative estimated contribution from the San Luis Drain to the monthly average Crows Landing boron concentrations is shown in Figure C-9.

Figure C-9 San Luis Drain's Contribution to Crows Landing Monthly Boron Concentration using the San Luis Drain to Crows Landing Boron Load Ratio



As a prediction of what boron concentrations may have been at Crows Landing without the boron load from the San Luis Drain, Figure C-10 backs out the potential contribution from San Luis Drain.

Figure C-10 Prediction of Monthly Boron Concentration at Crows Landing when Boron Contributions from San Luis Drain are not included.

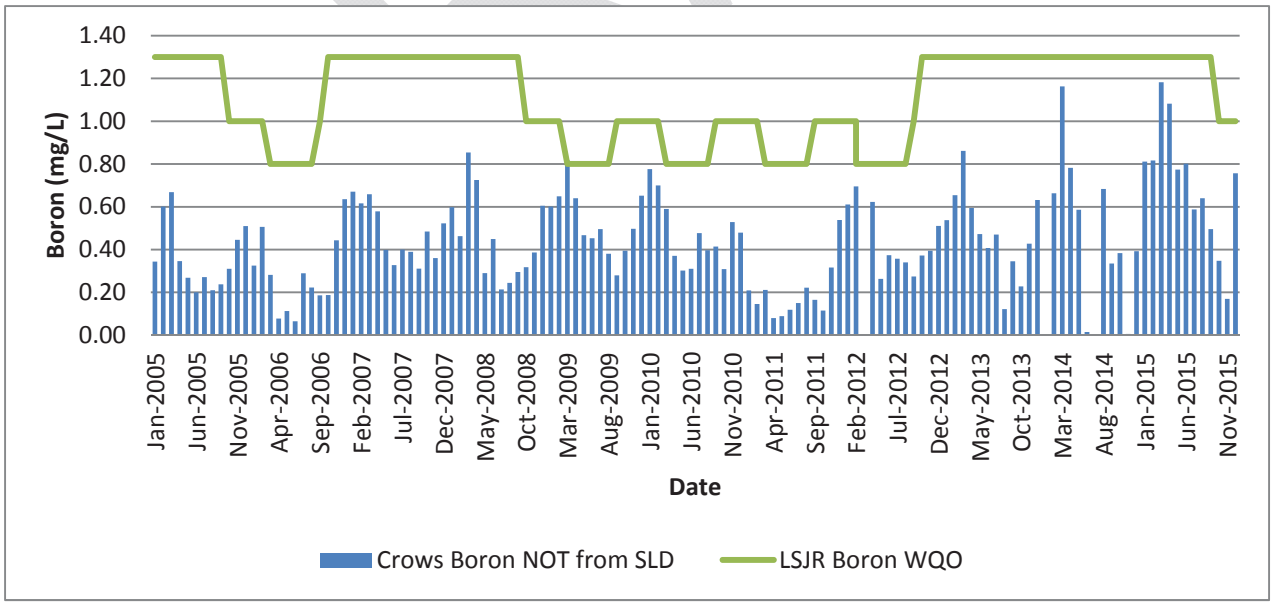


Figure C-10 indicates that without the boron loads from the Grasslands Bypass Project via the San Luis Drain, the boron concentrations in the LSJR at Crows Landing would remain below the boron WQOs.

Conclusion and Recommendations

These preliminary evaluations suggest that the EC to boron correlation in the LSJR River at Crows Landing may substantially change with conditions like more frequent Extended Dry Periods and the termination of flows from the Grasslands Bypass Project. Although a direct correlation to EC based on historic information indicates boron objectives will be exceeded at Crows Landing, boron loads from the San Luis Drain will no longer reach the LSJR after the end of 2019. As a result, it appears that the boron WQOs will be met at Crows Landing. Currently however, there is not enough data to be certain. Monitoring of the boron concentrations at Crows Landing and downstream after the adoption of the EC WQOs is necessary to determine impacts on boron concentrations and inform any decisions pertaining to the Basin Plan re-opener provision that is part of the proposed Implementation Program.

References

Central Valley Water Board. *Water Diversion and Discharge Points Along the San Joaquin River: Mendota Pool Dam to Mossdale Bridge*. 1989a.

Central Valley Water Board. *Hydrology Survey of Mud Slough (North). Merced County*. 1989b.

San Francisco Estuary Institute, Grasslands Bypass Project Website: http://www.sfei.org/projects/grassland-bypass-project#sthash.gCZWsUFf.dpbs. Last accessed on 2016 November 14.

Attachment A – Data Tables

Table 1. Daily Average Flow Data for Figures C-2, C-3, and C-8

Table 2. Crows Landing Weekly Boron Data for Figures C-4, C-5, C-6, C-7, and C-8

Table 3. Average Weekly Crows Landing EC for Figures C-5, C-6, and C-7

Table 4 San Luis Drain Daily Boron Data for Figure C-8