Evaluation of Salinity Patterns and Effects of Tidal Flows and Temporary Barriers in South Delta Channels

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South Delta Salinity Issues

There are several important water issues in the south Delta related to the San Joaquin River (SJR) inflow, Central Valley Project (CVP) and State Water Project (SWP) export pumping, reverse flows in Old and Middle Rivers, tidal water elevations and corresponding tidal flows in south Delta channels, effects of the temporary rock barriers that are installed seasonally by DWR in various south Delta channels, as well as the sources and longitudinal patterns of salinity caused by the net inflows, outflows, and tidal movement of water in south Delta channels. This study investigated the likely inflow locations of higher salinity water (i.e., sources) measured in Old River between the head of Old River and the Delta-Mendota Canal (DMC); the electrical conductivity (EC) at the Old River at Tracy Boulevard EC monitoring station was often the highest EC measured in the south Delta channels and has frequently exceeded the D-1641 EC objectives. The purpose and effects of the DWR Temporary Barriers Program on environmental conditions in the south Delta channels are described in documents and other materials available at: http://baydeltaoffice.water.ca.gov/sdb/tbp/web_pg/tempbar.cfm.

Previous State Water Resources Control Board (SWRCB) hearings (2005-2006) on the causes of higher salinity observed at the south Delta salinity monitoring stations, which included extensive background materials about the inter-related south Delta water issues, are available at: http://www.waterboards.ca.gov/waterrights/water_issues/programs/hearings/delta_salinity/.

This report presents detailed evaluations of the extensive tidal data (15-minute interval) in south Delta channels that has been routinely collected by the U.S. Bureau of Reclamation (Reclamation), the California Department of Water Resources (DWR), and the U.S. Geological Survey (USGS). The data analysis suggests that both Paradise Cut and Sugar Cut (tidal sloughs) are likely sources of higher salinity water that mixes with Old River water. The report also identifies regulatory options and compares several physical alternatives that might be implemented to reduce the high salinity often measured at the Old River at Tracy Boulevard EC monitoring station. Engineering feasibility and preliminary design studies are needed for the physical alternatives; Delta Simulation Model (DSM2) studies are also recommended to more accurately determine the salinity reduction benefits. If the engineering design and feasibility studies are acceptable, a demonstration project to install (construct) and monitor the salinity reduction effects of a proposed alternative is recommended; this should be a cooperative project between DWR, Reclamation, SWRCB, the Regional Water Quality Control Board (RWQCB), and the South Delta Water Agency (SDWA).

South Delta Salinity Patterns

Salinity (EC) in the SJR at Vernalis and at three south Delta stations is regulated by the SWRCB with EC objectives. The EC at the south Delta stations (SJR at Brandt Bridge, located about 5 miles downstream from the head [upstream end] of Old River; Old River at Middle River [Union Island], located about 5 miles downstream from the head of Old River; and Old River at Tracy Boulevard Bridge, located about 10 miles downstream from the head of Old River) are strongly influenced by the SJR at Vernalis EC. The EC at Brandt Bridge and at Union Island are generally similar to the SJR at Vernalis EC, with some increases of 25 to 50 µS/cm observed. However, the EC measured in Old River at Tracy Boulevard often is much higher than the EC in Old River at Union Island. The likely inflow locations for the higher salinity water (e.g., groundwater seepage or agricultural drainage) have been identified from analyses of longitudinal boat surveys of Old River EC measured by DWR in 2009 and 2010 (DWR 2012), and from analyses of additional EC monitoring stations installed by DWR in Sugar Cut and in Paradise Cut, beginning in 2009. Figure E-1 shows an example of the daily SJR flow and EC at the four EC compliance stations for 2012; the EC at Tracy Boulevard (red line) was often much higher than the upstream EC, and was sometimes greater than the EC objectives (green line). Periods of increased SJR flow usually reduced the SJR EC (i.e., flow-dilution effect).

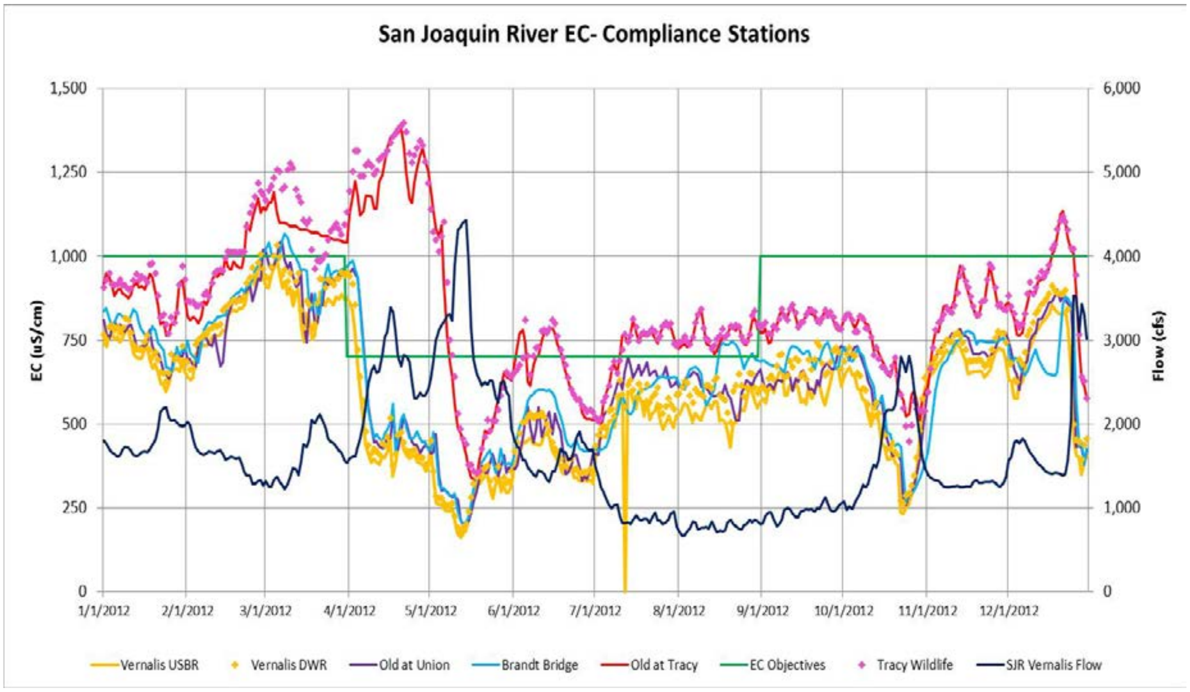

Figure E-1. Measured Daily Average SJR Flow at Vernalis and EC at Several Locations in 2012

Both Paradise Cut and Sugar Cut join Old River downstream from Doughty Cut, which conveys the majority of Old River flow to Grant Line Canal. The measured Old River at Tracy Boulevard flow, downstream from Doughty Cut, is generally about 10 percent of the head of Old River flow. The Paradise Cut and Sugar Cut EC monitoring stations both indicate periods of relatively high EC during low tides, when water from the tidal sloughs flows out of the tidal sloughs (during ebb-tides) to Old River. Higher EC water from the upstream end of these tidal sloughs appears to be the dominant sources of the increased EC observed in Old River at Tracy Boulevard. Figure E-2 shows the EC measured in Paradise Cut (blue boxes) and Sugar Cut (gold diamonds) and at several locations in Old River during 2010.

The higher salinity inflows along Old River were evaluated with a salt-budget approach; the increased daily average EC times the net flow indicates the salt source increment (tons/day). The movement of the higher salinity water leaving Paradise Cut and Sugar Cut is variable, depending on the tidal movement of water and the installation of the temporary barriers in Old River and Grant Line Canal. This report provides an integrated assessment of the tidal elevations and corresponding tidal flows in these tidal sloughs, and in Old River and Grant Line Canal, to identify periods when the higher salinity water was likely transported downstream in Old River to Tracy Boulevard and to estimate the increased EC in Old River at Tracy Boulevard.

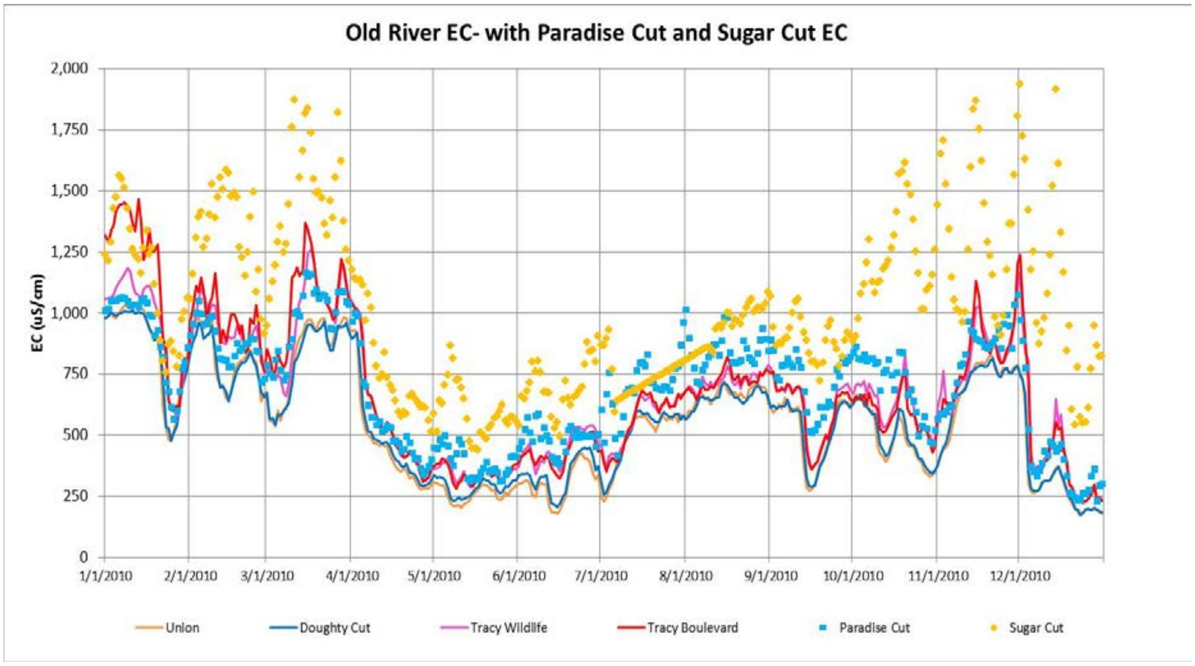

Figure E-2. Measured Daily Average EC in Paradise Cut and Sugar Cut Compared to the EC at Several Old River Locations in 2010

Tidal elevations and tidal flows in the south Delta channels are controlled by the tidal elevations in the San Francisco Bay and the south Delta channel bathymetry (i.e., depth, width and surface area). CVP and SWP pumping (Old River diversions) reduces the nearby tidal elevations, flood-tide (rising water elevation) flows upstream from the pumping intakes, and ebb-tide (falling water elevation) flows downstream from the intakes. DWR operates (annually installs and removes) three temporary (rock) barriers to provide increased minimum water elevations (i.e., 1.0 to 1.5 feet higher) during the summer irrigation season, to allow full agricultural diversions with siphons and pumps located upstream of the temporary barriers. Figure E-3 shows the effects of the temporary barriers on the minimum and maximum tidal elevations in 2013. The range of tidal elevations and tidal flows are substantially reduced by the temporary barriers.

A fourth barrier at the head of Old River has been installed by DWR in many years to protect migrating juvenile Chinook salmon in the spring (April and May) and adult Chinook salmon in the fall (October and November) of most years. The data analyses described in this report suggest that the temporary barriers reduce the tidal flows to about half of full tidal flows (without barriers) and may reduce or reverse the net flow in Old River at Tracy Boulevard, so the effects from higher salinity water from Sugar Cut and Paradise Cut on elevated EC at Tracy Boulevard may increase with the temporary barriers.

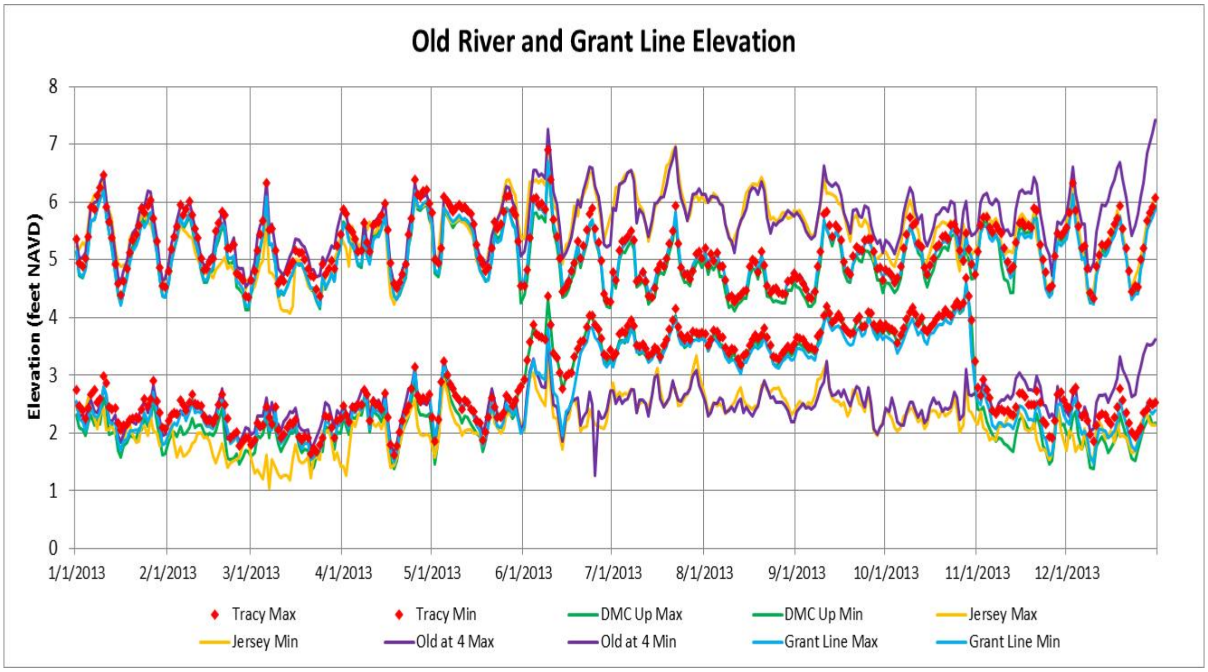

Figure E-3. Daily Minimum and Maximum Tide Elevations in Old River and Grant Line Canal at Several Locations Upstream and Downstream from the Temporary Barriers in 2013

Data Analysis Methods

Data analysis spreadsheet files with 15-minute and daily average data, calculations, graphical comparisons, and statistical summaries, were prepared for calendar years 2009-13. These integrated data files have been used to analyze and evaluate the tidal data with comparisons and calculations of the effects of CVP and SWP pumping and the temporary barriers on tidal elevations, tidal flows, and net flows in south Delta channels, as well as to identify potential salinity sources in the south Delta. These 5 years of historical data provide a wide range of SJR inflows, SWP and CVP pumping flows, and measured salinity conditions in the south Delta, including a period of Paradise Cut weir flow during 2011 when the SJR flow was high. Several data analysis methods were used to evaluate and compare the tidal flow and EC data. Results from previous tidal hydrodynamic and water quality modeling (e.g., DSM2) were discussed as part of the data evaluation. However, the DSM2 model results could not be used to identify or quantify the sources of higher salinity water, because sources of higher salinity water in the DSM2 model (i.e., agricultural drainage) were specified (assumed) in the Delta Island Consumptive Use module (DICU). The likely sources of higher salinity in Old River at Tracy Boulevard were, therefore, identified from the historical measurements.

The first data analysis method was to calculate the daily minimum, average, and maximum values for selected tidal (15-minute) measurements; this provided useful daily summaries of the tidal measurements at each station. Another data analysis method was to calculate the daily salt loads (i.e., load = conversion x flow x EC) and salt load increases (i.e., EC increment x flow increment) between measurement stations. The primary source of salt (load) in the south Delta channels is the SJR at Vernalis. The SJR at Vernalis daily salt load was calculated as the daily flow times the daily EC times a conversion factor. This method was also used to estimate the magnitude of salt sources from Paradise Cut and Sugar Cut, as well as salinity sources from agricultural drainage or shallow groundwater in the south Delta channels. The effects of wastewater discharges (e.g., City of Tracy) on the downstream Old River flow and EC were also calculated to show the relationships between flow, salinity, salt sources, and salt loads in the south Delta.

Daily average flow diversions were identified as a function of the river flow upstream from the diversion channel (or channel junction). The Paradise Cut diversion from the SJR (during high flows), the head of Old River diversion (i.e., channel junction) from the SJR, the head of Middle River diversion from Old River, and the Doughty Cut diversion from Old River to Grant Line Canal were evaluated and described with net flow diversion equations. This allowed the net daily flows in the south Delta channels to be estimated; these daily flow estimates were important for tracking the movement of water and the dilution of higher salinity inflows in each channel.

The general method for evaluating tidal flows (and confirming measured tidal flows) was to calculate the tidal flow from the 15-minute change in elevation times the estimated upstream surface area (i.e., tidal prism). For locations where tidal flow measurements were available, the upstream tidal surface area was estimated. Tidal flows are influenced (increased) by the net river flow. For example, ebb-tide flows are reduced downstream of the pump intakes and flood-tide flows are increased downstream of the intakes by the daily average CVP and SWP export pumping; however, because the Clifton Court Forebay (CCF) gates are opened and closed at specific times during the tidal cycle, the SWP diversion flow (and effects on the tidal flows) may change throughout the day.

Cumulative tidal flow volumes (acre-feet) were calculated by summing positive 15-minute tidal flow volumes for the ebb-tide volume and by summing negative 15-minute tidal flow volumes for the flood-tide volume. This allowed the tidal flows to be summarized as upstream and downstream movement of water. This method was used to evaluate the effects of the temporary barriers on tidal flows (tidal volumes) and flushing of the south Delta channels. The movement of salt in tidal sloughs (e.g., Paradise Cut and Sugar Cut) and the likely effects of a tidal gate in Old River at the DMC barrier (rather than a temporary barrier) were evaluated with this tidal flow volume method. Tidal flows at each of the temporary barriers were calculated with appropriate hydraulic equations for flow through the submerged culverts and flow over a submerged weir (plus the net flow). The upstream and downstream tidal elevations were used to estimate the tidal flows when the temporary barriers were installed. The calculated tidal flows compared quite well with the measured tidal flows in Old River at the DMC barrier, at the Head of Old River barrier (in 2012), and at the Grant Line Canal barrier. Figure E-4 shows the measured and calculated tidal flows at the Old River at DMC barrier in June 2013. Flood-tide flows through the culverts and over the crest (e.g., 500-1,000 cfs) were greater than ebb-tide flows over the crest (with culverts closed) and some leakage through the rocks.

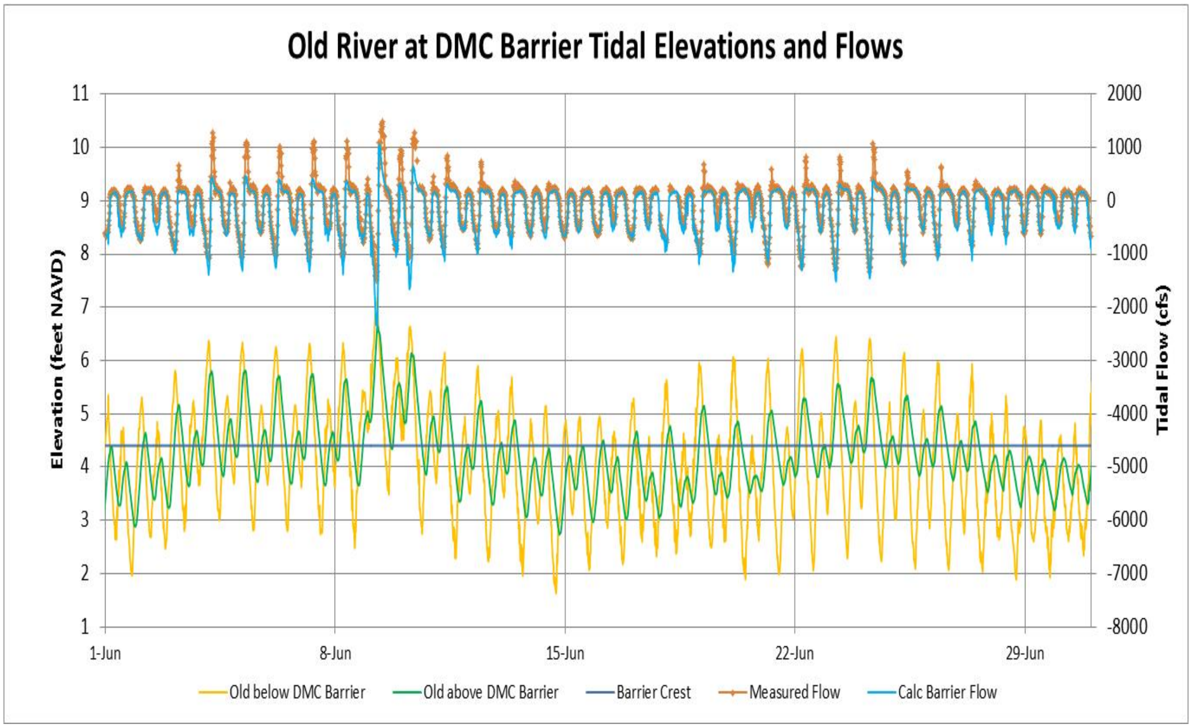

Figure E-4. Comparison of Measured Tidal Elevations and Measured Tidal Flows with Calculated Tidal Flows in Old River at the DMC Barrier in June 2013 (barriers installed)

A tidal "box-model" (water and salt budgets) of Paradise Cut, Sugar Cut, and Old River between Doughty Cut and Tracy Boulevard was used to evaluate the EC data and estimate the salt sources from these tidal sloughs. The box-model calculated the tidal movement of water between the channel segments, with specified salt sources at the upstream ends of Paradise Cut and Sugar Cut. The box-model used the measured tidal elevations and measured tidal flows at Tracy Boulevard. Because Tom Paine Slough diversions (from Sugar Cut) were relatively high during the irrigation season (e.g., 50-100 cfs), most of the Sugar Cut salt source was likely diverted to Tom Paine Slough and did not likely reach Old River during the irrigation season (with or without temporary barriers). Figure E-5 shows the measured and calculated EC increments from salt sources in Paradise Cut and Sugar Cut during 2010. The measured and calculated EC increments were similar; the EC increments at Tracy Boulevard averaged about 100 μS/cm, and the average salt load increase was about 35 tons/day. The salt sources from Paradise Cut and Sugar Cut were assumed to be relatively constant throughout the year, but the EC increments at Tracy Boulevard were somewhat lower during the irrigation season, when diversions from Sugar Cut to Tom Paine Slough were highest.

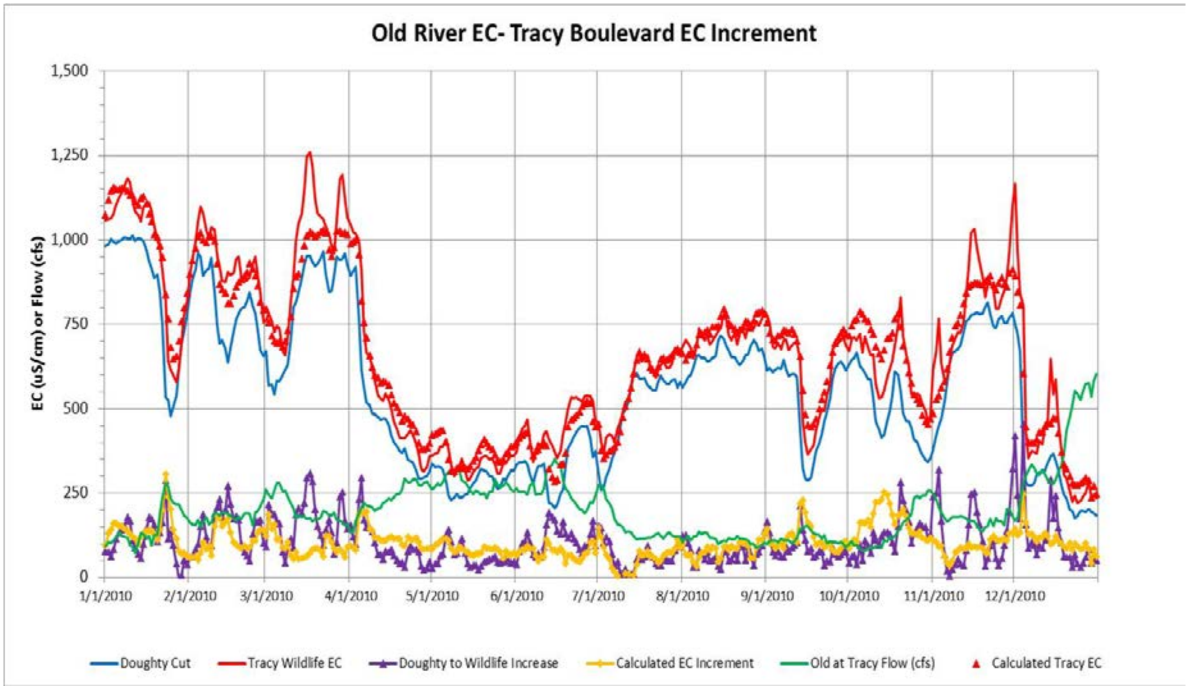

Figure E-5. Comparison of Measured and Calculated Daily EC Increments in Old River at Tracy Boulevard (Tracy Wildlife) in 2010

Another data analysis method was used to evaluate the water and salt sources for the combined CVP and SWP exports. The SJR at Vernalis and seawater intrusion in Old and Middle Rivers at Bacon Island were the two major salt sources causing increased export EC. The daily EC increment at the exports from the SJR was calculated from the SJR flow times the SJR EC (divided by the export pumping). The daily EC increment at the exports from seawater intrusion was calculated from the Old River at Bacon flow times the average EC and Middle River at Bacon flow times the average EC (divided by the export pumping). The average EC at the exports for 2011 was 250 µS/cm because high SJR flows reduced the EC to about 250 µS/cm and Delta outflow was high (no seawater intrusion). The average export EC was about 500 µS/cm in several other years. Figure E-6 shows the water and salt tracking for the CVP and SWP exports in 2009. The flows are shown in the bottom panel and the EC measurements are shown in the top panel. The seasonal variations in the export EC (purple diamonds) compared to Sacramento River water (with EC of 250 µS/cm) can be calculated from the SJR EC (red dots) and the Old and Middle River EC (dashed blue lines) and the corresponding flow fractions from the SJR, Old River, and Middle River. In 2009, the SJR EC increased the export EC (and export salt load) by 36 percent (red line), while seawater intrusion increased the export EC (and export salt load) by 72 percent (green line) compared to Sacramento River water (with EC of 250 µS/cm).

The final data analysis method was to summarize the daily average flow and EC measurements as monthly average flows, monthly average salinity (EC), and monthly salt loads (tons/month) for 2009-13. The monthly water and salt budgets for the south Delta channels, from the SJR at Vernalis to the head of Old River to the CVP and SWP exports was used to identify increases in salt loads between measurement stations and to describe the sources of water and salt in the CVP and SWP exports. These monthly water and salt budgets are presented in Attachment C.

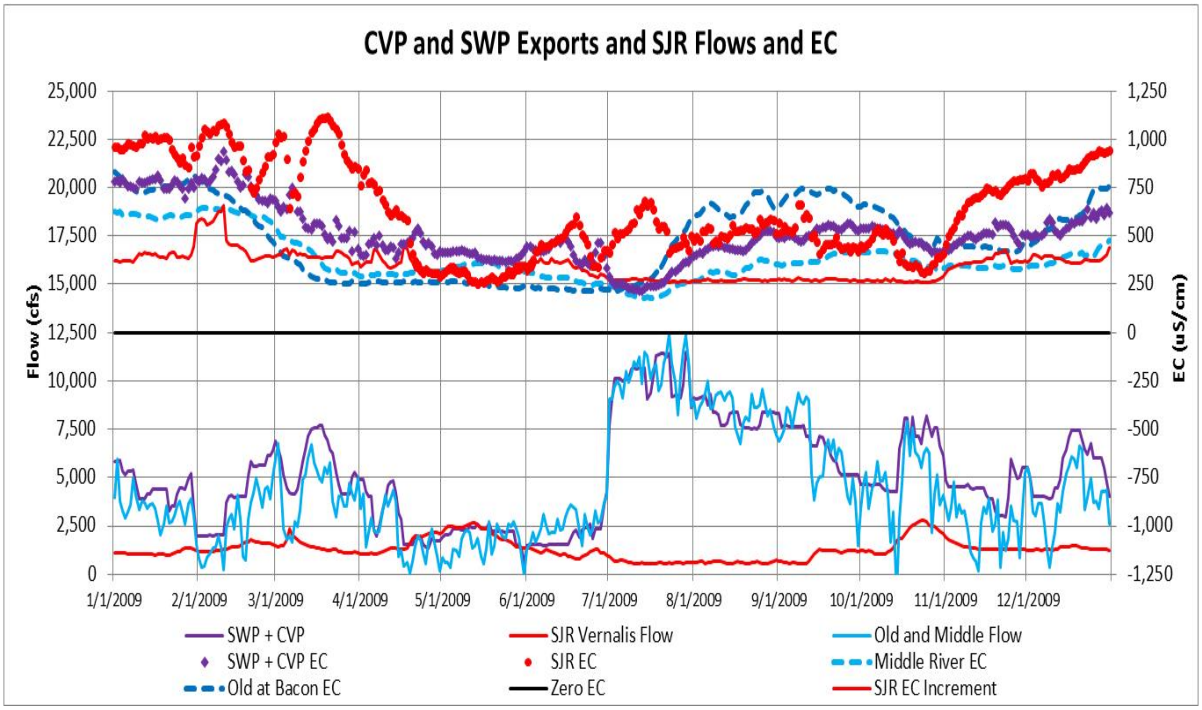

Figure E-6. Measured SJR Flows and EC, CVP and SWP Exports and EC, Old and Middle River Flows and EC, and Calculated Export EC Increments from SJR and Seawater Intrusion for 2009.

Regulatory Options and Physical Alternatives

Regulatory options were identified and several physical alternatives for reducing the higher EC measured in Old River at Tracy Boulevard were comparatively evaluated.

Regulatory Options

Based on the results shown in this report, the SWRCB might reconsider using the Old River at Tracy Boulevard monitoring station as an EC compliance station. The SWRCB could decide to retain the Old River at Tracy Boulevard as an EC monitoring station, and rely on the SJR at Brandt Bridge and the Old River at Union Island as EC compliance stations for the protection of south Delta agricultural water uses, because these stations protect the EC of water flowing into the south Delta channels. Because there are almost always EC increases in the SJR between the Vernalis EC monitoring station and the south Delta EC monitoring stations, the Vernalis EC objectives could be specified as 50 μS/cm or 100 μS/cm less than the south Delta EC objectives. For example, the SWRCB might consider adjusting the south Delta EC objectives to be 1,000 μS/cm (monthly average, year-round) at the SJR at Brandt Bridge and the Old River at Union Island stations, and might consider adjusting the SJR at Vernalis EC objective to be 900 μS/cm or 950 μS/cm (monthly average, year round). This would allow the south Delta EC objectives to be fully protective and compatible with the existing beneficial uses.

Physical Alternatives

Several physical alternatives for reducing the higher EC in Old River at Tracy Boulevard are summarized here; each will require additional feasibility and design studies:

- One previously suggested alternative was to provide flushing flows of 25 to 50 cfs from the SJR to the upper ends of Paradise Cut and Sugar Cut, to reduce (by dilution) the higher salinity in these tidal sloughs. However, preliminary evaluation of this alternative determined that because the EC in Paradise Cut and Sugar Cut is much higher than the SJR and Old River EC, the same excess salt load would enter Old River with the flushing flows, and the same elevated EC in Old River at Tracy Boulevard would likely be observed. [This alternative is therefore not recommended for further evaluation.]
- Creating a higher net flow in Old River downstream from Doughty Cut, which is currently about 10 percent of the head of Old River flow, likely would reduce the elevated EC in Old River at Tracy Boulevard. Installing the temporary barrier in Grant Line Canal without the temporary barrier in Old River at DMC likely would allow higher net flows in Old River at Tracy Boulevard (based on 2011 data). However, the minimum water levels upstream from the Old River at DMC barrier would be about 1.0 to 1.5 feet lower than with the barrier and may limit some agricultural diversions (i.e., siphons and pumps). [This alternative could be further investigated with special operations of the temporary barriers, such as removing the Old at DMC barrier first.]
- Dredging the Old River channel between Doughty Cut and Tracy Boulevard likely would allow a greater fraction of Old River flow to remain in Old River at Tracy Boulevard, and thereby likely reduce (with greater dilution) the elevated EC in Old River at Tracy Boulevard. A Geographical Information System (GIS) representation of the south Delta channel bathymetry was developed to support the evaluation of dredging volumes needed for this alternative (See Attachment A). Localized dredging may also be effective for improving minimum water elevation conditions at some existing agricultural diversions (i.e., siphons and pumps). [This alternative could be further investigated with more detailed bathymetric measurements and effects on tidal flows and flood elevations.]
- Pumping flows (e.g., 5 to 10 cfs) from the upstream ends of Paradise Cut and Sugar Cut to the SJR or to Old River upstream from Doughty Cut likely would eliminate the elevated EC in Old River at Tracy Boulevard, and would also reduce the EC of Tom Paine Slough water applied for irrigation on Pescadero Tract, and thereby might reduce the agricultural drainage EC reaching Paradise Cut. [The possibility of using the City of Tracy's pipeline to Old River upstream from Doughty Cut could be investigated once the planned new pipeline is completed; the need for water rights for the pumps should be considered.]
- Blocking the mouths of Paradise Cut and Sugar Cut with gates, dredging a 0.25-mile channel from Sugar Cut to Paradise Cut, and enlarging an existing ditch (remnant channel) from Paradise Cut to Old River upstream from Doughty Cut would allow the majority (e.g., 90 percent) of the tidal flow and salinity from Paradise Cut and Sugar Cut to flow through Doughty Cut to Grant Line Canal, and thereby reduce the elevated EC in Old River at Tracy Boulevard (to about 10 percent of the existing EC increment). [This alternative appears promising and could be further investigated with DSM2 modeling and engineering feasibility and design studies.]
- Replacing the Old River at DMC temporary barrier with a tidal-gate would create a net tidal flood-tide (upstream) flow in Old River. The tidal-gate would be opened at low tide to allow

water to flow upstream in Old River between the DMC and Tracy Boulevard during flood-tides (gate open). The tidal gate would be closed at high tide to allow Sugar Cut, Paradise Cut, and Old River upstream from the tidal-gate to tidally drain, flushing higher salinity water to Doughty Cut and Grant Line Canal during ebb-tides (gate closed). This tidal circulation with tidal-gates was proposed by DWR in the South Delta Improvements Program (SDIP; DWR 2005). This alternative might be designed and implemented as a modification of the Temporary Barriers Program. [This alternative could be further investigated with DSM2 modeling and engineering feasibility and design studies.]

- A more comprehensive salinity reduction alternative would divert the entire SJR flow at the head of Old River to Grant Line Canal, and separate the SJR water and salinity from the CVP and SWP export pumping. This alternative would include dividing walls and a river crossing to allow the SJR water flowing in Old River and Grant Line Canal flow over Victoria Canal (e.g., in a large box-culvert) carrying water from Middle River to the export pumps. This salinity-reduction alternative was included in the Bay Delta Conservation Plan (BCDP, now California WaterFix) Draft EIR/EIS as Alternative 9. This alternative could be compatible with the California WaterFix (tunnels), but would likely require additional planning efforts. [This alternative could be further investigated with DSM2 modeling and engineering feasibility studies; but a demonstration project would likely require more extensive coordination with other State and Federal water management, flood-control, and fish protection agencies.]

Recommended Next Steps

Based on the results shown in this report, the SWRCB might reconsider using the Old River at Tracy Boulevard monitoring station as an EC compliance station. Other regulatory options identified in this report might be considered by the SWRCB as part of their periodic review of the Bay-Delta Water Quality Control Plan. The effects of the salinity-reduction alternatives could be more accurately evaluated using the DSM2 tidal flow and salinity model to compare the effects of each alternative once the model is calibrated to match the historical EC conditions observed in recent years (2009-13). The DSM2 model could be adjusted with improved channel bathymetry, improved estimates of wastewater discharges (e.g., Lathrop, Stockton, and Tracy), and more accurate representations of agricultural diversions and agricultural drainage flows and salt sources in the south Delta channels. Based on further discussions with stakeholders and regulatory agencies, one of the salinity-reduction alternatives could be selected by DWR as a recommended demonstration project to actually install (construct) and measure the effectiveness of the selected alternative. The demonstration project might be permitted as a modification of the DWR Temporary Barriers Program. The selected demonstration project likely would be planned and evaluated in cooperation with the Central Valley RWQCB, SWRCB, Reclamation, and SDWA, and might be partially funded with water quality control grant funds.

The effects of the selected demonstration project could be monitored and evaluated using the tidal data analysis framework described in this report for the 2009-13 data. The tidal (15-minute) data for 2014 and 2015 might be added to the pre-project monitoring and analysis period. Some additional EC monitoring stations were recently (2014) installed by DWR, and some additional longitudinal EC profiles in Paradise Cut, Sugar Cut, Old River, and Grant Line Canal have also been measured by DWR. The evaluation of the effects of the selected demonstration project could be accurately determined with “before and after” comparisons of the tidal flows and EC patterns in the south Delta channels for a range of SJR flows and exports. If sufficiently successful in reducing the elevated EC in Old River at Tracy Boulevard, the demonstration project could be fully implemented (with any recommended design changes) as a permanent south Delta channel feature to reduce the EC in Old River and eliminate any future exceedances of the EC objectives at the Tracy Boulevard station.