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

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Disclaimer

The contents of this report reflect the largely independent work of the consultant ICF and author Dr. Russ Brown, with comments received from the Department of Water Resources, Office of the Delta Watermaster, and South Delta Water Agency. The Department of Water Resources provided funding and was the contract holder for the consultant, but does not guarantee the accuracy or completeness of this report. The alternatives and recommendations of the author are his independent opinion and do not commit or obligate the Department of Water Resources or other agencies mentioned within the report to accept or implement any of the alternatives or recommendations.

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Acronyms and Abbreviations

af	acre-feet
CCF	Clifton Court Forebay
CDEC	California Data Exchange Center
cfs	cubic feet per second
CVP	Central Valley Project
DES	Division of Environmental Services
DICU	Delta Island Consumptive Use module
DMC	Delta-Mendota Canal
DWR	California Department of Water Resources
EC	electrical conductivity
GIS	Geographical Information System
HEC	Hydrologic Engineering Center
ID	Irrigation District
mgd	million gallons per day
NAVD	North American Vertical Datum 1988
NCRO	North Central Regional Office
NWIS	National Water Information System
OMR	Old and Middle River
QA/QC	quality assurance and quality control
Reclamation	U.S Bureau of Reclamation
RWQCB	Regional Water Quality Control Board
SDIP	South Delta Improvements Program
SDWA	South Delta Water Agency
SJR	San Joaquin River
SWP	State Water Project
SWRCB	State Water Resources Control Board
USGS	U.S. Geological Survey
WDL	Water Data Library
µS/cm	microsiemens per centimeter

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).

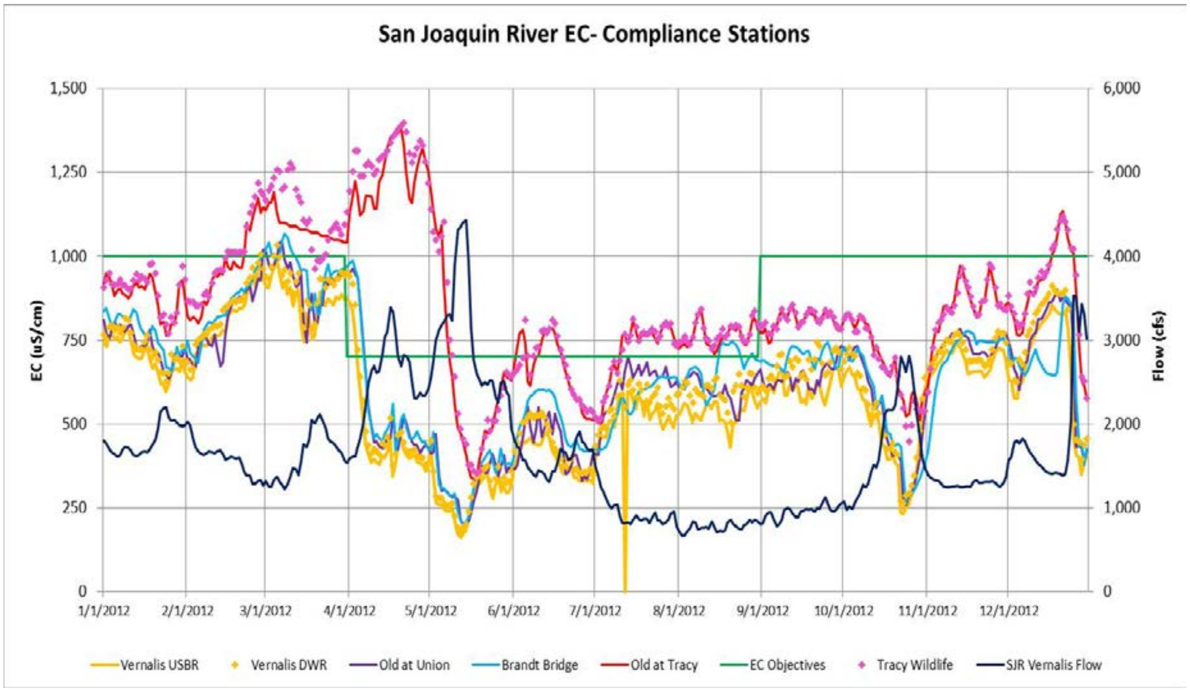


Figure E-1. Measured Daily Average SJR Flow at Vernalis and EC at Several Locations in 2012

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.

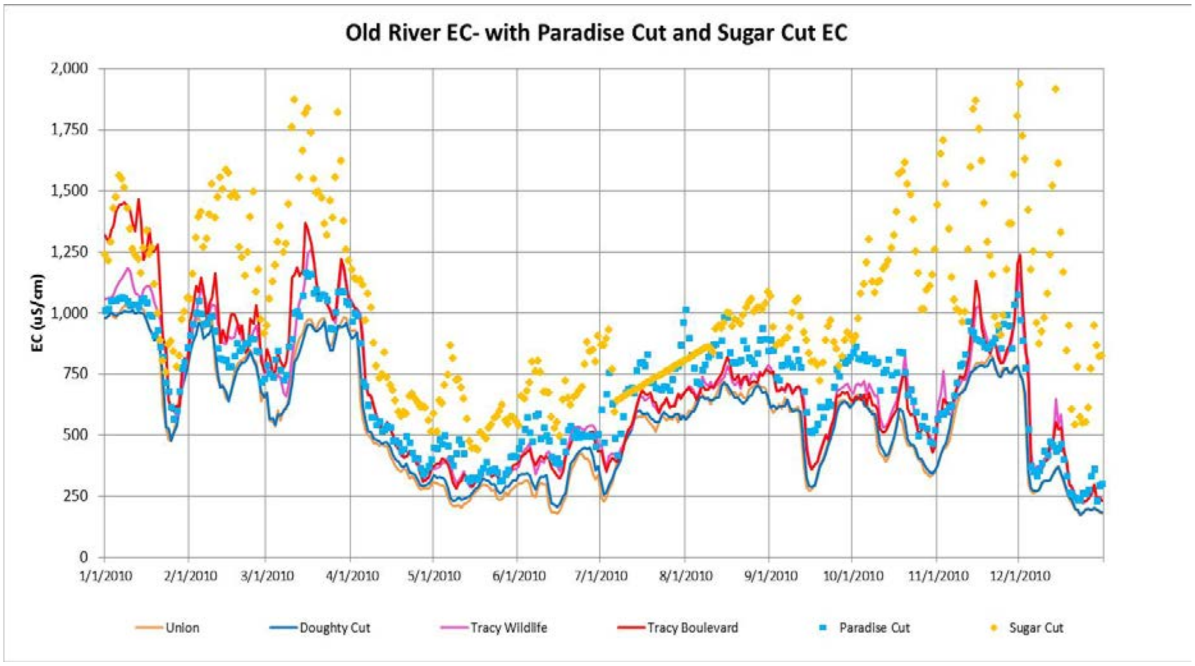


Figure E-2. Measured Daily Average EC in Paradise Cut and Sugar Cut Compared to the EC at Several Old River Locations in 2010

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.

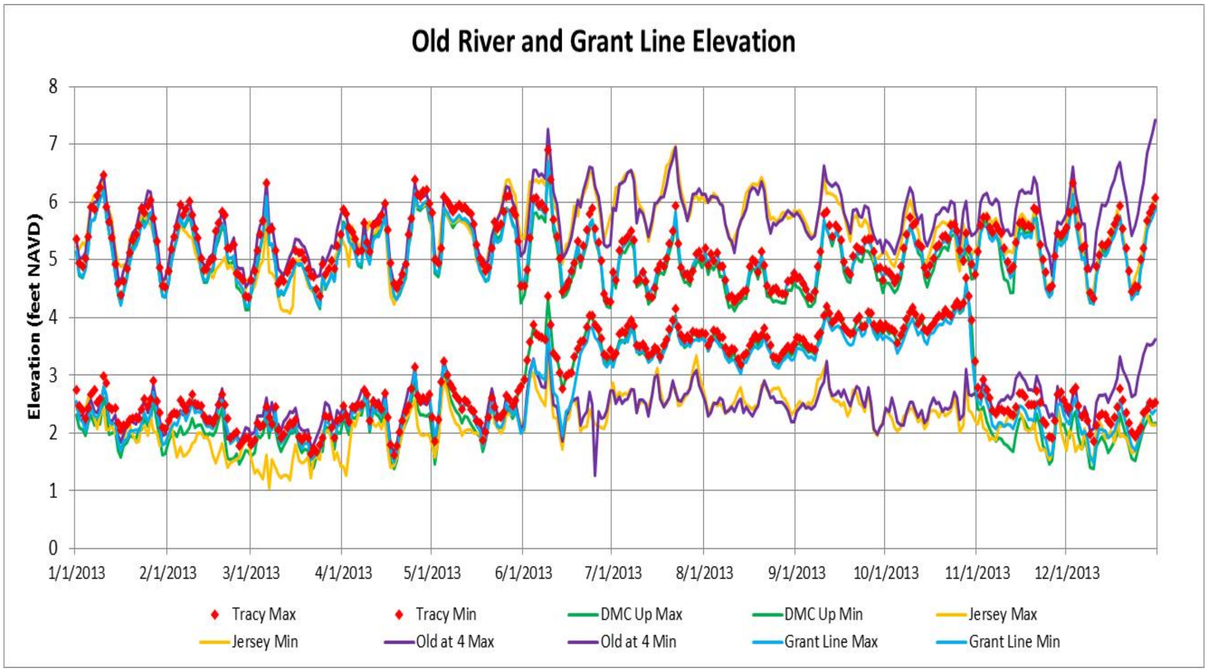


Figure E-3. Daily Minimum and Maximum Tide Elevations in Old River and Grant Line Canal at Several Locations Upstream and Downstream from the Temporary Barriers in 2013

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.

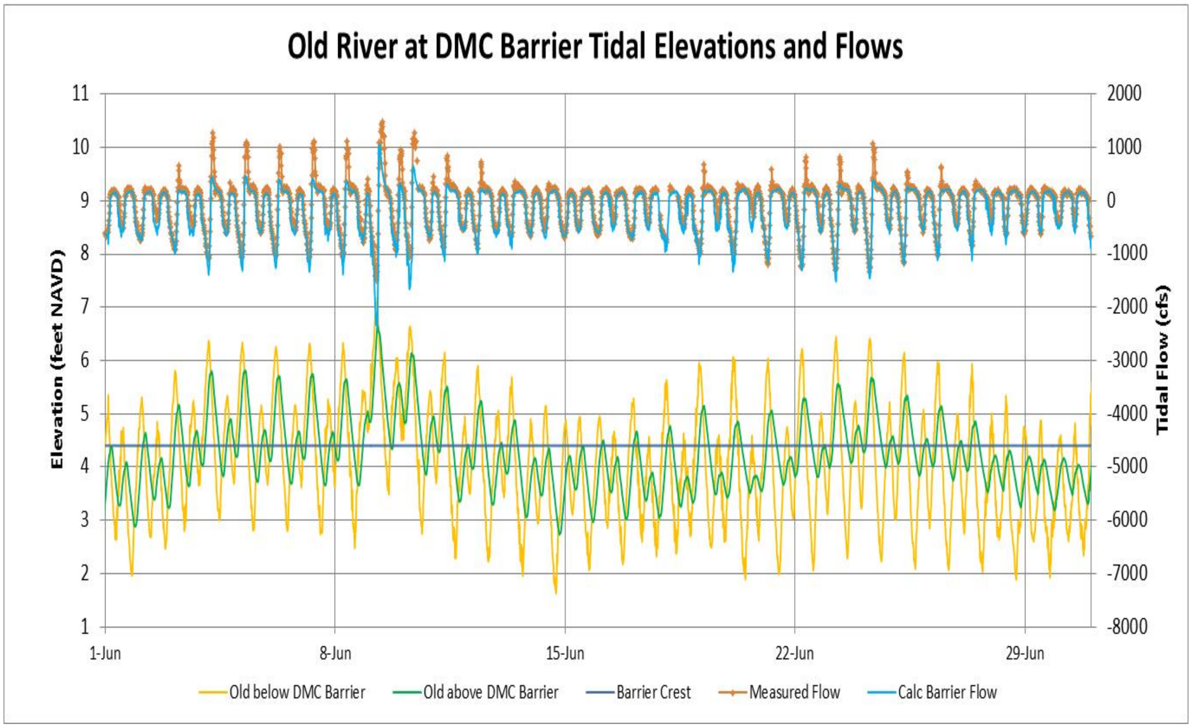


Figure E-4. Comparison of Measured Tidal Elevations and Measured Tidal Flows with Calculated Tidal Flows in Old River at the DMC Barrier in June 2013 (barriers installed)

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.

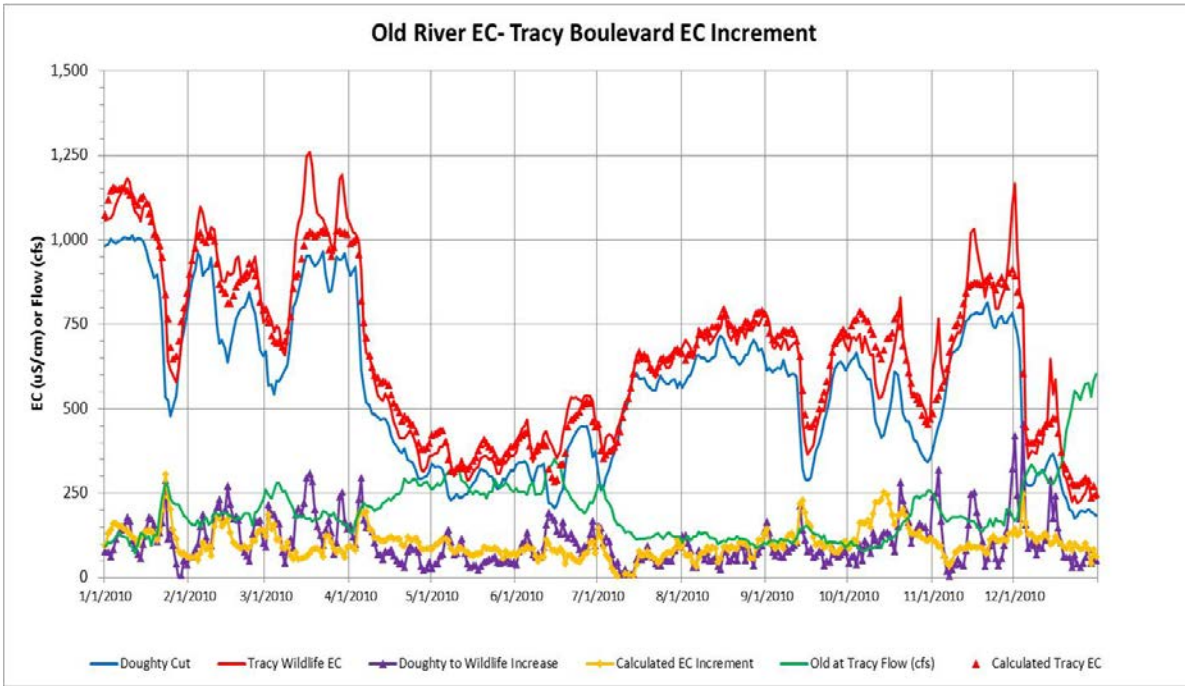


Figure E-5. Comparison of Measured and Calculated Daily EC Increments in Old River at Tracy Boulevard (Tracy Wildlife) in 2010

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.

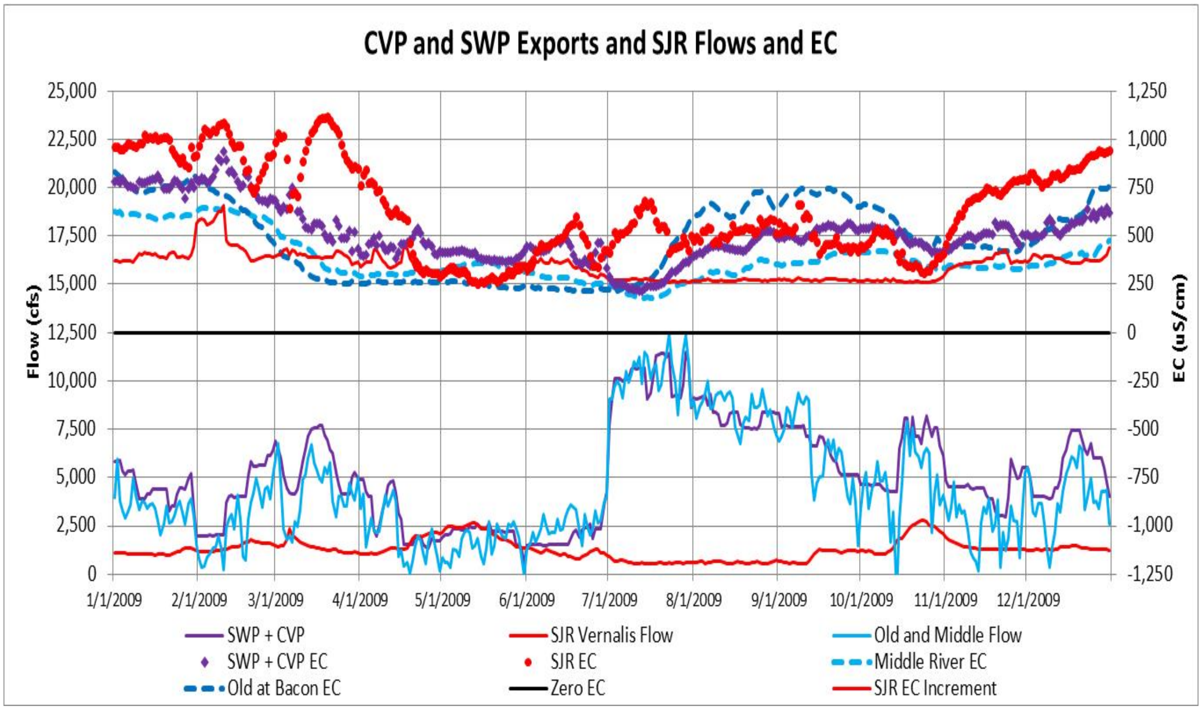


Figure E-6. Measured SJR Flows and EC, CVP and SWP Exports and EC, Old and Middle River Flows and EC, and Calculated Export EC Increments from SJR and Seawater Intrusion for 2009.

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.

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

Introduction

Sources of higher salinity water (e.g., inflows from shallow groundwater seepage or agricultural drainage) entering Old River between the head (i.e., upstream end) of Old River and the Delta-Mendota Canal (DMC) increase the Old River salinity at the Tracy Boulevard Bridge monitoring station. This report presents an integrated assessment of the effects of Central Valley Project (CVP) and State Water Project (SWP) pumping and the effects of temporary (rock) barriers on tidal elevations, tidal flows, net flows, and measured salinity patterns in south Delta channels (i.e., Old River, Middle River, and Grant Line Canal). This integrated assessment was based primarily on the extensive tidal data (15-minute interval) collected by the U.S. Bureau of Reclamation (Reclamation), the California Department of Water Resources (DWR), and the U.S. Geological Survey (USGS).

Salinity is measured as electrical conductivity (EC) at many stations in the Delta; the San Joaquin River salinity (EC) at Vernalis and at three south Delta compliance stations are regulated with EC objectives established by the State Water Resources Control Board (SWRCB):

1. San Joaquin River (SJR) at Brandt Bridge, located about 5 miles downstream from the head of Old River (near Lathrop);
2. Old River at Middle River (Union Island), located about 5 miles downstream from the head of Old River at the head of Middle River, at the southeast corner of Union Island; and
3. Old River at Tracy Boulevard Bridge (Tracy Boulevard), located about 5 miles north of the City of Tracy, about 10 miles downstream from the head of Old River and about 7.5 miles upstream from the DMC intake.

The EC objectives (D-1641) at the SJR at Vernalis station and at the three south Delta stations are currently the same; the monthly average EC must be less than 700 microsiemens per centimeter (μS/cm) from April through August, and must be less than 1,000 μS/cm for the remaining months. The measured EC at the SJR at Brandt Bridge station and the Old River at Union Island station are generally similar to that of the SJR at Vernalis station, with some increases of 25 to 50 μS/cm observed. However, the EC measured at the Old River at Tracy Boulevard station often is much higher than the EC at Old River at Union Island station, although the Tracy Boulevard station is only 6.5 miles downstream from the Old River at Union Island station. USGS, Reclamation, and DWR have installed many tidal elevation, tidal EC, and tidal velocity (tidal flow) monitoring stations in south Delta channels. In 2009, DWR added tidal EC stations in Sugar Cut (just upstream from Tom Paine Slough diversion dam) and near the mouth of Paradise Cut. Both Paradise Cut and Sugar Cut join Old River just downstream from Doughty Cut, which conveys the majority of Old River flow to Grant Line Canal. Therefore, the measured Old River flow downstream from Doughty Cut is only 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-tide periods, when water from the upstream ends of these tidal sloughs has moved towards Old River. This high salinity water from these tidal sloughs may originate from shallow groundwater seepage, agricultural tile drainage, or agricultural surface runoff, although surface runoff EC usually is not much higher than the applied water. Arbor

Road drain, a surface discharge at the upstream end of Sugar Cut, has a seasonal flow of 1 to 10 cubic feet per second (cfs); runoff from portions of Tracy and tile drainage from portions of the Westside Irrigation District lands contribute to this flow. Higher EC water from the upstream ends of these tidal sloughs appears to be the dominant sources for the increased salinity observed at Tracy Boulevard station.

Salinity (EC) monitoring at both Sugar Cut and Paradise Cut has documented many periods when the EC was greater than the EC objectives (700 µS/cm or 1,000 µS/cm), and, therefore, could be influencing the measured EC in Old River at Tracy Boulevard. Because the measured EC increase in Old River at Tracy Boulevard depends on the net river flow past Tracy Boulevard and the salt load of higher salinity water (i.e., source flow times source EC), the tidal flow measurements in the south Delta were used to estimate the daily net flows, and the net flows were used to calculate the daily salinity (loads) added to Old River between Union Island and Tracy Boulevard. Because of tidal flows in all of these south Delta channels, and the connection between Old River and Grant Line Canal through Doughty Cut, the movement of the higher salinity water leaving Paradise Cut and Sugar Cut is variable, depending on the tidal fluctuations and the installation of the temporary barriers in Old River and Grant Line Canal. This report evaluates the movement of higher salinity water from Sugar Cut and Paradise Cut to determine how much of the measured salinity increase in Old River between Union and Tracy Boulevard can be identified (i.e., explained), and describes several possible methods for reducing the EC at Tracy Boulevard to eliminate all periods of non-compliance with the EC objectives.

Reclamation is responsible for compliance with the SWRCB's Water Rights Decision D-1641 flow and salinity (EC) objectives for the SJR at Vernalis station, using releases from New Melones Reservoir to increase flows and reduce EC when necessary. The sources of water and salt (EC) in the SJR at Vernalis are not described in this report. When the Vernalis EC is almost equal to the EC objective, there is little remaining assimilative capacity for salt sources downstream of Vernalis, because the south Delta EC objectives are identical to the Vernalis EC objectives. Reclamation and DWR are held jointly responsible by the SWRCB for compliance with D-1641 salinity (EC) objectives at several Delta stations, although DWR and Reclamation may not have any direct control on the salinity at the three south Delta compliance stations, because the three south Delta EC compliance stations are most directly influenced by the SJR at Vernalis flow and EC.

The CVP Jones pumping plant and the SWP Banks pumping plant are located on Old River in the southwest corner of the Delta. The CVP intake to the DMC is located about 1 mile upstream (south) from the SWP intake to Clifton Court Forebay (CCF). CVP and SWP pumping (diversions) reduce nearby tidal elevations, flood-tide flows upstream from the intakes in Old River and Grant Line Canal, and ebb-tide flows downstream of the intakes in Old River, Victoria Canal and Middle River. The effects of pumping on south Delta water levels have been partially offset by operation of the CCF intake gates (i.e., closed during low tides and during the flood tide prior to the higher-high tide each day) and with the annual installation of temporary barriers at three locations in south Delta channels (in most years). DWR operates (annually installs and removes) the temporary barriers to provide increased minimum water elevations during the summer irrigation season, and to provide some circulation (net flows) in south Delta channels to maintain water quality conditions (EC) using culverts with flap gates to increase the flood-tide flows at each barrier. A fourth barrier at the head of Old River has been installed by DWR to protect migrating fish in the spring (juvenile Chinook salmon in April and May) and fall (adult Chinook salmon in October and November) of most years.

The operations of the temporary barriers (e.g., installation, opening culverts, and removal) generally are described in Water Rights Decision D-1641 and in permits granted by the U.S. Army Corps of Engineers, the National Marine Fisheries Service (NMFS), the U.S. Fish and Wildlife Service (USFWS), and the California Department of Fish and Wildlife. Several water quality monitoring stations and biological field surveys (e.g., for vegetation and aquatic species) are required by these permits. Many years of temporary barrier operations, as well as several tidal flow modeling studies, have indicated that although the temporary barriers maintain somewhat higher minimum daily water elevations upstream from the barriers, tidal flows are substantially reduced by the barriers, and net (daily average) flows in south Delta channels also are modified (i.e., shifted). The temporary barriers may cause net upstream flows in the portions of Middle River and Old River upstream from the barriers (as planned), but this may unintentionally reduce the Old River flow at Tracy Boulevard and allow the Tracy Boulevard EC to increase. Without temporary barriers, the measured Old River net flow at Tracy Boulevard is about 10 percent of the head of Old River net flow, because the majority of the Old River flow is diverted to Grant Line Canal through Doughty Cut. Higher salinity water from Sugar Cut and Paradise Cut often flows towards Tracy Boulevard, and the EC increases are greater with lower Old River flows. The temporary barriers reduce the tidal flows to about half of full tidal flows (without barriers) and may reduce or reverse the net flow at Tracy Boulevard, so the effects from higher salinity water from Sugar Cut or Paradise Cut may increase with the temporary barriers. The measured EC increase between Union Island and Grant Line Canal (at Doughty Cut or Tracy Boulevard) is smaller because the net flow in Grant Line Canal is much higher.

Sources of higher salinity water entering Old River downstream from Doughty Cut were evaluated from tidal elevation, tidal flow, and tidal EC data, as well as from longitudinal boat surveys of Old River EC conducted in 2009 and 2010 (DWR 2012). The tidal data analysis is presented in five south Delta Data Atlas Microsoft Excel files and in five Microsoft Word documents using a combination of graphs and text format (converted to pdf files). The Data Atlas framework includes the compilation, integration, and analysis of the 15-minute tidal elevation, tidal flow, and tidal EC data from about 25 south Delta stations located on the SJR, Old River, Middle River, Grant Line Canal, Victoria Canal, Paradise Cut, Sugar Cut, and Tom Paine Slough. Excel files with 15-minute and daily average data, calculations, graphical comparisons, and statistical summaries, has been prepared for calendar years 2009 through 2013.

This evaluation project also identified several possible solutions (alternatives) to reduce the higher salinity (EC) in Old River at Tracy Boulevard. One previously suggested solution 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 the higher salinity in these tidal sloughs. However, the preliminary evaluation determined that because the EC in Paradise Cut and Sugar Cut are much higher than the SJR and Old River EC, about the same excess (i.e. higher than Old River EC) salt load would enter Old River with the flushing flows and about the same incremental EC would likely be observed at Tracy Boulevard. Several other changes in south Delta channel conditions that possibly could reduce or eliminate the excess salinity which has been observed in Old River at Tracy Boulevard were identified and are described and comparatively evaluated in this report. The likely effects of these salinity-reduction alternatives could be more accurately evaluated using the DSM2 model to compare the effects of each alternative with the historical EC conditions observed in recent years. Although the DSM2 model could not be used to identify the locations of the higher EC water sources (i.e., inflows), the DSM2 model could be adjusted with improved channel bathymetry, improved estimates of wastewater discharges (e.g., Lathrop, Stockton, and Tracy), and more accurate representation of agricultural diversions and agricultural drainage flows in the south Delta channels. The calibrated DSM2 model (i.e. adjusted to match the historical data) could then be used to compare the likely changes that would be likely with each alternative.

Based on the DSM2 modeling results and further discussions with stakeholders and regulatory agencies, as well as more detailed engineering feasibility and design studies, one of the salinity-reduction alternatives could be selected by DWR as a recommended demonstration project to actually measure the effectiveness of the alternative. A selected demonstration project likely would be conducted in cooperation with the Central Valley RWQCB, SWRCB, Reclamation, and South Delta Water Agency (SDWA) with possible water quality control grant funding. The effects of a selected demonstration project could be evaluated using the same tidal data analysis framework described in the Data Atlas portion of this project. Some additional EC monitoring stations have recently (2014) been installed by DWR, and some additional longitudinal EC profiles in Paradise Cut, Sugar Cut, Old River, and Grant Line Canal have been measured by DWR, so that the effects of the selected demonstration project could be accurately determined and evaluated (with before and after comparisons). If monitoring and data analysis confirms that the demonstration project was successful in reducing salinity at Tracy Boulevard, the demonstration project could be fully implemented (with recommended design changes) as a permanent south Delta channel feature to eliminate any future exceedances of the EC objectives in Old River at the Tracy Boulevard EC compliance station.

South Delta Channel Flows and Salinity Patterns

Tidal flows in south Delta channels generally are controlled by tidal elevations in the San Francisco Estuary and channel geometry (i.e., width, depth, length and connections with other channels), as well as by the SJR at Vernalis flow and the CVP and SWP south Delta pumping plants (i.e., exports) that are located on Old River near Tracy. Salinity in south Delta channels is largely controlled by the SJR at Vernalis flow and salinity, as well as by agricultural diversions of water and salt from the channels, and drainage or groundwater seepage (i.e., inflows) of higher salinity water to the channels. Because a majority of CVP and SWP exports pumped from the south Delta is water from the Sacramento River that flows across the Delta, salinity in the south Delta channels is generally reduced with increased CVP and SWP pumping. Seawater intrusion during periods of low Delta outflow may increase the salinity in Old River (downstream of the CVP and SWP pumping plants),but rarely does seawater intrusion cause the salinity in the exports or in the south Delta channels to become greater than the SJR at Vernalis salinity (EC). Tidal flows provide substantial mixing of SJR water, Sacramento River water, agricultural drainage water and groundwater seepage water in south Delta channels. Tidal flows and tidal variations in the measured salinity patterns in south Delta channels are described in this section.

Tidal Flow Definitions and Concepts

“Tidal flow” is the movement of water past a location caused by tidal changes in water elevations. As water elevations increase (rise) in the ocean or downstream portion of a bay, channel, or slough, gravity (force) causes the water to move upstream because the water elevation gradient (higher to lower) slopes upstream. The upstream movement away from the ocean is called a “flood-tide,” and the tidal flow is referred to as the “flood-tide flow.” As the water elevation decreases (falls) in the ocean or downstream portion of a bay, channel, or slough, gravity (force) causes the water to move downstream because the water elevation gradient slopes downstream. The downstream movement toward the ocean is called an “ebb-tide,” and the tidal flow is referred to as the “ebb-tide flow.” The tidal flow is the tidal velocity (measured) times the cross-section of the channel at the velocity measurement station (changes with tidal elevation). Each tidal flow measurement station uses an elevation-area relationship to calculate the tidal flow from the tidal velocity and water elevation.

Both the sun and the moon have strong gravitational forces that cause tidal variations in ocean elevations. Because the lunar day (the time between the moon being directly overhead today and tomorrow) is about 24.84 hours (24 hours 50 minutes), a progressive lag exists between the greatest gravitational force from the sun and from the moon. This progressive lag causes interference in the two major tidal waves and thereby causes the spring-neap tidal cycle variations in the tidal range. The tidal range is greatest during “spring tides,” when the sun and the moon are aligned (new moon and full moon). The tidal range is smallest during “neap tides,” when the moon is sideways to the sun (first quarter and third quarter). The spring-neap cycle is about 28.5 days (24/0.84), and thus a full spring-neap lunar cycle is experienced once each month (with a few days remaining). Therefore, although the tidal water elevation variations are generally similar each day, with two solar tides (flood and ebb tides), the tidal fluctuations are slightly different each day because of the lunar spring-neap cycle. In south Delta channels, the tidal variations each day generally are similar, with a small lag at upstream stations, because they are connected (linked) to Pacific Ocean tidal elevations that propagate upstream in the San Francisco Bay, the SJR, Old River, and Middle River to the south Delta channels.

The SJR at Vernalis inflow generally is added to the tidal flows in the portion of the SJR channel that has water surface elevations within the zone of tidal elevations (i.e., < 5 feet NAVD). This zone of tidal flows extends upstream past Mossdale at low SJR flows (i.e., < 1,000 cfs). At higher flows, the water elevation (cross-section) and slope required to transport the water downstream eliminates the tidal flows. The downstream river flow is added to the tidal flows in the SJR channel; ebb-tide flows are increased, and flood-tide flows are decreased by the SJR inflow. The effects of the CVP and SWP diversions are similar to the effects of SJR flow; the diversion flows are subtracted from the flood-tide flows upstream of the diversions, and are subtracted from the ebb-tide flows downstream of the diversions. However, because the diversions also have effects on tidal elevations, some additional effects on tidal elevations and tidal flows are observed both upstream and downstream from the CVP and SWP diversions, in Old River, Grant Line Canal, Victoria Canal, and Middle River. All of these tidal variations and effects from SJR flows and from the CVP and SWP diversions are accurately recorded by the 15-minute tidal elevation and tidal flow measurements in south Delta channels.

Salinity Definitions and Concepts

Salinity in the Delta channels and in the agricultural soils is assumed to be “conservative,” meaning that salt mass (weight) is neither increased nor reduced by chemical reactions (i.e., dissolving or precipitating). The salt concentration may be increased by the addition of salt or the evaporation (or transpiration) of some of the water. The “load” of salt is the mass of salt per volume (i.e., concentration) times the water flow, or the mass of salt added (i.e., inflow source) or diverted per time. The river salt load (mass/time) increases with the addition of wastewater discharge or agricultural drainage; the river salt load does not change substantially with rainfall because the flow increases slightly but the salt concentration is reduced slightly (rainfall EC is less than 25 µS/cm); and the river salt load does not change with evaporation because the salt concentration increases slightly but the flow is reduced slightly. The basic analysis method used in this report is a salt balance of the SJR from Vernalis (i.e., inflow) through the south Delta channels to the CVP and SWP exports (i.e., outflow) near Tracy, including the agricultural diversions and drainage (i.e., return flows) in the south Delta channels. A salt balance between two flow and EC measurement stations can be used to identify the local inflows of higher salinity water (i.e., sources). A general salt balance is assumed for the agricultural irrigation areas, with the applied salt balanced by the return flows (i.e., less water with higher EC). This report does not measure or calculate the salt balance in the irrigated lands.

Salinity is measured as electrical conductivity (EC); as salinity increases, the electric current across an electrode gap of 1-cm (standard distance) increases. Devices have been developed to measure EC with a constant voltage potential and adjusted for water temperature. EC measurements generally are adjusted to 25 degrees Centigrade. Calibration of field devices is achieved by comparing the meter readings when the electrode is immersed in standard solutions, prepared by dissolving a known quantity of salt in the water. The range of EC in the Delta is 100 μS/cm (freshwater) to about 25,000 μS/cm (50 percent seawater); the range of EC in the south Delta channels is much less, with a maximum EC of about 2,500 μS/cm (5 percent seawater).

The EC stations (EC sensors) in the south Delta normally are calibrated by comparing the measurements in the laboratory, using a standard solution with an EC of about 2,500 μS/cm. This provides a good calibration for the normal range of EC measurements. However, because each station is independently calibrated, nearby EC station measurements on the same day (assumed to be measuring the same river water) may not be identical. Daily average EC variations of 10 to 25 μS/cm between nearby stations are regularly observed. Similar fluctuations in the 15-minute EC data from the SJR at Vernalis or Mossdale or Brandt Bridge are measured, suggesting that normal river water has a daily range of EC that is about 25 μS/cm. These EC measurement differences and fluctuations can be used to evaluate EC measurement accuracy (agreement between stations) for the south Delta. Wastewater discharge or agricultural drainage effects of less than 10 to 25 μS/cm are difficult to detect with the EC monitoring network because the daily average measurements from the stations generally vary by about 10 to 25 μS/cm.

Figure 1 shows the general accuracy of south Delta EC measurements. The DWR North Central Regional Office water quality assessment section maintains the EC probe at the head of Old River. Field crews visit the station every 2 to 3 weeks to retrieve data and change the measurement sonde (sensors module). A field crew member uses a handheld sensor to measure the EC (and other parameters) and compares this with the most recent monitoring data. Figure 1 shows the sequence of field-check EC values for 2009–13. The field-check EC usually was very similar to the monitoring records. The monitoring data are considered satisfactory if it is within 25 μS/cm (i.e., 1 percent of the calibration standard) of the field-check EC. The field-check EC measurements closely matched the EC monitoring records for the full range of Old River EC, from 125 μS/cm during high flow periods to almost 1,250 μS/cm during low flow periods.

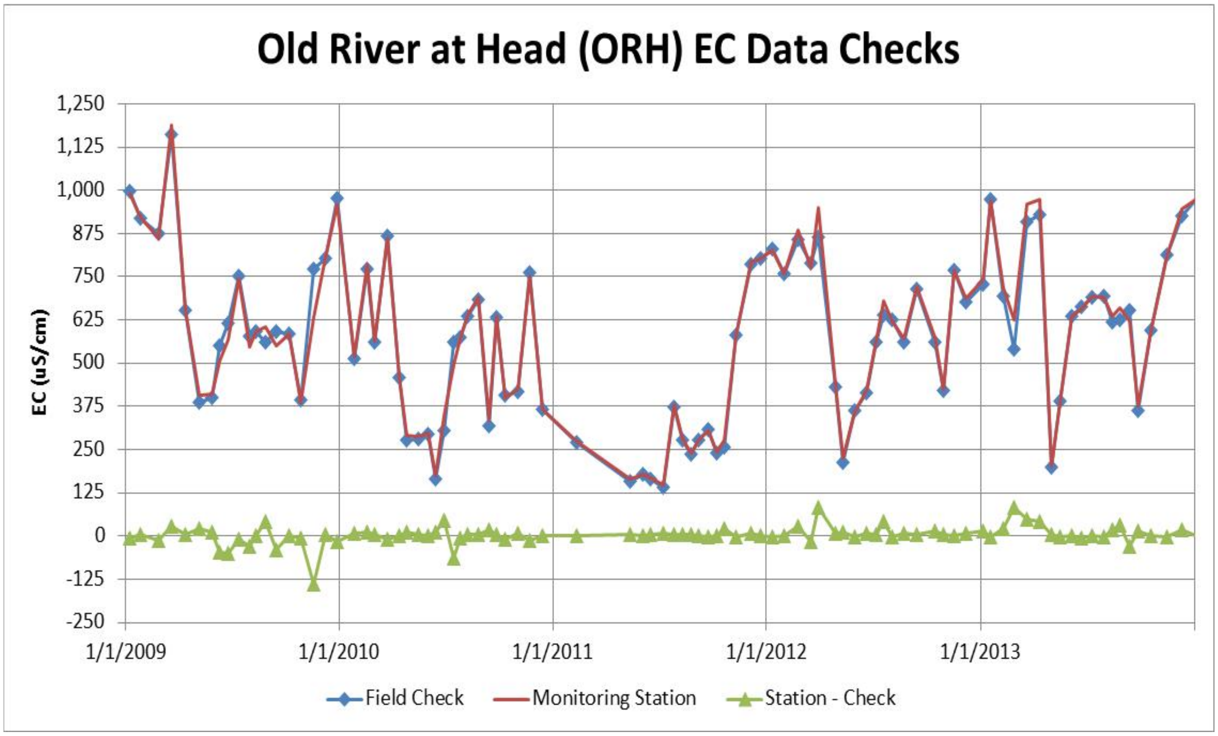


Figure 1. Comparison of Field-Check EC Measurements with EC Monitoring Records at the Old River at Head Station, 2009–13

Tidal Elevation, Tidal Flow, and Electrical Conductivity Measurements

Many monitoring stations in south Delta channels record tidal water elevation (feet, per North American Vertical Datum [NAVD]), tidal velocity (feet/second), tidal flow (cfs), and electrical conductivity (µS/cm) with a 15-minute measurement interval. These records provide 96 measurements each day to describe the tidal variations in these parameters. The analysis of the south Delta tidal data could begin only after all available and applicable data were downloaded and time-sequenced (compiled) into a master data file (spreadsheet).

Attachment B of this report provides a complete list of the stations with applicable data that were used for the south Delta Data Atlas files for 2009-13 and also describes the recommended procedures for obtaining and compiling the available tidal data from the south Delta stations. Table B-1 lists the monitoring stations that were accessed and parameters that were compiled for the south Delta Tidal Data Atlas files for 2009–13. Data for tidal elevation, tidal flow, tidal velocity, and EC parameters were obtained for each station, if available. The stations are listed in downstream order for the San Joaquin River, Old River (including Paradise Cut and Sugar Cut), Grant Line Canal (including Doughty Cut), and Middle River (including Victoria Canal). Each station has a period of record for each of the monitoring variables (i.e., elevation, velocity, flow, and EC). The agency that maintains the station is identified and the station ID (number or abbreviation) is shown. About 11 stations are along the SJR (e.g., three separate monitoring stations, maintained by three agencies, are located at Vernalis). Approximately 18 stations are along Old River and connecting tidal sloughs, about 5 stations are along Grant Line Canal, and about 5 stations are along Middle River and Victoria

Canal. Many of the 39 stations measure tidal elevations, about half of the stations measure EC, and about half of the stations measure tidal flow (and velocity).

Figure 2a shows the monitoring stations in south Delta channels, generally along channels and tidal sloughs (dead-end channels) located south or west of the SJR. The stations are designated by California Data Exchange Center (CDEC) code (of three characters), or the USGS or DWR station number. Several stations along the SJR are used for important boundary (reference) measurements. The SJR at Vernalis station is shown in the bottom right (southeast) corner of the figure. The SJR at Vernalis station is just downstream from the Stanislaus River and is the designated SJR inflow to the Delta. The SJR at Jersey Point station is in the middle left side of the figure. The Jersey Point station measures tidal elevation, tidal flow, and tidal EC; these data provide a reference for comparing Bay-Delta tidal fluctuations and seawater intrusion (increased EC) during periods of relatively low Delta outflow. The head of Old River station measures tidal elevation, tidal flow, and tidal EC; these data provide a reference for comparing the flows and EC in other south Delta channels. The Old River at Bacon station and the Middle River at Bacon station provide the reference tidal flows and EC entering the south Delta from the north. The combined daily net flow at these two stations is used as an index of the net flows in the Old and Middle Rivers (OMR) caused by the SJR inflow, exports, and agricultural or municipal diversions from the south Delta channels. The south Delta EC compliance stations; SJR at Brandt Bridge, Old River at Union Island, and Old River at Tracy Boulevard, provide a record of the salinity changes that are measured between Vernalis and these south Delta channel locations. Many other EC monitoring stations were used for the analyses of south Delta salinity changes.

Figure 2b shows a more detailed map of south Delta channels, which are the focus of this south Delta salinity investigation. The tidal monitoring stations are identified on the map along a portion of the SJR, along Old River from the head of Old River to the Highway 4 Bridge, along Middle River from Union Island to Victoria Canal, and along Grant Line Canal. The EC monitoring stations in Paradise Cut and Sugar Cut are of particular interest for evaluating the increased EC observed in Old River at Tracy Boulevard and Tracy Wildlife Association (nearby station) relative to the EC at upstream Old River stations (e.g., head of Old River, Union Island).

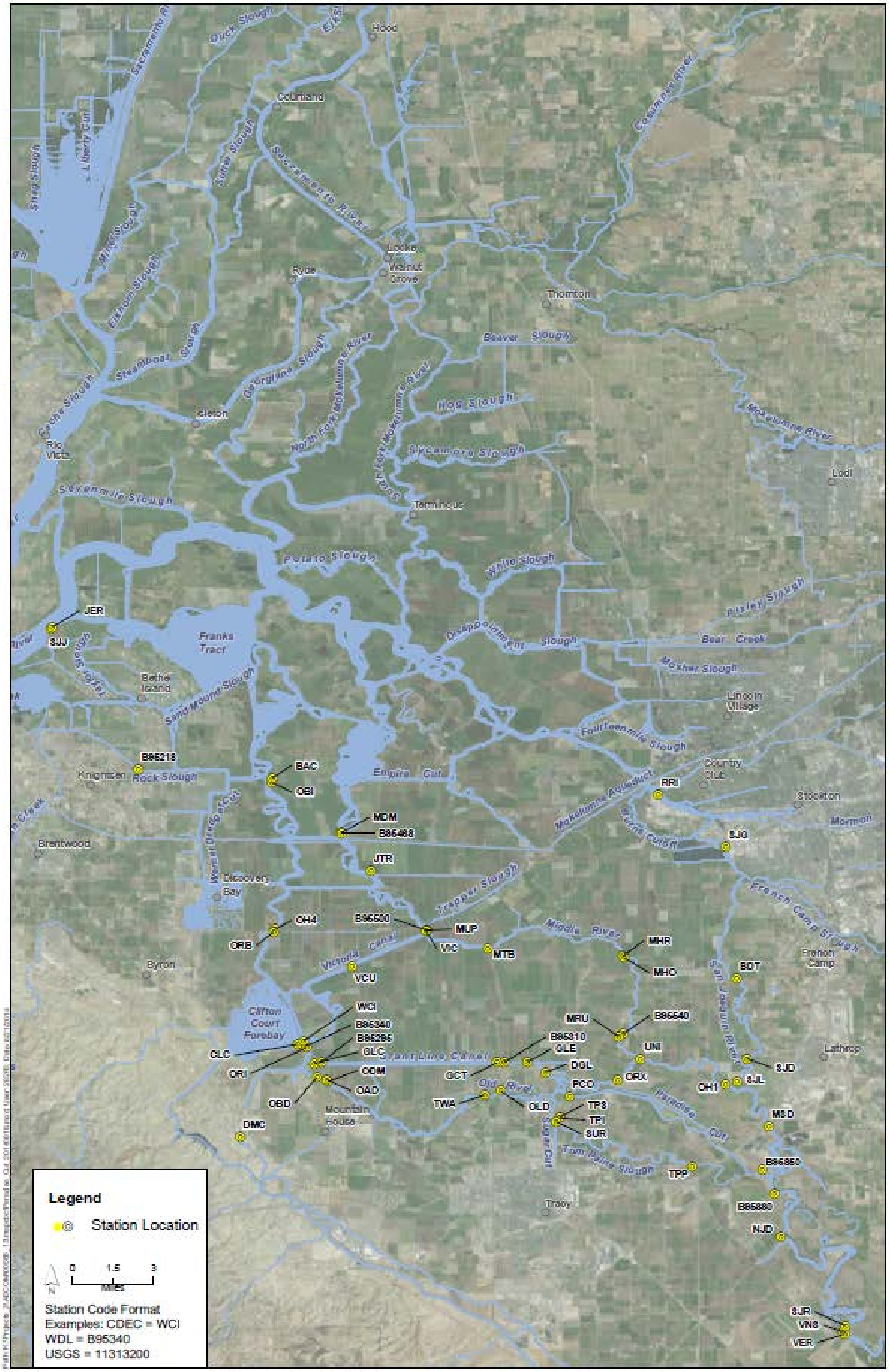


Figure 2a. Delta Tidal Monitoring Stations

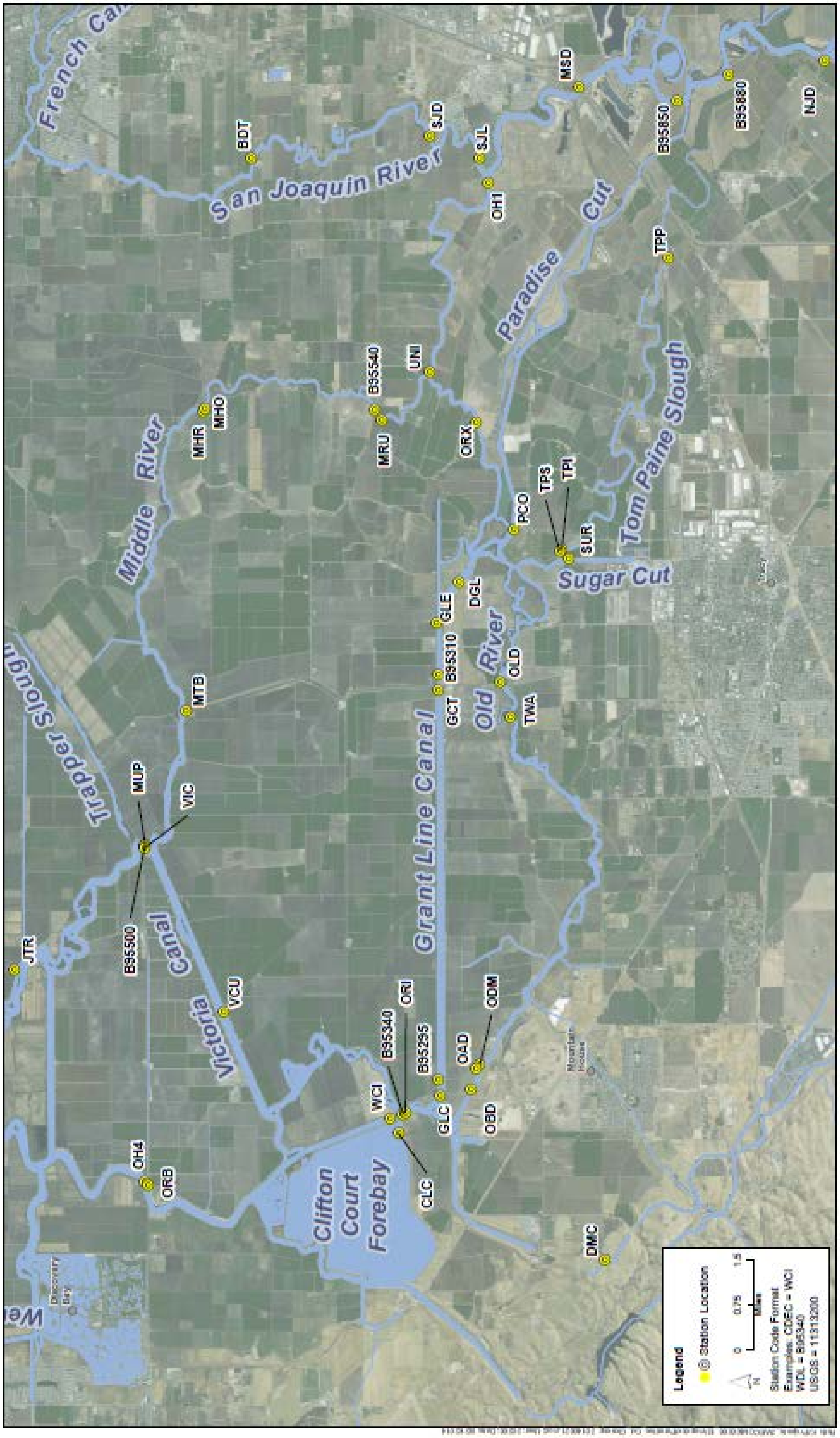


Figure 2b South Delta Tidal Monitoring Stations

Methods for Evaluating Tidal Elevation, Tidal Flow, and Tidal EC Data

The general methods that were used to evaluate the measured south Delta tidal elevations, tidal flows, and EC data are described in this section. More details about these methods are discussed where the results are shown and described in subsequent sections of this report. The various methods were used to summarize and evaluate or compare the measurements from different locations through time (5 years). Results from previous tidal hydrodynamic and water quality modeling (e.g., DSM2) are discussed as part of this data analysis and data interpretation. However, the DSM2 model results could not be used to identify or quantify the sources (i.e., inflows) of higher salinity water, because the only sources of higher salinity water included in the DSM2 model (i.e., agricultural drainage) are specified (assumed) in the Delta Island Consumptive Use module (DICU). DSM2 results for tidal elevations and tidal flows could be used to describe the south Delta channel hydrodynamics, but the model results for historical tides, inflows, and exports must be calibrated (adjusted) to match historical tidal elevation and tidal flow measurements. DSM2 historical simulations of EC for 2009-13 could be shown in comparison with the measured EC data to demonstrate the model reliability and to adjust (i.e., calibrate) the assumed agricultural drainage locations, inflows and inflow EC; this is recommended as a follow-up task using the historical data included in the south Delta Data Atlas files. The calibrated DSM2 simulations for historical 2009-13 conditions and with the various alternatives for reducing or eliminating the elevated salinity in Old River at Tracy Boulevard could be used to more accurately evaluate the effectiveness of the proposed alternatives. The methods used in this report to evaluate the measured south Delta tidal elevations, tidal flows, and tidal EC variations relied on direct calculations and comparisons of the 15-minute data, rather than DSM2 model results.

The first analysis method was to calculate the daily minimum, average, and maximum values for selected tidal (15-minute) measurements. This provided a useful summary of the 96 tidal measurements each day; for example, the daily tidal elevation range (maximum minus minimum) and the daily average (i.e., net) flow were calculated with this simple method. This method was used to summarize the tidal flows, tidal velocities, and EC data. This method could also be used to summarize the DSM2 modeling results, because the daily tidal elevation ranges and average tidal flows are the basic “daily” parameters for tidal hydrodynamics.

The next analysis method was to calculate the daily salt loads (i.e., load = conversion x flow x EC) and salt load increases between measurement stations (i.e., salt load increments). This was the basic method used to estimate the magnitude of salt sources (i.e., inflows) from Paradise Cut and Sugar Cut, as well as agricultural drainage or shallow groundwater salt sources (i.e., inflows) along the SJR and in south Delta channels. For example, the effects of a wastewater discharge (e.g., City of Tracy) on the downstream Old River flow and EC were calculated to show the relationships between flow, salinity, salt sources to the channel, and salt loads in the south Delta. This was an extension of a basic river flow-balance analysis, which determines inflows or diversions from the change in flow between two measurement locations. A major difficulty with applying this method is that both diversions and discharges may occur between measurement locations, and neither the flows nor the EC of the higher salinity discharges or inflows are measured.

Daily average flows were used to identify the flow diversions (or channel junction flows) 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 (channel junction flow) 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 flow diversion equations. This allowed the net daily flows in the south Delta channels to be estimated; these daily channel flow estimates were important for tracking the movement of water and the dilution of higher salt sources (i.e., inflows) in each channel.

Although tidal flows (i.e., velocities) have been measured at several locations in recent years, the general method for estimating tidal flows and comparing (confirming) measured tidal flows was to calculate the tidal flows from the 15-minute changes in elevation times the estimated upstream surface area (i.e., tidal prism):

Tidal flow (cfs) = 15-minute elevation change (feet) x upstream surface area (acres) x 43,560/900

For channels with a net daily flow, the net daily flow was added to the calculated tidal flows. For locations with tidal flow measurements, the measured tidal flows were compared (confirmed) with the calculated tidal flows plus the net daily flow. This comparison was very useful for matching the measured tidal flows in Old River and Middle River (at Bacon Island). The tidal flows were shifted upstream (negative flow) by the daily average CVP and SWP export pumping (diversion); however, because the Clifton Court Gates are opened and closed at specific times during the tidal cycle, the SWP diversion flow changes throughout the day. When two channels (e.g., Old River and Middle River) convey tidal flows to upstream areas, the total upstream surface area must be divided between the two channels, depending on their conveyance area (assuming the same tidal water slopes in both channels). As an example, the measured tidal flows in Middle River were slightly higher than the measured tidal flows in Old River, indicating the upstream area for the Middle River tidal flow station was greater. The total upstream area was estimated to be 3,750 acres, and the upstream area estimated for the Middle River flow station was 2,000 acres (53 percent). The tidal flows and net flows in each Delta channel are accurately calculated with the DSM2 model; the geometry for each connected channel and the tidal elevations at the downstream end of the model (i.e., Martinez), together with the inflows and diversions throughout the Delta are accurately simulated. However, the estimated tidal flows at various locations within the south Delta channels were calculated from the measured tidal elevation changes and the estimated upstream surface areas as a basic data analysis method, without reference to the DSM2 model results.

Cumulative tidal flow volumes (acre-feet [af]) were calculated by summing positive 15-minute tidal flow volumes (i.e., af = tidal flow (cfs) x 900 /43,560) for the ebb-tide volume or by summing negative 15-minute tidal flow volumes for the flood-tide volume. This provided a daily summary of the upstream (i.e., flood-tide) and downstream (i.e., ebb-tide) tidal volumes (four tidal volumes each tidal day). The upstream and downstream tidal movements (miles) were estimated for each channel by dividing the tidal flow volume by the channel volume (volume per mile). This was similar to calculating the travel time in a channel (i.e., travel time = volume/flow). This method was used to evaluate the effects of the temporary barriers on tidal flows (tidal volumes) and flushing of 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 these tidal flow volume and tidal movement methods.

Tidal flows at each of the temporary barriers were calculated as the flow through the submerged culverts (i.e., flow = coefficient x area x head^0.5) and flow over the submerged weirs (i.e., flow = coefficient x length x head^1.5) plus the net daily flow. The upstream and downstream tidal elevations were used to estimate the tidal flows when the temporary barriers were installed;

the tidal flows without the temporary barriers were estimated from the tidal elevation changes and the upstream surface area. The calculated tidal flows at the temporary barriers 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; this suggested that the calculated tidal flows at the Middle River barrier and at the Tom Paine Slough diversion barrier also were reasonably accurate.

Another analysis method used to evaluate the salinity sources (i.e., inflows) indicated by the measured EC increases in Old River at the Tracy Boulevard EC monitoring station (and confirmed by the Tracy Wildlife EC monitoring station) was a tidal "box-model" of Paradise Cut, Sugar Cut, and Old River between Doughty Cut and Tracy Boulevard (a small portion of the DSM2 model). The box-model calculated the tidal movement of water between the channel segments, and also calculated the tidal movement of specified (i.e., assumed) salt sources (i.e., flow and EC) 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 these tidal elevations and flows changed when the temporary barriers were installed, the box-model was used to evaluate water and salt movement for conditions with barriers and without barriers. Because Tom Paine Slough diversions were relatively high during the irrigation season (e.g., 50-100 cfs) most of the Sugar Cut salt source likely was diverted to Tom Paine Slough and very little likely reached Old River during the irrigation season (with or without temporary barriers). The box-model was used to evaluate the possibility (i.e., hypothesis) that most of the observed EC increases at Tracy Boulevard (and Tracy Wildlife) originated from the specified (i.e., assumed) Paradise Cut and Sugar Cut salinity sources (i.e., inflows).

The last analysis method used to evaluate salinity sources (i.e., higher salinity inflow locations) in Old River was calculating the tidal movement of longitudinal EC profiles, previously measured by DWR during 2009 and 2010 (DWR 2012). The Old River EC profiles were measured periodically from Old River at Union Island to Old River at the DMC intake (just downstream from the Old River at DMC temporary barrier). Longitudinal EC profiles also were measured in Paradise Cut in 2009. These longitudinal EC profiles would shift upstream at high tide and would shift downstream at low tide. This method used the EC gradient as a water movement tracer. The tidal shifting of a measured EC profile can be most easily described for a dead-end tidal slough like Paradise Cut or Sugar Cut. The tidal movement distance was assumed to be proportional to the upstream surface area (tidal prism) divided by the channel cross-section. For a uniform channel, the movement would linearly decrease from the mouth to the upstream end. Little shifting occurred at the upstream end of Paradise Cut, while considerable shifting (3 to 5 km) occurred at the mouth of Paradise Cut. In Old River the tidal shifting was relatively minor at Tracy Boulevard (not much tidal flow), but was about 3 to 5 km near the DMC intake, depending on the daily tidal elevation range at the DMC intake. The longitudinal EC profiles (shifted to high tide and low tide) matched the daily minimum and maximum EC that was measured near the mouth of Paradise Cut and in Old River near the DMC intake and DMC barrier. This method was also used to approximate the likely effects of a tidal gate in Old River (to replace the Old River at DMC temporary barrier). An upstream movement (3 to 5 km) of lower salinity water during flood-tides (tidal gate open) would reduce the EC in Old River upstream from the DMC barrier to Tracy Boulevard, and would flush the salt sources from Sugar Cut and Paradise Cut into Doughty Cut and Grant Line Canal during ebb- tides (tidal gate closed). A tidal gate in Old River at the DMC temporary barrier location would provide a net upstream flow in this portion of Old River (tidal circulation), as originally proposed by DWR in the South Delta Improvements Program (SDIP).

These tidal data analysis methods were used to describe the daily patterns of flows and salinity that were measured in 2009-13; a series of daily graphs for each year will be described and the major conditions or "events" observed during this five-year period will be briefly discussed in the next section of this report. The subsequent major sections of this report will show several tidal (15-minute) flow and salinity graphs (3-months each) and describe in more detail the tidal variations in elevations, flows, and EC in the south Delta channels.

San Joaquin River Flow and Salinity

The basic analysis method used in this report is a salt balance of the SJR from Vernalis (i.e., inflow) through the south Delta channels to the CVP and SWP exports (i.e., outflow) near Tracy, including the agricultural diversions and drainage (i.e., return flows) in the south Delta channels. A salt balance between two tidal flow and EC measurement stations can be used to identify the local inflows of higher salinity water (i.e., sources). A general salt balance is assumed for the agricultural irrigation areas, with the applied salt balanced by the return flows (i.e., less water with higher EC). This report, however, does not measure or calculate the soil salt balance for the irrigated lands.

Determining the daily net flow and daily average EC patterns is the first step in analyzing and evaluating the salinity patterns in south Delta channels. The two major sources of water in south Delta channels are (1) diversions (channel junction flows) from the SJR at the head of Old River near Mossdale and (2) Sacramento River water that is "moved" across the central Delta channels by slightly greater tidal elevation gradients (i.e., increased upstream flow towards the pumps on flood-tide and reduced downstream flow on ebb-tide) caused by the CVP and SWP pumping plants. The SJR salinity (EC) is measured at Vernalis and Mossdale, just upstream from the head of Old River diversions. The SJR at Vernalis is the major source of water in the south Delta channels and therefore controls the salinity (EC) measured at the Brandt Bridge EC station and in Old River at the Union Island and Tracy Boulevard EC stations. Agricultural diversions may reduce the flow in the south Delta channels, while agricultural drainage, rainfall (runoff), and groundwater seepage may increase the flow and salinity in the south Delta channels. The EC of the water entering south Delta channels from the north (in Old River and Middle River) is a mixture of predominantly Sacramento River water, with some agricultural drainage from Delta islands and some seawater intrusion during periods of low Delta outflow (e.g., less than 5,000 cfs). The salinity (EC) of this "northern" water is almost always less than the EC of the SJR; therefore, CVP and SWP pumping generally have a freshening effect on the EC of the exported water. Increased CVP and SWP pumping does not cause increased EC in south Delta channels (e.g., Old River Bacon and Middle River at Bacon) unless the Delta outflow is reduced to less than 5,000 cfs by the pumping (i.e., increased seawater intrusion). This condition was generally observed in September-October of the low runoff years (e.g., 2009, 2010, 2012, and 2013; see the Data Atlas graphs of "CVP and SWP Exports and Salt Sources").

The measured SJR at Vernalis EC is strongly dependent on the measured flow (i.e., flow-dilution), because the agricultural salt loads from the watershed are relatively constant from year to year, although a seasonal pattern occurs with rainfall runoff (i.e., high volumes, low EC) in the winter months and groundwater seepage (i.e., low volumes, high EC) in the summer and fall months. The SJR salt loads are greatly reduced in years with low irrigation (i.e., reduced drainage and groundwater seepage), such as in 2014 and 2015 (not evaluated in this report). Because a substantial portion of the SJR salt loads originate from the irrigated portion of the west side of the San Joaquin Valley (north of the SJR Mendota Pool), the seasonal SJR salt loads depend on runoff as well as irrigation and drainage practices. Releases from tributary reservoirs on the Stanislaus, Tuolumne, and Merced Rivers provide strong dilution of the seasonal salt load, because the EC of the released water is very low (e.g., generally less than 50 μS/cm).

The daily salt load of a river or channel can be calculated from the flow and EC values as:

$$\textbf{Salt load (tons/day)} = \textbf{5.4 x flow (cfs) x EC (}\mu\textbf{S/cm) x 0.65/2,000}$$

$$=\textbf{0.00175 x flow (cfs) x EC (}\mu\textbf{S/cm)}$$

where 0.65 is the assumed conversion ratio (TDS/EC) between 1μS/cm (EC units) and 1 mg/L of salt (TDS), and 5.4 is the conversion between 1 cfs and 1 mg/L to pounds per day. Some variations occur in the TDS/EC ratio of SJR source water because of different salt/EC ratios for the major negative ions (Cl, SO_4, HCO_3) and positive ions (Na, Ca, K) in the water. A general value of 0.65 was assumed for the TDS/EC ratio when calculating salt loads in the SJR and south Delta channels (e.g., water with EC of 1,000 μS/cm would have a TDS concentration of 650 mg/L).

Figures 3a through 3e show the SJR flow at Vernalis (black line, right scale) and the measured SJR EC at several locations in 2009–13. Two measurements of EC at Vernalis are shown; the Reclamation (gold line) and DWR (gold diamonds) values generally were similar. The SJR EC generally increases with lower SJR flows, and the SJR EC is reduced considerably when reservoir releases are made to provide a spring peak flow for improved juvenile Chinook salmon migration. The monthly average EC objectives at Vernalis and the south Delta EC compliance stations are shown for reference (green line). The EC at Brandt Bridge and the EC in Old River at Union Island usually were similar to the Vernalis EC, but the EC in Old River at Tracy Boulevard (red line) and at Tracy Wildlife (pink diamonds) often were much higher than the Vernalis EC. The Tracy Boulevard EC was determined to be erroneous (higher than Tracy Wildlife EC and higher than Old at DMC EC) from June 2009 to January 2010.

The SJR at Vernalis salt load (tons/day) was calculated from the daily flow and EC values. For example, the average SJR at Vernalis flow in 2009 (Figure 3a) was 1,285 cfs, and the average EC was 640 μS/cm. Because the higher daily EC values are usually measured at lower flows, the flow-weighted average EC was 613 μS/cm (96 percent of the daily average EC), and the average calculated salt load was 1,403 tons/day (513,000 tons/year). The average SJR at Vernalis flow in 2010 (Figure 3b) was 3,085 cfs, the average EC was 500 μS/cm (flow-weighted EC was 407 μS/cm), and the average salt load was 2,320 tons/day (846,000 tons/year). The average SJR at Vernalis flow in 2011 (Figure 3c) was much higher at 9,290 cfs, the average EC was much lower at 280 μS/cm (flow-weighted EC was 204 μS/cm), and the average salt load was 3,500 tons/day (1,278,000 tons/year). The average SJR at Vernalis flow in 2012 (Figure 3d) was 1,650 cfs, the average EC was 583 μS/cm (flow-weighted EC was 544 μS/cm), and the average salt load was 1,680 tons/day (613,000 tons/year). The average SJR at Vernalis flow in 2013 (Figure 3e) was 1,347 cfs, the average EC was 617 μS/cm (flow-weighted EC was 581 μS/cm), and the average salt load was 1,485 tons/day (542,000 tons/year). The main purpose for this evaluation project was to identify the major salt sources (i.e., higher salinity inflows) that likely increased the measured EC at the south Delta EC compliance stations in the SJR at Brandt Bridge, in Old River at Union Island, and in Old River at Tracy Boulevard compared to the measured SJR at Vernalis EC. The monthly water and salt budgets for the south Delta channels and the CVP and SWP exports are presented in Attachment C.

Except for 2011 (high runoff), the SJR at Vernalis EC was fairly close to the EC objectives; this was the result of Reclamation actively managing (increasing) New Melones Reservoir releases to control the Vernalis EC. The SJR flow and EC measured upstream at Maze (just downstream of the Tuolumne River) provides the necessary information about the salt load that must be diluted by the Stanislaus River flow; sometimes the releases are increased by Reclamation above the minimum flow required for fish habitat to provide this salt management flow. However, whenever the SJR at Vernalis EC is close to the EC objective, downstream inflows of higher salinity water (i.e., treated wastewater, groundwater seepage or agricultural drainage) may cause the SJR at Brandt Bridge EC or Old River at Union EC or Old River at Tracy Boulevard EC to exceed the EC objective.

The effects of increased SJR flows on reduced EC can be observed in each of the years; the dilution effects were strongest for reservoir releases (e.g., during spring and late October pulse flows) and the dilution effects were reduced (i.e., less change in EC) when the increased flow was from watershed runoff. Conversely, the SJR at Vernalis EC generally increased during periods with decreasing flows. Because the Stanislaus River is the last major inflow to the SJR, the SJR at Vernalis EC was lower than the EC at all downstream south Delta locations. The EC at downstream SJR locations (e.g., Brandt Bridge), the EC in Old River (e.g., Union, Tracy Boulevard and Tracy Wildlife), and the EC in Grant Line Canal were generally similar to the Vernalis EC (within 50 to 100 µS/cm). The measured EC in Old River at Tracy Boulevard (and at Tracy Wildlife) were, however, sometimes higher than the EC at Brandt Bridge and at Union, and were generally the highest EC measured in the south Delta channels (except in Paradise Cut and Sugar Cut). This report attempts to identify the causes of the variations in the south Delta channel EC measurements in comparison to the SJR at Vernalis EC patterns.

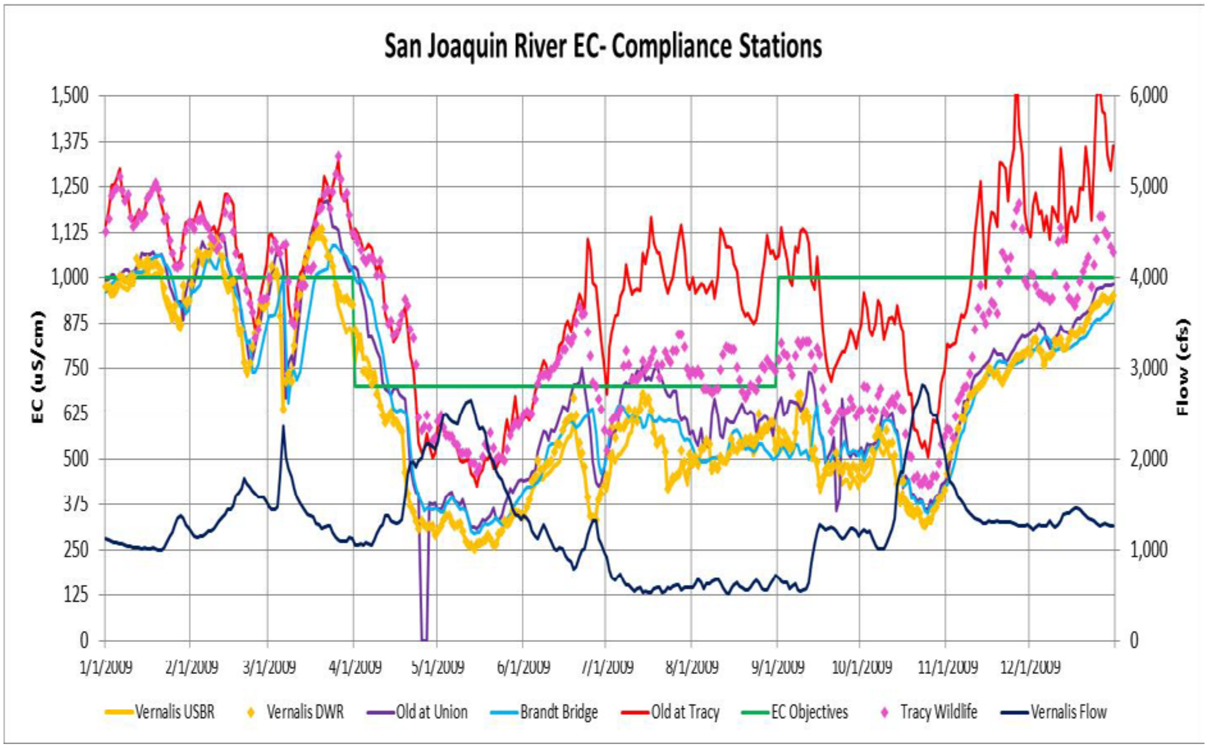


Figure 3a. Measured Daily Average SJR Flow at Vernalis and EC at Several Locations in 2009

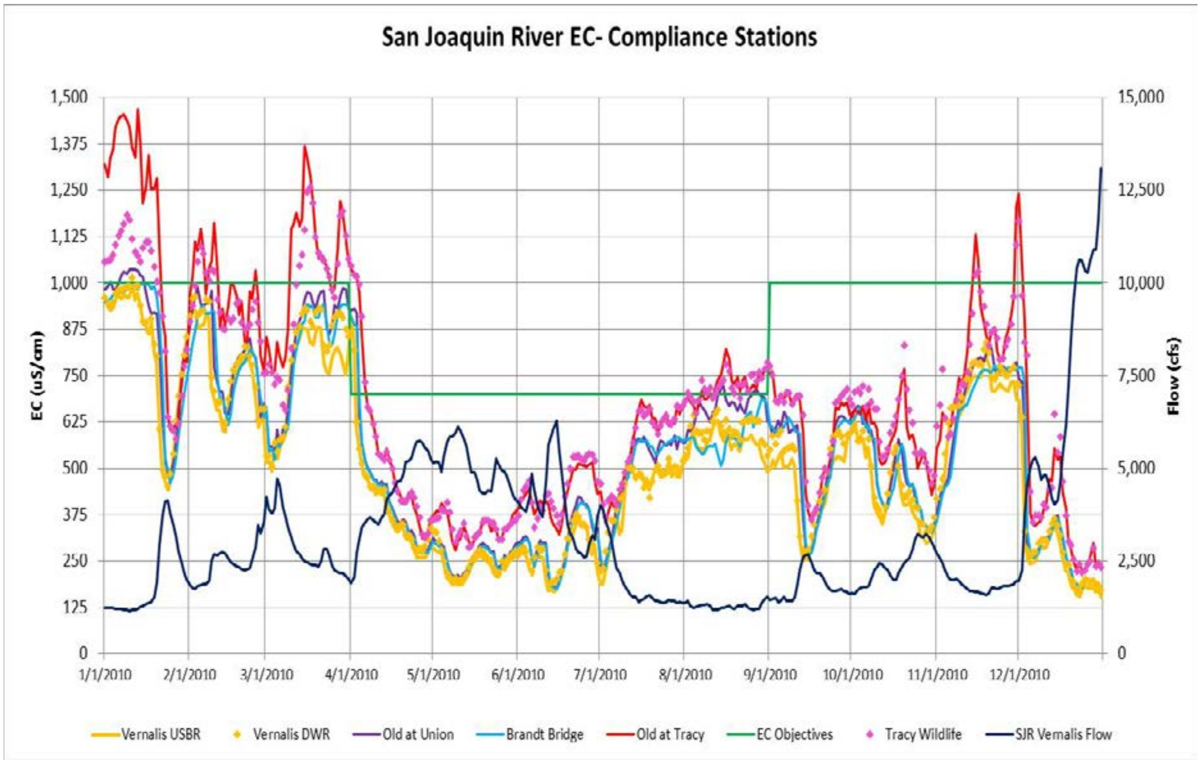


Figure 3b. Measured Daily Average SJR Flow at Vernalis and EC at Several Locations in 2010

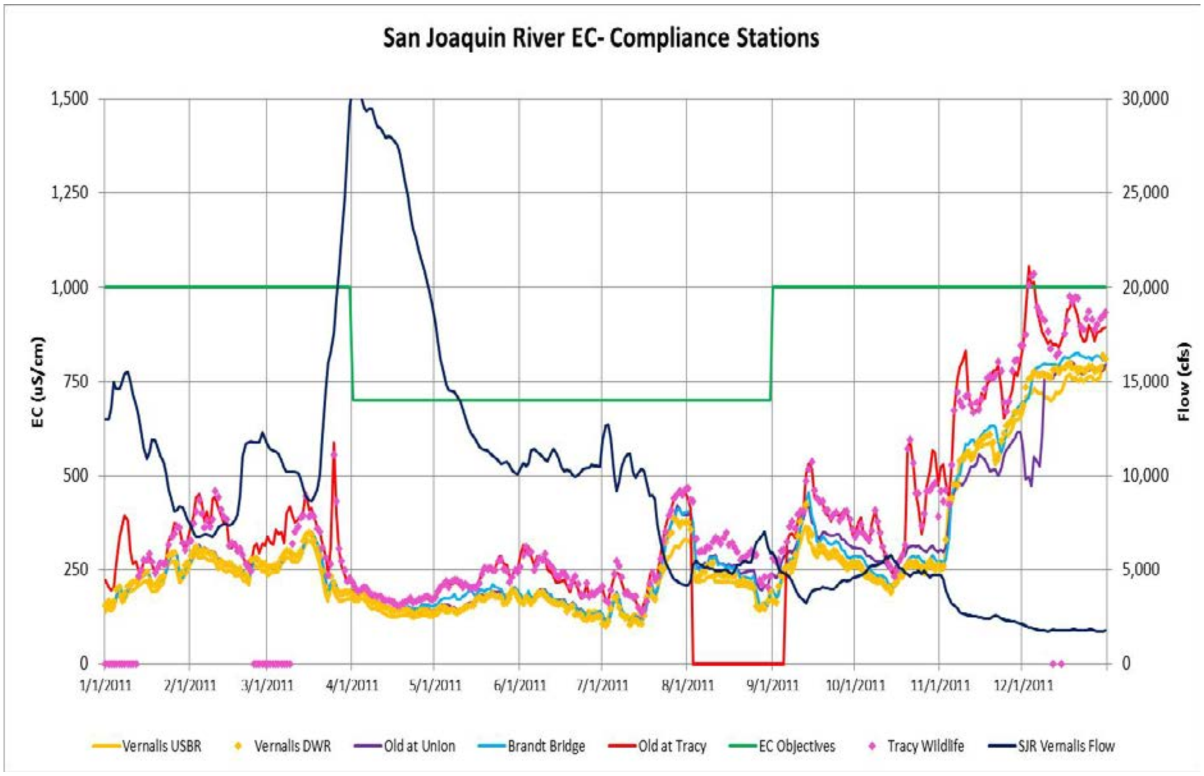


Figure 3c. Measured Daily Average SJR Flow at Vernalis and EC at Several Locations in 2011

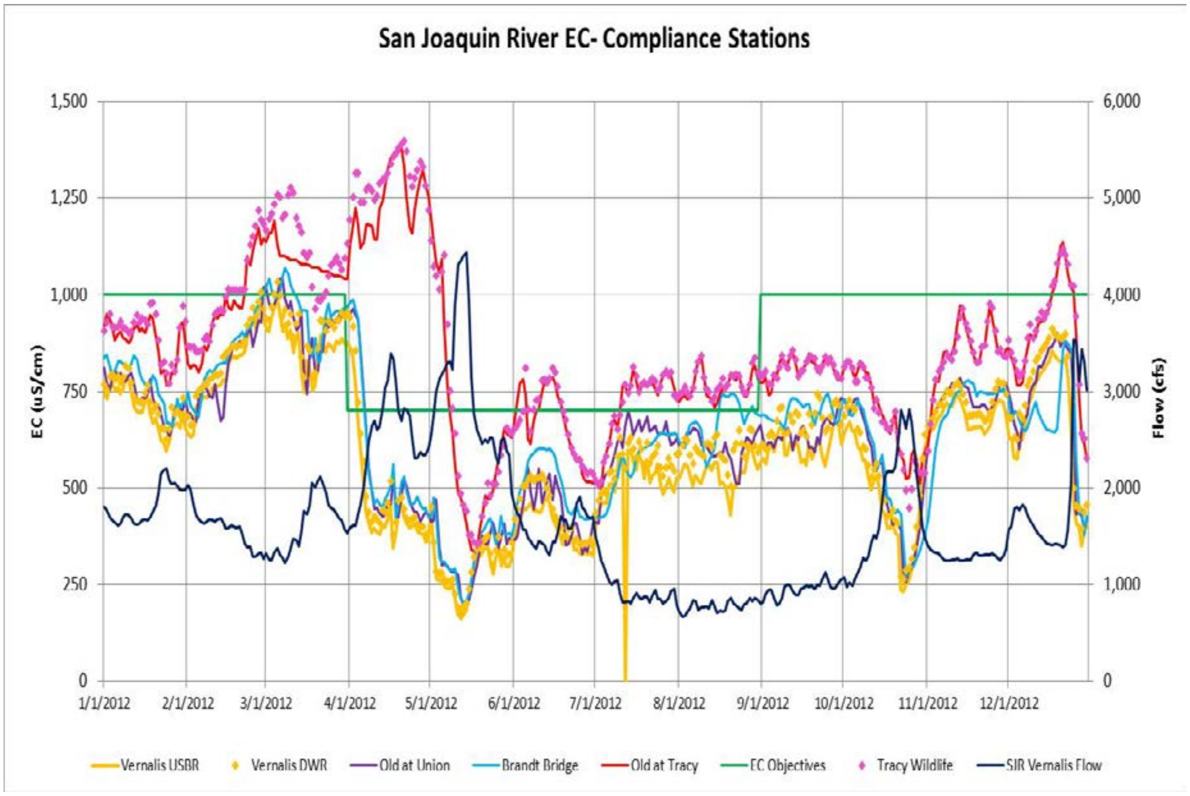


Figure 3d. Measured Daily Average SJR Flow at Vernalis and EC at Several Locations in 2012

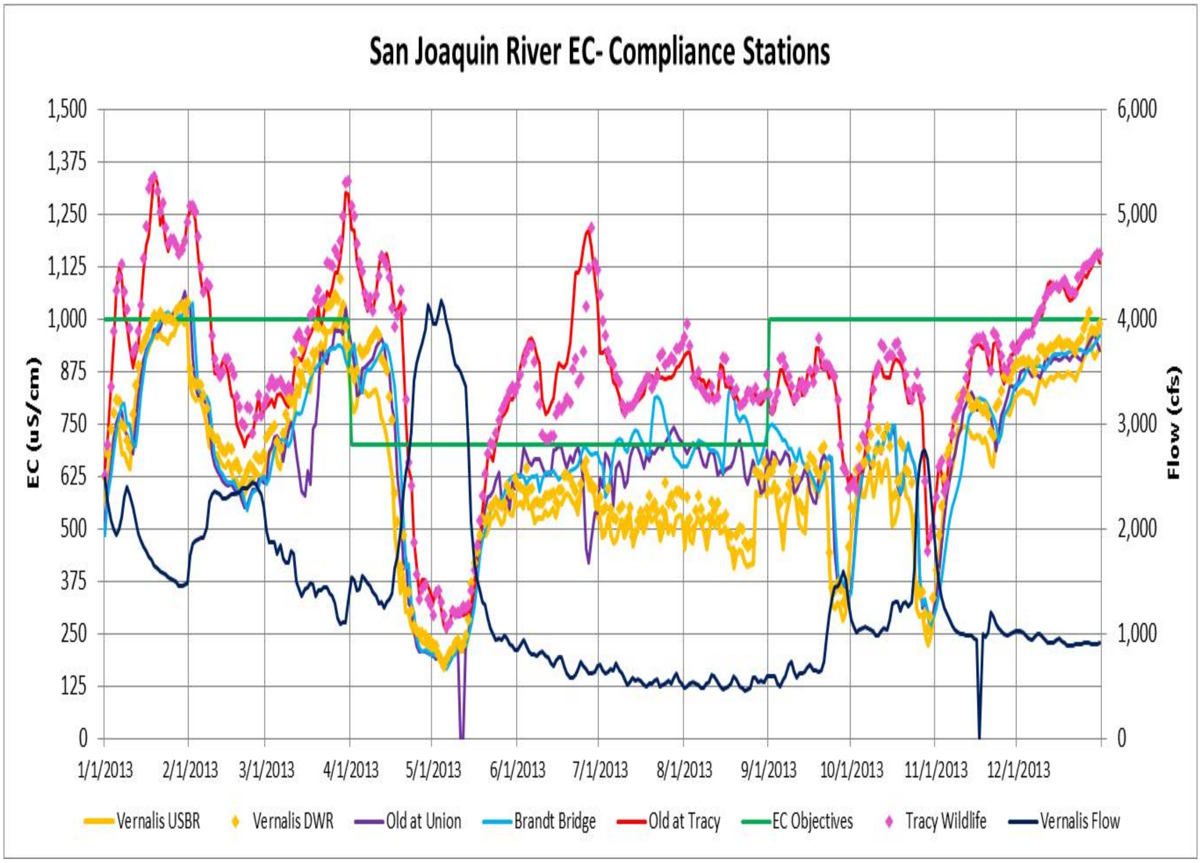


Figure 3e. Measured Daily Average SJR Flow at Vernalis and EC at Several Locations in 2013

Effects of Wastewater and Agricultural Discharges

A number of important agricultural diversions exist along the SJR downstream from Vernalis and in the south Delta. Some of these are major irrigation district diversions; for example, the Banta-Carbona Irrigation District intake is located downstream from Vernalis and has a maximum diversion flow of about 175 cfs. Others are small riparian diversion pumps for individual farmers, with flows of 5 cfs or less. The diversion of water does not change the salinity of the water remaining in the river, but because the downstream river flow is reduced, the effects of any downstream agricultural drainage flows or treated wastewater discharges on salinity are greater.

The agricultural drainage EC can be approximated by assuming that agricultural drainage EC is about five times the water supply EC, because crop evapotranspiration generally is assumed to use about 80 percent of the applied water (i.e., 80 percent irrigation efficiency, with 20 percent percolation to shallow groundwater below the root zone). For example, most of the agricultural drainage from the Banta-Carbona Irrigation District is returned to the SJR just downstream from the pumping plant at the New Jerusalem Drain. The New Jerusalem Drain discharges most of the drainage from Banta-Carbona Irrigation District and has a relatively high salinity (e.g., 2,000 to 3,000 µS/cm). The agricultural diversions (and associated drainage or groundwater seepage) along the SJR or in the south Delta channels can be estimated from the irrigated acreage and assumed crop evapotranspiration and percolation (i.e., soil drainage). Several small diversions and two larger diversions, for the Naglee-Burk Irrigation District (ID) in Tracy and for the Westside ID at Wicklund Cut are located along Old River; these diversion reduce the net flow in Old River (downstream of

Tracy Boulevard) during the irrigation season. For example, Table 1 shows the reported monthly diversions for the Westside ID in 2009–13. The diversions were about 60 cfs in April, increased to 80 cfs in July (82.5 cfs pump capacity), and decreased to about 50 cfs in September. The reported seasonal diversions were about 23,000 af, and because the irrigated area was reported to be about 5,100 acres, the average water application rate was about 4.5 feet/year. The monthly diversions along Old River could be estimated from the irrigated acreage served by the other pumps. Although the return flows from these irrigation diversions are not measured, an average assumed drainage flow of 20 percent of the applied water (with an assumed EC of about 5 times the applied EC) can be used to approximate the salinity sources (i.e., inflows) to the south Delta channels. Because the average EC during the irrigation season will vary each year, the expected salinity sources returning to the south Delta channels will also vary each year.

The cumulative effect of south Delta diversions would reduce the downstream net flows, but would not change the tidal flows, because the tidal flows are controlled by the tidal elevations. However, the temporary barrier in Old River at the DMC reduces the flood tide and ebb-tide flows over the barrier and may cause a net upstream flow through the culverts (with flap gates). During the summer with relatively low Old River flow, this may cause the net flow in Old River at Tracy Boulevard to approach 0 cfs or to reverse (net upstream flow). These low net flows may affect the salinity at Tracy Boulevard, because more of the salt sources from Sugar Cut, Paradise Cut, and other agricultural drainage discharges may accumulate in Old River between Doughty Cut and the DMC barrier; these conditions of low net flows with accumulating salinity are sometimes referred to as a "null zone."

Table 1. Monthly Average Diversions for Westside Irrigation District

Month	2009	2010	2011	2012	2013
March	2	0	0	31	40
April	58	8	38	41	28
May	77	59	51	64	49
June	64	57	53	55	53
July	74	71	76	79	70
August	62	67	65	68	61
September	45	41	51	47	44
October	5	9	9	13	14

Note:
Monthly diversion totals are shown in cubic feet per second.

Source: SWRCB WRIS license #00138

A discharge or inflow with the same EC as the river or channel does not change the EC of the channel; only if the discharge EC is different than the channel EC does the discharge cause the channel EC to change. An inflow with a lower EC (e.g., Stanislaus River) will reduce the downstream river EC; agricultural drainage and wastewater discharges will generally increase the river or channel EC. The excess EC is the difference between the discharge EC and the river or channel EC; the excess salt load is the portion of a salt load that would increase the EC of the river or tidal slough.

The excess (incremental) salt load was calculated as:

Excess salt load (tons/day) = 0.00175 x discharge flow (cfs) x [EC (µS/cm) of discharge – EC (µS/cm) of river]

The discharge EC will cause a greater increase of the channel EC if the discharge flow is a large fraction of the river flow or the discharge EC is much greater than the river EC. The effect of agricultural drainage or treated wastewater effluent on river EC depends on the relative flows (i.e., dilution of discharge) and the difference between the discharge EC and the river EC (i.e., excess EC). The effects of a discharge on the downstream river EC can be calculated as:

Downstream EC = (River EC x River Flow + Discharge EC x Discharge)/(River Flow + Discharge)

The EC change downstream from the discharge can therefore be calculated as:

Downstream EC Change = (Discharge EC – River EC) x Discharge/(River Flow + Discharge)

The downstream EC change is called the incremental EC. Treated wastewater has a higher EC than the water supply; the wastewater EC generally is increased by 250 to 500 µS/cm (higher increment from water softening). Treated wastewater discharge EC may be greater than the channel EC and may cause a slight increase in the downstream channel EC, similar to the effects of agricultural drainage. The effects of wastewater discharges are easier to evaluate, however, because the discharge flow and EC are often measured.

For example, the Manteca wastewater discharge is just upstream from the Mossdale EC monitoring station. The Manteca wastewater discharge has a capacity of about 15 cfs (9.7 million gallons per day [mgd]), with an assumed EC of about 1,400 µS/cm. The effects of the Manteca discharge on SJR EC can be estimated for any river flow and EC; with an assumed river flow of 1,500 cfs and an EC of 700 µS/cm (irrigation season EC objective), the Manteca wastewater discharge would increase the river EC by about 7 µS/cm (i.e., 700 µS/cm x 15/[1,500 + 15]). The Manteca wastewater discharge into the SJR would be strongly diluted because the assumed flow in the SJR was much greater than the discharge. The increase in river EC from the Manteca wastewater discharge would be slightly greater for lower river flows and for lower river EC values.

The City of Tracy wastewater discharge also is about 15 cfs (9.7 mgd), with a measured average EC of about 1,250 µS/cm. The City of Tracy has made considerable progress in reducing the wastewater EC (e.g., previously 1,750 µS/cm), with a drinking water supply pipeline from the South San Joaquin Irrigation District replacing some DMC deliveries and some groundwater pumping. Therefore, the daily salt load (total) is about 32 tons, although the incremental salt load and EC increment depends on the Old River EC. For example, if the Old River flow was about 750 cfs with an EC of about 700 µS/cm (irrigation season EC objective), the City of Tracy discharge would have an incremental daily salt load of 14 tons (i.e., [1250-700] x 15 x 0.00175), and would increase the Old River EC by about 11 µS/cm (i.e., [1250-700] x 15/765). The City of Tracy is currently planning to implement a recycled water master plan which will further reduce the City's wastewater discharge to Old River and decrease the City's net water demand. The recycled water master plan may reduce overall salt loading to the south Delta; however, the daily incremental effects on EC in Old River will likely be small because the wastewater discharge is a small fraction of typical Old River flows. A quantitative analysis of these effects is not included in this report.

This salt-balance approach can be used to estimate the total salt load (flow x EC) and incremental salt load (discharge x excess EC) between any two river EC stations with flow estimates; however, net flow measurements in the south Delta channels have only been feasible in recent years (with improved tidal flow measurement equipment). This salt-balance approach is more difficult for south Delta channels because (unmeasured) agricultural diversions and drainage discharges occur along the same channels. Furthermore, the tidal flows move in both directions at different times during the day. A complete understanding of the sources of increased salinity measured at the Old River at Tracy Boulevard EC station requires an integrated analysis of all available tidal data from south Delta channels.

Figures 4a through 4e show the calculated daily incremental effects of the City of Tracy's wastewater discharge on the Old River EC in 2009–13, compared to the measured EC increment between Union Island and Doughty Cut. The daily measured discharge and weekly measured EC were used to calculate the incremental EC caused by the City of Tracy wastewater discharge. The incremental EC was greatest at lower flows and when the Old River EC was lower, but because lower EC generally was caused by higher SJR flows, the greatest incremental EC occurred during periods of low flows with higher Old River EC. The incremental EC calculations assumed that the upstream and downstream EC measurements were accurate, and that Old River flow was increased only by the Tracy discharge. The measured EC increments were often higher than the calculated EC increments in the summer months, indicating there likely were other sources of higher salinity water (perhaps from Paradise Cut or Sugar Cut). Some of the highest EC increments were likely caused by EC measurement errors (e.g., spikes in the daily average EC) at one of the EC stations.

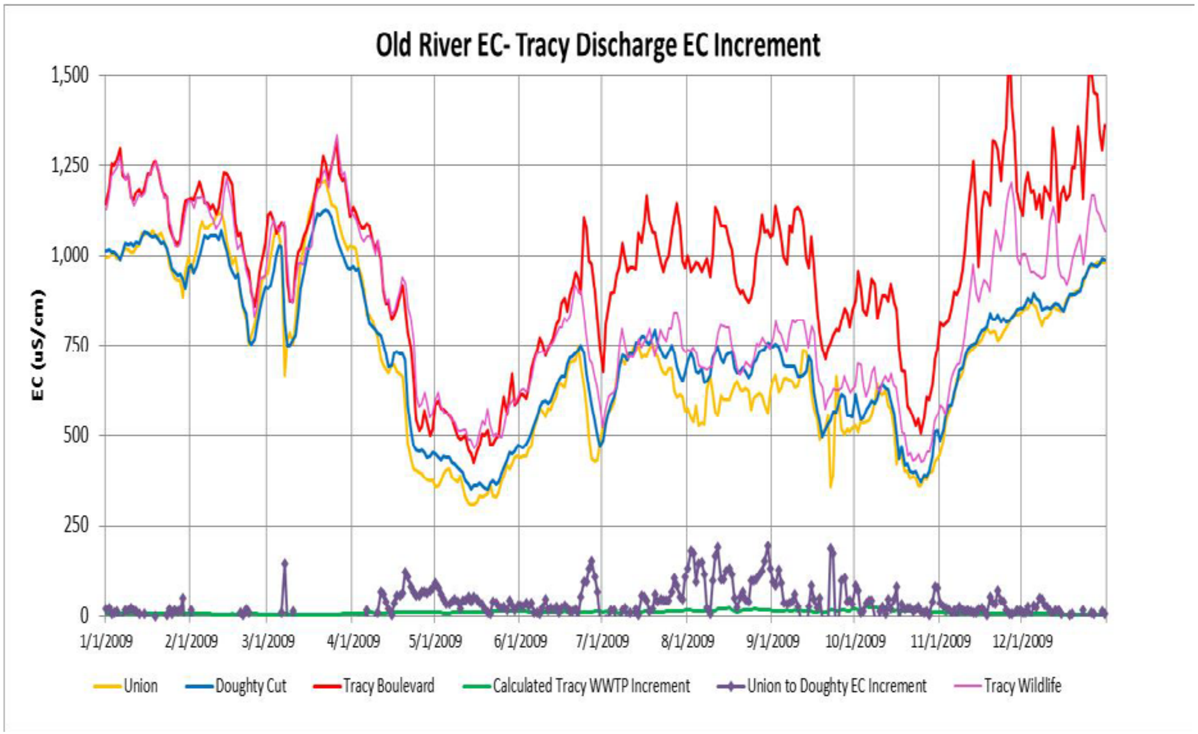


Figure 4a. Measured Old River EC at Several Locations and the Calculated Effects of the Tracy Wastewater Discharge on the EC Increment between Union Island and Doughty Cut in 2009

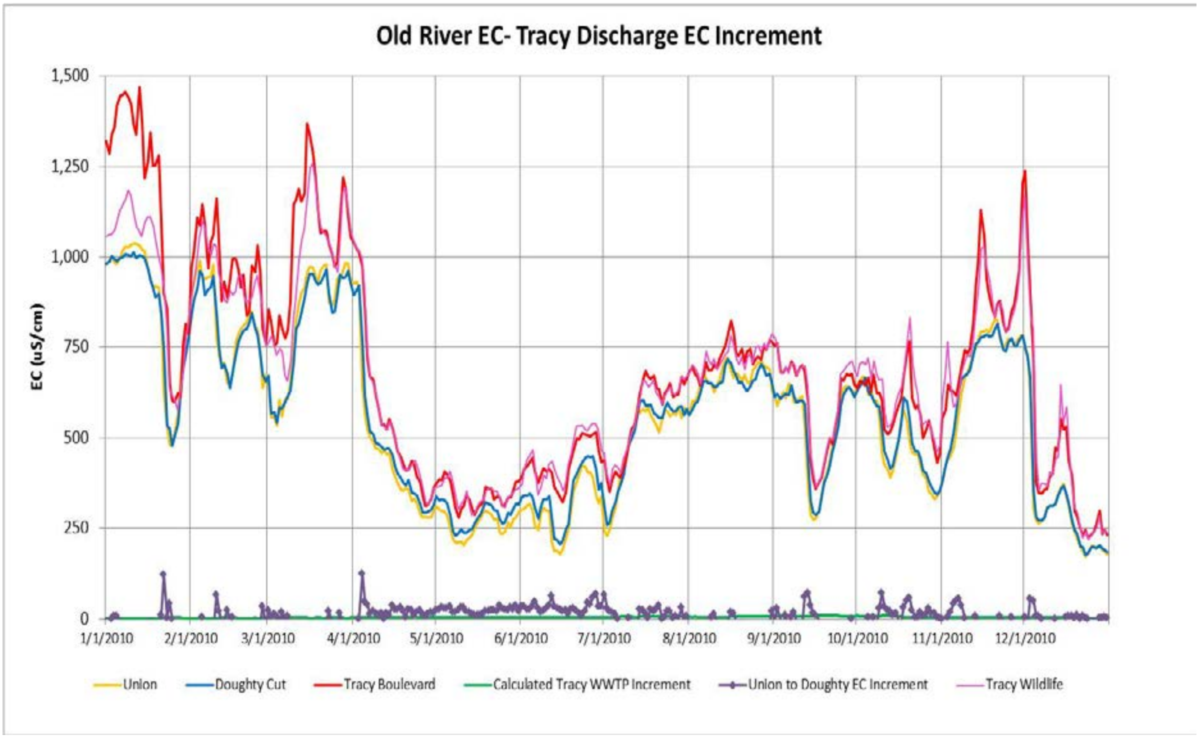


Figure 4b. Measured Old River EC at Several Locations and the Calculated Effects of the Tracy Wastewater Discharge on the EC Increment between Union Island and Doughty Cut in 2010

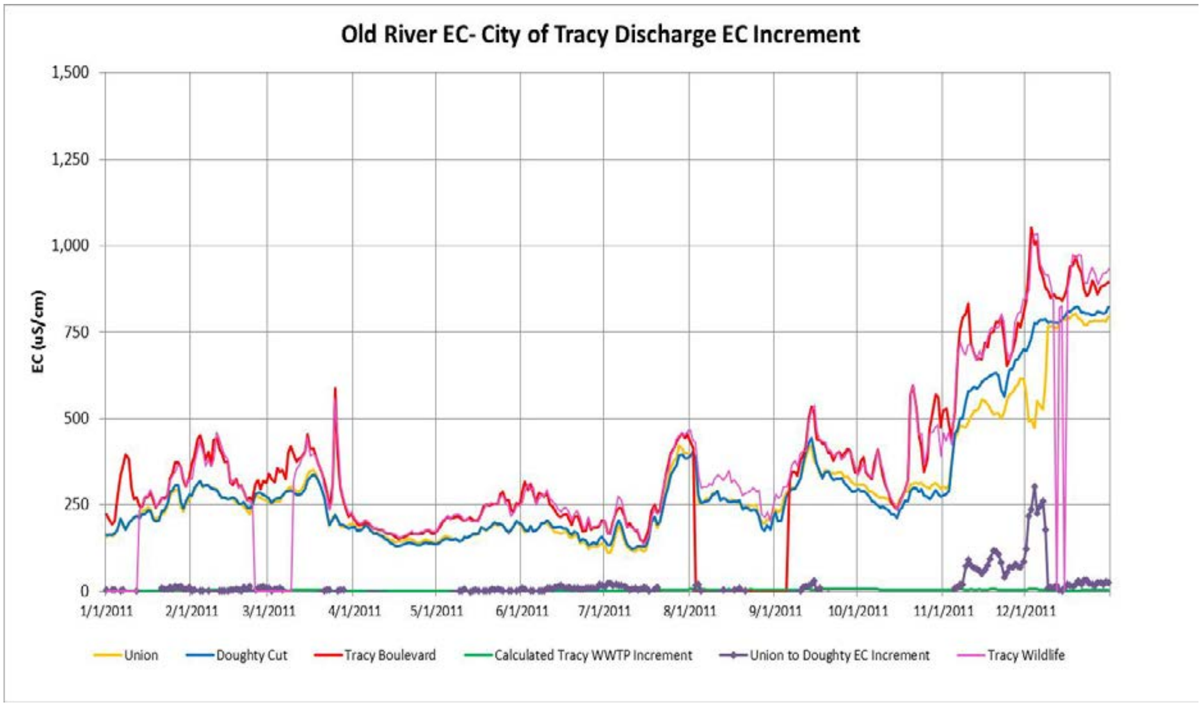


Figure 4c. Measured Old River EC at Several Locations and the Calculated Effects of the Tracy Wastewater Discharge on the EC Increment between Union Island and Doughty Cut in 2011

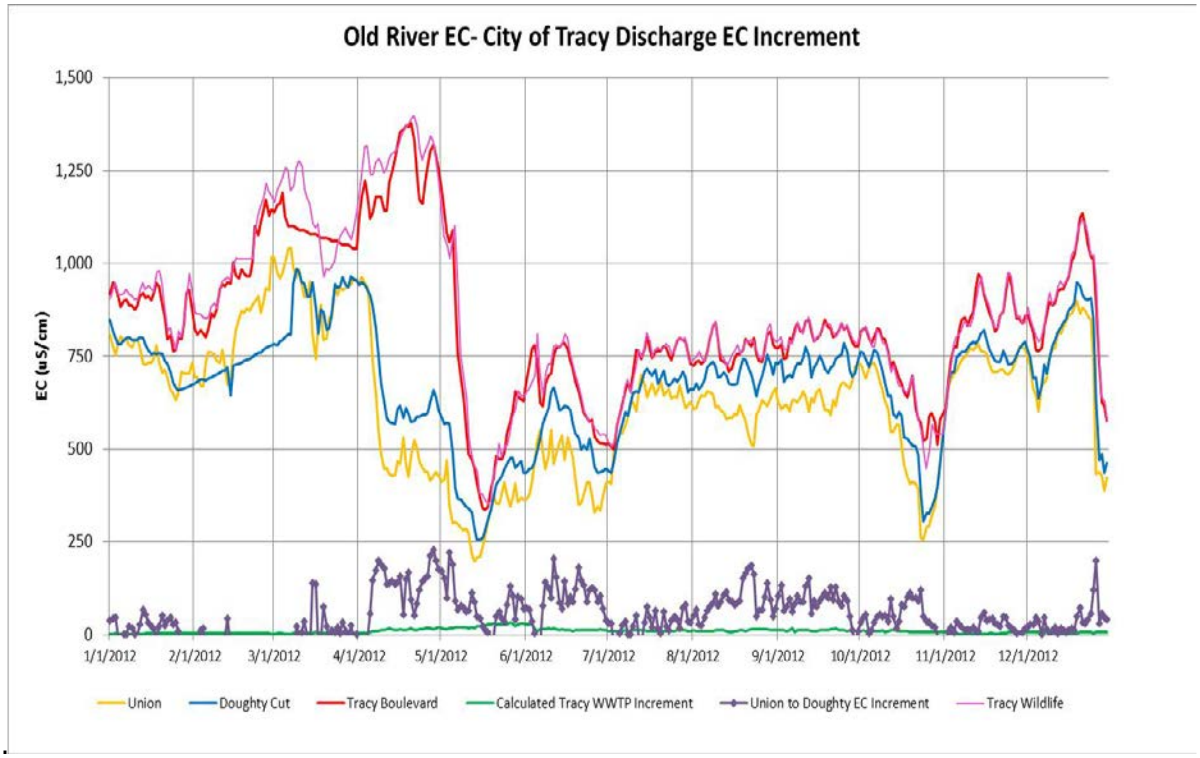


Figure 4d. Measured Old River EC at Several Locations and the Calculated Effects of the Tracy Wastewater Discharge on the EC Increment between Union Island and Doughty Cut in 2012

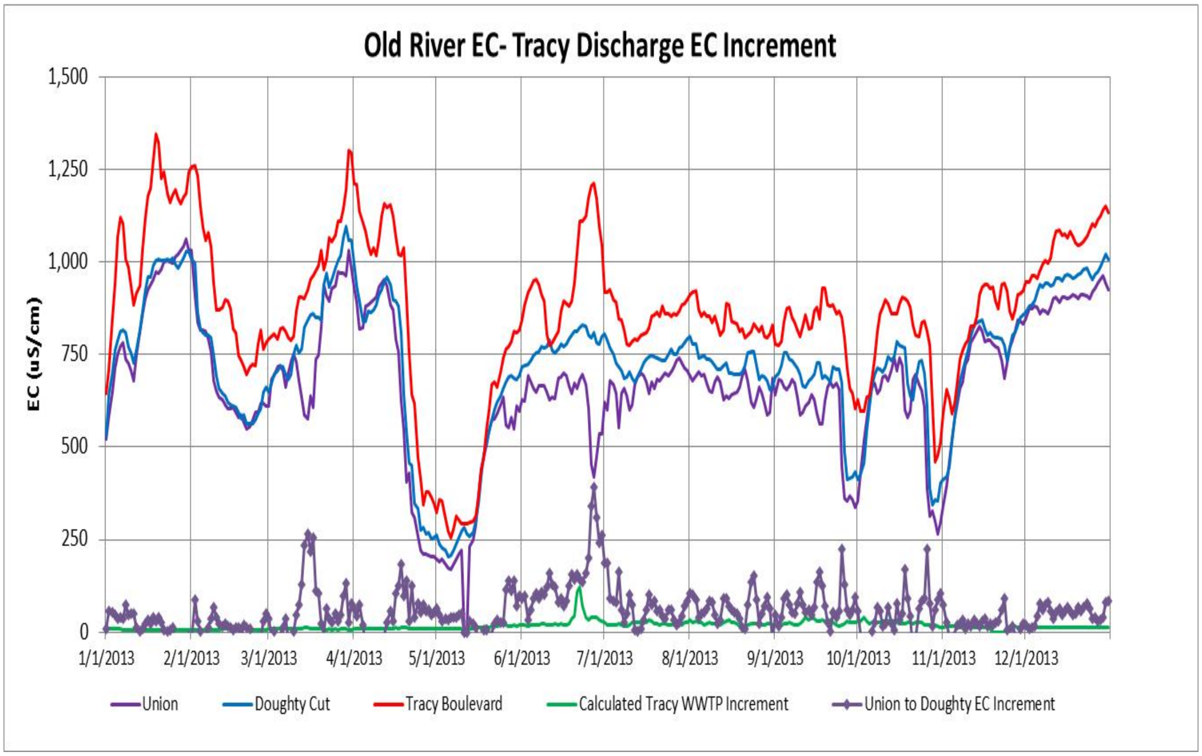


Figure 4e. Measured Old River EC at Several Locations and the Calculated Effects of the Tracy Wastewater Discharge on the EC Increment between Union Island and Doughty Cut in 2013

Net Daily Flows in South Delta Channels

The daily average flows in south Delta channels are controlled by the SJR inflow at Vernalis and the CVP and SWP pumping, as well as the average channel flow diversions (channel junction flows) that are controlled by the channel geometry and tidal elevation gradients, and the agricultural diversions and discharges along each channel. Because tidal flows dominate south Delta channels, the flow diversions at channel junctions must be considered during flood-tide (upstream flows) and ebb-tide (downstream flows). Flow diversions during ebb-tide become flow convergences during flood-tide, and flood-tide flows may have a somewhat different pattern than ebb-tide flows. Although generally similar (same upstream area at each elevation), each flood-tide and ebb-tide is slightly different because of the tidal variation (beginning and ending elevation), and therefore the tidal flows are slightly different. Because tidal flows are often much larger than the net flows in south Delta channels, and because of the variations in tidal flows, it is difficult to separate the tidal flows from the net flows; the general method was to evaluate the net flows with daily averages (24 hours), tidal averages (24.75 hours), or moving-averages (multiple days) of the 15-minute tidal flows. The summary of major flow diversions in this section were based on historical flow measurements in 2009-13 and previous DSM2 modeling results. The CVP pumping to the DMC and the SWP pumping to the California Aqueduct from CCF have substantial effects on the daily net flows in Old River downstream from the DMC intake and in Victoria Canal and Middle River downstream from Victoria Canal. The combined flows in Old River at Bacon and in Middle River at Bacon are referenced as the OMR flow. CVP and SWP pumping reduce OMR flow (i.e., larger negative upstream flow). The CVP pumping is uniform, with a maximum permitted capacity of 4,600 cfs (actually more than 5,000 cfs with existing motors and pumps). The SWP diversions to CCF are not uniform, because the gates open and close on a tidal pattern, but the net daily effects on the Old River and Middle River flows are similar to the effects from CVP pumping. The maximum permitted SWP diversion is 6,680 cfs, although the physical pumping capacity is about 10,300 cfs.

The first flow diversion (channel junction) from the SJR to south Delta channels is the Paradise Cut Weir. The Paradise Cut Weir is about 180 feet wide, with a crest elevation of about 15 feet NAVD. The hydraulics (velocity and flow) of the weir are controlled by the river elevation above the weir crest, or water head (i.e., flow = C x length x water head^1.5). The flood-flow bypass weir begins to spill when the SJR at Vernalis flow is about 17,500 cfs (elevation of about 15 feet at the weir) and results of hydraulic modeling of the SJR and Paradise Weir (with DSM2 or HEC-RAS) indicate that the weir diverts about 50 percent of the additional SJR flow (greater than 17,500 cfs). This assumed flow diversion generally was confirmed during the high flows of April 2011. Therefore, the Paradise Cut Weir flow can be estimated as:

Paradise Weir Flow (cfs) = 0.5 x [SJR Flow at Vernalis (cfs) – 17,500]

The diversion of SJR flow into the head of Old River (i.e., channel junction) is important for calculating the daily average flows in south Delta channels. The general flow diversion (based on DSM2 or HEC-RAS modeling results) can be approximated as 50 percent of the SJR flow being diverted to Old River and 50 percent of the SJR flow continuing downstream to Stockton. However, the CVP and SWP pumping will increase the diversion flow into Old River, increasing the diversion by about 5 percent of the combined pumping. For example, if the CVP and SWP pumping were at maximum permitted capacity (4,600 cfs for CVP and 6,680 cfs for SWP), the Old River diversion for typical summer conditions of 1,500 cfs at Vernalis would increase from 750 cfs (without pumping) to 1,315 cfs (i.e., 750 cfs plus 5 percent of 11,280 cfs). With the maximum CVP and SWP pumping, the head of Old River diversion flow will increase by 564 cfs, and the SJR flow passing the head of

Old River (towards Stockton) will be reduced by 564 cfs (to 185 cfs for this example). This estimated head of Old River diversion flow is similar to the calculation used in the OMR Flow Index, which was recently implemented by Reclamation for OMR flow compliance (with the USFWS and NMFS RPA-allowed OMR flows).

The head of Middle River (i.e., channel junction) is about 4 miles downstream from the head of Old River, at the southeast tip of Union Island. The Old River at Union Island EC station is located at this diversion location. The DSM2 model results indicate that about 3-5 percent of the Old River flow is diverted into the Middle River during periods without temporary barriers (and low irrigation diversions). Therefore, the Old River flow at the Tracy wastewater discharge location (downstream from Middle River) is about 95-97 percent of the head of Old River flow.

The Old River channel is complex (e.g., bends, side-channels) in the vicinity of Doughty Cut, Salmon Slough, and the mouth of Paradise Cut and Sugar Cut (Tom Paine Slough); several of the channel sections are very shallow at low tide. Generally about 85 percent of the head of Old River flow is diverted at Doughty Cut to the upstream end of Grant Line Canal. Therefore, only about 10 percent of the head of Old River flow remains in Old River downstream from Doughty Cut and flows past the mouth of Paradise Cut, the mouth of Sugar Cut (Tom Paine Slough), and past Tracy Boulevard. The tidal flow measurements in Old River at Tracy Boulevard are not accurate enough to resolve differences from the assumed 10 percent of the head of Old River flow; variations from this average flow fraction might be expected with temporary barriers or with higher pumping. This section of Old River is quite shallow, and the shallow depth may prevent a greater fraction of the head of Old River flow from continuing down Old River to Tracy Boulevard. The tidal flow measurements in Grant Line Canal (western end) are not accurate enough to resolve differences from the assumed 85-87 percent of the head of Old River flow (subtracting Middle River and Old River at Tracy Boulevard flows). Temporary barriers in Middle River, Grant Line Canal, and Old River at DMC did not substantially change the flow diversions from Old River to Middle River, nor did they change the flow diversions from Old River to Grant Line Canal (Doughty Cut).

Tidal flow measurements in Old River at Bacon Island and in Middle River at Bacon Island indicate that about 45 percent of the net upstream flow that is needed to supply the CVP and SWP exports and agricultural diversions, after subtracting the head of Old River flow (net export flow), comes from Old River at Bacon, and about 55 percent of the net export flow comes from Middle River at Bacon Island. Some of the Middle River net flow (10 percent of the net export flow) is transferred to Old River (through Woodward Canal and Railroad Cut) so that the net flow in Old River at Highway 4 is about 55 percent of the net export flow, and the net flow in Victoria Cut is about 45 percent of the net export flow. The net export flow measured in Old River at Bacon Island and Middle River at Bacon Island also is called OMR flow.

Figures 5a through 5e show the measured and estimated daily flows at the head of Old River, in Old River at Tracy Boulevard, and at the DMC barrier in calendar years 2009–13. Tidal flow measurements in Old River at Tracy Boulevard and at the DMC barrier were very low compared to flows at the ,head of Old River and in Grant Line Canal. The temporary barrier operations are indicated with index numbers on the right-hand scale (0–20). A value of 0 indicates that the barrier was not installed, an index value of 5 indicates that the barrier was being installed or removed, an index value of 10 indicates that the barrier was installed but the culvert flap gates were open, and an index value higher than 10 indicates the number of culvert flap gates operating (open on flood-tide, closed on ebb-tide). The majority of the Old River flow was diverted to Grant Line Canal. The tidal velocity at Tracy Boulevard was very low, making the daily average tidal flow difficult to calculate.

The Old River at Tracy Boulevard flow was estimated as 10 percent of the head of Old River flow (dashed red line); the installation of the temporary barriers (barrier operation index value of 10 or more, indicating the number of culverts with flap gates) did not seem to change the net flow fraction at Tracy Boulevard for relatively low flows, but the Grant Line Canal barrier may have increased the fraction of Old River flow at Tracy Boulevard for higher flows.

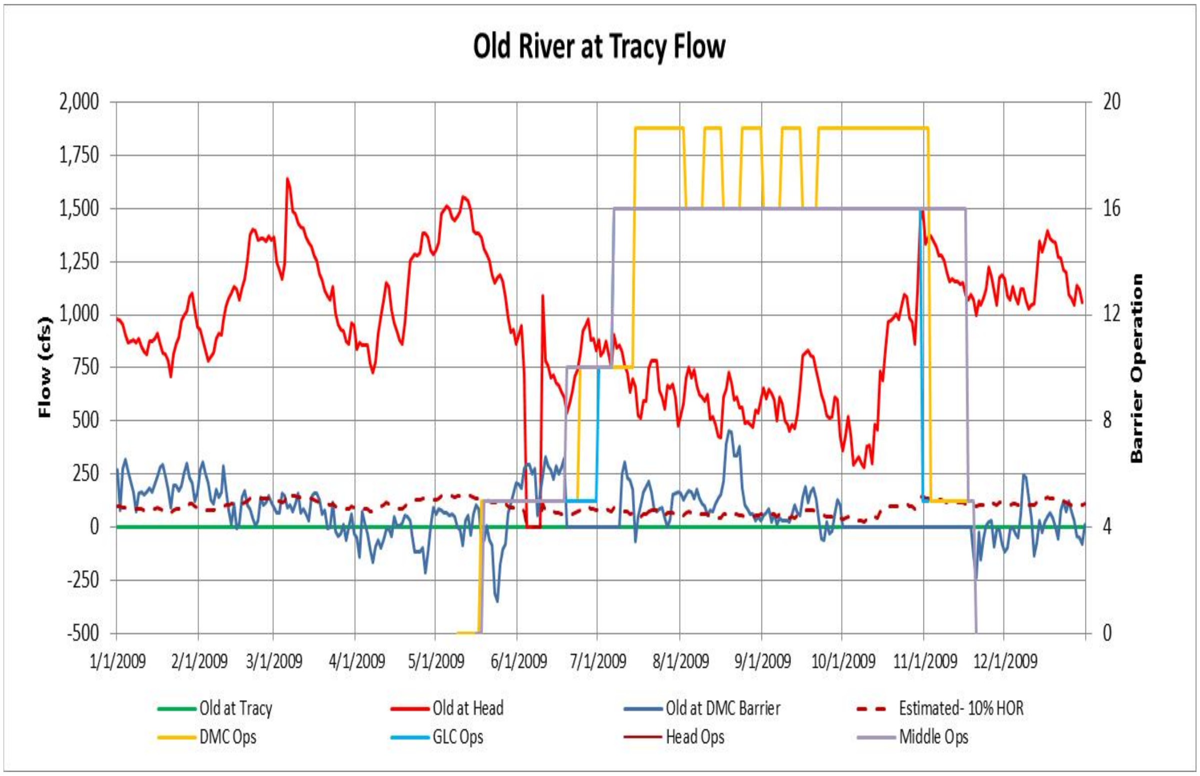


Figure 5a. Measured and Calculated Daily Average Old River Flow at Tracy Boulevard and the DMC Barrier in 2009

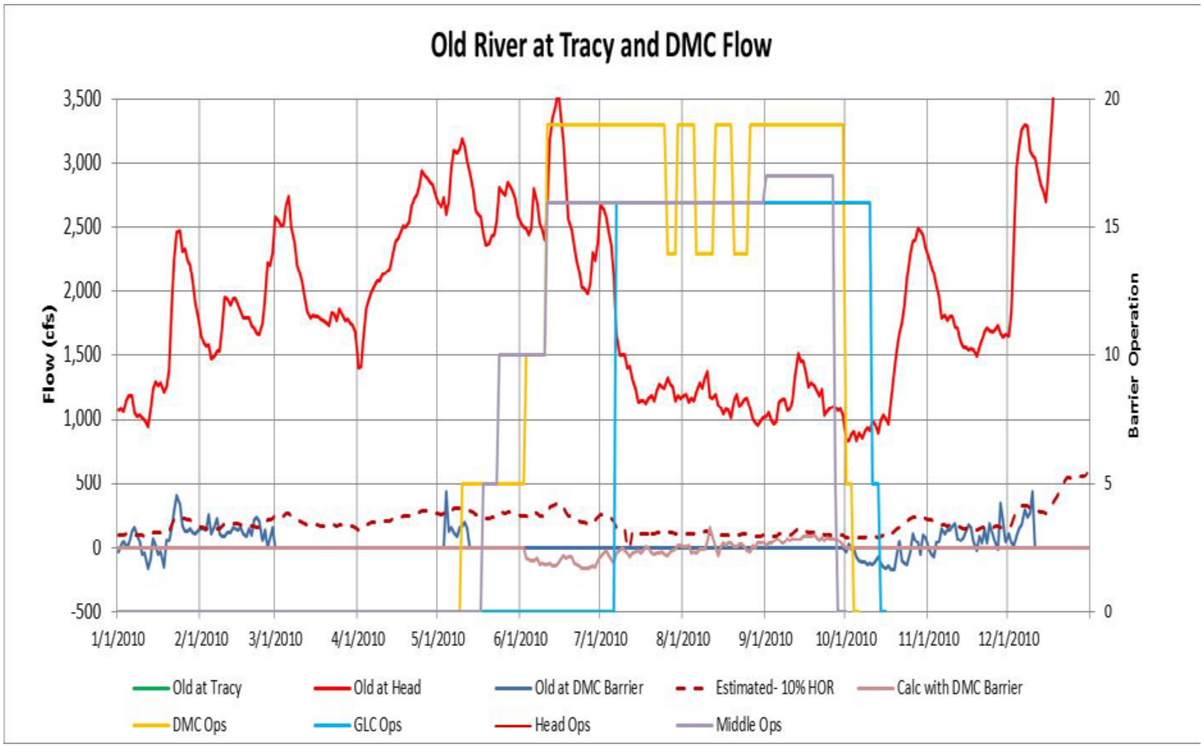


Figure 5b. Measured and Calculated Daily Average Old River Flow at Tracy Boulevard and the DMC Barrier in 2010

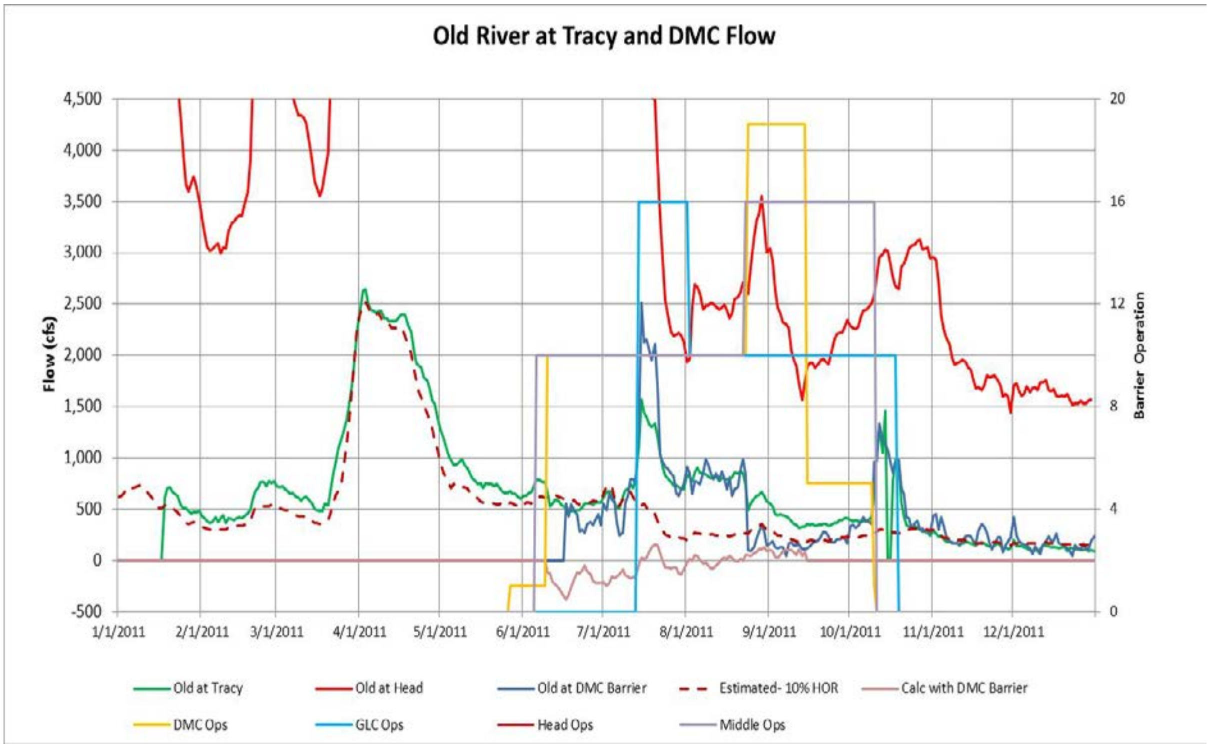


Figure 5c. Measured and Calculated Daily Average Old River Flow at Tracy Boulevard and the DMC Barrier in 2011

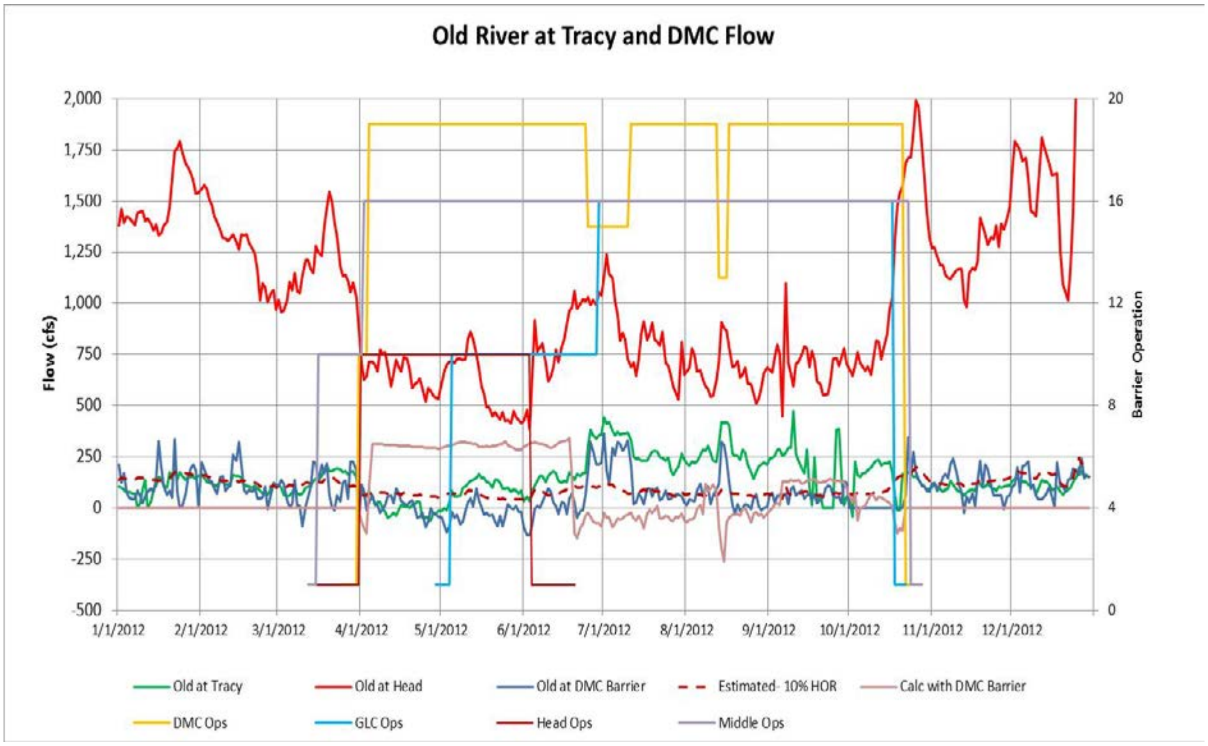


Figure 5d. Measured and Calculated Daily Average Old River Flow at Tracy Boulevard and the DMC Barrier in 2012

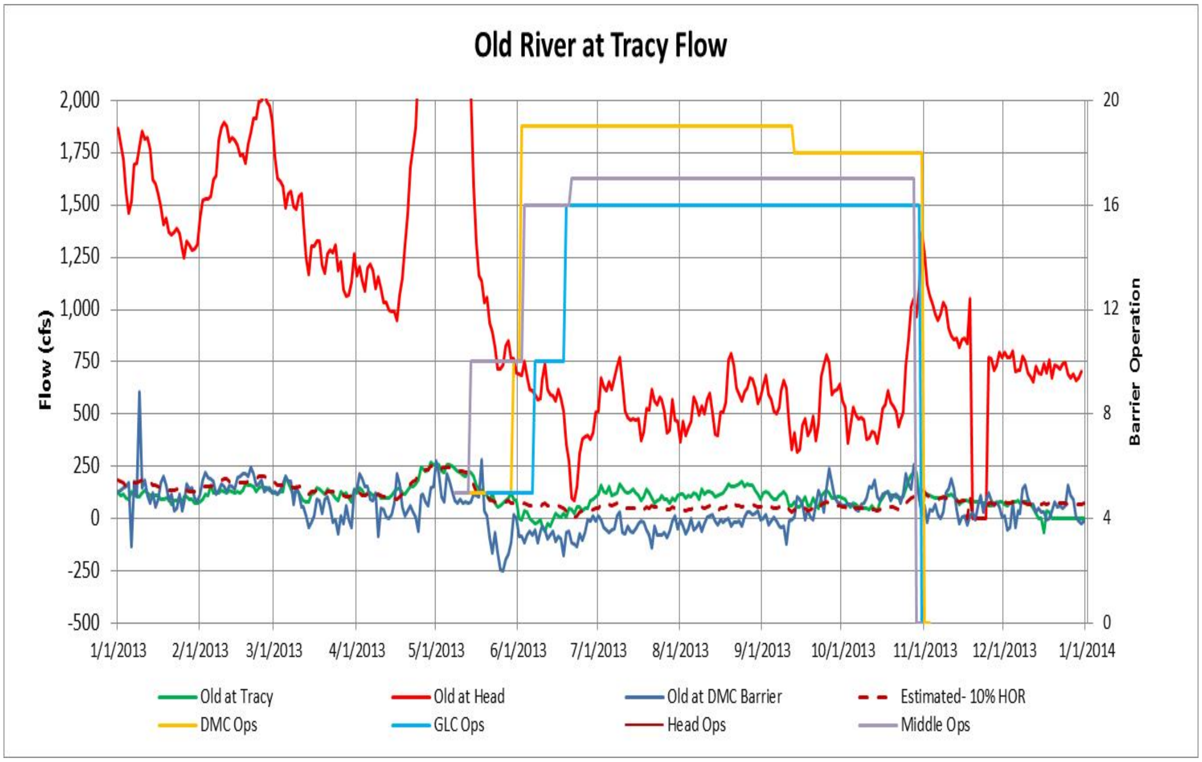


Figure 5e. Measured and Calculated Daily Average Old River Flow at Tracy Boulevard and the DMC Barrier in 2013

Tidal Exchange and Salinity in Paradise Cut and Sugar Cut

The tidal flows in tidal sloughs (dead-end channels) are controlled by the variations in tidal elevations and the channel geometry (cross-section, surface area, and volume) of the tidal sloughs, assuming a flat water surface elevation provides a good estimate of the tidal flow filling and draining the tidal slough (i.e., flow = elevation change x surface area). Two major tidal sloughs in the south Delta are Paradise Cut and Sugar Cut. These two tidal sloughs are located along Old River just downstream from Doughty Cut (connecting Old River and Grant Line Canal) and are both upstream from Tracy Boulevard. Paradise Cut is about 6 miles long, with a surface area of about 170 acres and a volume of about 1,000 af at mean tide (4 feet NAVD). Sugar Cut is about 2 miles long, with a surface area of about 55 acres and a volume of 425 af at mean tide. Tom Paine Slough, which is connected to Sugar Cut, with culverts and siphons (with flap gates to prevent ebb-tide outflow during the irrigation season) is about 7 miles long, with a surface area of about 65 acres and a volume of 230 af (from the DSM2 geometry file).

Tidal exchange (water movement) in a tidal slough with a possible inflow (or outflow) at the upstream end is controlled by tidal elevations and the surface area of the slough. The 15-minute tidal flow volumes into the slough (during flood-tide) and out of the slough (during ebb-tide) are calculated as:

Tidal volume (acre-feet) = - elevation change (feet) x area (acres) + Inflow (cfs) * 900/43560

The negative sign shows a negative flow (upstream) when the water elevation is increasing and a positive flow (downstream) when the water elevation is decreasing. Salt flushing from a tidal slough depends on the salt source (flow and EC) and on the tidal exchange flows and mixing along the tidal slough. The salt source (seepage or drainage flow) initially is mixed in the tidal volume that moves past the discharge or seepage location. Because the tidal flows are proportional to the upstream surface area, tidal flows decrease from the mouth of the slough to the upstream end of the slough. The EC increase from a salt source is greater if the salt source is located further upstream in the slough, where less tidal water movement for dilution occurs. The higher EC water is tidally mixed throughout the slough and is transported out of the slough during ebb-tides. The subsequent filling of the slough from the downstream channel (Old River) creates and maintains a longitudinal salinity gradient that generally increases from the mouth of the slough to the upstream end of the slough.

Possible salt sources in Paradise Cut and Sugar Cut were evaluated with tidal flow and salinity calculations, using these basic tidal slough flow and salinity concepts. Sugar Cut actually is connected to Tom Paine Slough just upstream from the diversion barrier, which operates with flap gated box culverts and siphons. However, for this study, Sugar Cut was used as the name of the tidal slough, and Tom Paine Slough was used as the name of the channel upstream from the diversion barrier. The measured tidal elevations in Old River were used to calculate the tidal exchange volumes using the tidal slough geometry (volumes and surface areas). The EC measurements near the mouth of Paradise Cut and in Sugar Cut upstream from the Tom Paine Slough diversion were used to estimate the salt sources that would match the measured tidal EC patterns. The salt sources for each tidal slough were specified as a flow (cfs) and EC (µS/cm) that were initially assumed to remain constant throughout the year; the actual salt sources may have a seasonal or fluctuating pattern. The mouths of Paradise Cut and Sugar Cut are downstream from Doughty Cut, which diverts most of the head of Old River flow to Grant Line Canal. Because the net flow in Old River at Tracy Boulevard is only about 10 percent of the head of Old River flow, the salt sources from

Paradise Cut and Sugar Cut have a relatively large effect on the EC in Old River at Tracy Boulevard, because the net flow (dilution) past Tracy Boulevard is often small.

Figures 6a through 6e show the measured daily average EC at several locations in Old River in 2009–13, including the EC at Doughty Cut (upstream from Paradise Cut and Sugar Cut) and the EC at Tracy Boulevard and at Tracy Wildlife (downstream from Paradise Cut and Sugar Cut). The EC in Paradise Cut and in Sugar Cut generally were higher than the EC at Tracy Boulevard, indicating that tidal exchange from these tidal sloughs may be the source of the elevated EC (incremental EC) observed at Tracy Boulevard. Because the Tracy Boulevard EC was considerably higher than the Tracy Wildlife EC from July to December 2009, and was higher than the longitudinal EC profiles measured by DWR in 2009, the Tracy Boulevard EC data was determined to be inaccurate during this period. The Tracy Boulevard EC matched the Tracy Wildlife EC again in February 2010. This discrepancy between the two nearby EC measurements suggested the importance of replicate measurements (and frequent field checks) for the most important data locations.

The accurate interpretation of these measured daily patterns of EC along Old River and in Paradise Cut and Sugar Cut was difficult because of the many factors that may influence the south Delta EC. The SJR flow and EC at Vernalis are the primary (dominant) factors, but the head of Old River flow and the Old River flow at Tracy Boulevard control the dilution of the salt sources from Paradise Cut and Sugar Cut. The Sugar Cut EC was often the highest EC measurement, because the EC station is located upstream of the Tom Paine Slough diversion near the source of the higher EC water at the upstream end of Sugar Cut. The Paradise Cut EC was often similar to the head of Old River EC or the Doughty Cut EC, because the EC station is located near the mouth of Paradise Cut, with the greatest tidal exchange of water with Old River (during flood-tide). The temporary barriers reduce the tidal elevation variations and tend to isolate the tidal sloughs, causing the measured EC to increase; but the high flows in 2011 also reduced the tidal variations and caused higher EC in Paradise Cut and Sugar Cut (i.e., lower tidal flushing).

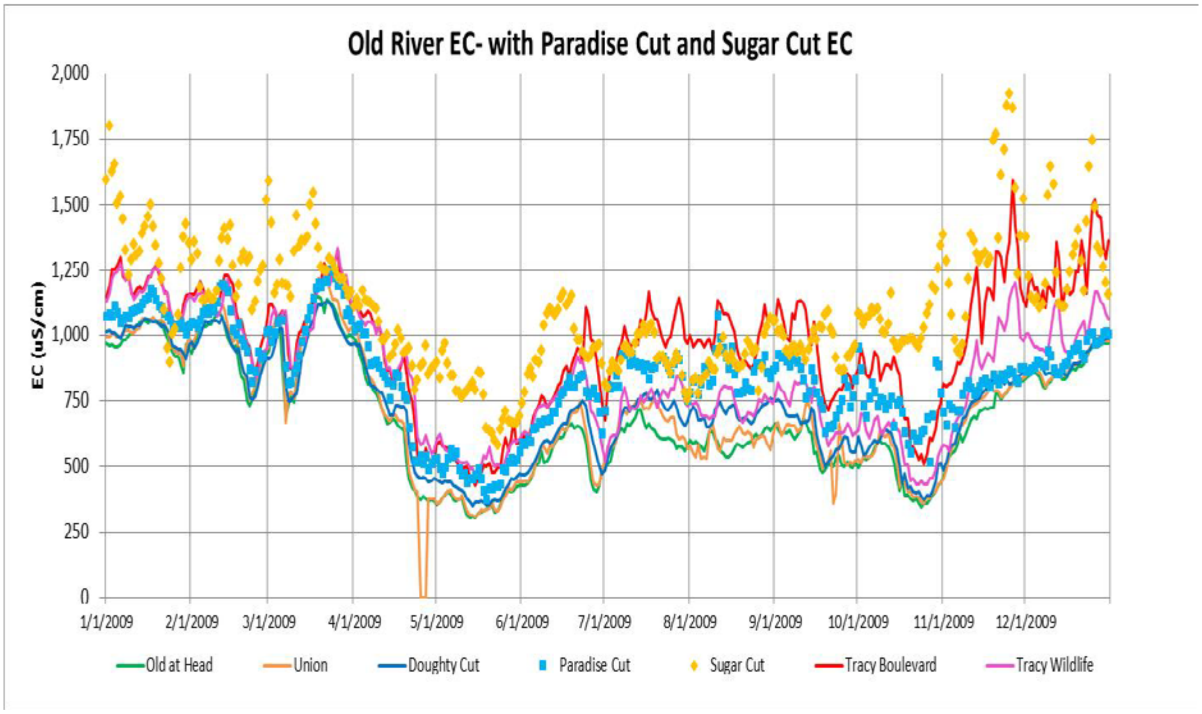


Figure 6a. Measured Daily Average EC in Paradise Cut and Sugar Cut Compared to the EC at Several Old River Locations in 2009

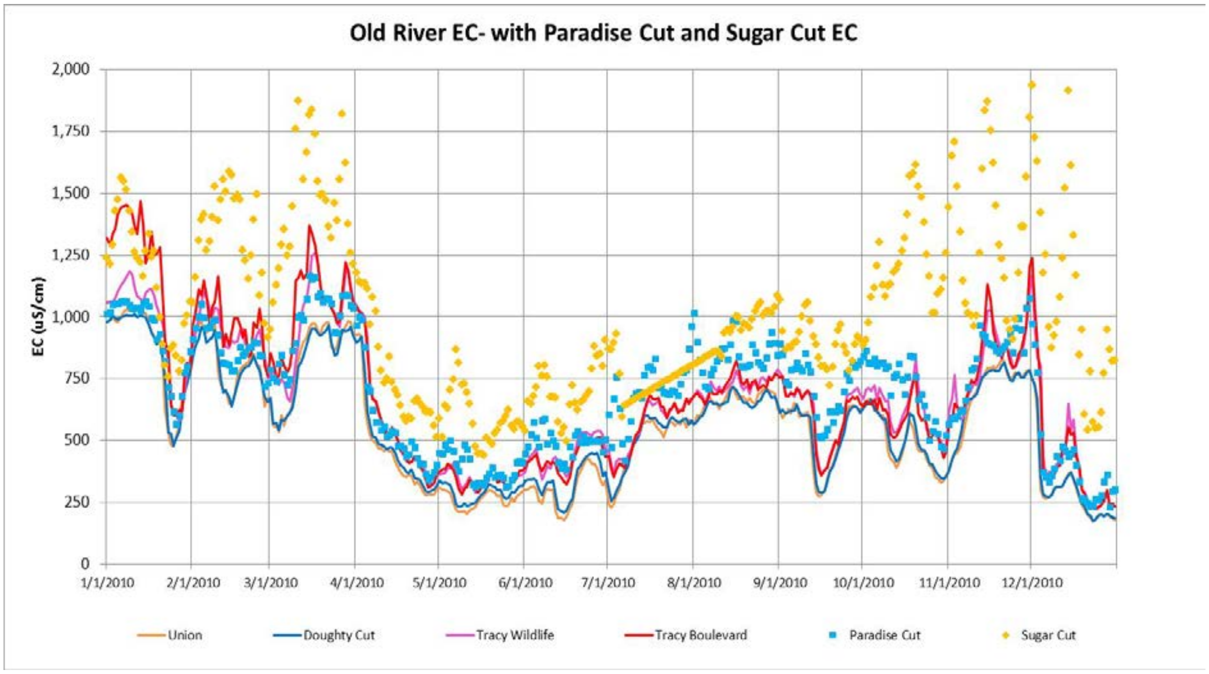


Figure 6b. Measured Daily Average EC in Paradise Cut and Sugar Cut Compared to the EC at Several Old River Locations in 2010

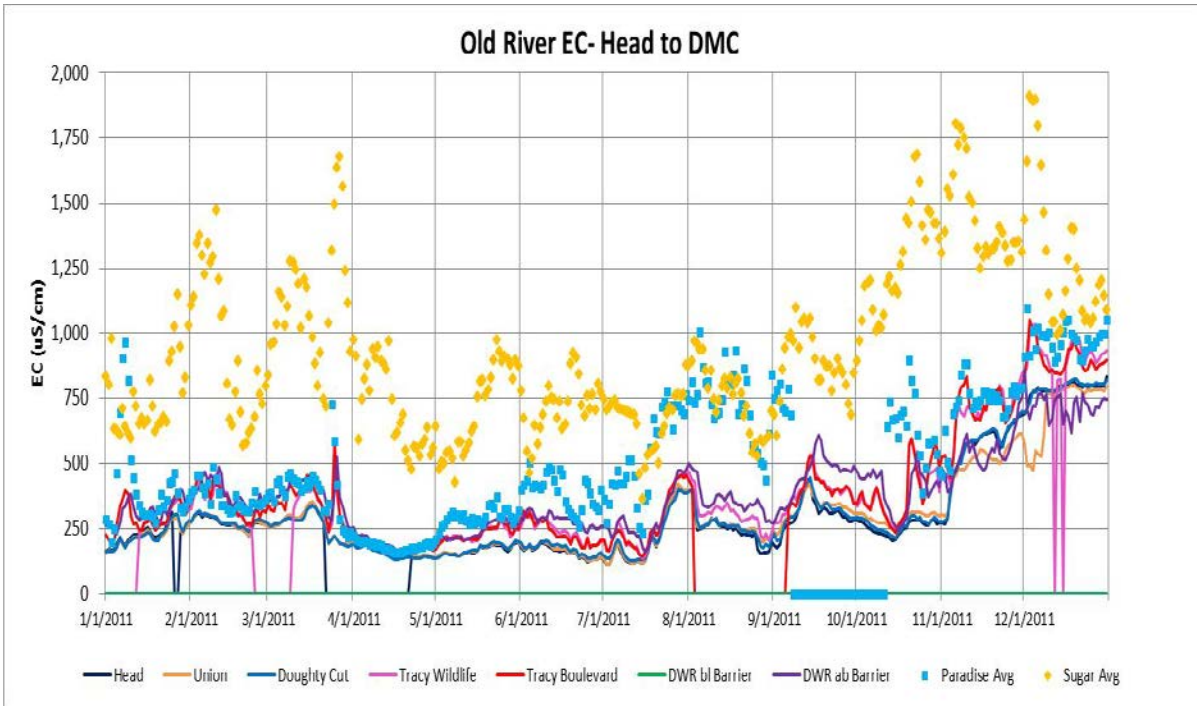


Figure 6c. Measured Daily Average EC in Paradise Cut and Sugar Cut Compared to the EC at Several Old River Locations in 2011

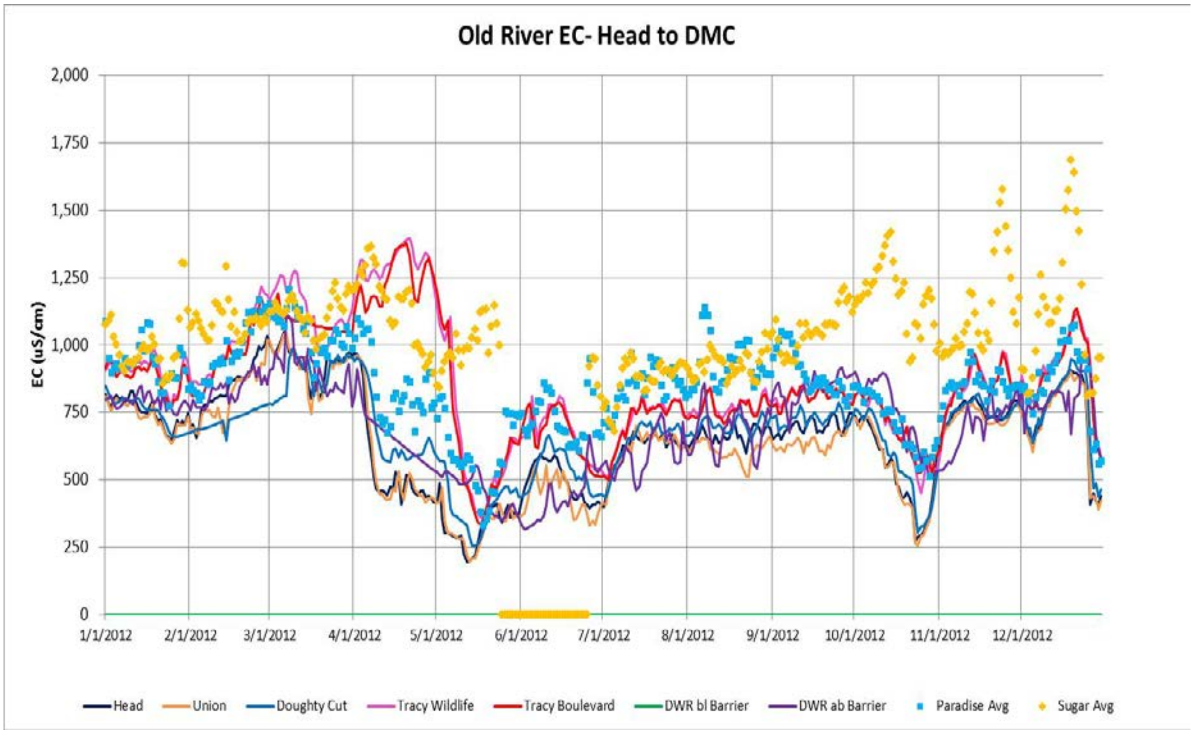


Figure 6d. Measured Daily Average EC in Paradise Cut and Sugar Cut Compared to the EC at Several Old River Locations in 2012

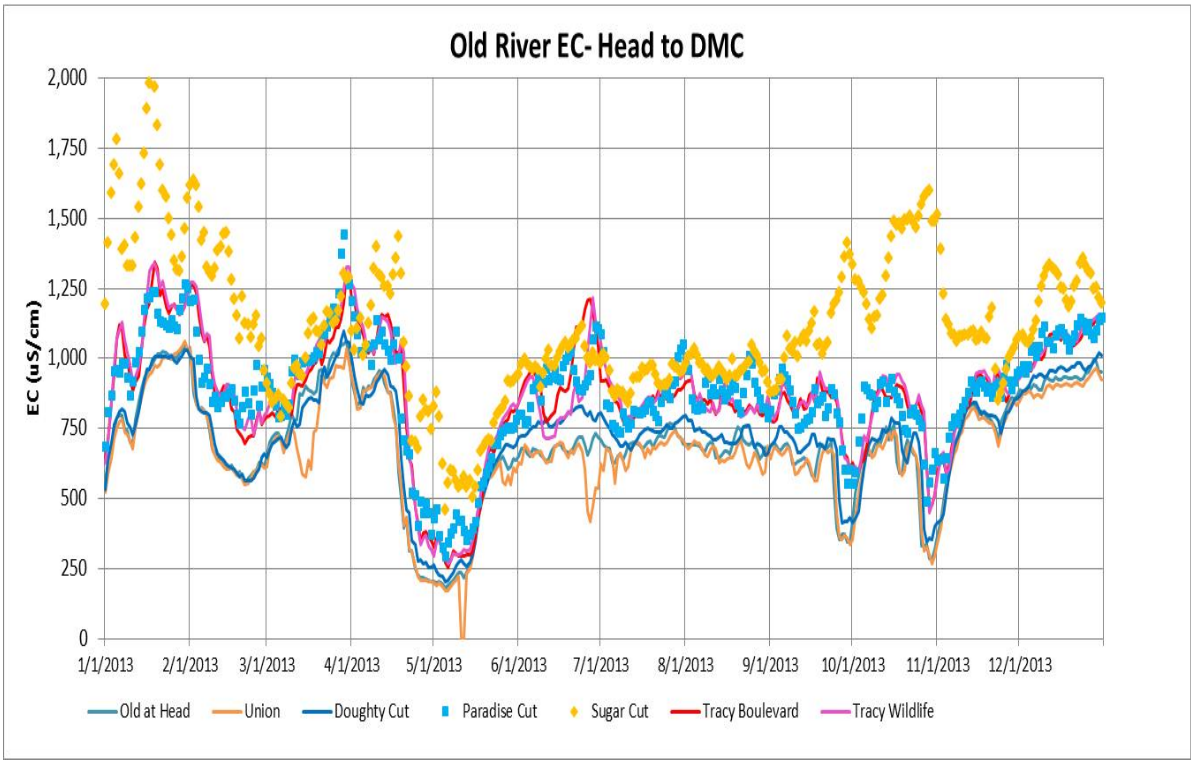
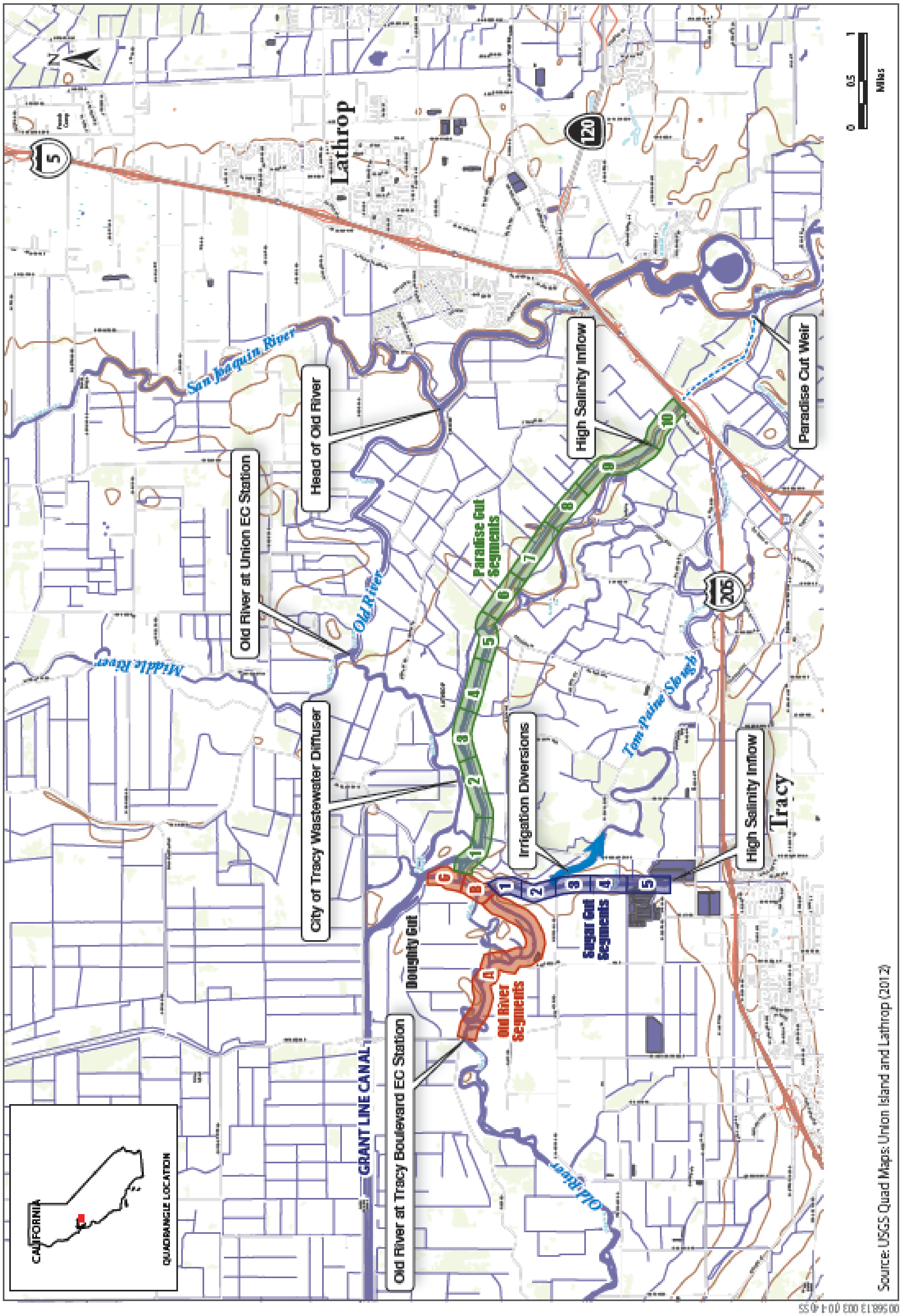


Figure 6e. Measured Daily Average EC in Paradise Cut and Sugar Cut Compared to the EC at Several Old River Locations in 2013

Figure 7 shows the channel segments used for the tidal flow and salinity calculations for Paradise Cut, Sugar Cut, and Old River between Doughty Cut and Tracy Boulevard. The channels are represented by volume segments that fill during flood-tide and are partially emptied (drain) during ebb-tide. The tidal slough calculations used three-volume segments for Old River: segment A between Sugar Cut and Tracy Boulevard; segment B between Paradise Cut and Sugar Cut; and segment C between Doughty Cut and Paradise Cut. The tidal slough calculations used 10 volume segments for Paradise Cut and 5 volume segments for Sugar Cut. This allowed the longitudinal tidal exchange and mixing of salinity to be approximated, but not as accurately represented as with the DSM2 tidal flow and salinity model (once calibrated). The segmented calculations cannot track the movement of Old River water into the tidal sloughs during flood-tide as accurately as the DSM2 model; the EC in downstream segments remain too high and the EC in upstream segments become too low (too much longitudinal mixing). However, the box-model approximation of the tidal exchange of water and salt in Paradise Cut, Sugar Cut, and the Old River segments between Doughty Cut and Tracy Boulevard allows changes in the assumed salt sources to be quickly reviewed and compared for the 5 years being evaluated (i.e., 2009-13), each of which contains many combinations of Old River flow and EC, and with different periods of Head of Old River barrier and temporary barrier operations (installation and flap gate operation).



Source: USGS Quad Maps: Union Island and Lathrop (2012)

Figure 7
Segments for Tidal Model of Paradise Cut, Sugar Cut and Old River Salinity

Paradise Cut has a surface area of about 170 acres, with a volume of 1,000 af at mean tide (elevation of 4 feet NAVD); the volume will change by about 17 percent of the mean tide volume for each 1-foot change in tidal elevation (assuming a rectangular channel). Paradise Cut is about 6 miles long with a uniform channel cross-section (assumed), so water from about 16 percent of the slough length (1 mile) flows to Old River as the elevation decreases by 1 foot from mean tide, and 16 percent of the slough length (volume) is filled with water from Old River as the elevation increases by 1 foot to mean tide.

Sugar Cut has a surface area of about 55 acres, with a volume of 425 af at mean tide (elevation of 4 feet NAVD); the volume will change by about 13 percent for each 1-foot change in tidal elevation (assuming a rectangular channel). Sugar Cut is about 2 miles long with a uniform channel cross section, so water from about 13 percent of the slough length (0.25 mile) flows to Old River as the elevation decreases by 1 foot from mean tide, and 13 percent of the slough length is filled with water from Old River as the elevation increases by 1 foot to mean tide.

The tidal calculations for Sugar Cut include a tidal diversion (i.e., culverts with flap gates) to Tom Paine Slough for irrigation; this diversion is about 1 mile upstream from the mouth of Sugar Cut. The assumed daily diversion flow varies seasonally from March through October, with a maximum daily average diversion flow of about 100 cfs assumed in the summer. The actual diversion flow through the culverts depends on the water elevation difference, so the diversion is greater at higher tide elevations. Although the Sugar Cut tidal flows at the mouth often are greater than the diversion flow, the diversion flow was much greater than the assumed salt source flow, so most of the salt source at the upstream end of Sugar Cut was likely diverted to Tom Paine Slough during the irrigation season. Because the mouth of Paradise Cut is just upstream from the mouth of Sugar Cut, some of the assumed salt source from Paradise Cut that enters the Old River channel may be diverted subsequently into Sugar Cut during flood-tides and some into Tom Paine Slough during the irrigation season.

The tidal flows through the flap gates into Tom Paine Slough provide water supply to Pescadero Tract, with an irrigated area assumed to be about 8,000 acres. The daily diversions necessary to support the seasonal irrigation of this area can be roughly estimated as follows. Assuming that a total of 3.75 feet of water is applied during the year, with 20 percent assumed soil drainage (0.75 feet) and evaporation-transpiration of 3 feet, a seasonal total of 30,000 af of water per year would be diverted from Sugar Cut to Tom Paine Slough at the flap gates. Assuming that the irrigation water is applied with a seasonal pattern (i.e., half-sine wave shape) from March through October (the predominant crop is alfalfa), the maximum daily flow would be about 100 cfs (12.5 cfs per 1,000 acres). The agricultural drainage from the soils in this area would total about 6,000 af per year (assuming 20 percent soil drainage). The assumed Tom Paine diversion flow was specified in the box-model to more accurately calculate the fraction of the assumed Sugar Cut salt source that reached Old River in the summer irrigation season.

If irrigation water drainage to the shallow groundwater with seepage to the south Delta channels is relatively uniform throughout the year, the average drainage flow from Pescadero Tract will be about 8 cfs. The Pescadero Tract (8,000 acres) and other irrigated lands in the south Delta will have similar diversions for irrigation and similar agricultural drainage flows, with an average agricultural drainage flow of about 1 cfs per 1,000 acres. Because the drainage flow is assumed to be 20 percent of the applied water, the EC of the drainage water would be about 5 times the applied EC. For example, if the average EC of the applied water was 500 μS/cm, the average drainage water EC would be about 2,500 μS/cm. Therefore, the soil drainage water from the irrigated lands in the south Delta could have a measureable effect on the Old River EC. The effects from agricultural drainage will be greatest during periods of low Old River flows, or during periods with highest drainage flow if the drainage flow is not uniform during the year. Drainage flow from the shallow groundwater may be increased during wet periods if rainwater infiltration causes increased water table elevations near south Delta channels (increased seepage) and the EC also may be seasonal.

Because flood tide (upstream) flows in Old River at Tracy Boulevard are relatively small (with a net downstream flow), most of the flood-tide flows entering Sugar Cut and Paradise Cut likely are coming from Doughty Cut and Grant Line Canal. During ebb-tide, however, tidal flows from Sugar Cut and Paradise Cut are more likely to flow downstream in Old River towards Tracy Boulevard (with the net flow). Therefore, the measured tidal elevations and flows in Old River at Tracy Boulevard were used (when available) to calculate the tidal flows in Old River just upstream from Sugar Cut, just upstream from Paradise Cut, and just downstream from Doughty Cut. This allowed the effects of the salt sources from Paradise Cut and Sugar Cut to be accurately calculated; some of the assumed salt source was transported downstream in Old River to Tracy Boulevard, some was diverted to Tom Paine Slough for irrigation, and some was transported upstream in Old River to Doughty Cut and Grant Line Canal. The tidal slough calculations were compared to the measured EC patterns in Sugar Cut upstream from the Tom Paine Slough diversion, near the mouth of Paradise Cut, and in Old River at Tracy Boulevard to estimate the likely salt sources in Paradise Cut and Sugar Cut.

Effects of Temporary Barriers on Tidal Elevations and Flows

The CVP pumping to the DMC and the SWP pumping to the California Aqueduct from CCF have substantial effects on the net flows, tidal elevations, and tidal flows in south Delta channels. The CVP pumping is relatively uniform, with a maximum permitted pumping of 4,600 cfs (actually 5,000 cfs with existing motors and pumps). Results from previous DSM2 modeling suggest that the effects of the CVP pumping on south Delta tidal elevations are moderate, reducing the tidal elevations in Old River and Grant Line Canal by about 0.5 feet (SDIP 2005:Figure 5.2-15). The effects of the SWP pumping are more difficult to evaluate because the CCF tidal gates are closed during low tide elevations and the flood-tide before the higher-high (highest) tide each day. At full permitted SWP pumping of 6,680 cfs, with 4,600 cfs CVP pumping, the DSM2-simulated effects of full SWP pumping on minimum elevations (without temporary barriers or CCF gate operations) were relatively small (reduced an additional 0.25 feet), but the maximum elevations also were reduced by about 1 foot. However, comparison of measured high tide elevations (e.g., Old River at Bacon Island with Old River at the DMC barrier, or Grant Line Canal at Tracy Boulevard) for periods of high and low SWP and CVP pumping suggests that the CCF gate operation rules are very effective in maintaining high tidal elevations in south Delta channels.

DWR operates (annually installs and removes) three temporary barriers in south Delta channels to provide increased minimum water elevations during the summer irrigation season. The temporary barriers each have several 4-foot-diameter culverts with flap gates to allow upstream (flood-tide) flows. Sometimes the flap gates are held open to allow both ebb-tide and flood-tide flows. The barriers are located in Old River upstream from the DMC intake, in Middle River upstream from Victoria Canal, and in Grant Line Canal upstream from Tracy Boulevard (see Figure 2b). A higher elevation weir crest at the Old River at DMC barrier (4.5 feet NAVD) and at the Middle River barrier (4.5 feet NAVD) than at the Grant Line Canal barrier (3.5 feet NAVD) was intended to provide a net upstream flow (i.e., circulation) in Middle and Old Rivers (upstream from the barrier), to maintain acceptable minimum water elevations and adequate water quality (EC). The ebb-tide flows in Old River and Middle River upstream from the barriers were expected to move upstream (reverse), after the water elevations decrease to the barrier crest elevation of 4.5 feet and flow downstream in Grant Line Canal (with crest elevation of 3.5 feet). However, because the Grant Line Canal weir crest elevation is only 1 foot lower, the period of upstream ebb- tide flow may be limited; tidal flows decrease as the water elevations upstream of the barriers approach 3.5 feet.

Many years of temporary barrier operations, as well as tidal flow modeling studies (DSM2) have indicated that although the temporary barriers maintain higher minimum daily water elevations upstream from the barriers, maximum elevations are reduced and tidal flows upstream of the barriers are substantially reduced by the barriers. Periods of upstream ebb-tide flow in Old River and Middle River are very limited. The DWR SDIP proposed to replace the temporary barriers with operable tidal gates. The proposed gates would be open during flood-tide and the Old River and Middle River gates would be closed during ebb-tide to maximize the upstream circulation (net flows) in Old River and Middle River. The proposed Grant Line Canal gate would be located at the western end of Grant Line Canal, and would be partially closed to regulate the water elevations upstream from the gate during ebb-tide.

Another barrier at the head of Old River often has been installed in the fall months of September to November to increase SJR flows at Stockton to provide higher attraction flows for adult Chinook salmon migrating upstream to spawn in the SJR tributaries (Stanislaus, Tuolumne, and Merced Rivers). The Head of Old River barrier also has been installed in the spring months (April and May) of many years to reduce the diversion of SJR salmon juveniles (smolts) into Old River with subsequent entrainment (or salvage) at the CVP and SWP pumping plants. However, the fall barrier was not installed in 2009–13, and the spring barrier was installed only in 2012, with eight culverts left open to provide a minimum head of Old River flow of about 500 cfs.

Figures 8a through 8e show the daily minimum and maximum elevations at several locations along Old River in 2009–13. The SJR at Jersey Point tide elevations (gold line) are used as a reference for the estuary tidal conditions. During months without temporary barriers, the tidal ranges (minimum and maximum tide elevations) were very similar at Highway 4, at the DMC barrier, and at Tracy Boulevard (red diamonds). The minimum tide and maximum tide elevations fluctuate from day to day because the spring-tide elevation range is generally greater and the neap-tide elevation range is usually smaller. The low tide elevations (1.5 feet to 3.0 feet NAVD) were more uniform than the high tide elevations (4 feet to 7 feet NAVD). The minimum tide elevations were increased and the maximum tide elevations were decreased from July through October at the DMC barrier and Tracy Boulevard stations compared to Jersey Point, when the temporary barriers were installed with flap gate culverts. The changes in the minimum and maximum tidal elevations upstream from the temporary barriers were the most obvious effects of installing the temporary barriers, but the temporary barriers also had substantial effects on the tidal flows and salt flushing patterns upstream from the barriers. The following sections of the report present more specific results from the various analysis methods that were used to evaluate the tidal elevation, tidal flow, and tidal EC data from the south Delta channels to determine the effects of the temporary barriers and identify the likely sources of higher EC water measured at the Tracy Boulevard and Tracy Wildlife EC stations.

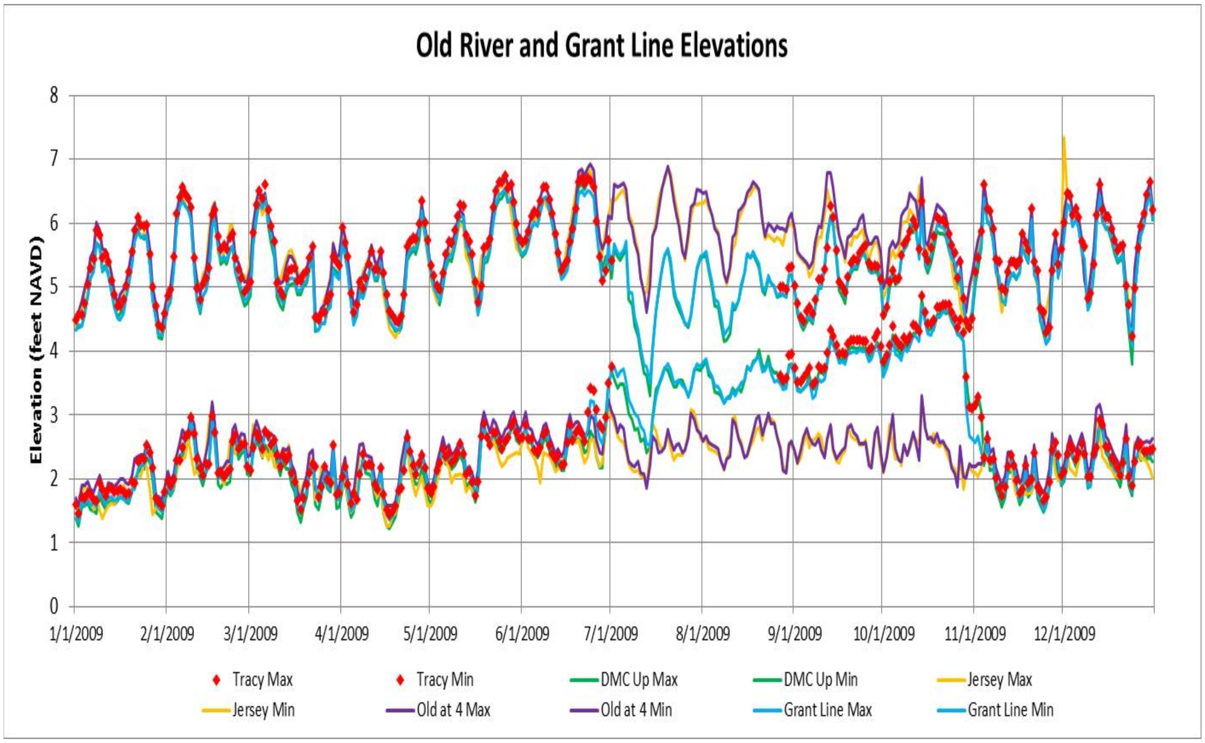


Figure 8a. Daily Minimum and Maximum Tide Elevations in Old River and Grant Line Canal at Several Locations Upstream and Downstream from the Temporary Barriers in 2009

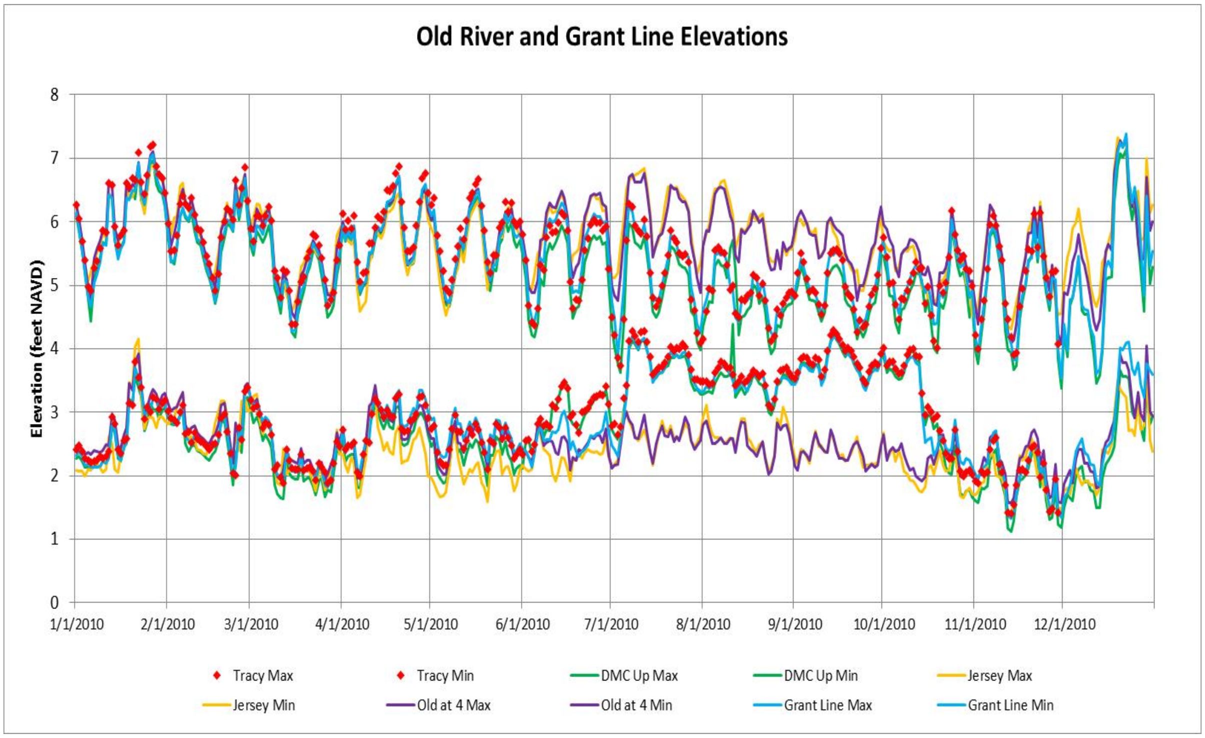


Figure 8b. Daily Minimum and Maximum Tide Elevations in Old River and Grant Line Canal at Several Locations Upstream and Downstream from the Temporary Barriers in 2010

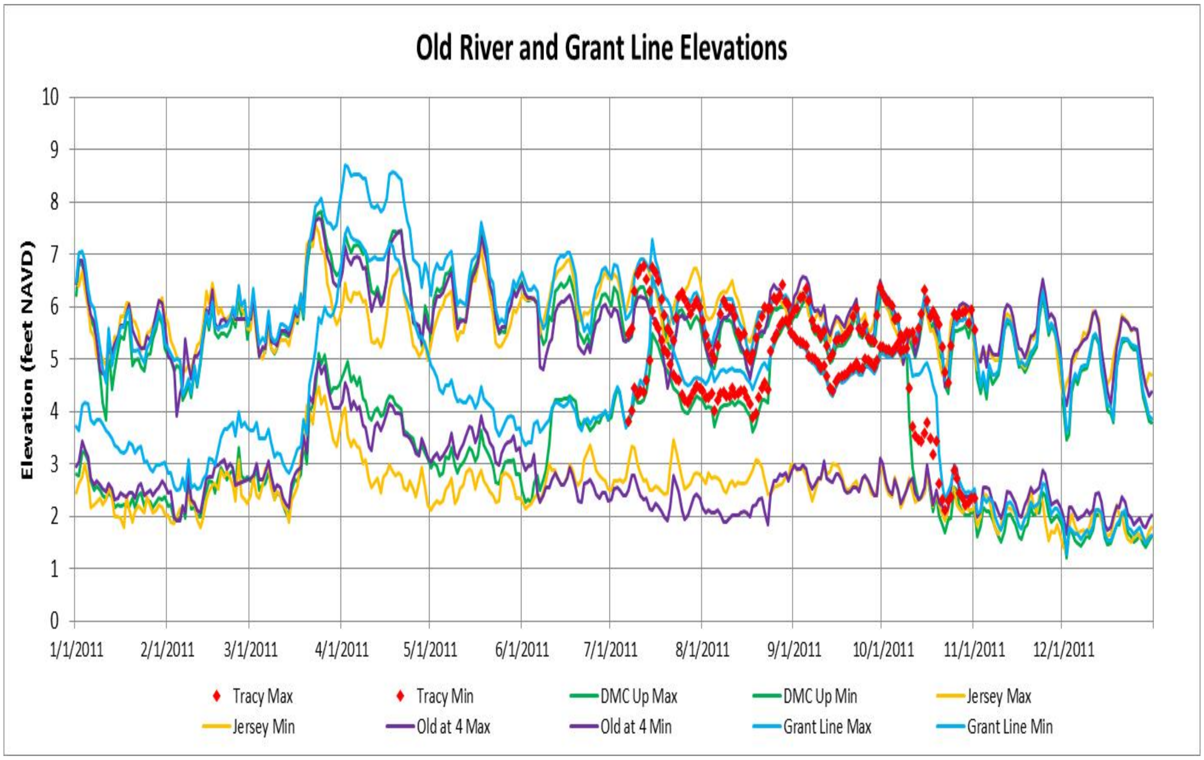


Figure 8c. Daily Minimum and Maximum Tide Elevations in Old River and Grant Line Canal at Several Locations Upstream and Downstream from the Temporary Barriers in 2011

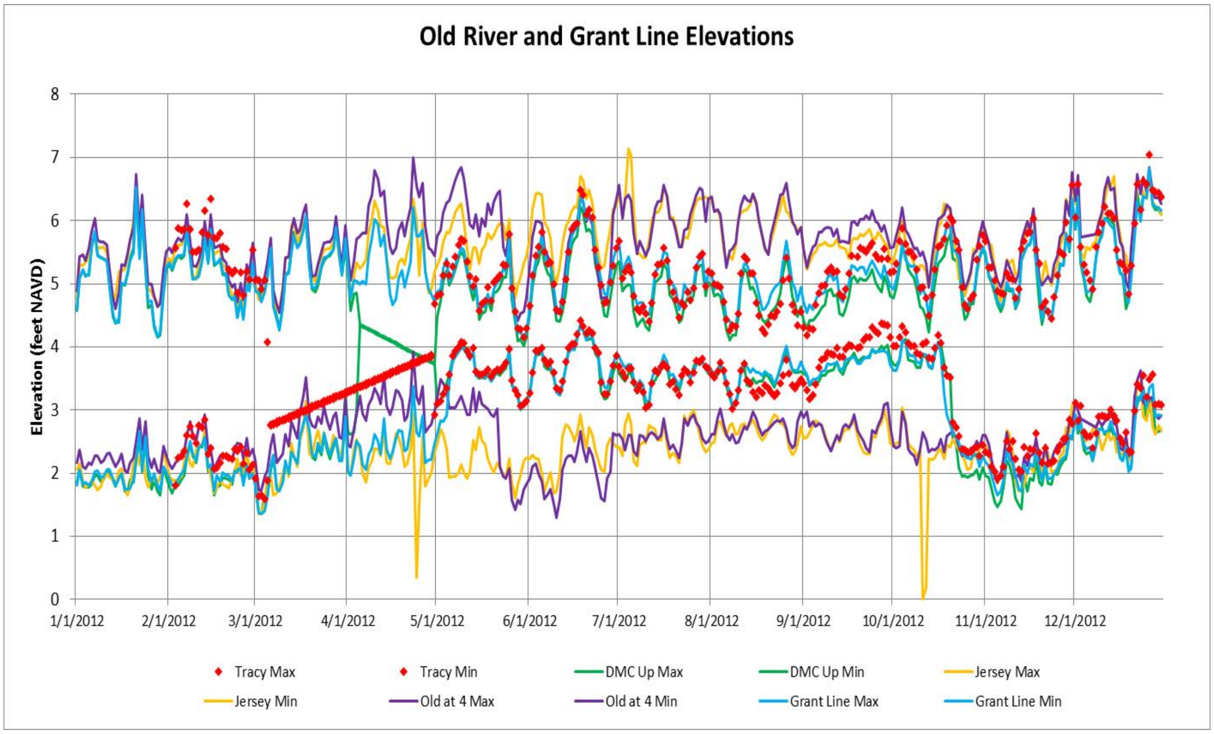


Figure 8d. Daily Minimum and Maximum Tide Elevations in Old River and Grant Line Canal at Several Locations Upstream and Downstream from the Temporary Barriers in 2012

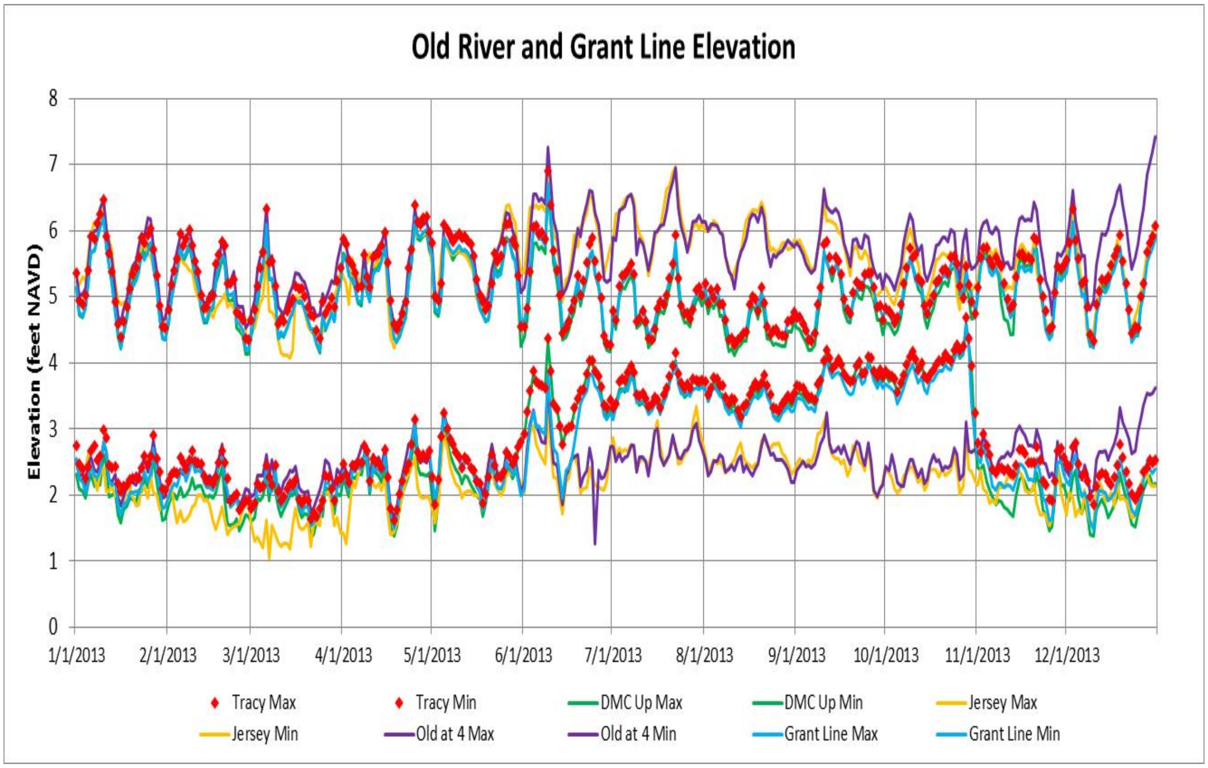


Figure 8e. Daily Minimum and Maximum Tide Elevations in Old River and Grant Line Canal at Several Locations Upstream and Downstream from the Temporary Barriers in 2013

Evaluation of Tidal Elevation, Tidal Flow, and EC Measurements in the South Delta in 2009–13

The historical tidal (15-minute) elevation, flow, and EC data provide a very accurate picture of salinity conditions in south Delta channels during relatively low flow conditions observed in 2009-10 and 2012–13, as well as during the high flow conditions observed in 2011 (e.g., Paradise Cut Weir spilled in April). The daily SJR flows and the daily CVP and SWP pumping (diversions) were integrated with the tidal elevations and flows in south Delta channels to evaluate the salinity (EC) measured at several locations in the south Delta. The primary focus for this study was to understand the higher salinity sources and tidal movement in the tidal sloughs and channels near the Old River at Tracy Boulevard EC monitoring station, because this EC compliance station often has measured the highest EC in the south Delta. Many other water management issues (e.g., effects of the temporary barriers, effects of CVP and SWP pumping) also can be investigated and evaluated with the extensive tidal elevation, flow, and EC data collected in south Delta channels (i.e., Data Atlas Files).

Because the tidal flows in south Delta channels are controlled by Pacific Ocean tidal elevations, which have substantial variations during the spring–neap (lunar month) tidal cycle, the daily average tidal flows (24-hour average) have a relatively large variation within each month. The daily average (net) flows in south Delta channels are the result of the SJR inflows and the CVP and SWP pumping; the daily average SJR flows and daily average channel flow diversions (e.g., SJR to the head of Old River, Old River to Middle River, Old River to Doughty Cut and Grant Line Canal) can be used to evaluate the salinity patterns in south Delta channels.

The tidal data for 2009–13 has been integrated and evaluated for this project. The method selected for the presentation of the tidal data and evaluation results was to prepare "Data Atlas" documents for each calendar year. The format for the data atlas documents is a combination of a graph with a brief descriptive text on each page. The 15-minute tidal data are shown with quarterly graphs (i.e., January to March, April to June, July to September, October to December), while daily data are shown with annual graphs. The seasonal patterns and deviations from expected patterns or relationship are described in paragraphs below each graph. The data analysis graphs were similar for each year, although some new data stations were added through time, so some of the data analysis graphs changed slightly for each year.

The following sections provide a summary of the general relationships and important results from the 5 years of tidal data analyses. The tidal flows and salinity patterns in south Delta channels are shown with example graphs from the data atlas documents. The major topics described and illustrated in this section include: 1) tidal flows and tidal flow volumes in south Delta channels; 2) effects of the temporary barriers on tidal elevations and tidal flows; and 3) effects of salt sources on south Delta channel salinity. A more thorough analysis and evaluation of the 2009–13 tidal data is provided in the graphs and paragraphs of data atlas documents.

The results from the data analyses of the 2009–13 measurements were used to identify several possible salinity-reduction alternatives that may be effective in reducing the elevated EC measurements in Old River at Tracy Boulevard. The last major section of this report presents a general description and preliminary feasibility comparison of these south Delta salinity-control alternatives.

Tidal Flows and Tidal Flow Volumes

The tidal flows in south Delta channels are controlled by the tidal elevation changes at the downstream end of each channel segment. As the water elevations rise (during flood-tide) in the Old and Middle River channels, water flows upstream to fill (to the high tide elevation) south Delta channels. As the water elevations decrease (during ebb- tide) in the Old and Middle River channels, water flows downstream to drain (to the minimum tide elevation) south Delta channels. Because two ebb-tide periods and two flood-tide periods generally occur each day, the tidal flows have been converted to cumulative tidal flow volumes for positive flows (during ebb-tide) and negative flows (during flood-tide). During periods with relatively low SJR flow and low CVP and SWP exports, the tidal flows are "balanced" and the daily flood-tide flow volumes entering a channel and the ebb- tide flow volumes leaving a channel are about the same. Agricultural diversions will cause a slight upstream net flow, and the CVP and SWP exports cause a larger net upstream flow that increases the flood-tide flow volumes and reduces the ebb-tide flow volumes. A large SJR flow causes a net downstream flow in Old River and Grant Line Canal, equal to about half of the SJR flow (diverted at the head of Old River), that increases the ebb-tide flows and decreases the flood-tide flows in these channels. Only if the CVP and SWP exports are less than the head of Old River flow diversion is the net flow positive in Old River, Victoria Canal, and the Middle River downstream from the exports (ebb-tide volume greater than flood-tide volume).

The tidal flows and tidal flow volumes at several of the tidal flow measurement stations are shown in this section to illustrate and summarize the measurements. The 15-minute tidal flows (cfs) were converted to volumes (af) and were summed for each tidal period (positive or negative flows). For reference, a flow of 1,000 cfs for 15 minutes would be about 20 af (volume). The ebb-tide volumes (positive) and flood-tide volumes (negative) were reset at the beginning of each day to show the daily (24-hour) flow volumes. The data atlas documents show the measured and calculated tidal flows and tidal flow volumes for the entire year (with four quarterly graphs). Examples of these graphs are shown in this section to describe the general results from the evaluation of the south Delta tidal flows.

Tidal Flows in Old River

Figure 9 shows the measured tidal flow volumes at the head of Old River (gold line), at Tracy Boulevard (red line), and at the DMC barrier (bright blue line) in April through June 2013 (with temporary barriers installed in June). The Head of Old River barrier was not installed in 2013. The head of Old River tidal flow volumes usually were positive (small reverse flows) and were about 1,000 af in early April (with two tidal flow periods each day), increased to about 5,000 af (one tidal flow period each day; no reverse flows) during the April to May pulse flow period, and were about 500 af (two tidal periods) in June. The Old River at the DMC barrier tidal flows showed the more typical pattern of two positive and two negative tidal volumes passing the station each day. During April and May (without the DMC barrier), the positive (downstream) tidal flow volumes ranged from 250 af to 1,000 af, while the negative (upstream) tidal volumes were more uniform and averaged about -500 af (two tidal flow periods each day). The Old River at the DMC barrier tidal flows were greatly reduced by the temporary barriers in June, with measured tidal flow volumes of about 25 percent of the tidal flow volume without barriers (125 af compared to 500 af). The measured Old River at Tracy tidal flow volumes were small (less than half) compared to the tidal flow volumes at the DMC barrier and were very small (less than 10 percent of the tidal flow volumes) at the head of Old River. In June with the temporary barriers installed, the tidal flows in Old River at Tracy Boulevard and at the DMC barrier were very small; this was caused by the temporary barriers blocking the majority of the flood-tide flows, which is further described in the next section.

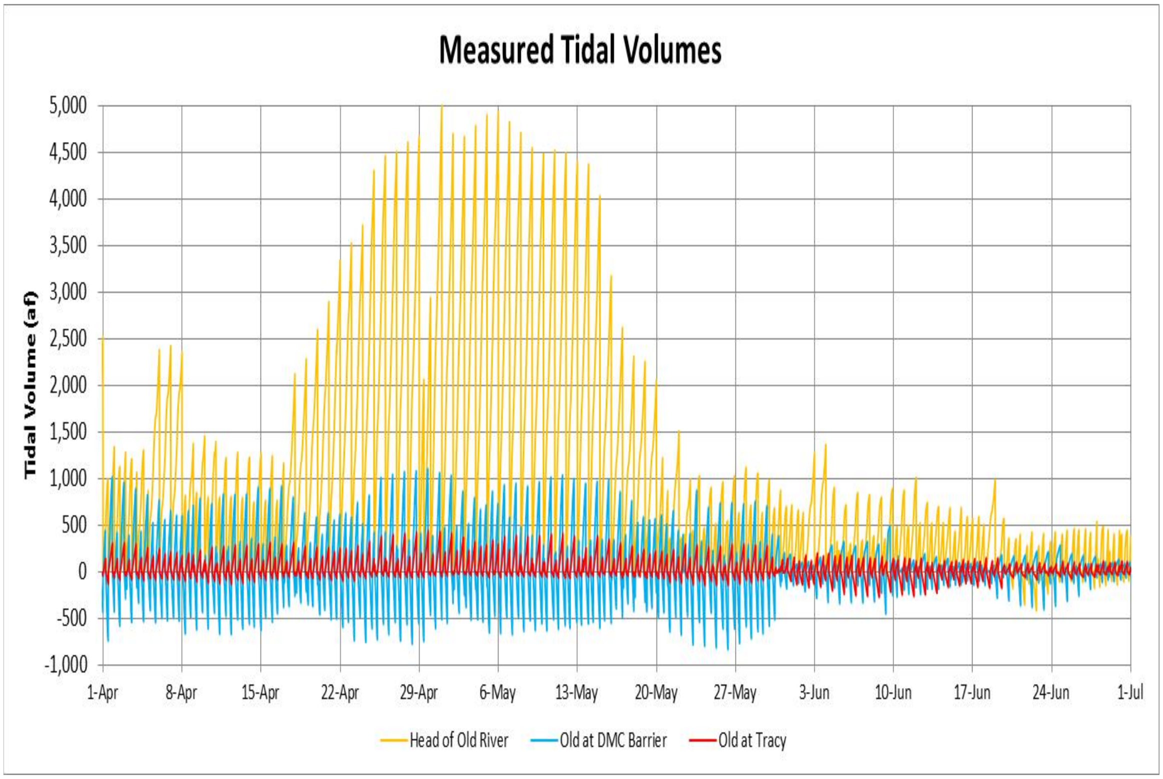


Figure 9. Measured Tidal Flow Volumes (af) in the Head of Old River, at Tracy Boulevard, and at the DMC barrier in April–June 2013

Where the tidal flows are not measured, the tidal flow volumes can be estimated from the measured change in tidal elevations at a location. Because the water elevations rise or fall uniformly in south Delta channels (flat water surface assumption), the tidal flow volume can be calculated as the change in water elevation times a specified upstream channel area that is filled or drained from this channel location. The net flow in the channel must be added to the ebb-tide and subtracted from the flood-tide flows. The estimated tidal flow volumes can be used to check (confirm) the measured tidal flow volumes. For example, at the Old River at the DMC barrier location, the flood-tide flow volume of -500 af in April and May (without barriers) corresponds to an upstream tidal area of about 250 acres, with an average flood-tide elevation change of 2 feet.

Figure 10 shows the measured tidal volumes in Old River at Tracy Boulevard (red line) compared to the calculated tidal volumes at Tracy Boulevard (green crosses) in January to March 2013 without temporary barriers (full tidal flows). The 15-minute tidal volumes were calculated as the measured change in elevation at Tracy Boulevard times an assumed upstream surface area of 50 acres (estimated by matching the measured tidal volumes), with a net downstream flow assumed to be 10 percent of the head of Old River flow:

Tidal volume (acre-feet) = -elevation change (feet) x area (acres) + net flow (cfs) * 900/43560

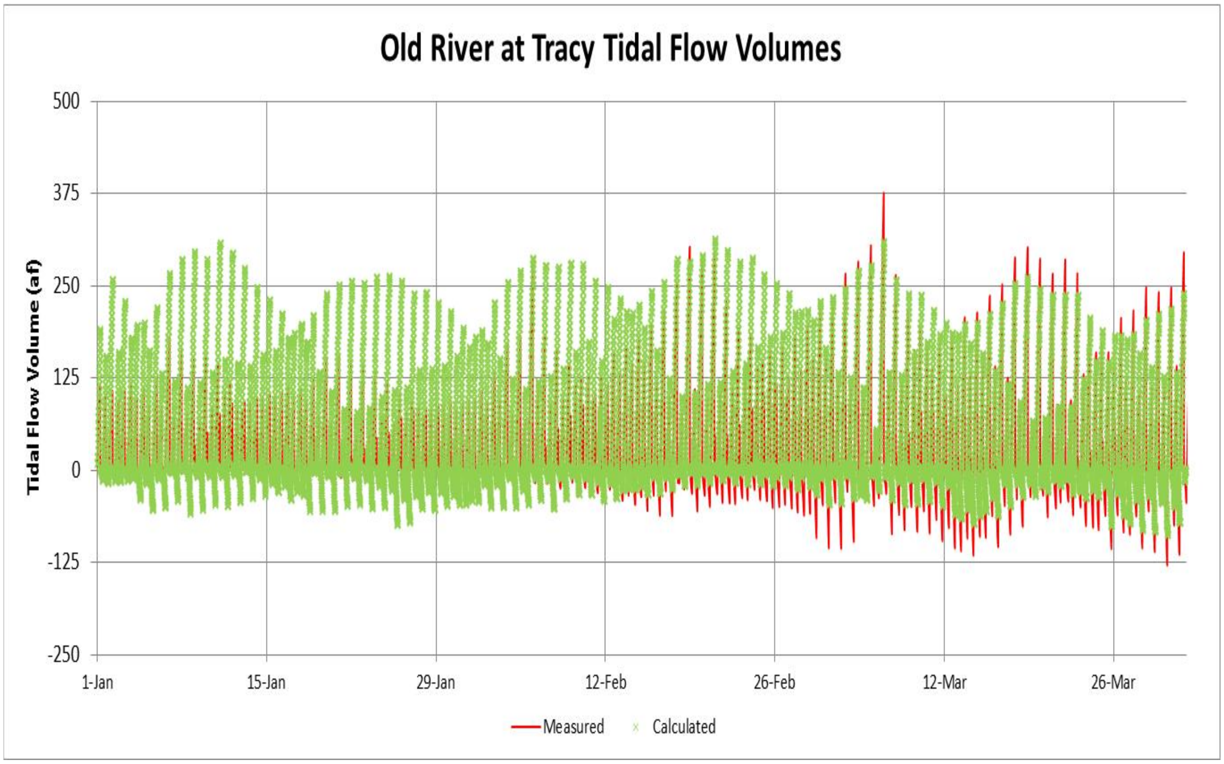


Figure 10. Measured and Calculated Tidal Flow Volumes in Old River at Tracy Boulevard in January–March 2013 (no temporary barriers)

An increased elevation (flood-tide) corresponds to a negative tidal volume while a reduced elevation (ebb-tide) corresponds to a positive tidal volume. The calculated tidal volumes generally matched the measured tidal volumes (particularly in February and March). The two flood-tide volumes each day were small and similar (-25 af to -50 af) while the two ebb-tide volumes were much larger and more variable (100 af to 300 af), with an average of about 200 af. The tidal flows in Old River at Tracy Boulevard were dominated by the ebb-tide flows in this period; very little upstream tidal volume (flood-tide) was measured at Tracy Boulevard. This suggests that most of the flood-tide flow to fill Paradise Cut, Sugar Cut, and the Old River channel upstream from Tracy Boulevard likely was supplied by the head of Old River flow or from flood-tide (upstream) flows in Grant Line Canal. However, most of the ebb-tide flow (with higher salinity) from Sugar Cut and Paradise Cut likely would flow downstream in Old River past Tracy Boulevard. The higher ebb-tide flows with lower flood-tide flows in Old River at Tracy Boulevard likely is the major tidal flow characteristic (feature) that causes most of the salt load from Sugar Cut and Paradise Cut to flow downstream in Old River and increase the EC at Tracy Boulevard.

Figure 11 shows the measured tidal volumes in Old River at the DMC barrier (red line) compared to the calculated tidal volumes (green crosses) in January to March 2013 without temporary barriers (full tidal flows). The 15-minute tidal volumes were calculated as the measured change in elevation at the DMC barrier times an assumed (adjusted) upstream surface area of 250 acres (200 acres more than for the Tracy Boulevard station), with a net downstream flow assumed to be 10 percent of the head of Old River flow. The calculated tidal volumes matched the measured tidal volumes and indicated that the two flood-tide volumes each day were similar (an average of about -500 af), and the two ebb-tide volumes were more variable (250 af to 1,000 af), with an average of about 600 af. Because the surface area of the Old River channel between the DMC barrier and Tracy Boulevard is about 250 acres (DSM2 geometry file), the flood-tide flows in Old River at the DMC barrier do not provide enough water to fill Old River upstream from Tracy Boulevard (or Sugar Cut and Paradise Cut); these channels likely are filled with the head of Old River flow or with tidal flows from Grant Line Canal.

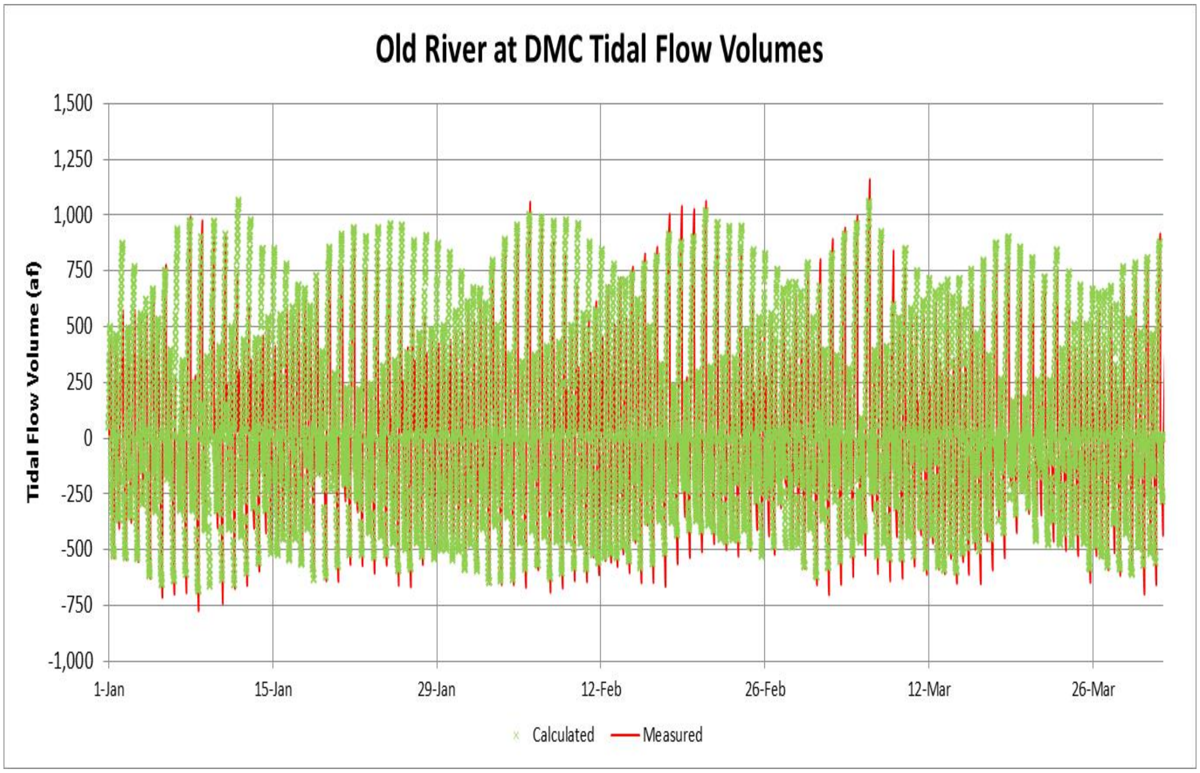


Figure 11. Measured and Calculated Tidal Flow Volumes in Old River at the DMC Barrier in January–March 2013 (no temporary barriers)

Figure 12 shows the measured and calculated tidal volumes in Old River at the DMC barrier in July to September 2013, when the temporary barriers were installed. The measured flood-tide volumes moving through the culverts or over the barrier crest were less than 250 af, and the measured ebb-tide volumes moving over the crest (but not through the culverts with flap gates) also were less than 250 af; therefore, the net flow in Old River at the DMC barrier was small. The Old River at DMC temporary barrier generally reduced the tidal volumes to less than half of the full tidal flow volumes of about 500 af. The small net flow at the DMC barrier was likely upstream, because agricultural diversions between Tracy Boulevard and the DMC barrier were greater than the net flow at Tracy Boulevard (assumed to be 10 percent of the Head of Old River flow).

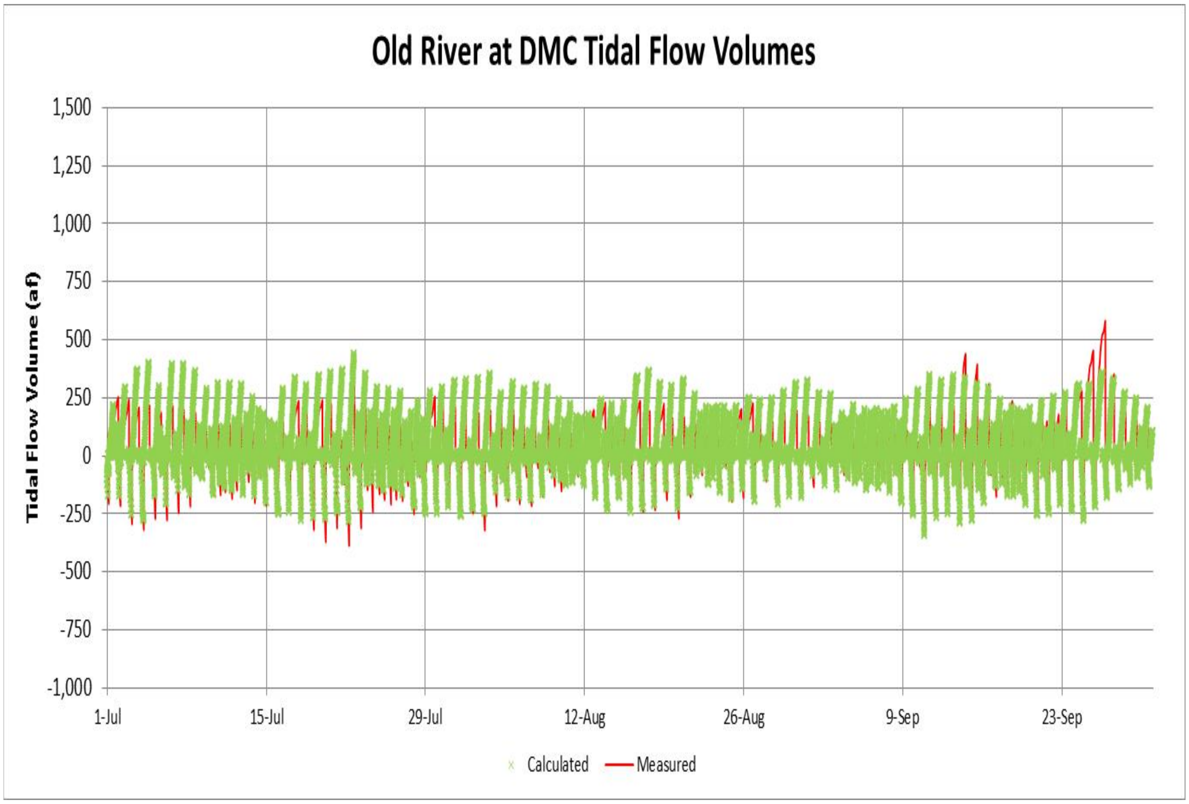


Figure 12. Measured and Calculated Tidal Flow Volumes in Old River at the DMC barrier in July–September 2013 (with temporary barriers)

Tidal Flows in Paradise Cut and Sugar Cut

The tidal flows in Paradise Cut and Sugar Cut were estimated by the tidal elevations and the upstream area in each tidal slough. Tidal flows in Sugar Cut also were influenced by the diversions for irrigation water at the Tom Paine Slough diversion dam (flap gate culverts and siphons) during the irrigation season (March to October). Figure 13 shows the calculated tidal volumes in Paradise Cut and Sugar Cut in April to June 2013. The assumed surface area for Paradise Cut was about 170 acres, and the assumed surface area for Sugar Cut was about 55 acres. With an average tidal elevation change of 2 feet, the flood tide flow volumes (two each day) were about 340 af for Paradise Cut and about 110 af for Sugar Cut. The average flood tide volume was equal to the average ebb-tide volume for Paradise Cut, but the average flood tide volume was about 150 af greater than the average ebb-tide volume for Sugar Cut because of the irrigation diversion of about 75 cfs to Tom Paine Slough. The tidal volumes were reduced considerably (smaller range of tidal elevations) by the temporary barriers that were installed in June.

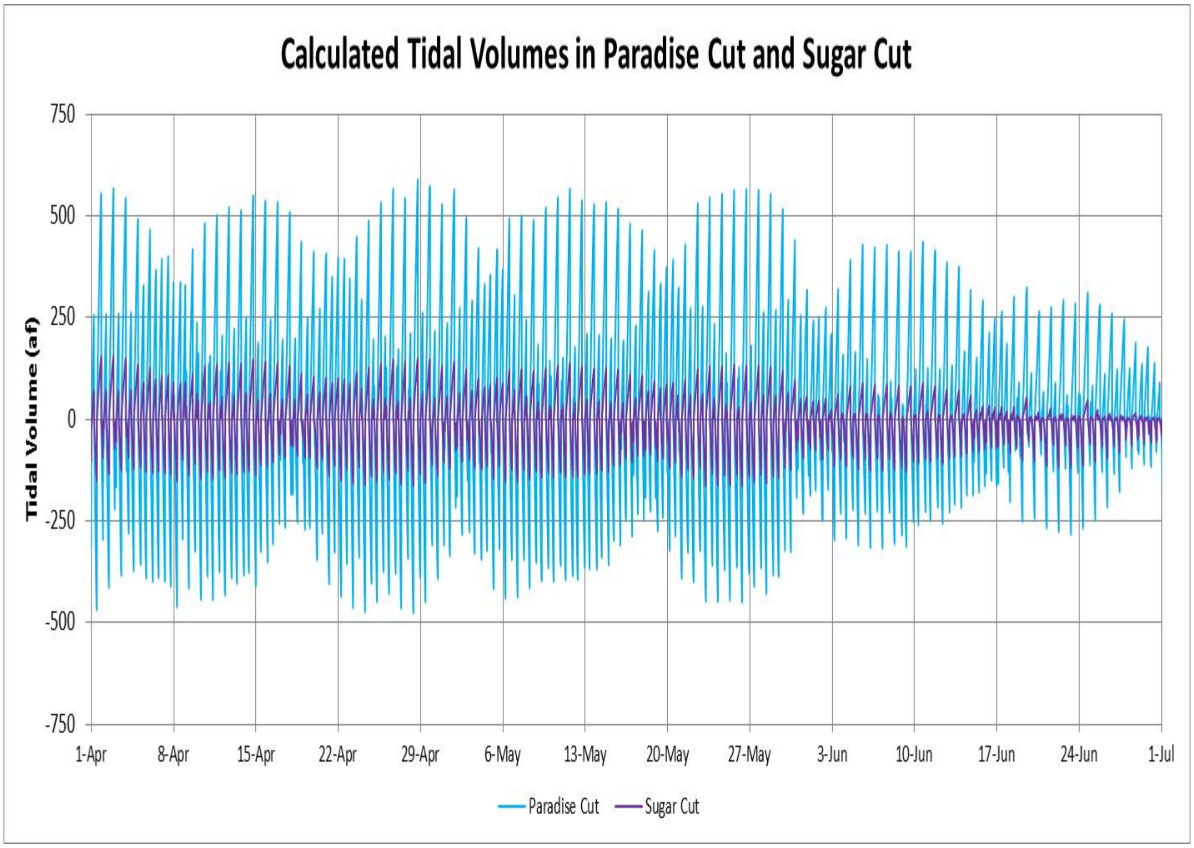


Figure 13. Measured and Estimated Tidal Flow Volumes in Old River at the DMC barrier in April–June 2013

Tidal Flows in Grant Line Canal

Figure 14a shows the measured tidal volumes in Grant Line Canal upstream from the barrier at the east end (red line) compared to the calculated tidal volumes (green crosses) in January to March 2013. The upstream surface area was 500 acres (adjusted to match the measured flood tide volume), and the net flow was assumed to be 85 percent of the head of Old River flow. The calculated tidal volumes generally matched the measured tidal volumes, with the net flow dominating the tidal flows. The flood-tide volumes (two each day) varied from about -125 af to -625 af, with an average of about -250 af. The ebb-tide volumes (two each day) varied from about 750 af to 2,500 af, with an average of about 1,750 af. The average net flow in January to March 2013 was about 1,500 cfs (3,000 af per day, 750 af per tidal period); therefore, the full tidal volumes without any net flow would be about 1,000 af per tidal period, corresponding to the assumed upstream area of 500 acres with an average elevation change of about 2 feet.

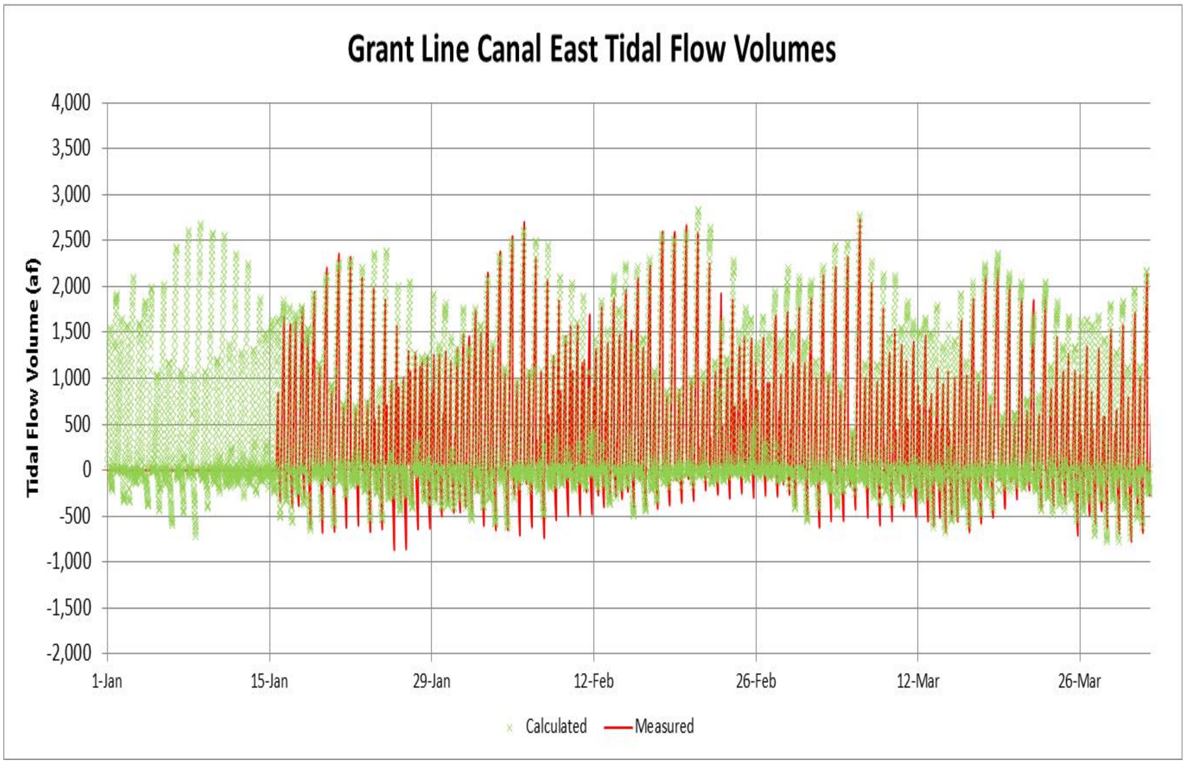


Figure 14a. Measured and Estimated Tidal Flow Volumes at the East End of Grant Line Canal (Tracy Boulevard) in January–March 2013 (no temporary barriers)

Figure 14b shows that the tidal volumes in Grant Line Canal upstream from the barrier at the east end were reduced considerably in July to September 2013, when the temporary barriers were installed. The measured and calculated flood-tide volumes moving through the culverts or over the barrier crest averaged about -250 af, while the measured and calculated ebb-tide volumes moving over the barrier weir crest averaged about 750 af. The Grant Line Canal barrier increased the minimum tidal elevations but reduced the tidal elevation range, and thereby reduced the tidal flows upstream from the barrier. The assumed upstream area of 500 acres provided a good match with the measured tidal volumes, indicating that the reduced tidal elevation range accounted for the reduced tidal flows. The Grant Line Canal temporary barrier blocked the flood-tide until the elevation reached the weir crest (3.5 feet NAVD), but flows over the weir crest were sufficient to fill the same upstream area (although the maximum tide elevations were reduced). Tidal filling of the Old River channel upstream from Doughty Cut, as well as Paradise Cut and Sugar Cut, likely originated from the head of Old River and from Grant Line Canal (during flood-tide periods), and not from Old River at Tracy Boulevard. But some ebb-tide flows from Sugar Cut and Paradise Cut likely moved downstream in Old River to Tracy Boulevard, increasing the EC at Tracy Boulevard. The temporary barriers did not appear to change this tidal flow pattern of filling from Grant Line Canal but draining to Old River at Tracy Boulevard.

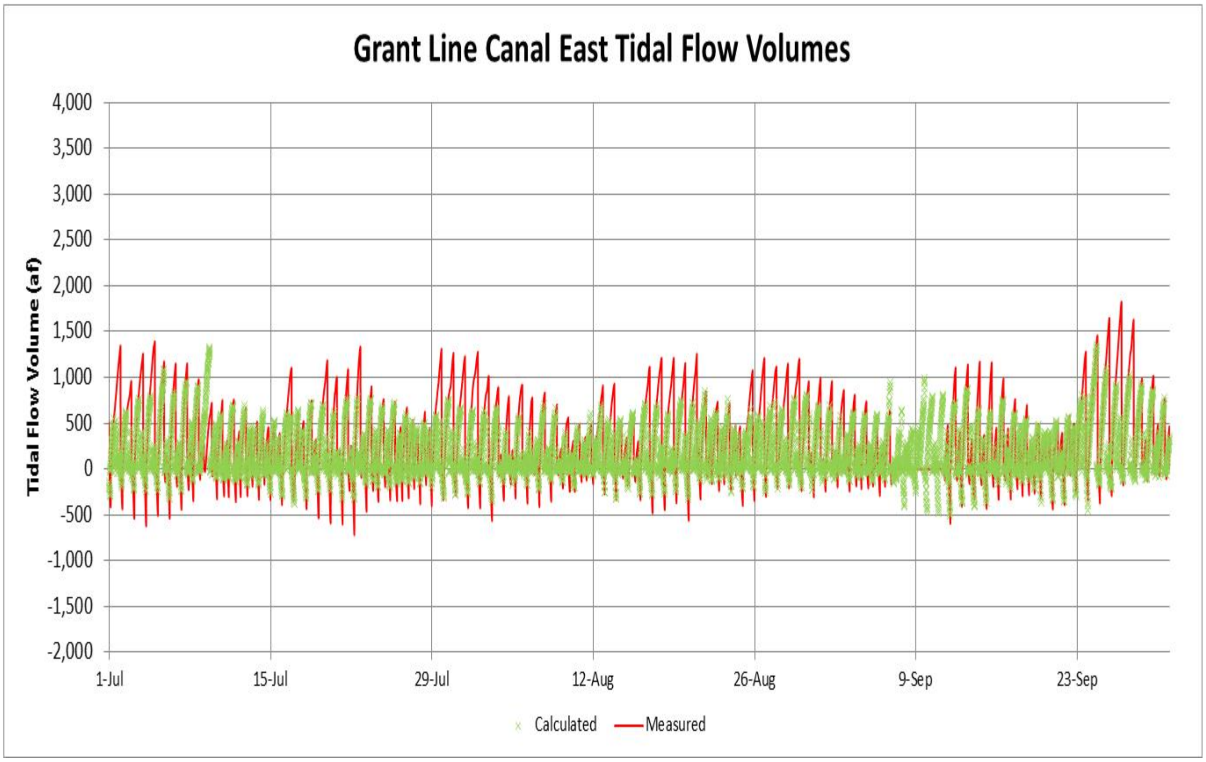


Figure 14b. Measured and Estimated Tidal Flow Volumes at the East End of Grant Line Canal (Tracy Boulevard) in July–September 2013 (with temporary barriers)

Figure 15 shows the calculated tidal volumes in Grant Line Canal at the west end (green crosses) generally matched the measured tidal volumes (red line) in January to March 2013 without temporary barriers (full tidal flows). The assumed (adjusted) upstream surface area was 750 acres and the net flow was assumed to be 85 percent of the head of Old River flow. The surface area of Grant Line Canal and Doughty Cut is about 375 acres, the surface area of Old River upstream from Doughty Cut is about 200 acres, the surface area of Paradise Cut is about 175 acres, and the surface area of Sugar Cut is about 50 acres (total of 800 acres). The calculated tidal volumes generally matched the measured tidal volumes; the flood-tide volumes (two each day) varied from about -500 to -1,500 af, with an average of about -750 af. The ebb-tide volumes (two each day) varied from about 1,000 to 4,000 af, with an average of about 2,250 af. The average net flow in January to March 2013 was about 1,500 cfs (3,000 af per day). About 25 percent of this net flow volume (750 af) was added to each ebb-tide and each (negative) flood-tide volume. Therefore, the full tidal flow volumes without any net downstream flow would be about 1,500 af (ebb-tide and flood-tide) with an average elevation change of 2 feet. The tidal flows at the west end of Grant Line Canal were not appreciably different with the barriers installed, because the tidal elevations at the west end of Grant Line Canal were not changed appreciably (although the flows over the Grant Line Canal barrier were reduced by 25-50 percent because the maximum elevations upstream from the barriers were reduced by 0.5 to 1.0 feet).

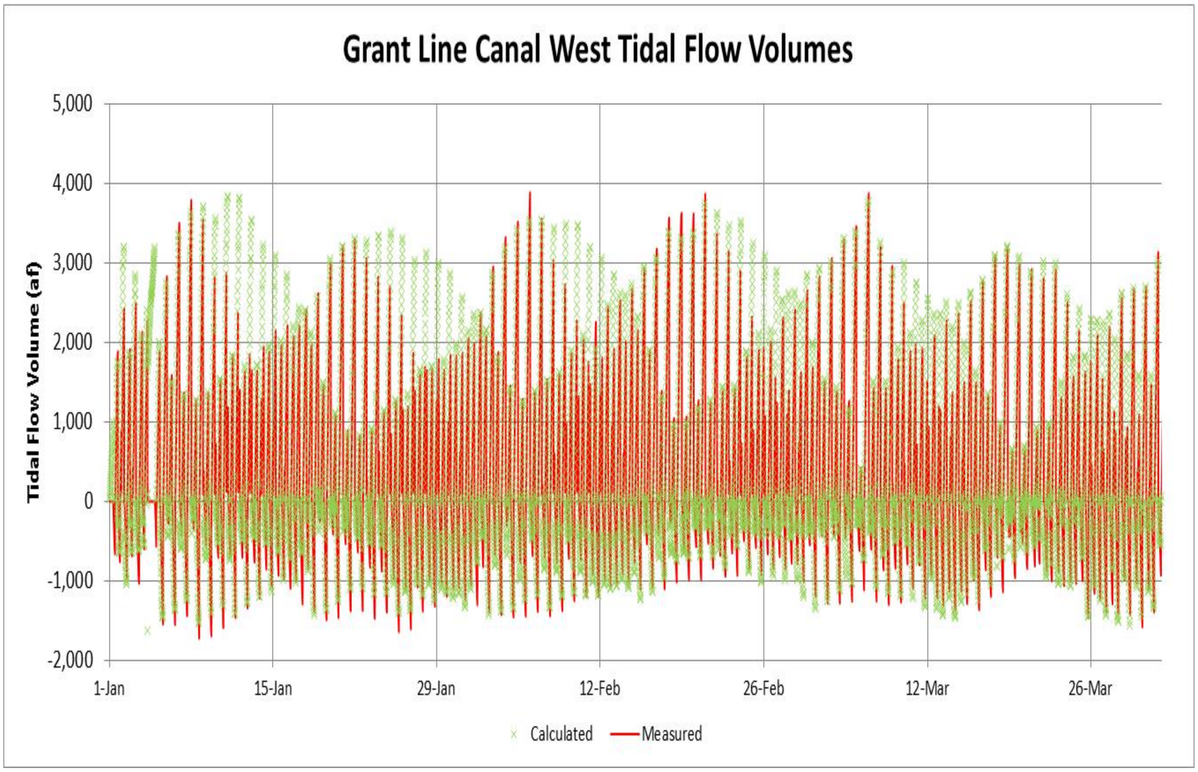


Figure 15. Measured and Estimated Tidal Flow Volumes at the West End of Grant Line Canal (near mouth) in January–March 2013 (no temprary barriers)

Tidal Flows in Middle River

Figure 16a shows the measured tidal volumes in the upstream end of the Middle River (near the head of Middle River) at Undine Road (red line) compared to the calculated tidal volumes (green crosses) in January to March 2013. The upstream tidal area was estimated to be 20 acres (adjusted to match the measured flood tide volume) and the net flow was estimated to be 3 percent of the head of Old River flow (by matching the measured flows). The calculated flood-tide volumes matched the measured flood-tide volumes, but the calculated ebb-tide volumes were somewhat higher than the measured ebb-tide volumes, with the ebb-tide flow (net flow direction) dominating the tidal flows. The flood-tide volumes (two each day) were about -10 to -20 af. The ebb-tide volumes (two each day) varied from about 25 to 50 af.

Figure 16b shows the measured tidal volumes in the upstream end of the Middle River (near the head of Middle River) at Undine Road (red line) compared to the calculated tidal volumes (green crosses) in April to June 2013. The upstream tidal area was estimated to be 20 acres (adjusted to match the measured flood tide volume) and the net flow was assumed to be 3 percent of the head of Old River flow. The calculated flood-tide volumes were greater than the measured flood-tide volumes in these months; the irrigation diversions along the Middle River were likely causing a greater net flow into the Middle River from Old River. The calculated ebb-tide volumes of about 100 af per day in April and May generally matched the measured ebb-tide volumes, but the net downstream flow (with irrigation diversions) in June was higher than the calculated ebb-tide flows. The tidal flows in the Middle River at Undine Road were relatively small compared to other south Delta tidal flows.

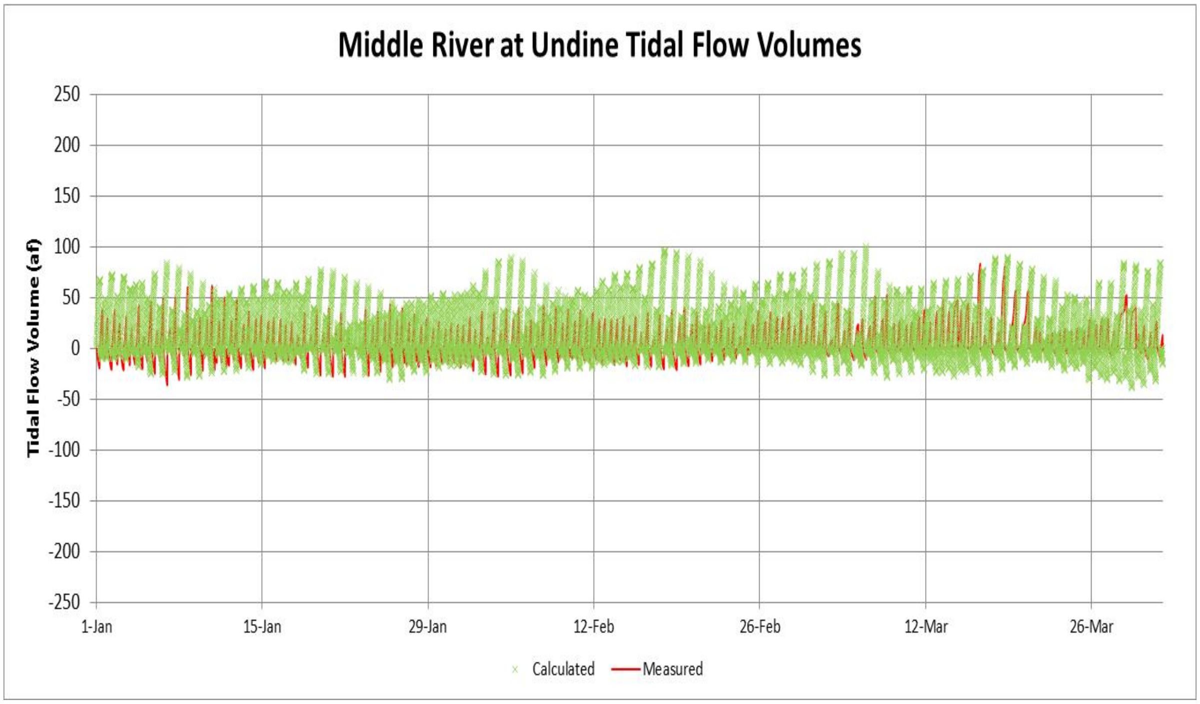


Figure 16a. Estimated Tidal Flow Volumes in Middle River at Undine Road (upstream end) assuming 20 acres of upstream tidal area and 3 percent of the Head of Old River flow in January–March 2013 (no temporary barriers)

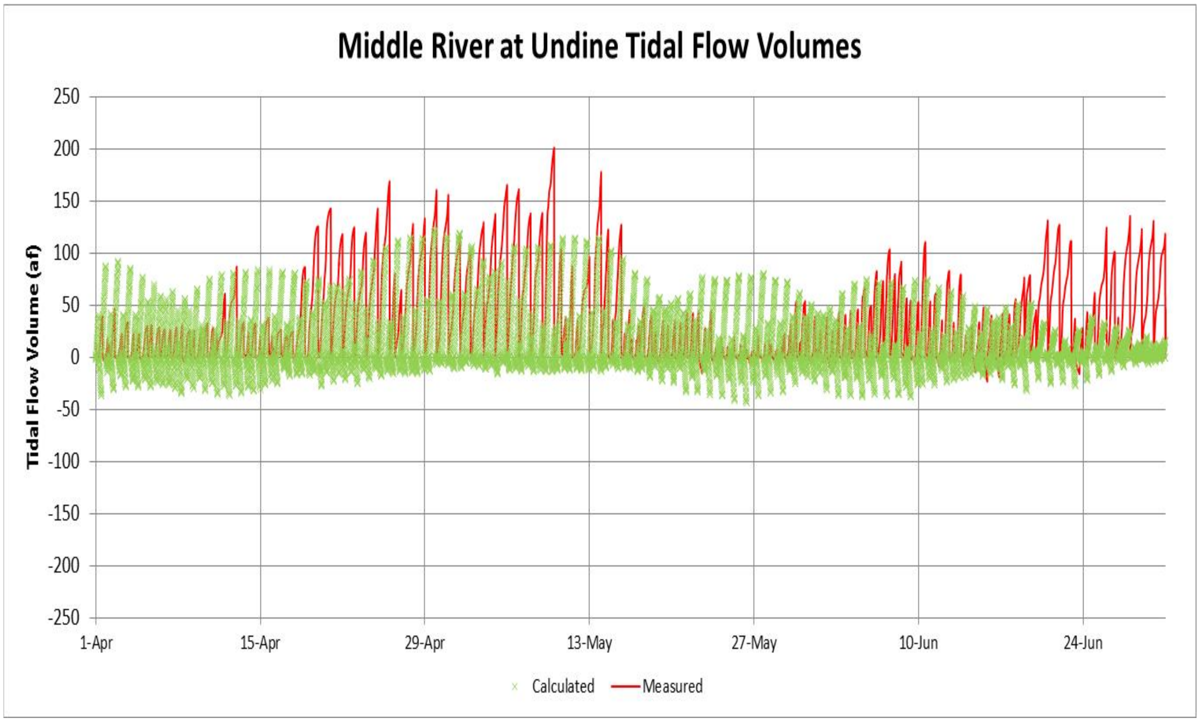


Figure 16b. Estimated Tidal Flow Volumes in Middle River at Undine Road (upstream end) assuming 20 acres of upstream tidal area and 3 percent of the Head of Old River flow in April–June 2013 (temporary barriers in June)

Figure 17a shows the calculated tidal volumes in Middle River at the temporary barrier location (between Tracy Boulevard and Victoria Canal) in April to June 2013. The Middle River temporary barrier was installed in mid-May with the culverts open (for fish passage). The culverts were closed in early July 2013. The net flow was assumed to be 0 cfs and the upstream area was estimated to be 150 acres based on the Middle River surface area upstream from the barrier (DSM2 geometry file). No flow measurements were taken in Middle River near the temporary barrier location in 2009–13 (a flow meter was installed in January 2014). The calculated flood-tide volumes (two each day) were about -200 to -400 af (average of -300 af). The calculated ebb-tide volumes (two each day) also varied from about 200 to 400 af because the net flow was assumed to be 0 cfs.

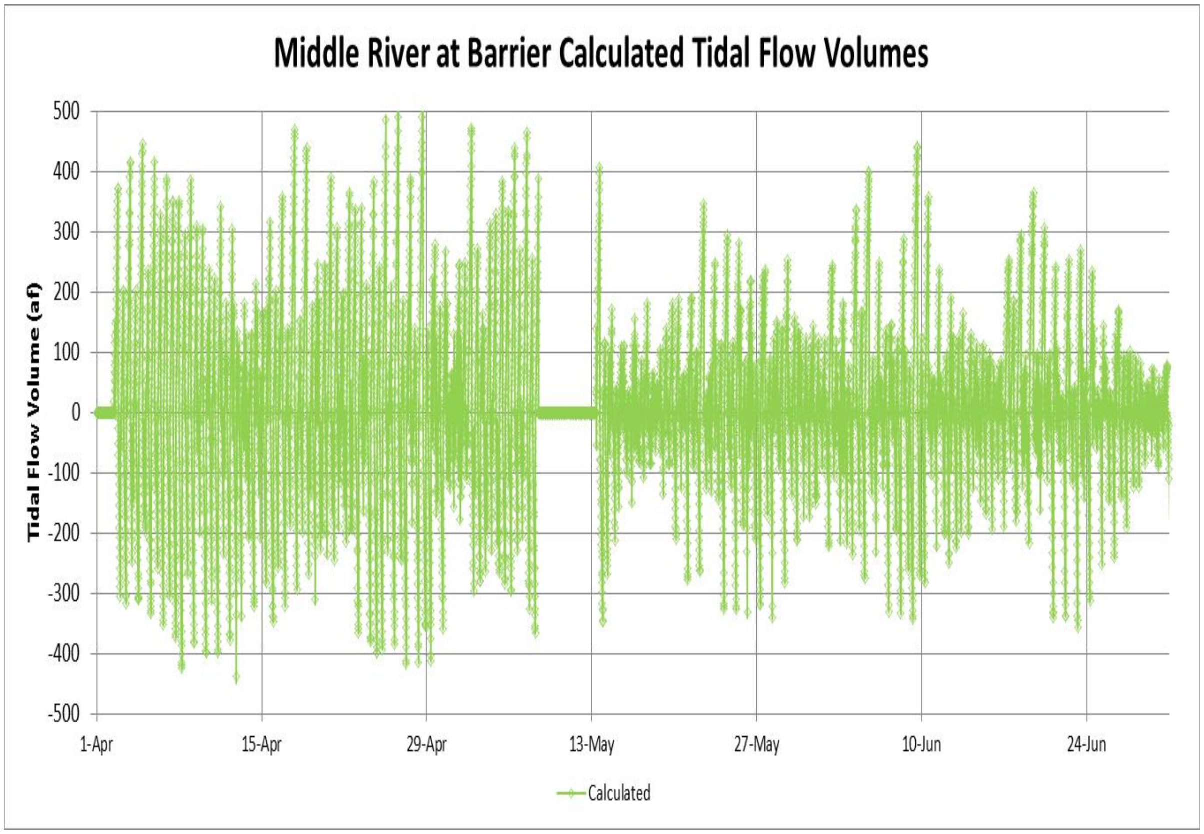


Figure 17a. Estimated Tidal Flow Volumes in Middle River at the Temporary Barrier Location (near Victoria Canal) assuming 150 acres of upstream tidal area and no net flow in April–June 2013 (temporary barrier installed in mid-May with culverts open)

Figure 17b shows the calculated tidal volumes in the Middle River at the temporary barrier location in July to September 2013. The Middle River temporary barrier culverts were closed in early July. The net flow was assumed to be 0 cfs and the upstream area was estimated to be 150 acres. The temporary barrier reduced the tidal range and tidal flow volumes upstream of the barrier considerably. The calculated flood-tide volumes (two each day) were about -50 to -300 af (average of -150 af). The calculated ebb-tide volumes (two each day) also varied from about 50 to 300 af, with an average of 150 af, because the net flow was assumed to be 0 cfs. The Middle River temporary barrier reduced the tidal volumes to less than 50 percent of the full tidal volumes, just as was observed at the other temporary barrier locations.

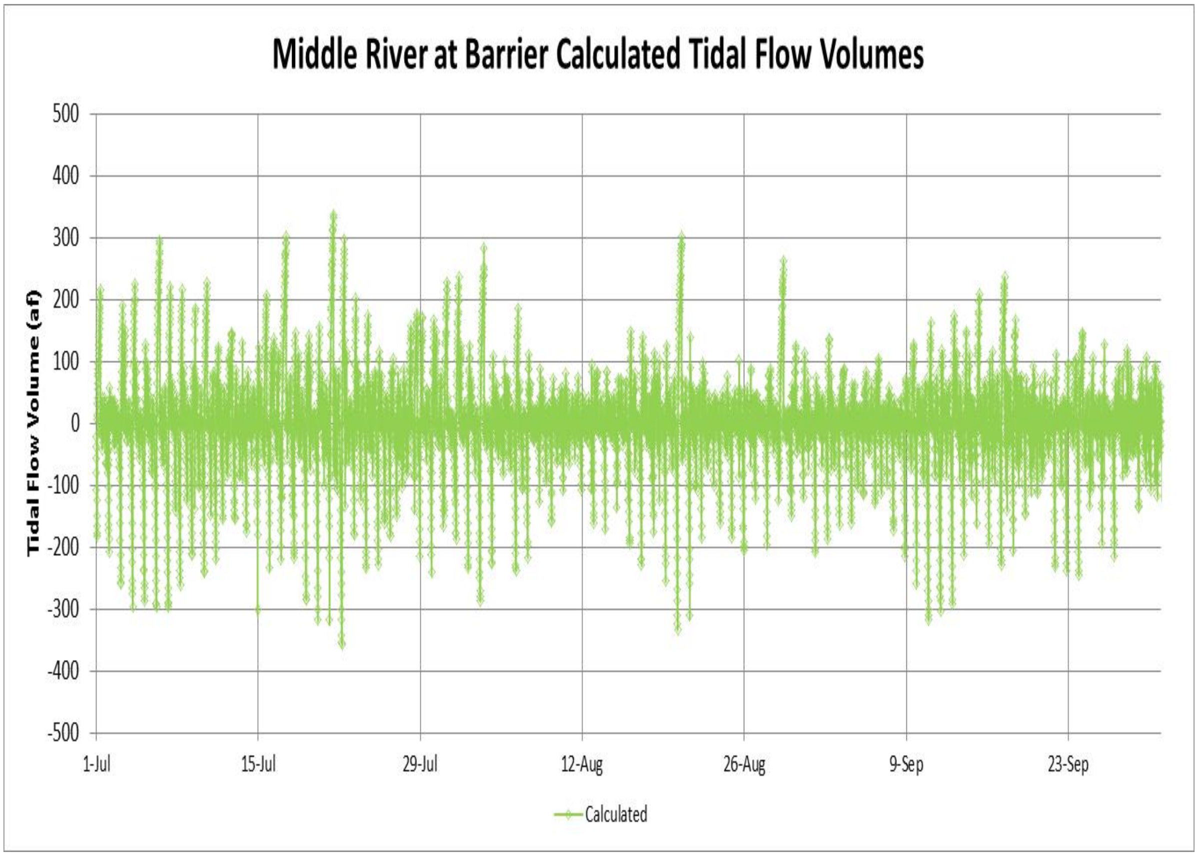


Figure 17b. Estimated Tidal Flow Volumes in Middle River at the Temporary Barrier Location (near Victoria Canal) assuming 150 acres of upstream tidal area and no net flow in July–September 2013 (temporary barrier with culverts closed)

Tidal Flows in Old River and Middle River at Bacon Island

Figure 18 shows the measured and calculated tidal volumes in Old River at Bacon Island in January to March 2013. The total surface area of all channels south of the Old and Middle River tidal flow stations was about 3,750 acres (DSM2 geometry file). The upstream tidal area of 1,750 acres was adjusted to match the measured tidal volumes, with a net upstream flow of about half the combined CVP and SWP exports. In January to March 2013, the export pumping was about 5,000 cfs and the head of Old River flow was about 1,500 cfs, and thus the net upstream flow in Old River and Middle River was about -3,500 cfs. The net flow in Old River was estimated to be -1,750 cfs. The calculated tidal volumes matched the measured tidal volumes throughout each month; variations from the spring-neap tidal cycle were well-matched because the measured tidal elevations reflected these lunar-cycle variations. Because water elevations are much easier to measure than tidal flows, these calculated tidal volumes (based on the tidal elevations, specified tidal area, and specified daily net flow) provide accurate estimates of the Old River at Bacon Island tidal volumes and can be used to verify the measured tidal volumes (or fill missing tidal flow records).

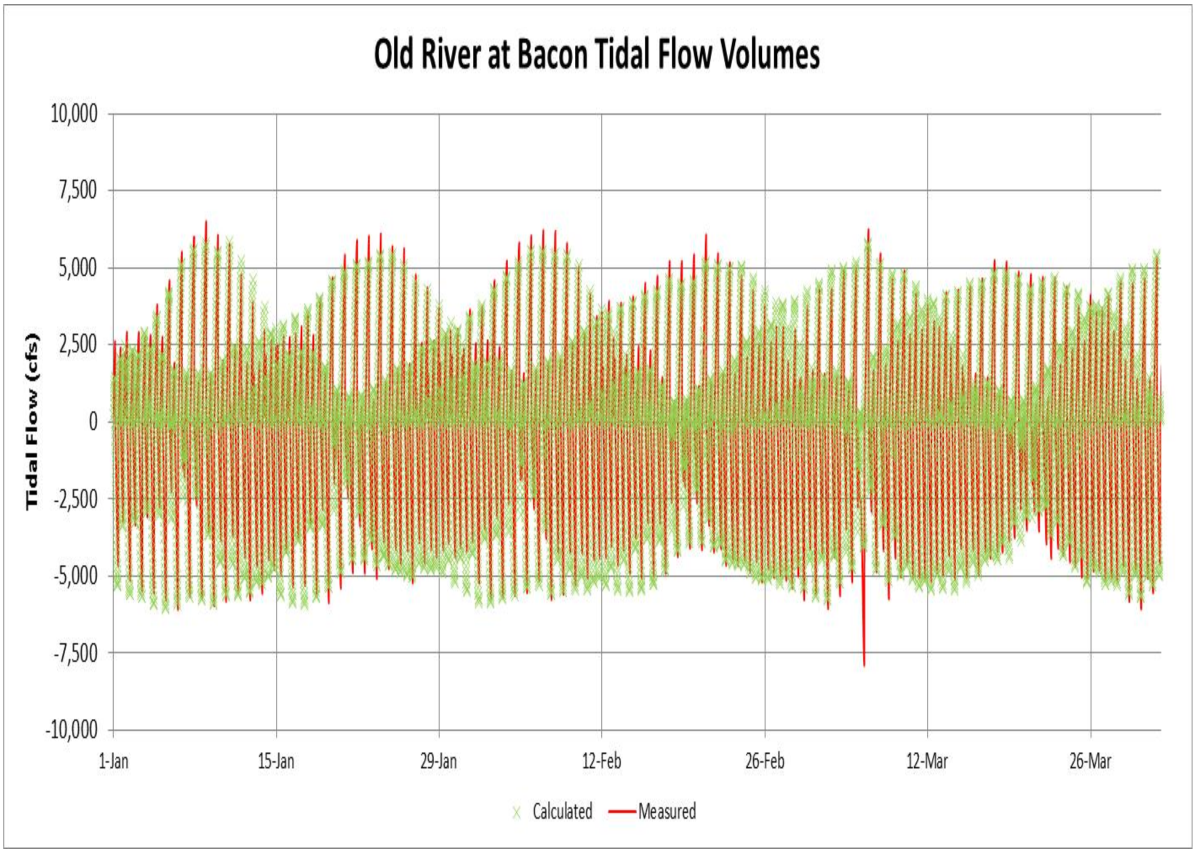


Figure 18. Measured and Estimated Tidal Flow Volumes in Old River at Bacon Island in January–March 2013

Figure 19 shows the measured and calculated tidal volumes in the Middle River at Bacon Island in January to March 2013. The upstream surface area of 2,000 acres was adjusted to match the measured tidal volumes, with a net upstream flow of about half the CVP and SWP exports. In January to March 2013, the net flow in Middle River was estimated to be -1,750 cfs. Most of the tidal flows entering or leaving the south Delta are measured at the Old River at Bacon and Middle River at Bacon flow stations, with some tidal flow in Rock Slough and Indian Slough (connect with Old River). Tidal flows are caused by changes in tidal elevations at these downstream stations and can be reliably estimated from the measured tidal elevations and the estimated upstream tidal area.

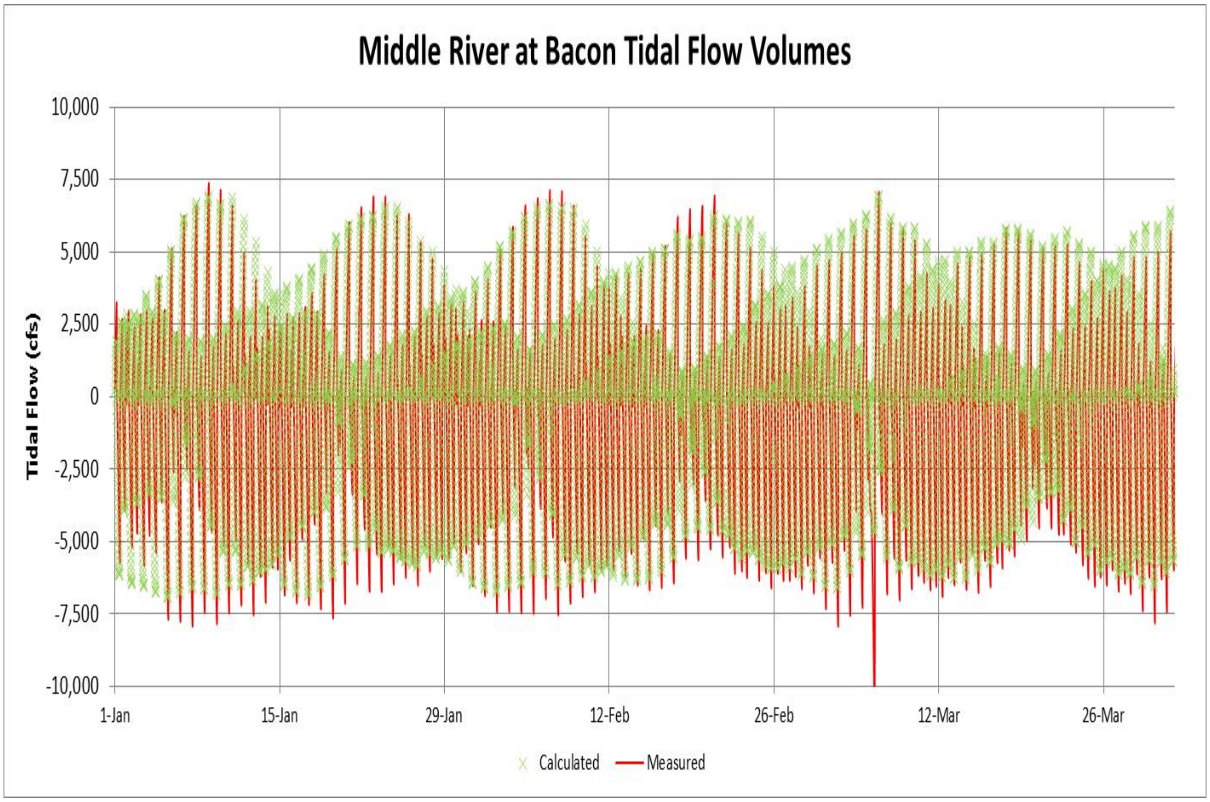


Figure 19. Measured and Estimated Tidal Flow Volumes in Middle River at Bacon Island in January–March 2013

Effects of the Temporary Barriers on Tidal Elevations and Tidal Flows

The measured effects of the temporary barriers on tidal elevations and tidal flows already have been shown in the comparison of tidal flows in Middle River, Grant Line Canal, and Old River at the barriers in the January to March period (without barriers) and the July to September period (with barriers). The purpose of the temporary barriers was to increase the minimum water elevations to allow water diversions (e.g., siphons and pumps with relatively shallow intakes) to operate without interruption at low tide. Because the three agricultural temporary (rock) barriers have similar designs with a weir crest of 3.5 or 4.5 feet NAVD, the effects on the upstream tidal elevations were similar; the minimum elevations were increased by 1.0 to 1.5 feet and the maximum elevations were reduced by about 0.5 to 1.0 feet. This reduced the full tidal range from about 4 feet to about 2 feet, and thereby reduced the tidal flows and tidal volumes by about 50 percent. Tidal flushing (water movement) in Old River and Middle River upstream from the temporary barriers was substantially reduced. For example, the Old River at DMC flood-tide volumes were about 500 af without the barrier and were reduced to less than 250 af with the barrier. The channel volume of Old River at high tide was about 250 af per mile, so full tidal flushing (movement) of water from downstream of the DMC (with generally lower EC) extended upstream about 2 miles without the barrier, but extended upstream about 1 mile with the temporary barrier installed.

A similar reduction in the tidal range and tidal flushing of Middle River upstream from the barrier would likely occur when the Middle River temporary barrier was installed. The calculated flood-tide volume of about 250 af would likely be reduced to about 125 af with the barriers (tidal flow measurements began in 2014 at the Middle River barrier location). Measured tidal flows at each south Delta barrier were used to confirm the calculated tidal flows and evaluate the likely effects of different weir crest elevations or different culverts and flap gates. Some of the salinity reduction alternatives would include changes in the temporary barrier configuration and/or operation. Evaluating the effects of changes in these tidal flows on EC in the south Delta channels (EC in Old River at Tracy Boulevard in particular) is more complicated, because the salt sources and the differences between the SJR EC and Old River EC and Middle River EC are also important factors. Before alternatives for reducing the EC in Old River at Tracy Boulevard are considered, the effects of the temporary barriers on tidal flows and water movement in the south Delta channels will be calculated and compared to tidal elevation and tidal flow measurements.

Tom Paine Slough Diversion Dam

The calculated irrigation diversions at the Tom Paine Slough diversion dam (with culverts and siphons with flap gates) are shown in comparison with the tidal elevations upstream and downstream from the barrier. The tidal flows through the culverts and siphons are controlled by the water elevation difference. During the irrigation season the flap gates are operating and flow is upstream (negative). Both the culverts and the siphons have hydraulic flow equations that vary with the square-root of the elevation difference. The combined flow of the two 4-foot by 4-foot box culverts and the four 36-inch-diameter siphons were calculated (when the downstream elevation was greater than the upstream elevation) as:

Tom Paine Slough diversion flow (cfs) = 300 x elevation difference (feet) ^ 0.5

The Tom Paine Slough diversion flow would be about 300 cfs (estimated from previous field measurements) with an elevation difference of 1 foot, would be 212 cfs with an elevation difference of 0.5 foot, and would be 150 cfs with an elevation difference of 0.25 foot. These calculated culvert and siphon flows were calibrated to match field measurements at a range of elevation differences (KSN 2013).

Figure 20a shows the elevations and estimated tidal diversions (with flap gates) in April to June 2013 before the temporary barriers were installed in the south Delta channels. The maximum calculated diversions were 250 to 350 cfs, with an average daily diversion of about 100 to 150 cfs. Figure 20b shows the elevations and estimated tidal diversions (with flap gates) in July to September 2013, when the temporary barriers were installed. The reduced tidal range (i.e., reduced high tides) reduced the maximum calculated diversions. The maximum diversions were reduced to about 200 to 250 cfs, although the average daily diversions remained about 100 cfs because the siphons and culverts were open more of the time. The water elevations in Tom Paine Slough generally were maintained at about 4 feet NAVD to allow water to be pumped from the upstream end of Tom Paine Slough. The diversions would be higher if the upstream water elevation (in Tom Paine Slough) could be reduced to 3 feet NAVD (would likely require dredging of Tom Paine Slough).

The effects of this large diversion from Sugar Cut (just downstream of the EC measurement station) on the portion of the salt source from the upstream end of Sugar Cut (i.e., Arbor Road Drain) reaching Old River at Tracy Boulevard will be discussed later; the agricultural diversion to Tom Paine Slough is much larger than the high salinity inflow to the upstream end of Sugar Cut, and most of the salt source is likely diverted to Tom Paine Slough during the irrigation season.

Old River at DMC Barrier

Calculated flows in Old River at the DMC temporary barrier were based on the measured elevations (upstream and downstream from the barrier), the weir crest geometry and the nine culverts with flap gates. The 4-feet diameter culverts each allowed a flow of about 50 cfs (based on tidal flow measurements), with an elevation difference of 1 foot. The upstream (negative) flow through the nine culverts (with flap gates) and leakage through the rock barrier (assumed to be 150 cfs for an elevation difference of 1 foot) was estimated whenever the downstream elevation was higher than the upstream elevation as:

Upstream culvert flow (cfs) = 600 x (upstream elevation – downstream elevation) ^ 0.5

The flap gates blocked downstream (positive) flow through the culverts when the upstream elevation was higher than the downstream elevation, but downstream seepage flow would occur. If the flap gates were left open, the downstream flow would increase by 50 cfs for each open culvert (with an elevation difference of 1 foot). The downstream (positive) leakage flow was estimated as:

Downstream seepage flow (cfs) = 150 x (upstream elevation – downstream elevation) ^ 0.5

The flow over the barrier crest was more difficult to estimate because the velocity over the barrier crest (4.4 feet NAVD) is controlled by the depth and the local water slope (unknown). The barrier crest flow was assumed to be similar to flow over a weir (i.e., weir flow = C x width x weir water depth ^ 1.5) with C estimated as 2 (calibrated to match the measured DMC barrier flow). The weir crest flow is positive if the upstream elevation is higher than the downstream elevation, and is negative if the downstream elevation is higher than the upstream elevation. The DMC barrier crest flow (width of 75 feet) when the upstream elevation was higher than the downstream elevation was calculated as:

Barrier crest flow = net flow + 2 x 75 x (upstream water elevation – crest elevation) ^ 1.5

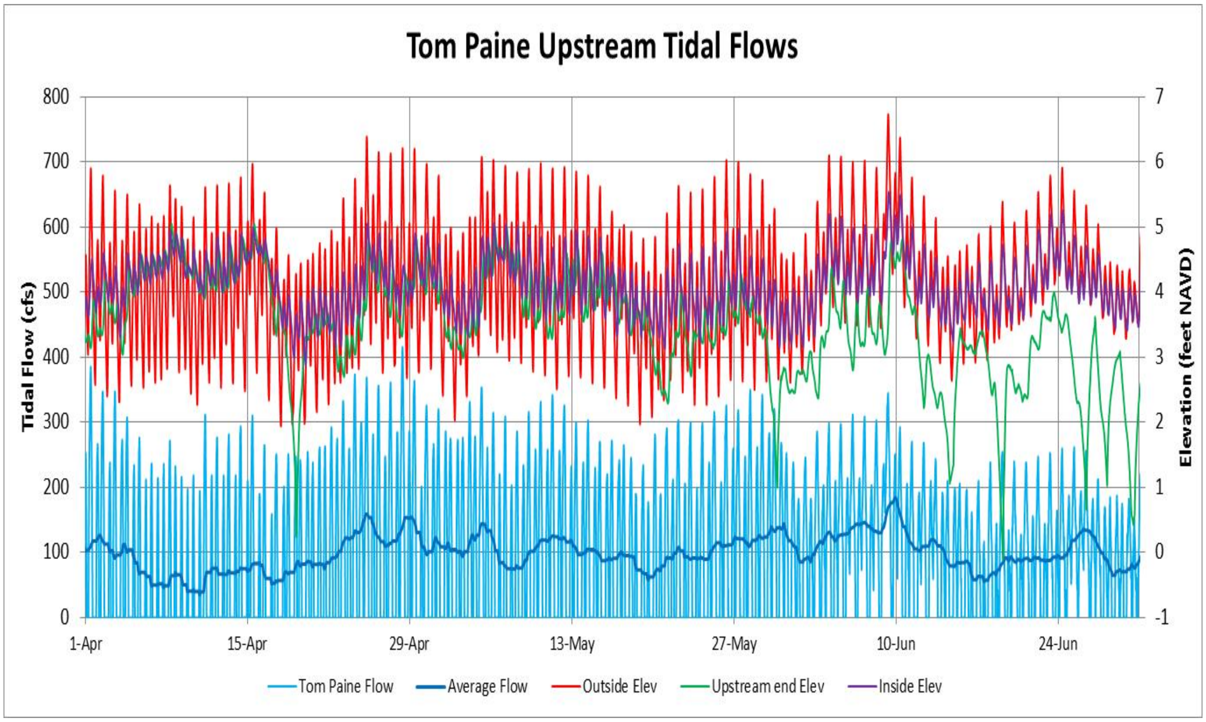


Figure 20a. Measured Elevations and Estimated Tidal Diversions at Tom Paine Slough Diversion Dam in April–June 2013

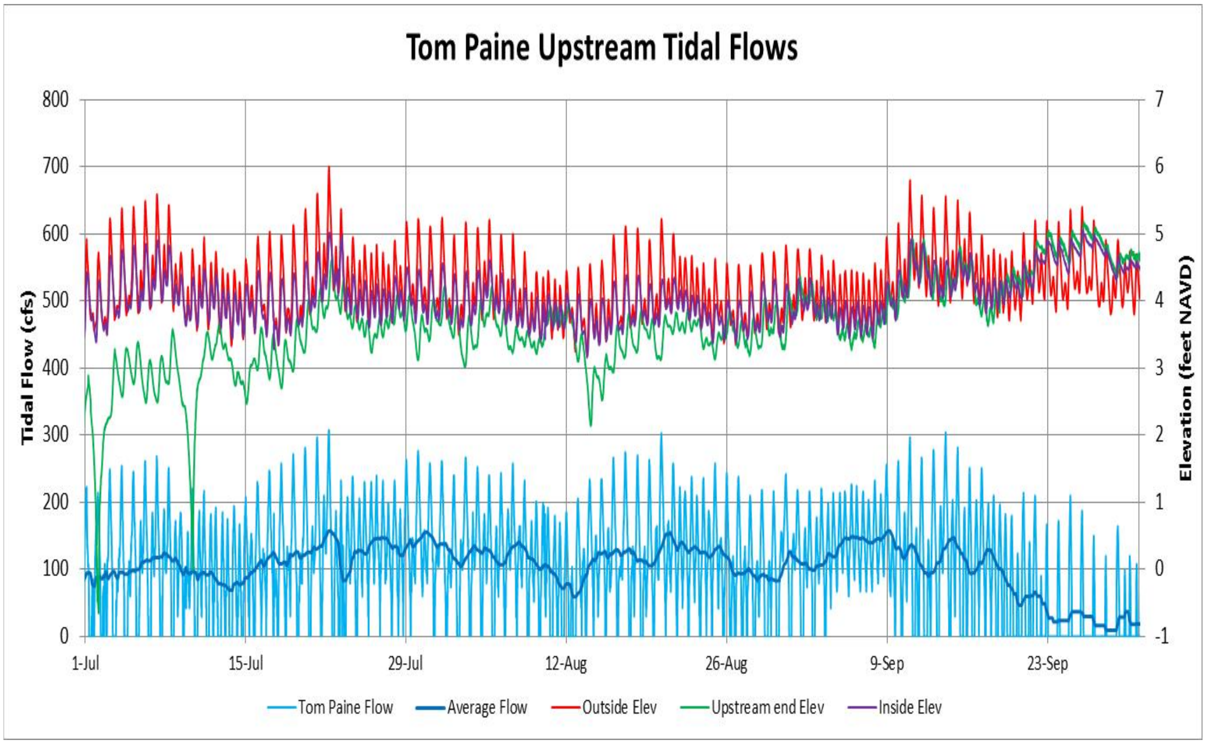


Figure 20b. Measured Elevations and Estimated Tidal Diversions at Tom Paine Slough Diversion Dam in July–September 2013

The DMC barrier crest flow (width of 75 feet) when the downstream elevation was higher than the upstream elevation was calculated as:

Barrier crest flow = net flow - 2 x 75 x (downstream water elevation – crest elevation) ^ 1.5

Figure 21a shows the measured tidal elevations and measured tidal flows compared with the calculated tidal flows in Old River at the DMC barrier in May 2013, before the DMC barrier was installed. The measured tidal flows were quite large, with ebb-tide flows of 1,000 to 2,000 cfs and flood-tide flows of 1,000 to 2,000 cfs. The full tidal flows were generally balanced in May, with a small downstream flow of 125 cfs in the first half of May and an upstream net flow of -125 cfs in the second half of May. No appreciable elevation differences occurred until the temporary barrier was installed, and thus the calculated barrier flows were small for most of May. On the last two days of May, the tidal flows were reduced (barrier installed) and the calculated barrier flows matched the measured flood-tide flows. The measured ebb-tide flows were greater than the calculated flows, suggesting that some of the flap gates were open. Figure 21b shows the measured and calculated tidal volumes in May 2013 at the DMC barrier. The flood-tide volumes and the ebb-tide volumes were variable but averaged about 500 af each during each tidal period (two each day). The calculated tidal volumes were based on the change in tidal elevation upstream from the DMC barrier, with an assumed tidal area of 250 acres; the average tidal elevation change was about 2 feet, and thus the calculated tidal volumes averaged 500 af.

Figure 22a shows the measured tidal elevations and measured tidal flows compared with the calculated tidal flows in Old River at the DMC barrier in June 2013 with the DMC barrier installed. The measured tidal flows were quite small, with ebb-tide flows of less than 200 cfs, except at high tides when the downstream elevation decreased faster than the upstream elevation and allowed barrier crest flows of about 1,000 cfs for an hour. The flood-tide flows (through the nine culverts) generally were less than 500 cfs unless the downstream elevation (gold line) was higher than the barrier crest (blue line), when maximum upstream flows of 1,000 to 1,250 cfs were measured (and accurately calculated). The calculated barrier flows matched the measured tidal flows for June with the barriers installed and all flap gates operating.

Figure 22b shows the measured and calculated tidal volumes in June 2013 at the DMC barrier. The flood-tide volumes and the ebb-tide volumes were much lower than the full tidal flow volumes in May. The flood-tide volumes averaged about 250 af and the ebb-tide volumes averaged about 125 af. The flood-tide volumes were reduced to about 50 percent of the full tidal flow (with culverts), but the ebb-tide volumes were just 25 percent of the full tidal flow (no culverts open). The DMC barrier therefore created a small upstream net flow of about 50 to 100 cfs. The calculated ebb-tide flow volumes were higher than the measured ebb-tide volumes, suggesting that the assumed net flow (10 percent of the head of Old River flow) was too high, perhaps because of agricultural diversions downstream of Tracy Boulevard.

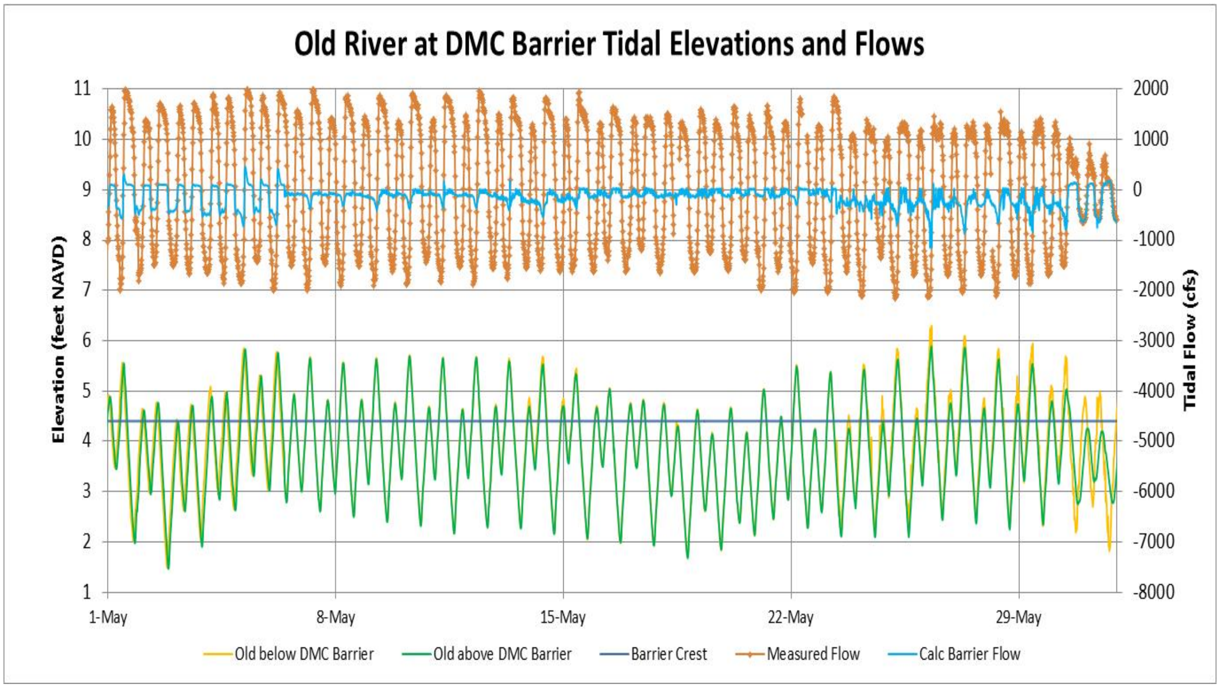


Figure 21a. Comparison of Measured Tidal Elevations and Measured Tidal Flows with Calculated Tidal Flows in Old River at the DMC Barrier in May 2013 (without barriers)

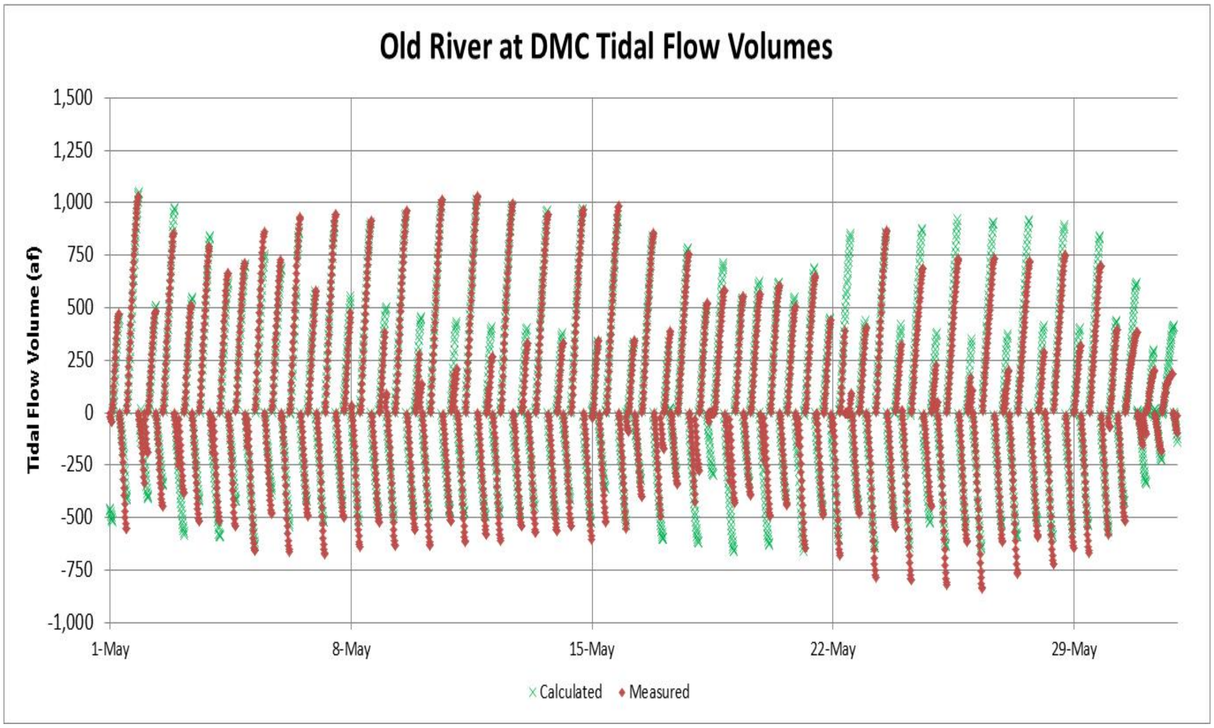


Figure 21b. Comparison of Measured and Calculated Tidal Flow Volumes (af) in Old River at the DMC Barrier in May 2013 (without barriers)

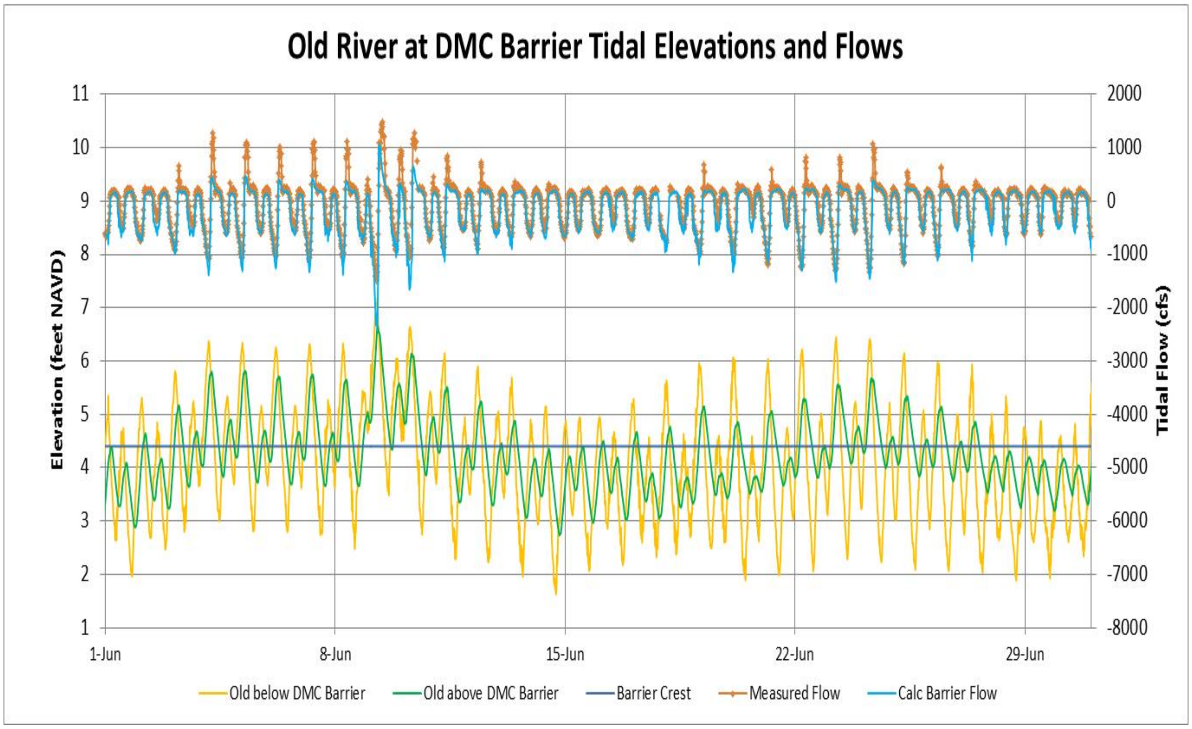


Figure 22a. Comparison of Measured Tidal Elevations and Measured Tidal Flows with Calculated Tidal Flows in Old River at the DMC Barrier in June 2013 (barriers installed)

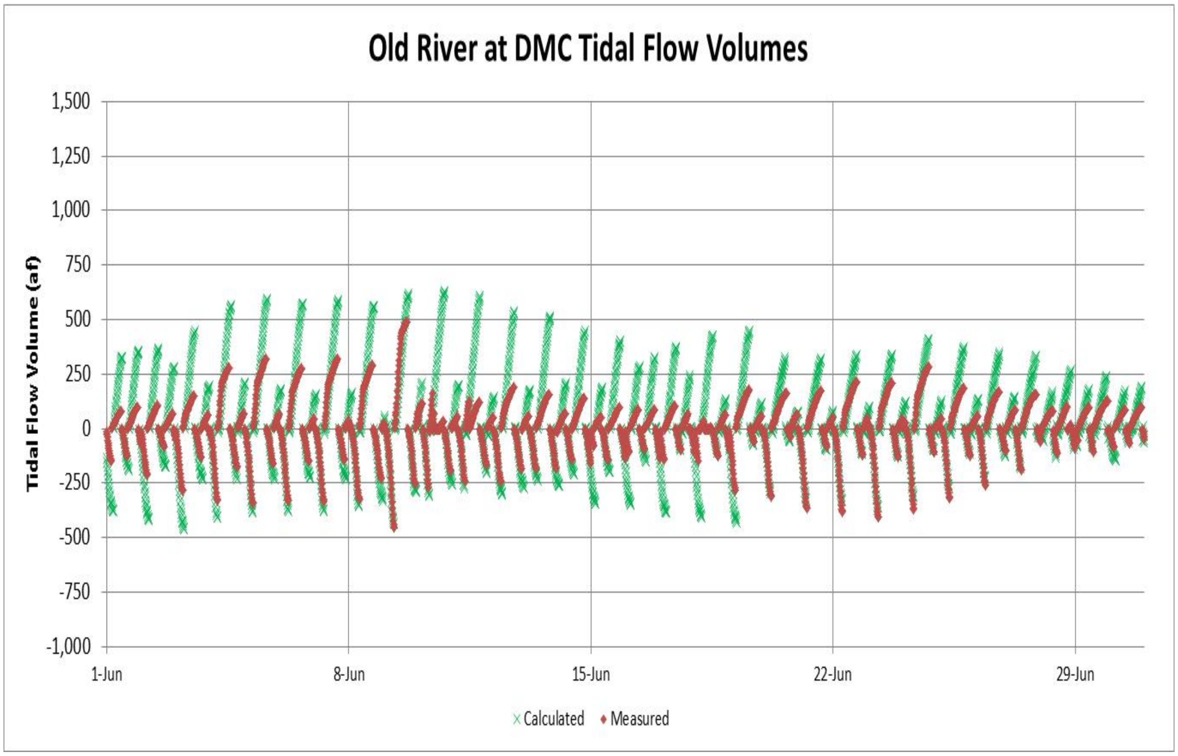


Figure 22b. Comparison of Measured and Calculated Tidal Flow Volumes in Old River at the DMC Barrier in June 2013 (barriers installed)

Figure 23a shows the measured tidal elevations and measured tidal flows compared with the calculated tidal flows in Old River at the DMC barrier in July 2013 with the DMC barrier installed. The measured tidal flows were quite small and similar to the measured tidal flows in June. The flood-tide flows (through the nine culverts) generally were less than 500 cfs unless the downstream elevation (gold line) was higher than the barrier crest (blue line) when maximum upstream flows of 1,000 to 1,500 cfs were measured (and accurately calculated). Although some high measured crest flows at the beginning of ebb-tides were not calculated, the calculated tidal flows with the barrier installed generally matched the measured flows very well.

Figure 23b shows the measured and calculated tidal volumes in July 2013 at the DMC barrier. The flood-tide volumes and the ebb-tide volumes were much lower than the full tidal flow volumes in May. The flood-tide volumes averaged about 200 af and the ebb-tide volumes averaged about 125 af. The flood-tide volumes were reduced to about 50 percent of the full tidal flow, but the ebb-tide volumes were just 25 percent of the full tidal flow. The DMC barrier therefore created a small upstream net flow of about 50 to 100 cfs.

Grant Line Canal Barrier

Calculated flows at the Grant Line Canal barrier (just upstream from Tracy Boulevard) were based on the measured head of Old River flow and the measured elevations (upstream and downstream from the barrier), the weir crest geometry, and the six culverts with flap gates. The net flow was assumed to flow over the barrier regardless of the upstream elevation, because the net flow maintains the upstream water elevation higher than the barrier crest (3.5 feet NAVD). The 4-feet diameter culverts each allowed a flow of about 50 cfs, with an elevation difference of 1 foot. The upstream (negative) flow through the culverts (with flap gates) and leakage through the rock barrier (assumed to be equivalent to three culverts, 150 cfs with an elevation difference of 1 foot) was estimated whenever the downstream elevation was higher than the upstream elevation as:

Upstream culvert flow (cfs) = - 450 x (downstream elevation – upstream elevation) ^ 0.5

The flap gates blocked downstream (positive) flow through the barriers when the upstream elevation was higher than the downstream elevation, but downstream seepage flow would occur. If the flap gates were left open, the downstream flow would increase by 50 cfs for each open culvert (with an elevation difference of 1 foot). The downstream (positive) leakage flow was estimated as:

Downstream flow (cfs) = 150 x (upstream elevation – downstream elevation) ^ 0.5

The flow over the barrier crest (in addition to the net flow) was assumed to be similar to a weir (i.e., weir flow = C x width x water depth ^ 1.5) with C estimated as 2. The weir crest flow is positive if the upstream elevation is higher than the downstream elevation and is negative if the downstream elevation is higher than the upstream elevation. The Grant Line Canal barrier crest flow (width of 125 feet) when the upstream elevation was higher than the downstream elevation included the net flow and was calculated as:

Barrier crest flow = net flow + 2 x 125 x (upstream elevation – crest elevation) ^1.5

The flow over the Grant Line Canal barrier crest, when the downstream elevation was higher than the upstream elevation, was reduced by the net flow and was calculated as:

Barrier crest flow = net flow - 2 x 125 x (downstream elevation – crest elevation) ^1.5

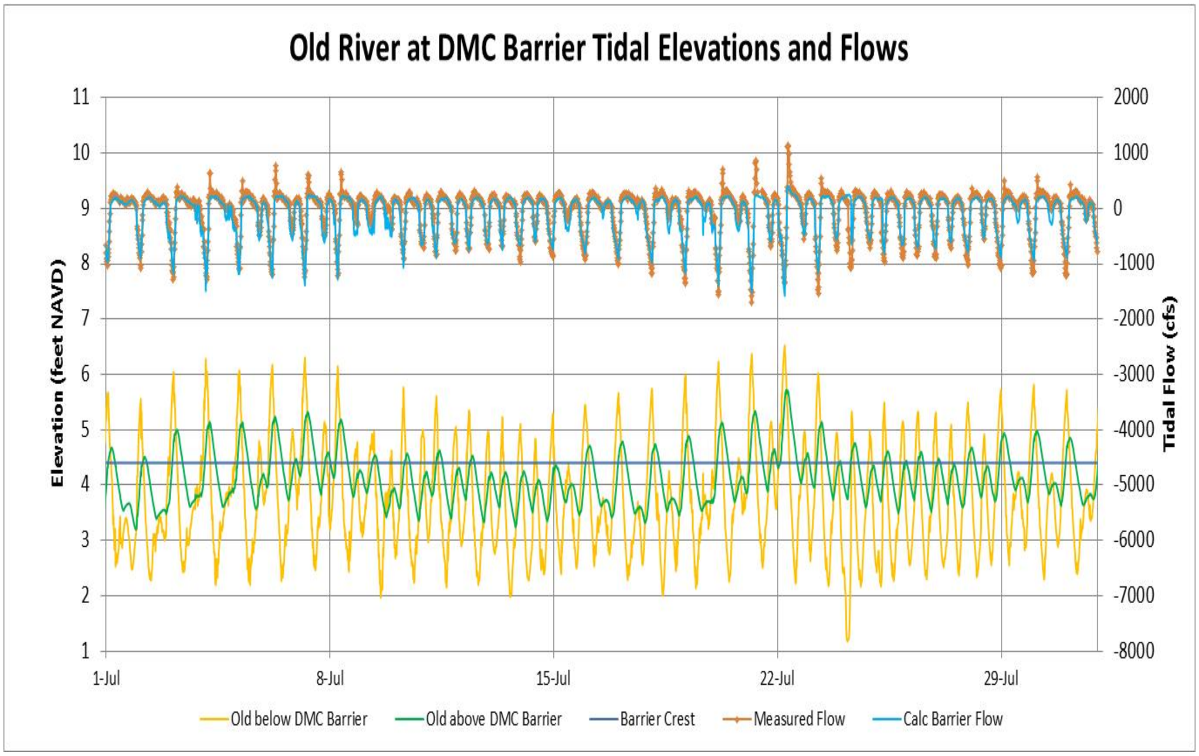


Figure 23a. Comparison of Measured Tidal Elevations and Measured Tidal Flows with Calculated Tidal Flows in Old River at the DMC Barrier in July 2013 (barriers installed)

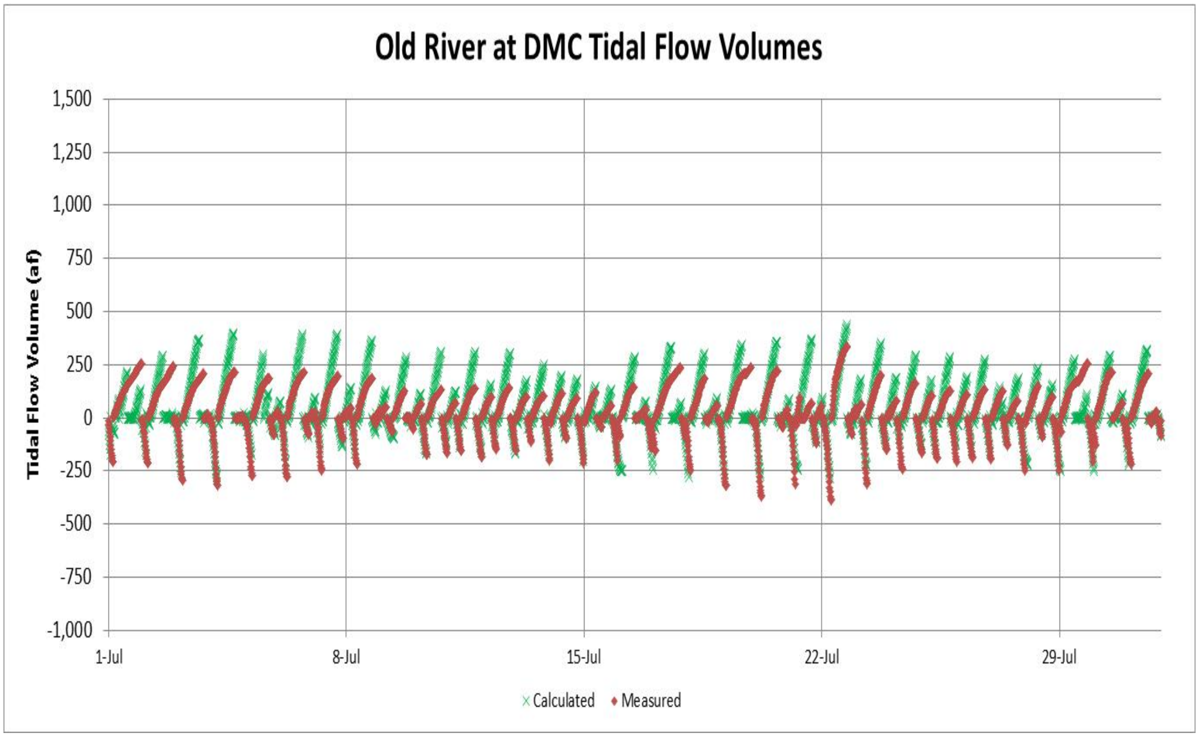


Figure 23b. Comparison of Measured and Calculated Tidal Flow Volumes (af) in Old River at the DMC Barrier in July 2013 (barriers installed)

Figure 24a shows the measured tidal elevations and tidal flows compared with the calculated tidal flows at the Grant Line Canal barrier in July 2013 with the barrier installed. The measured upstream flows through the culverts and over the barrier crest were highest at high tide, with a peak flow of about 1,000 to 2,000 cfs. The calculated upstream flows were similar but higher. The measured downstream flows over the barrier crest were about 500 cfs to 1,000 cfs, with a few flows of 2,000 cfs at highest tides (2.5 feet higher than the barrier crest). The calculated downstream flows were similar to the measured flows; the calculated flows provide confirmation for the measured tidal flows at the Grant Line Canal barrier. Figure 24b shows the measured and calculated tidal volumes at the Grant Line Canal barrier in July 2013. The ebb-tide volumes were definitely greater than the flood-tide volumes (because of the large net flow). The Grant Line Canal barrier substantially reduced the full tidal flows upstream of the Grant Line Canal barrier. The flood-tide volumes were about 500 af per day and the ebb-tide volumes were about 1,000 af per day.

Figure 25a shows the measured tidal elevations and tidal flows compared with the calculated tidal flows at the Grant Line Canal barrier in August 2013 with the barrier installed. The measured upstream flows through the culverts and over the barrier crest were highest at high tide, with a peak flow of about 1,000 to 2,000 cfs. The calculated upstream peak flows were similar. The measured downstream flows over the barrier crest were about 500 cfs to 1,000 cfs, with a few flows of 2,000 cfs at highest tides (2.5 feet higher than the barrier crest).

Figure 25b shows the measured and calculated tidal flow volumes at the Grant Line Canal barrier in August 2013. The ebb-tide flow volumes (downstream flow) were definitely greater than the flood-tide flow volumes (upstream flow). The Grant Line Canal barrier substantially reduced the full tidal flow at the Grant Line Canal barrier. The flood-tide flow volumes were about 500 af per day, and the ebb-tide flow volumes were about 1,000 af per day. The calculated tidal flows at the Grant Line Canal temporary barrier, based on the elevations upstream and downstream of the barrier, were added to the daily average flow in Grant Line Canal to match the measured tidal flows at the barrier.

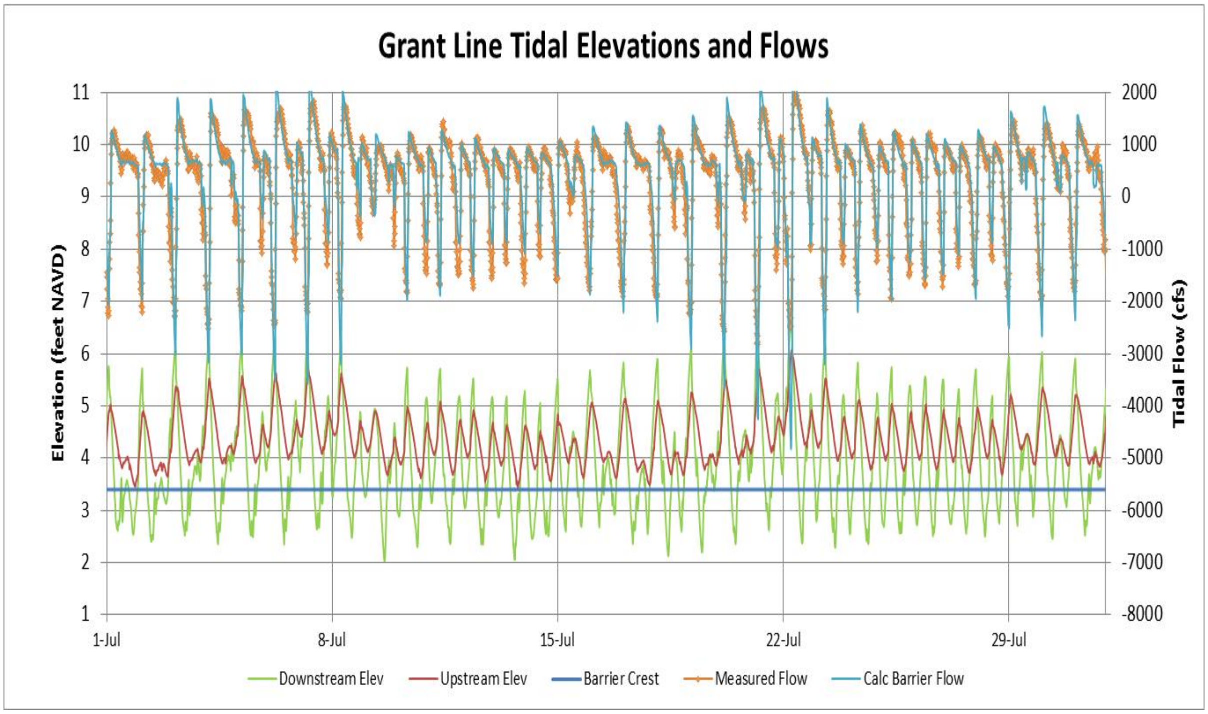


Figure 24a. Comparison of Measured Tidal Elevations and Measured Tidal Flows with Calculated Tidal Flows at the Grant Line Canal Barrier in July 2013 (barriers installed)

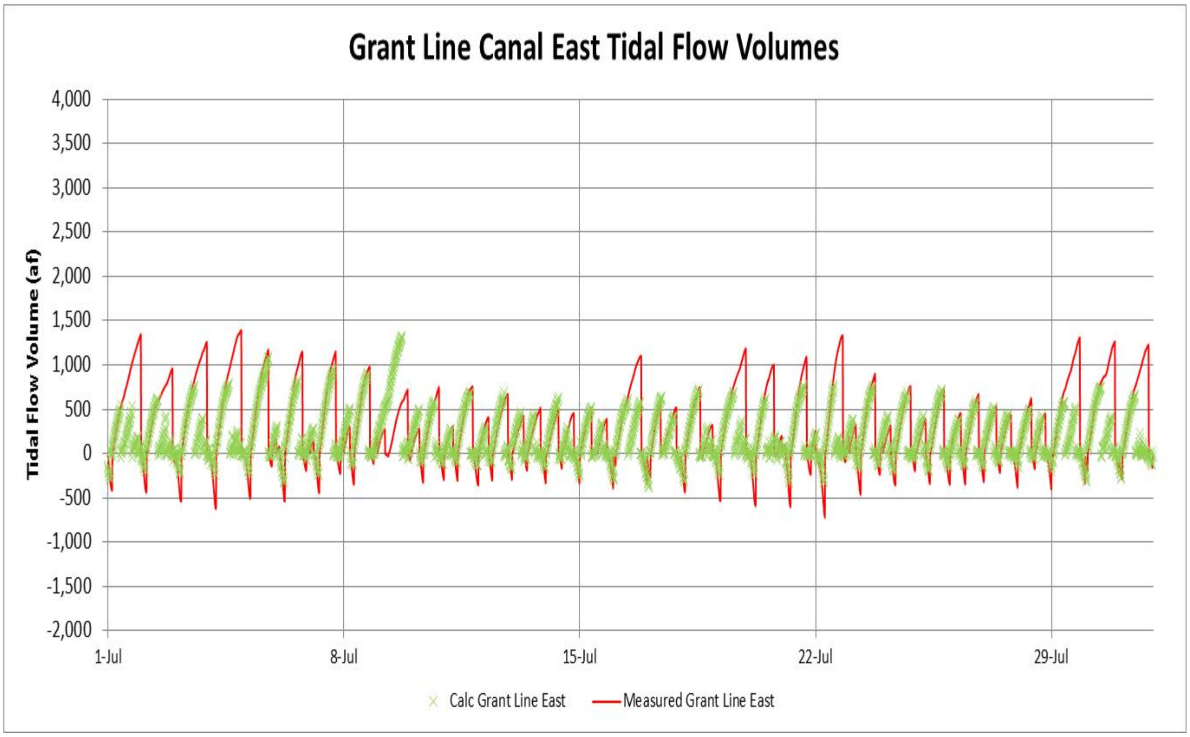


Figure 24b. Comparison of Measured and Calculated Tidal Flow Volumes (af) at the Grant Line Canal Barrier in July 2013 (barriers installed)

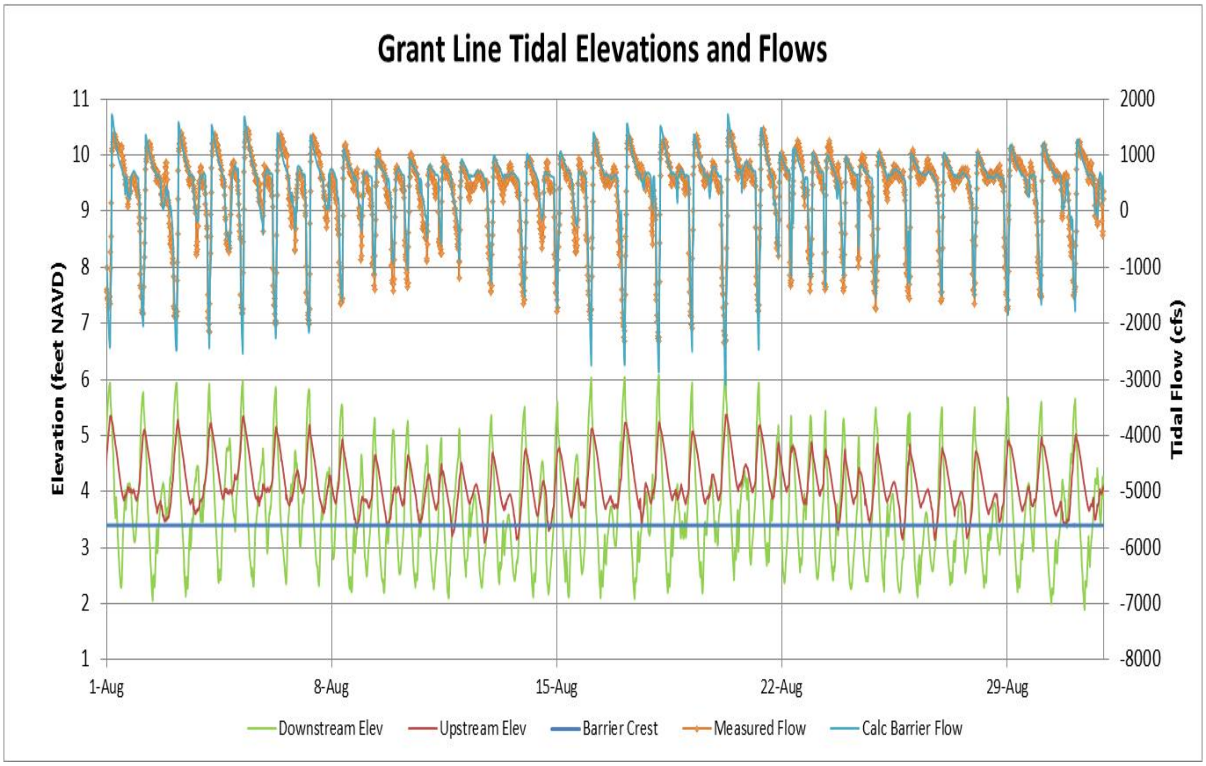


Figure 25a. Comparison of Measured Tidal Elevations and Measured Tidal Flows with Calculated Tidal Flows at the Grant Line Canal Barrier in August 2013 (barriers installed)

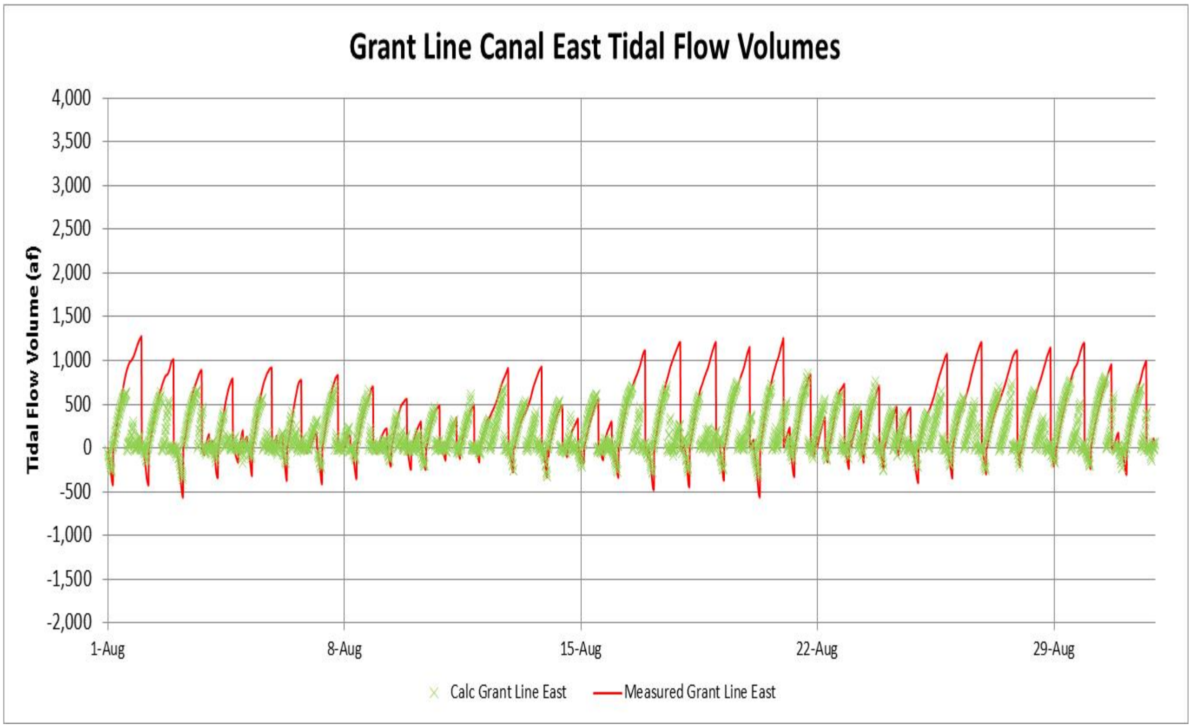


Figure 25b. Comparison of Measured and Calculated Tidal Flow Volumes (af) at the Grant Line Canal Barrier in August 2013 (barriers installed)

Middle River Barrier

A new tidal flow measurement station was installed by DWR at the Middle River barrier in January 2014. These measured tidal flows were evaluated by calculating the tidal volumes from the measured tidal elevations. Figure 26 shows the measured tidal elevations, measured tidal volumes and calculated tidal volumes in March 2014 at the Middle River barrier station. The flood-tide volumes and ebb-tide volumes generally were balanced in the first half of March (before the temporary barrier was installed), with an average tidal volume of about 300 af. The net flow was assumed to be 0 cfs and the upstream area was adjusted to be 150 acres (to match measured flows). This matched the Middle River surface area (at mean tide elevation of 4 feet) upstream from the barrier (DSM2 geometry file).

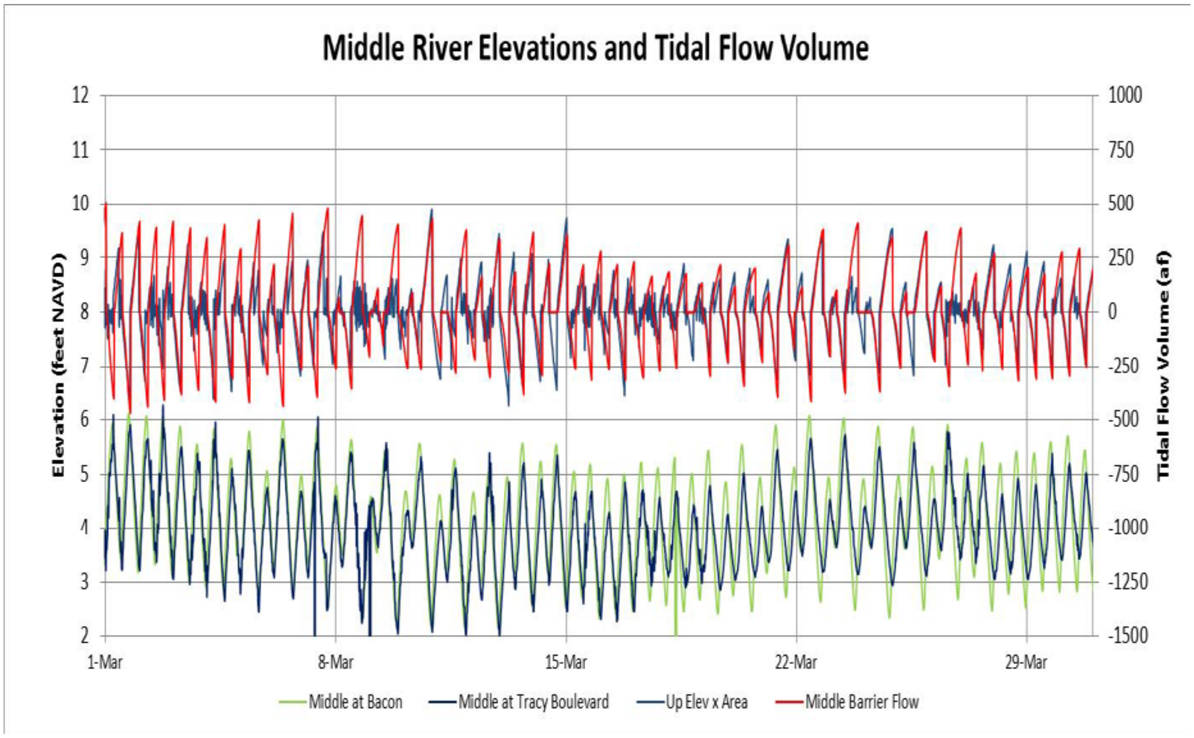


Figure 26. Measured and Estimated Tidal Flow Volumes in Middle River at the Temporary Barrier in March 2014

The Middle River barrier was closed on March 17, with a (reduced) crest elevation of about 3.5 feet NAVD. The minimum elevations were increased slightly, in comparison to the tidal elevations in Middle River at Bacon Island, but the six culverts were held open until April 8. The calculated tidal volumes (blue line) matched the measured tidal flow volumes (red line) throughout the entire month with different tidal elevations. The net flow in Middle River was assumed to be 0 cfs and the leakage flow was assumed to be similar to the leakage flow at the other barriers (150 cfs with a head of 1 feet). Thus, the tidal flow when the downstream elevation was higher than the upstream elevation was:

Upstream culvert flow (cfs) = - 450 x (downstream elevation – upstream elevation) ^ 0.5

The downstream (positive) leakage flow was estimated as:

Downstream flow (cfs) = 150 x (upstream elevation – downstream elevation) ^ 0.5

The flow over the barrier crest (in addition to the net flow) was assumed to be similar to flow over a weir (i.e., weir flow = C x width x water depth ^ 1.5) with C estimated as 2. The weir crest flow is positive if the upstream elevation is higher than the downstream elevation and negative if the downstream elevation is higher than the upstream elevation. The Middle River barrier crest flow (width of 140 feet) when the upstream elevation was higher than the downstream elevation included the net flow and was calculated as:

Barrier crest flow = net flow + 2 x 140 x (water elevation – crest elevation) ^1.5

The flow over the Middle River barrier crest, when the downstream elevation was higher than the upstream elevation, was reduced by the net flow and was calculated as:

Barrier crest flow = net flow - 2 x 140 x (downstream water elevation – crest elevation) ^ 1.5

These Middle River tidal flow measurements further confirmed that tidal flow volumes in south Delta channels can be accurately estimated as the change in elevation times the upstream surface area that the tidal flows are filling and draining (i.e., tidal prism area). This simple estimate of the tidal flow also applies when the upstream tidal elevation range (variation) is reduced by the temporary barriers. The flows over the barriers and through the culverts can also be calculated with simple hydraulic equations that depend on the water elevations and the estimated net flows.

The effects of tidal flows on salinity (EC) in the south Delta channels are also complicated by the channel junctions, because the tidal flows at each junction will depend on the upstream surface areas, channel cross-section areas, and water elevations in the diverging channels. The movement of salt in the south Delta channels can be evaluated by considering the flood-tide (upstream) flow patterns and the ebb-tide (downstream) flow patterns separately. For example, the tidal movement of water filling and draining Paradise Cut can be identified for ebb-tide and flood-tide conditions. During ebb-tide, water moves from the mouth of Paradise Cut to Old River, and moves with the ebb-tide flow in Old River (generally downstream toward Tracy Boulevard). However, with the temporary barrier at DMC installed, the ebb-tide flow in Old River at Paradise Cut may be upstream (toward Doughty Cut), so that water from Paradise Cut moves upstream in Old River to Doughty Cut and downstream to Grant Line Canal. During flood-tide, water from Old River flows into Paradise Cut; some fraction of the water comes from upstream and some comes from downstream, depending of the flood-tide flow in Old River at Tracy Boulevard. If the flood-tide flow in Old River at Tracy Boulevard is greater than the flood-tide flow entering Paradise Cut, all of the water comes from downstream (past Tracy Boulevard). But if the flood-tide flow in Old River at Tracy Boulevard is restricted by the temporary barrier at DMC, some of the flood-tide flow entering Paradise Cut comes from upstream (Doughty Cut). The results from the tidal calculations of water movement and EC in Paradise Cut, Sugar Cut, Tom Paine Slough, and Old River at Tracy Boulevard that used these tidal movement methods will be shown in the next section.

Calculated Effects of Paradise Cut and Sugar Cut Salinity Sources on Old River EC at Tracy Boulevard

The tidal flows in Paradise Cut and Sugar Cut were calculated from the elevation changes in Old River at Tracy Boulevard (or at Doughty Cut). As shown in Figure 7, both Paradise Cut and Sugar Cut enter Old River downstream from Doughty Cut, where the net flow in Old River is generally about 10 percent of the head of Old River flow. Because Paradise Cut has a surface area of about 170 acres with a volume of 1,000 af (at mean tide, 4 feet NAVD), the volume changes by about 170 af

(17 percent) for each 1 foot change in tidal elevation (assuming a rectangular channel). Paradise Cut is about 6 miles long, so water fills about 1 mile of the channel for each 1 foot of elevation increase (assuming a uniform channel). Without the temporary barriers, water from Old River fills about 4 miles of Paradise Cut between low tide (2 feet) and high tide (6 feet); with temporary barriers, the tidal exchange is about half of the full tidal exchange, and water from Old River fills about 2 miles of Paradise Cut between low tide (3 feet) and high tide (5 feet).

Sugar Cut has a surface area of about 55 acres with a volume of 425 af at mean tide (elevation of 4 feet NAVD); the volume changes by 55 af (13 percent) for each 1 foot change in tidal elevation (assuming a rectangular channel). Sugar Cut is about 2.5 miles long with a uniform channel cross-section, and thus water from Old River fills about 1.3 miles of Sugar Cut between low tide (2 feet) and high tide (6 feet); with temporary barriers, the tidal exchange is about half of the full tidal exchange, and water from Old River fills about 0.65 miles of Paradise Cut between low tide (3 feet) and high tide (5 feet).

Both Paradise Cut and Sugar Cut have an assumed salinity source near the upstream end; the Paradise Cut salt source was estimated to be 10 cfs with an EC of about 3,000 μS/cm (about 53 tons/day of total salt load) and the Sugar Cut salt source was estimated to be 10 cfs with an EC of 2,000 μS/cm (about 35 tons/day of total salt load). However, the excess salt sources (loads) that causes an EC increment in Old River at Tracy Boulevard depends on the Old River EC. The incremental salt source from Paradise Cut is reduced to 35 tons/day (two-thirds of total) if the Old River EC is 1,000 μS/cm and the incremental salt source from Sugar Cut is reduced to about 17 tons/day (one-half of total) if the Old River EC is 1,000 μS/cm.

The tidal calculations for Sugar Cut included the tidal diversion (culverts and siphons with flap gates) to Tom Paine Slough for irrigation; this diversion is located about 1 mile upstream from the mouth of Sugar Cut. The assumed (specified) daily diversion flow varied seasonally from March through October, with a maximum diversion flow of about 100 cfs in summer. Because the diversion flows were much greater than the assumed salt source flow, most of the salt source was diverted to Tom Paine Slough during the irrigation season. Because the mouth of Paradise Cut is just upstream from the mouth of Sugar Cut, some of the salt source from Paradise Cut that enters the Old River channel during ebb-tide may be diverted subsequently into Sugar Cut during the next flood-tide and diverted into Tom Paine Slough during the irrigation season. The tidal flows and salinity calculations included each of these possible tidal flow pathways; excess salt from Paradise Cut and from Sugar Cut can end up in the Tom Paine Slough irrigation water, in Old River upstream at Doughty Cut (during flood tides), or in Old River downstream at Tracy Boulevard (during ebb-tides). A higher net flow in Old River at Tracy Boulevard will increase the fraction of the salt loads from Paradise Cut and Sugar Cut moving downstream to Tracy Boulevard, but will provide more dilution of the excess salt load.

Figure 27a shows the calculated tidal volumes (af) at the mouth of Paradise Cut and Sugar Cut, and in Old River (upstream of Paradise Cut and downstream of Sugar Cut) in April 2013 without the temporary barriers. The ebb-tide flow volumes at Tracy Boulevard (red line) were about 250 af for the major ebb-tide each day, while the tidal volumes from Paradise Cut were about 500 af, and the tidal volumes from Sugar Cut were about 125 af. During ebb-tide, some of the water from the tidal sloughs moved downstream past Tracy Boulevard, but some of the water moved upstream in Old River to Doughty Cut and to Grant Line Canal, because the tidal flows in Old River at Tracy Boulevard were constricted (limited) by the small channel section. During flood-tide, the tidal flow volumes in Old River at Tracy Boulevard were not large enough to fill Sugar Cut and Paradise Cut, and thus most of the flood-tide water moved upstream in Grant Line Canal and Doughty Cut to fill Paradise Cut and Sugar Cut. The fraction of the tidal flows filling or draining Paradise Cut and Sugar Cut depend on the channel geometry, the net flows in Old River, and the tidal elevations (tidal flows) in Old River at Tracy Boulevard and in Grant Line Canal upstream of the barrier (eastern end).

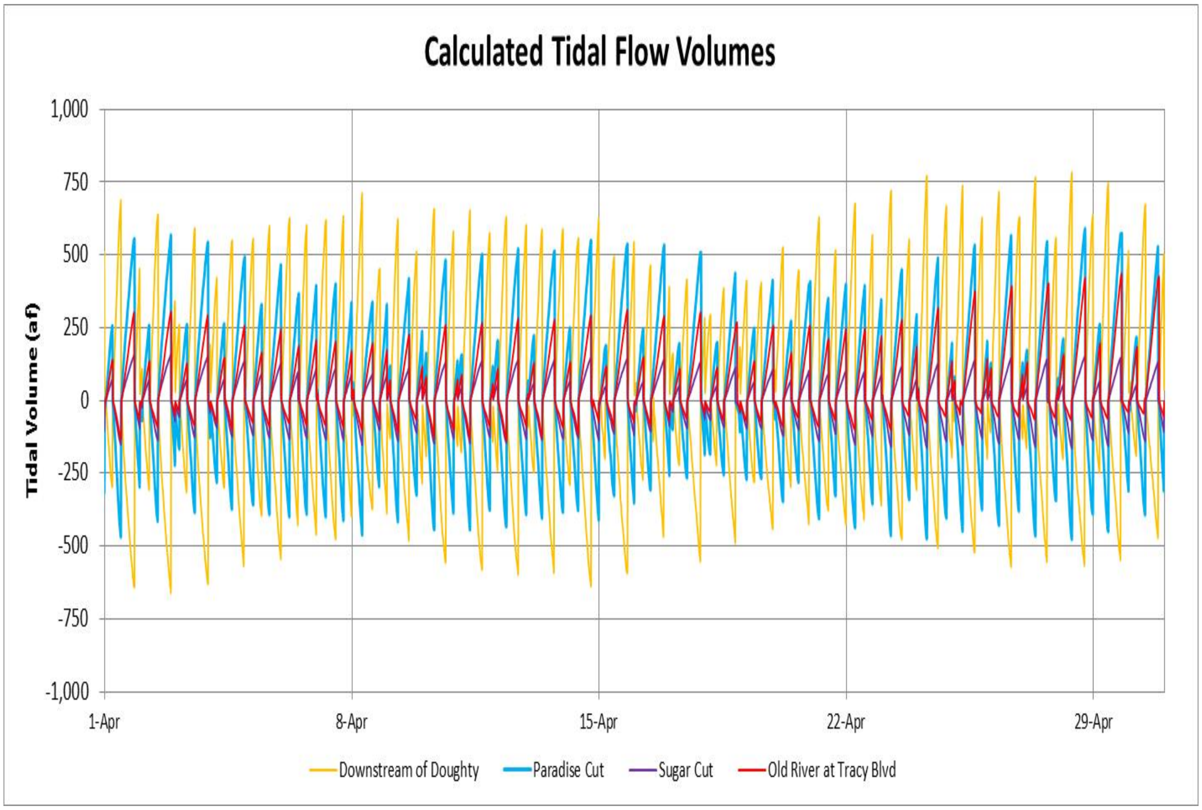


Figure 27a. Calculated Tidal Flow Volumes in Old River downstream from Doughty Cut, mouth of Paradise Cut, mouth of Sugar Cut, and in Old River at Tracy Boulevard in April 2013 (no temporary barriers)

Figure 27b shows the calculated tidal volumes in July 2013 when the temporary barriers were installed and Old River flows were moderately low. Measured tidal volumes (af) at Tracy Boulevard were quite small; the ebb-tide flow volume was about 125 af during the major ebb-tide each day. The tidal flows in Paradise Cut were reduced to about half of the April volumes, because the temporary barriers reduced the tidal range by about half. The ebb-tide flow volumes in Sugar Cut were eliminated and the flood-tide volumes were increased by the irrigation diversions in Tom Paine Slough. Tracking the salt from Paradise Cut during periods with the barriers installed was more uncertain because the movement of water in Old River during ebb-tides was more sensitive to the tidal elevations and Old River at Tracy Boulevard net flows. The calculation of EC in Paradise Cut, Sugar Cut, and Old River was based on the calculated tidal flows, the net flow, and EC at the head of Old River, the diversion flow in Sugar Cut, and the assumed upstream salt sources in Paradise Cut and Sugar Cut. In addition to the effects of the temporary barriers on reduced tidal volumes, there are effects from agricultural diversions during the summer months on reduced net flows in Old River.

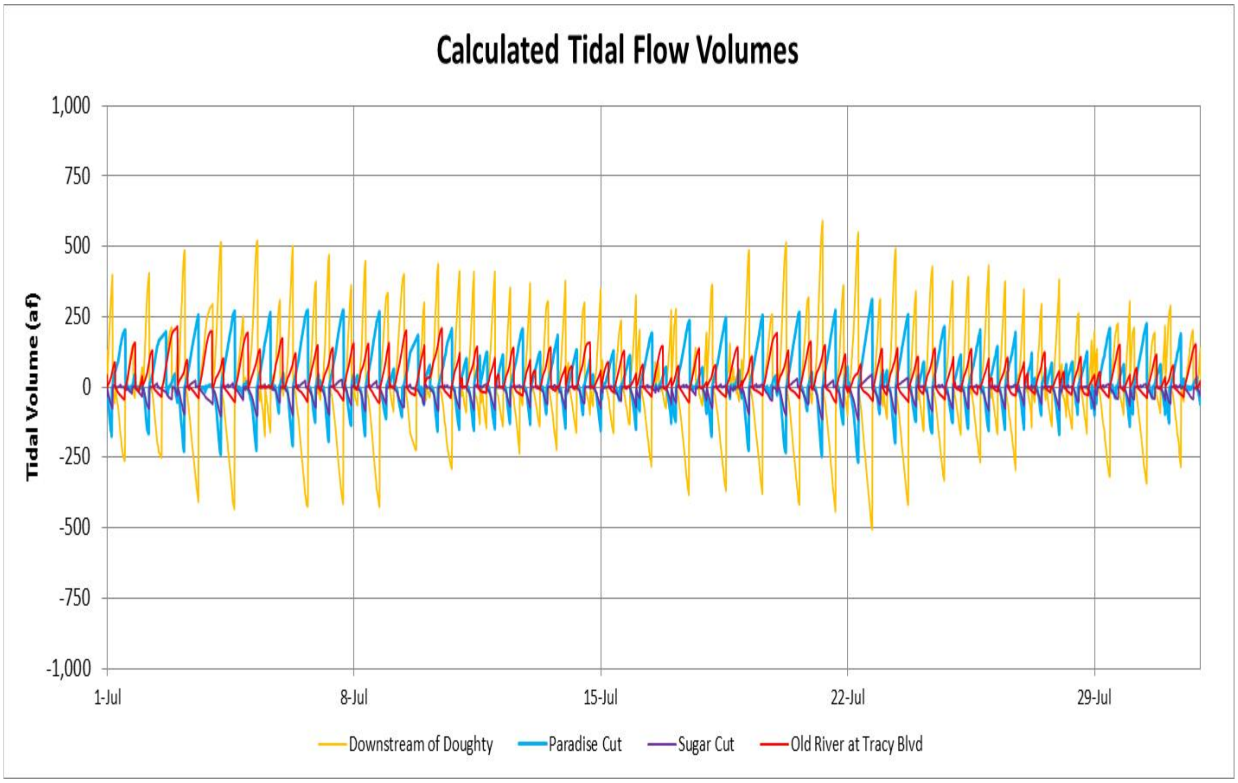


Figure 27b. Calculated Tidal Flow Volumes in Old River downstream from Doughty Cut, mouth of Paradise Cut, mouth of Sugar Cut, and in Old River at Tracy Boulevard in July 2013 (temporary barriers)

Figure 28a shows the calculated (gold line) and measured (green line) Paradise Cut EC (near the mouth) in April 2013 without temporary barriers. The upstream Old River EC at Doughty Cut was about 1,000 μS/cm in the first half of April and then was reduced by the SJR pulse flow (for fish migration) to about 250 μS/cm at the end of April. The full tidal flows into and out of Paradise Cut caused the measured EC (green line) to fluctuate from the Old River EC (at high tide) to about 500-750 μS/cm greater than the Old River EC (at low tide). The calculated EC (gold line) showed a similar fluctuation pattern, but did not increase as much as the measured EC, because of the fully-mixed box model approximation used for the salinity calculations. The measured Old River at Tracy EC (red line) indicated that a considerable EC increment of 50-250 μS/cm was caused by the Paradise Cut and Sugar Cut excess salinity (i.e., higher than upstream Old River EC) in April 2013.

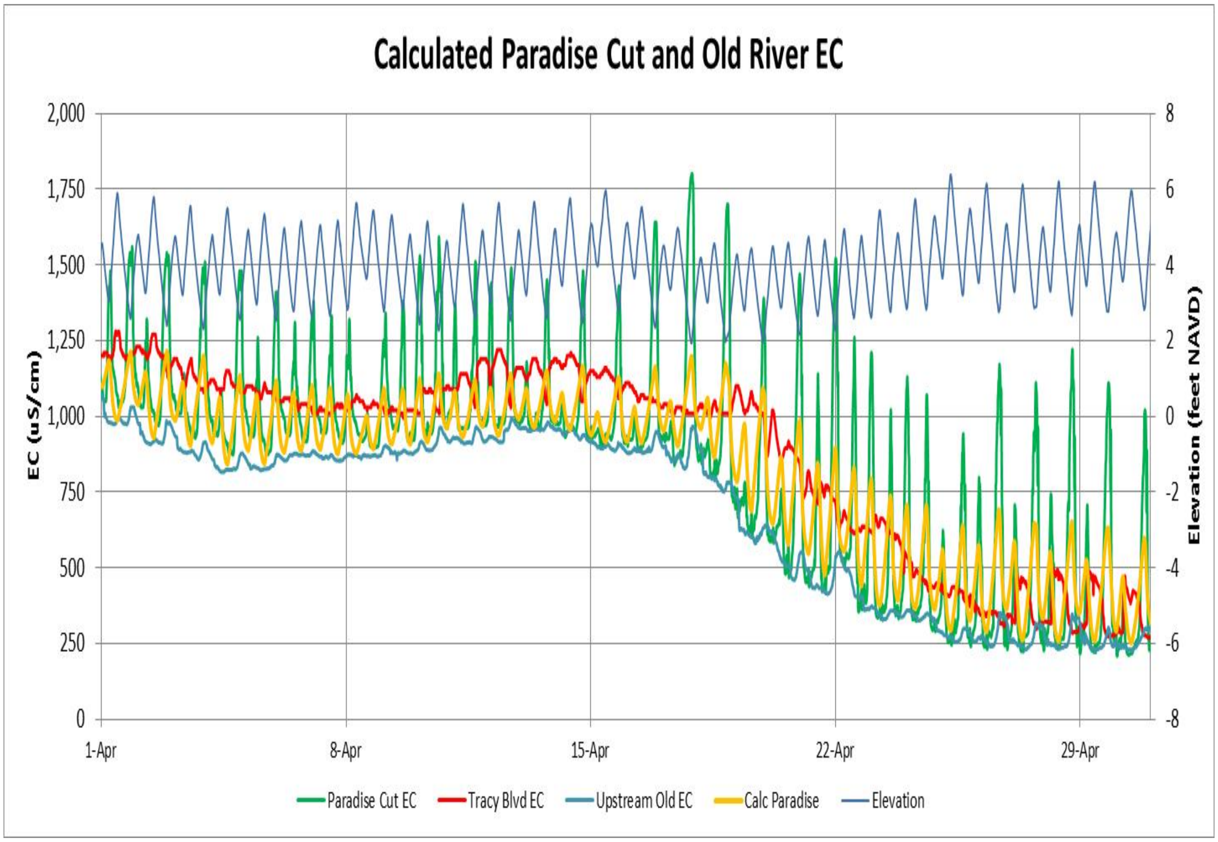


Figure 28a. Comparison of Calculated and Measured Paradise Cut EC with Old River EC and Tidal Elevations in April 2013 (no temporary barriers)

Figure 28b shows the calculated (gold line) and measured (green line) Paradise Cut EC (near the mouth) in July 2013 with temporary barriers installed. The upstream Old River EC at Doughty Cut was about 750 µS/cm. The reduced tidal flows caused the measured EC to fluctuate from the Old River EC (at high tide) to about 125-500 µS/cm greater than the Old River EC (at low tide). The calculated EC (gold line) showed a similar fluctuation pattern. The measured Old River at Tracy Boulevard EC (red line) indicates a considerable EC increment of 100 to 125 µS/cm in Old River between Doughty Cut and Tracy Boulevard) was caused by Paradise Cut and Sugar Cut excess salinity in July 2013.

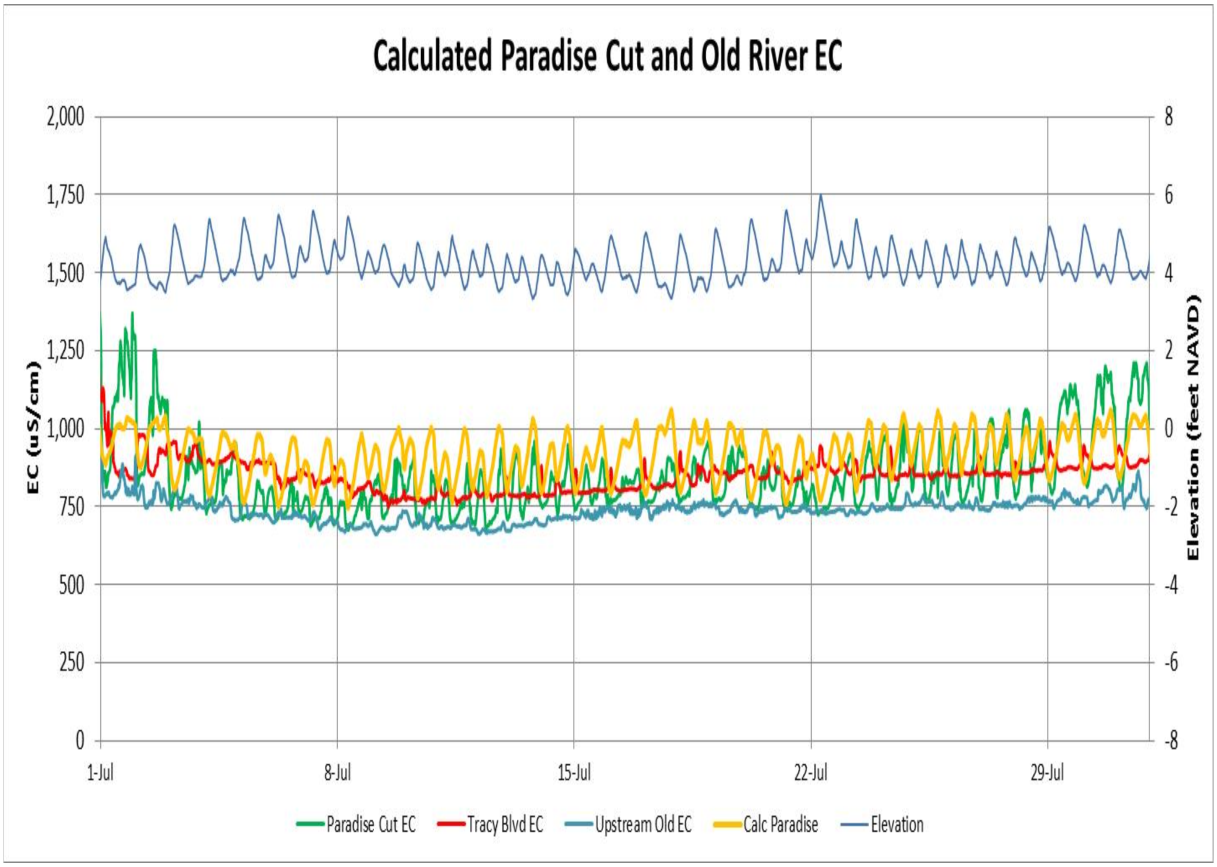


Figure 28b. Comparison of Calculated and Measured Paradise Cut EC with Old River EC and Tidal Elevations in July 2013 (temporary barriers)

Figure 29a shows the calculated (gold line) and measured (green line) Sugar Cut EC (just upstream from Tom Paine Slough diversion dam) in April 2013 without temporary barriers. The upstream Old River EC at Doughty Cut was about 1,000 µS/cm in the first half of April and then was reduced by the SJR pulse flow (for fish migration) to about 250 µS/cm at the end of April. The full tidal flows into and out of Sugar Cut caused the measured EC to fluctuate about 125 to 500 µS/cm and the measured EC remained greater than the Old River EC (at low tide). The flood-tide volumes were not large enough to move Old River water past the Tom Paine Slough diversion dam and some water was diverted to Tom Paine Slough in April. The calculated EC showed a reduced fluctuation pattern and the calculated EC remained 500 to 750 µS/cm higher than the Old River EC. The calculated EC at Tracy Boulevard (purple line) was similar to the measured EC at Tracy Boulevard (red line). The average measured EC increment in Old River between Doughty Cut and Tracy Boulevard in April 2013 was 196 µS/cm and the average calculated EC increment was 145 µS/cm. The average measured excess salt load increment was 62 tons/day and the average calculated excess salt load increment was 55 tons/day.

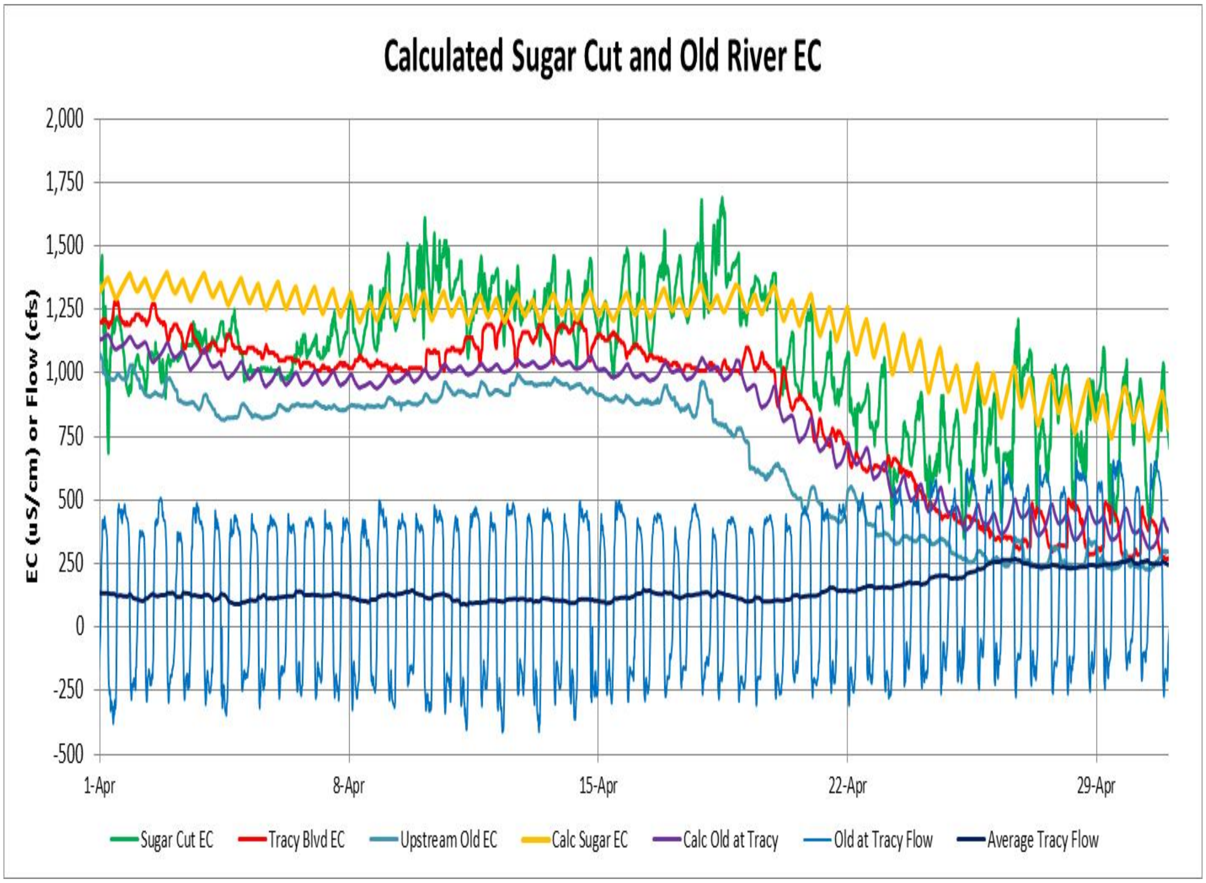


Figure 29a. Comparison of Calculated and Measured Sugar Cut EC and Old River at Tracy Boulevard EC for Measured Upstream Old River EC and Measured Tidal Flows in April 2013 (no temporary barriers)

Figure 29b shows the calculated (gold line) and measured (green line) Sugar Cut EC in July 2013 with temporary barriers. The upstream Old River EC at Doughty Cut was about 750 µS/cm for the entire month. The reduced tidal flows and higher Tom Paine Slough diversions caused the measured Sugar Cut EC tidal fluctuations to be less than 125 µS/cm and the measured EC remained about 250 µS/cm higher than the Old River EC. The calculated Sugar Cut EC tidal fluctuations also were small, but the calculated Sugar Cut EC was about 1,250 µS/cm, almost 500 µS/cm higher than the Old River EC. The calculated EC at Tracy Boulevard (purple line) was less than the measured EC at Tracy Boulevard (red line). The average measured EC increment in Old River between Doughty Cut and Tracy Boulevard in July 2013 was 112 µS/cm, while the average calculated EC increment was 55 µS/cm. The average measured excess salt load increment was 37 tons/day, while the calculated salt load increment was 11 tons/day. The calculated excess salt source from Paradise Cut and Sugar Cut to Old River at Tracy Boulevard was smaller than the measured excess salt source in July. Additional EC measurements (near the mouth of Sugar Cut and in Tom Paine Slough) as well as a better representation of the tidal movement of water and salt in the tidal sloughs (replace the mixed box approach) would likely improve the EC increment calculations.

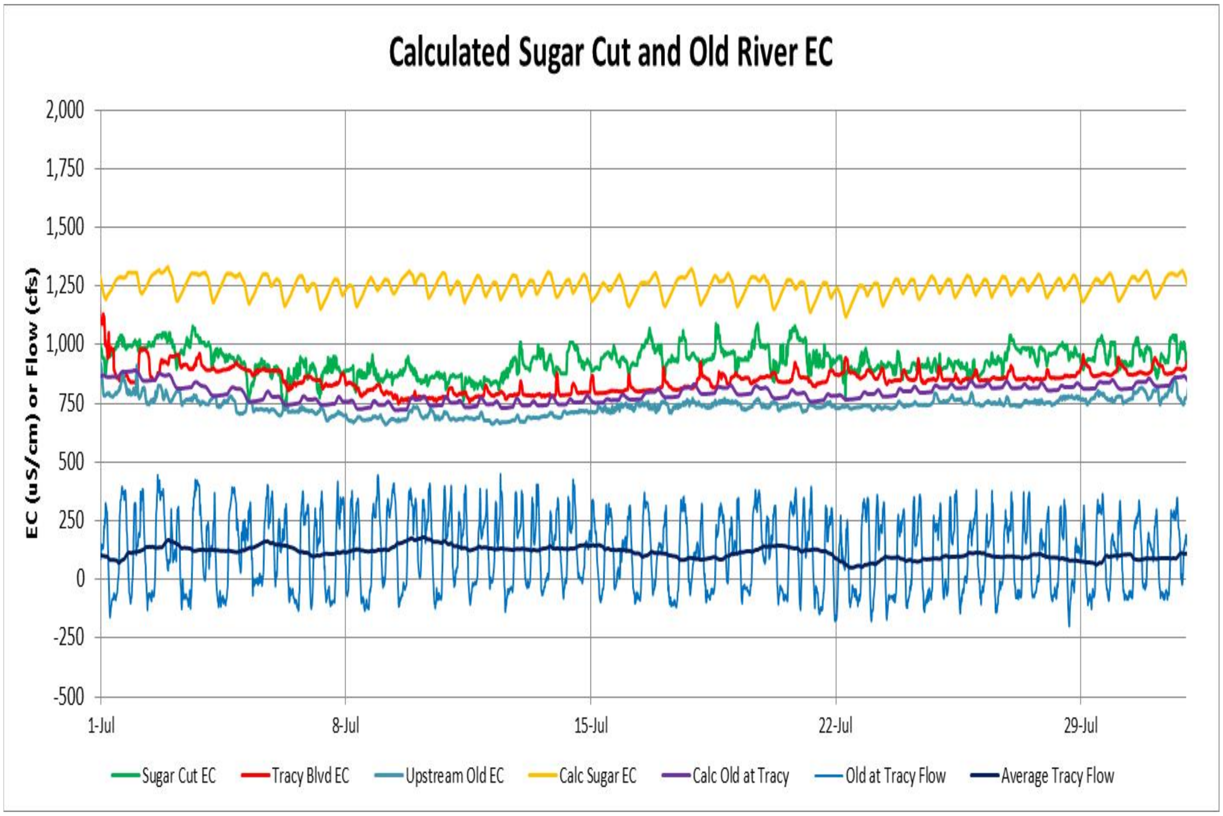


Figure 29b. Comparison of Calculated and Measured Sugar Cut EC and Old River at Tracy Boulevard EC for Measured Upstream Old River EC and Measured Tidal Flows in July 2013 (temporary barriers)

Figure 30a shows the daily average measured EC in Old River upstream at Doughty Cut (blue line) and downstream at Tracy Wildlife (red line) compared to the calculated EC at Tracy Boulevard (red triangles) from the estimated salt sources in Paradise Cut and Sugar Cut in 2009. The Tracy Boulevard EC was much higher than the Tracy Wildlife EC in the second half of 2009 and was determined to be inaccurate during this period. The estimated salt sources in Paradise Cut and in Sugar Cut were assumed to remain uniform throughout the year (could be seasonal), but the Tom Paine Slough diversions from Sugar Cut were seasonal and diverted most of the Sugar Cut salt source during the irrigation season. The bottom of the graph shows the Old River flow (cfs) at Tracy Boulevard (green line) and the measured EC increment in Old River between Doughty Cut and Tracy Wildlife (purple diamonds) compared to the calculated EC increments (gold diamonds). The general magnitude of the calculated EC increments matched the measured EC increments for 2009, although some of the high EC measurements at Tracy Wildlife were not calculated, and the calculated EC was higher than the measured EC in August-October of 2009. The average calculated EC increment was 113 μS/cm, and the average measured EC increment was 110 μS/cm for 2009. The average measured salt load increase was 19 tons/day with an average (estimated) net flow of 95 cfs at Tracy Boulevard.

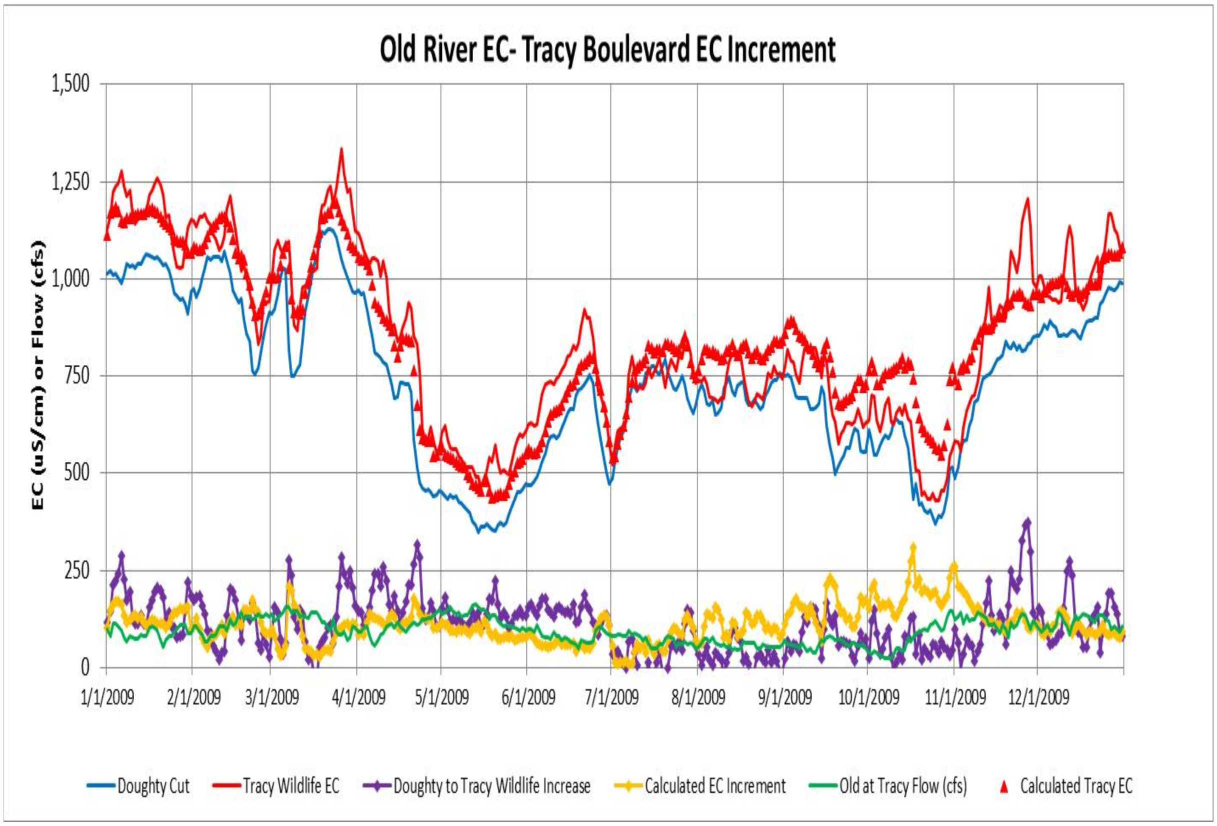


Figure 30a. Comparison of Measured and Calculated Daily EC Increments in Old River at Tracy Boulevard (Tracy Wildlife) in 2009

Figure 30b shows the daily average measured EC in Old River upstream at Doughty Cut (blue line) and downstream at Tracy Wildlife (red line) compared to the calculated EC at Tracy Boulevard (red triangles) from the estimated salt sources in Paradise Cut and Sugar Cut in 2010. The Tracy Boulevard EC was much higher than the Tracy Wildlife EC in the first part of 2010 and was determined to be inaccurate during this period. The bottom of the graph shows the Old River flow at Tracy Boulevard (green line) and the measured EC increment in Old River between Doughty Cut and Tracy Wildlife (purple diamonds) compared to the calculated EC increments (gold diamonds). The seasonal pattern appears to match very well for 2010, although some high EC was measured at Tracy Wildlife that was not calculated. The average calculated EC increment was 100 µS/cm and the average measured EC increment was 103 µS/cm for 2010. The average measured salt load increase was 36 tons/day with an average (estimated) net flow of 200 cfs at Tracy Boulevard.

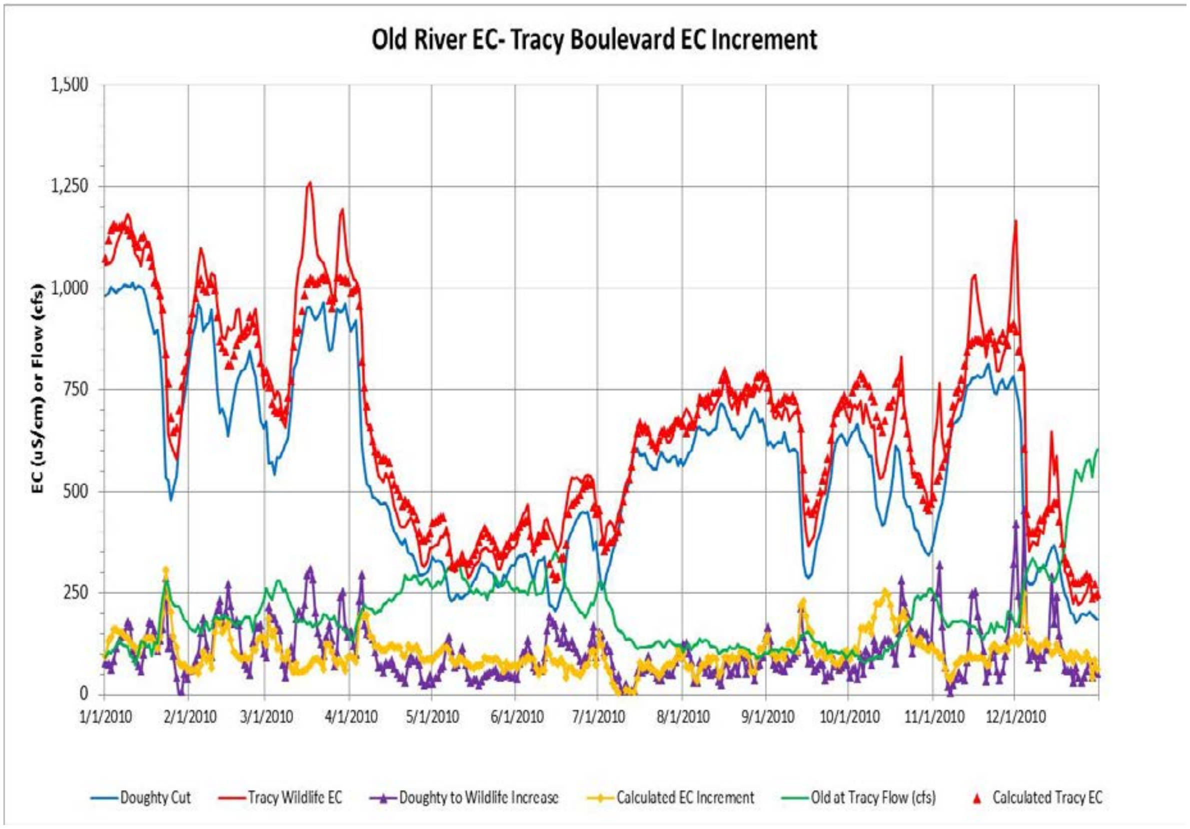


Figure 30b. Comparison of Measured and Calculated Daily EC Increments in Old River at Tracy Boulevard (Tracy Wildlife) in 2010

Figure 30c shows the daily average measured EC in Old River upstream at Doughty Cut (blue line), at Tracy Boulevard (red line), and at Tracy Wildlife (pink line) compared to the calculated EC at Tracy Boulevard (red triangles) from the estimated salt sources in Paradise Cut and Sugar Cut in 2011. The Old River flow at Tracy Boulevard was estimated as 10 percent of the head of Old River flow plus 10 percent of the Paradise Weir flow (in April). The bottom of the graph shows the measured EC increment at Tracy Boulevard (purple diamonds) compared to the calculated EC increments (gold diamonds). The seasonal pattern appears to match very well for 2011; the EC increments were generally reduced in 2011 because the Old River at Tracy Boulevard flows were greater than 500 cfs for most of the year. The average calculated EC increment was 74 μS/cm, and the average measured EC increment was 78 μS/cm for 2011. The average measured salt load increase was 48 tons/day with an average net flow of 710 cfs at Tracy Boulevard.

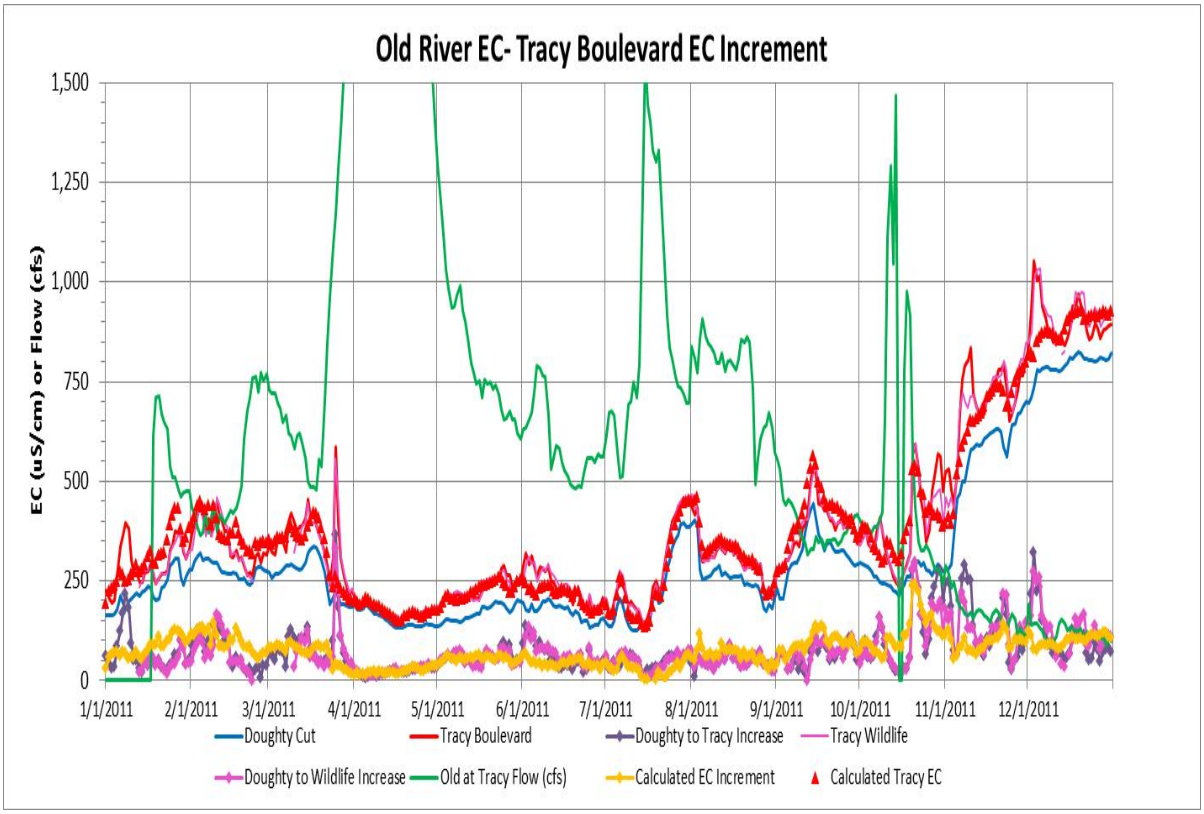


Figure 30c. Comparison of Measured and Calculated Daily EC Increments in Old River at Tracy Boulevard in 2011

Figure 30d shows the daily average measured EC in Old River upstream at the head of Old River (blue line), at Tracy Boulevard (red line), and at Tracy Wildlife (pink line) compared to the calculated EC at Tracy Boulevard (red triangles) from the estimated salt sources in Paradise Cut and Sugar Cut in 2012. The Old River flow at Tracy Boulevard was estimated as 10 percent of the head of Old River flow, with the flow through the culverts and leakage maintaining a flow of more than 500 cfs. The EC at Tracy Boulevard increased dramatically when the Head of Old River barrier was installed in April. The bottom of the graph shows the measured EC increment at Tracy Boulevard (purple diamonds) compared to the calculated EC increments (gold diamonds). The seasonal pattern appears to match reasonably well for 2012, except in April when the measured EC increments were 750 µS/cm. The average calculated EC increment was 85 µS/cm and the average measured EC increment was 170 µS/cm for 2012. The measured EC increments in April could not be calculated from the assumed salinity sources in Paradise Cut and Sugar Cut. Something else (e.g., negative flows in Old River at Tracy Boulevard) apparently caused the high measured EC at Tracy Boulevard and at Tracy Wildlife during the period that the Head of Old River barrier was installed. The average measured salt load increase was 30 tons/day with an average net flow of 157 cfs at Tracy Boulevard.

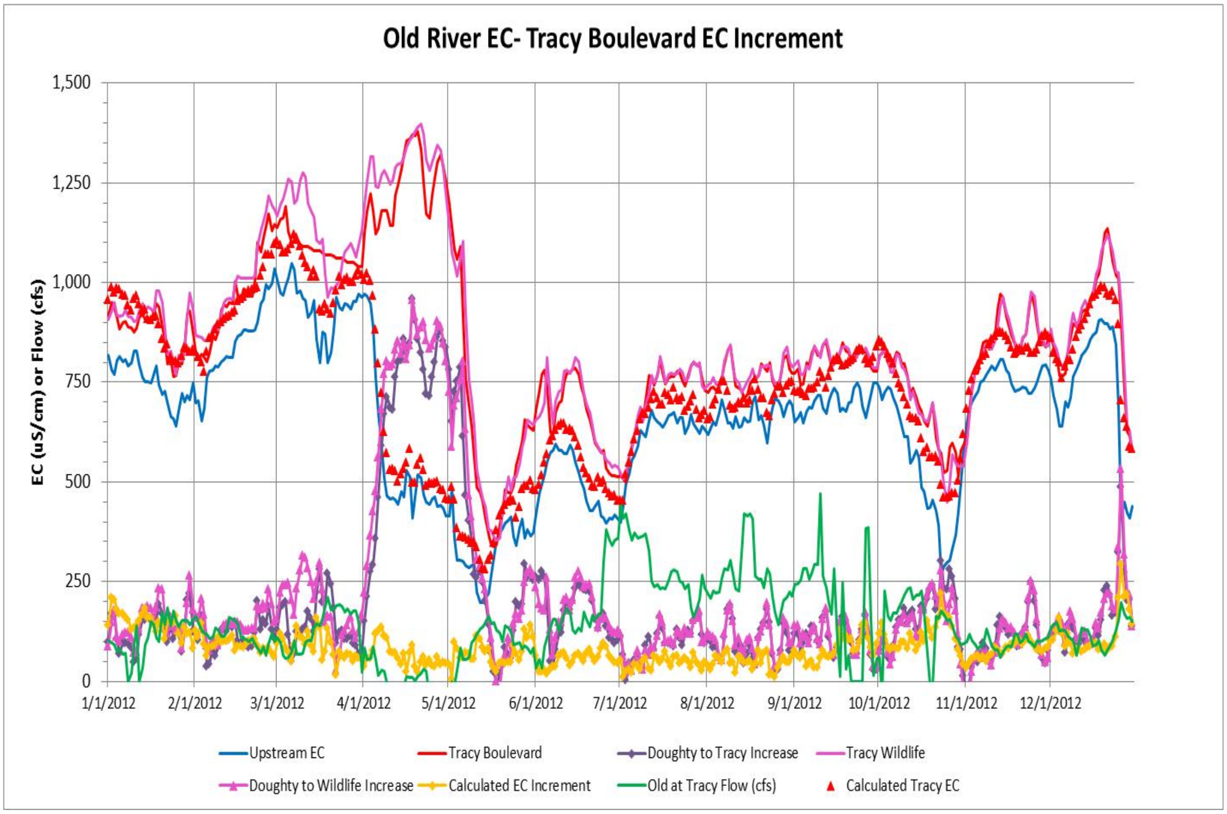


Figure 30d. Comparison of Measured and Calculated Daily EC Increments in Old River at Tracy Boulevard in 2012

Figure 30e shows the daily average measured EC in Old River upstream at Doughty Cut (blue line), at Tracy Boulevard (red line), and at Tracy Wildlife (pink line) compared to the calculated EC at Tracy Boulevard (red triangles) from the estimated salt sources in Paradise Cut and Sugar Cut in 2013. The Old River flow at Tracy Boulevard was measured in 2013 (green line). The bottom of the graph shows the measured EC increment at Tracy Boulevard (purple diamonds) compared to the calculated EC increments (gold diamonds). The seasonal pattern appears to match reasonably well for 2013; some high measured EC increments did not match the calculated EC increments. The average calculated EC increment was 95 µS/cm and the average measured EC increment was 141 µS/cm for 2013. The average measured salt load increment was 29 tons/day with an average net flow of 110 cfs at Tracy Boulevard. These 5 years of measured data in Old River provide a very consistent pattern of increased EC between the Union Island and Tracy Boulevard stations; the calculated EC increments from the box-model provided a very good match with these measured EC increments.

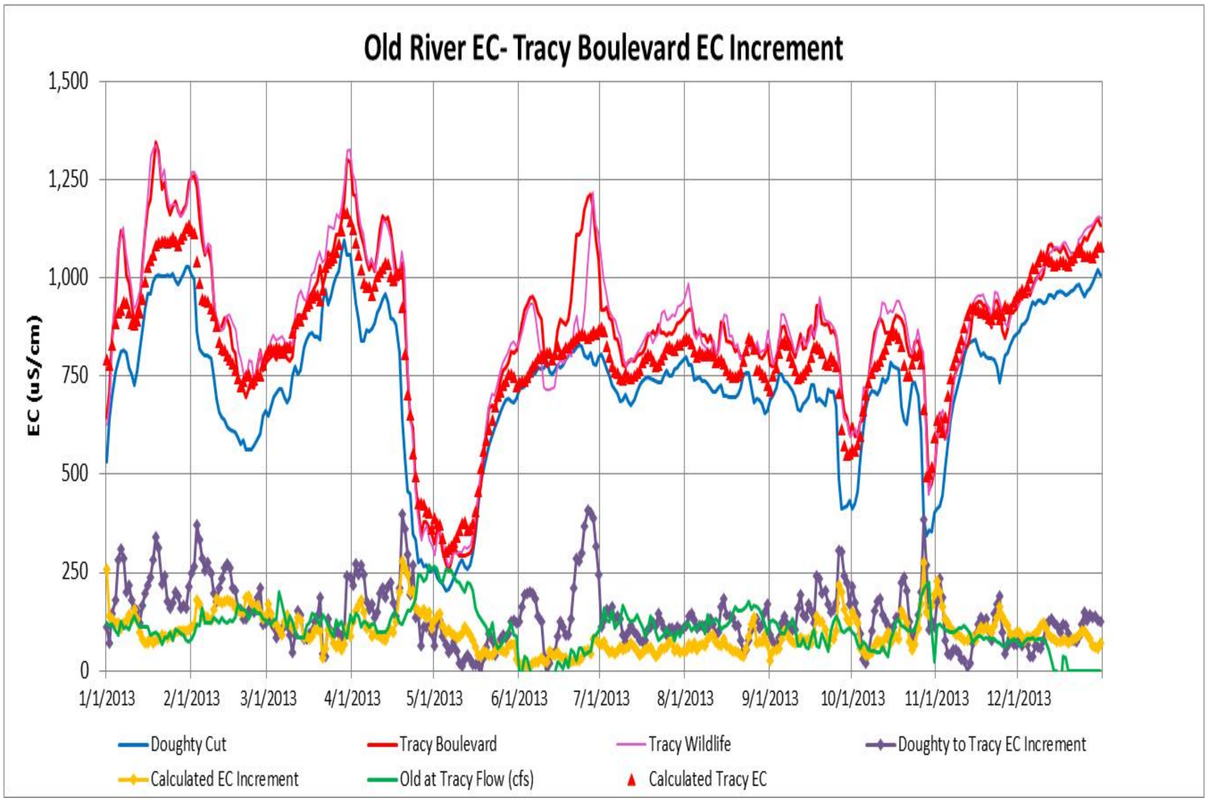


Figure 30e. Comparison of Measured and Calculated Daily EC Increments in Old River at Tracy Boulevard in 2013

Longitudinal EC Measurements in Old River and Paradise Cut

DWR's Division of Operations and Maintenance collected longitudinal EC profiles along Old River in 2009 and 2010 and in Paradise Cut in 2009, to identify salinity sources (high EC) along Old River. These EC profiles in Old River and in Paradise Cut (no EC profiles were measured in Sugar Cut) were combined with the EC monitoring station data as part of this south Delta salinity evaluation project. The tidal EC profiles in Paradise Cut at high tide and low tide are described first, because the tidal flows and movement of water (and EC profiles) were easily estimated from the tidal elevations and the volume of Paradise Cut (tidal slough). The tidal EC profiles in Old River were estimated using the same methods, but the effects of net flow in Old River and diversions to the DMC on the Old River EC profiles require additional calculations.

Paradise Cut EC Profiles

Paradise Cut EC profiles were collected on 14 days between January 29, 2009, and August 20, 2009. On 12 of these days, full EC profiles were measured from the mouth to near the first railroad bridge, about 10 km upstream. The profiles were collected at higher tide elevations so that a boat could be used to collect data as far upstream as possible; hand samples were collected at about six locations upstream from the railroad bridge. Because Paradise Cut is filled with Old River water during flood tide, the higher EC water is shifted upstream. The EC profiles showed much higher EC in the upstream portion (greater than 5 km upstream of the mouth) of Paradise Cut, with lower EC (similar to Old River EC) in the downstream portion (less than 5 km upstream). The EC monitoring station is located near the mouth (1 km upstream), and the highest EC was measured at lower tide elevations (less than 4 feet NAVD). To compare the measured profiles with the EC monitoring station data (daily minimum and maximum), the measured EC profile (for a selected day) was shifted to a low tide and high tide EC profile (for the day) using a simple elevation-water movement procedure. This provided an estimate of the likely movement of the EC profile between high tide and low tide, and allowed the daily maximum and minimum EC at the monitoring station to be compared to the estimated EC profiles at high tide and low tide.

The volume of Paradise Cut between Old River (0 km) and the railroad bridge (10 km) is about 850 af at low tide (2.5 feet NAVD) and 1,525 af at high tide (6.5 feet NAVD). The cumulative volume from the upstream end at high tide is 850 af about 6 km upstream from the mouth; the 675 af tidal volume increase (between low tide and high tide) moves water from the mouth at low tide (850 af from upstream end) to about 6 km at high tide, corresponding to a 4-foot elevation increase. The upstream movement (tidal excursion) from the mouth of Paradise Cut at low tide is about 1.5 km for each 1 feet of tidal elevation change. The movement of water starting at upstream locations is proportional to the distance remaining to the railroad bridge, assuming the Paradise Cut channel surface area and volume (depth) is uniform from the mouth to the railroad bridge (10 km). Water from the mouth moves 6 km upstream for a 4-foot tide rise; water from 5 km moves upstream 3 km (to 8 km upstream from mouth) for a 4-foot tide rise.

The low tide EC profiles were estimated by shifting the measured EC downstream by the estimated tidal movement between the measured elevation and the low tide for the day; the movement was assumed to be linearly increasing with distance from the upstream end. The high tide EC profiles were adjusted in the same way, although the measured EC profiles in Paradise Cut generally were made near high tide for the day, so the upstream shifts to high tide EC profiles generally were smaller. The tidal shifting does not change the maximum measured EC, but the low tide EC profile will be higher than the measured EC profile downstream from the maximum measured EC location.

The measured and shifted EC profiles for Paradise Cut are shown for a few days to illustrate this method; the shifted low tide EC profile should match the daily maximum EC measured at the Paradise Cut station, located 1 km upstream from the mouth. Because the tidal movement of water into Paradise Cut was large (4 to 6 km), the downstream portion of Paradise Cut was filled with Old River water during each flood-tide, and the Paradise Cut EC at the monitoring station generally was high only when the tide elevation was relatively low (less than 4 feet NAVD).

Figure 31a shows the measured (3.3 feet) and shifted (low tide at 2.7 feet and high tide at 5.4 feet) Paradise Cut EC profiles on February 10, 2009. The measured EC at the mouth was 1,000 µS/cm, increased to 1,500 µS/cm at 4 km, and increased to about 2,500 µS/cm between 7 km and 10 km. The low tide EC essentially was the same as the measured EC (0.6 feet difference), but the high tide EC profile was shifted by about 3 km (2.7 feet difference), so that the shifted EC profile was 1,000 µS/cm at 3 km and 1,500 µS/cm at 6 km. The maximum EC at the monitoring station was about 1,250 µS/cm, which matched the measured and low tide EC profiles.

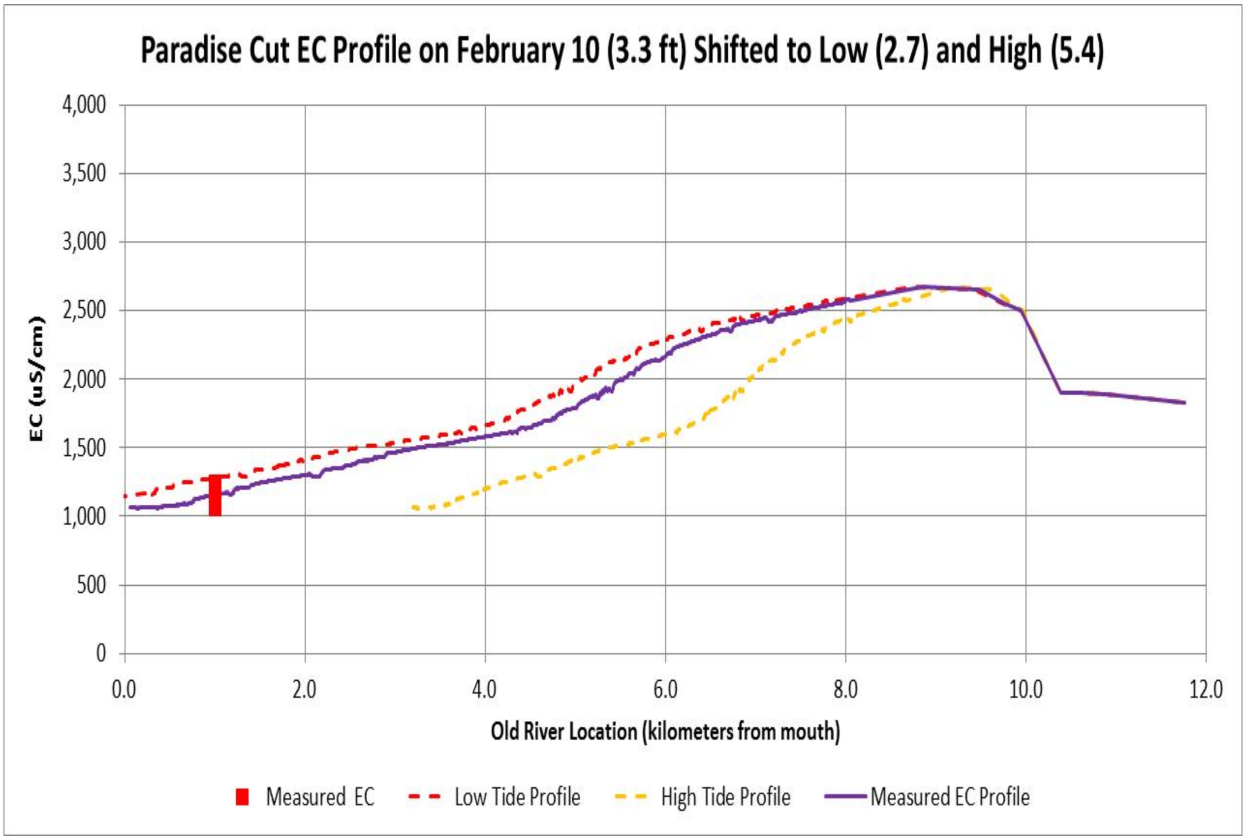


Figure 31a. Measured and Shifted (low and high tide) Paradise Cut EC Profiles on February 10, 2009

Figure 31b shows the measured (4.5 feet) and shifted (low tide at 2.0 feet and high tide at 5.3 feet) Paradise Cut EC profiles on March 16, 2009. The measured EC was 1,000 µS/cm from the mouth to 2 km, was 2,000 µS/cm at 6 km, and increased to about 3,000 µS/cm between 9 km and 10 km. The high tide EC essentially was the same as the measured EC (0.8 feet difference), but the low tide EC profile was shifted by about 4 km (2.5 feet difference), so that the shifted EC profile was 1,500 µS/cm at 0 km and 2,500 µS/cm at 5 km. The maximum EC at the monitoring station was about 1,500 µS/cm, which matched the low tide EC profile.

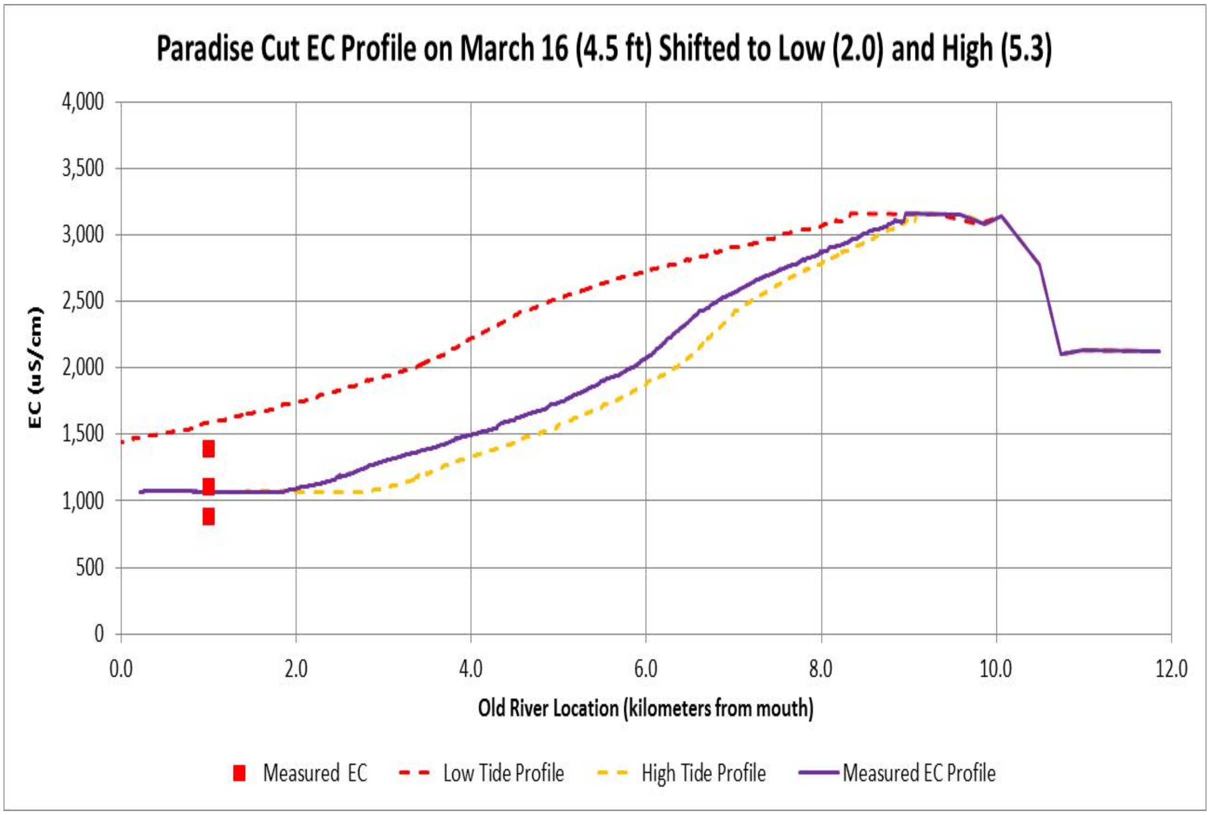


Figure 31b. Measured and Shifted (low and high tide) Paradise Cut EC Profiles on March 16, 2009

Figure 31c shows the measured (5.7 feet) and shifted (low tide at 2.0 feet and high tide at 5.9 feet) Paradise Cut EC profiles on April 1, 2009. The measured EC was 1,000 µS/cm from the mouth to about 5 km and increased to about 3,000 µS/cm between 8 km and 10 km. The high tide EC essentially was the same as the measured EC (0.2 feet difference), indicating that the measured EC profile was collected at high tide. The low tide EC profile was shifted by about 5 km (3.7 feet difference), so that the shifted EC profile was 1,500 µS/cm at 2 km and 2,500 µS/cm at 6 km. The maximum EC at the monitoring station was about 1,250 µS/cm, which matched the shifted low tide EC profile.

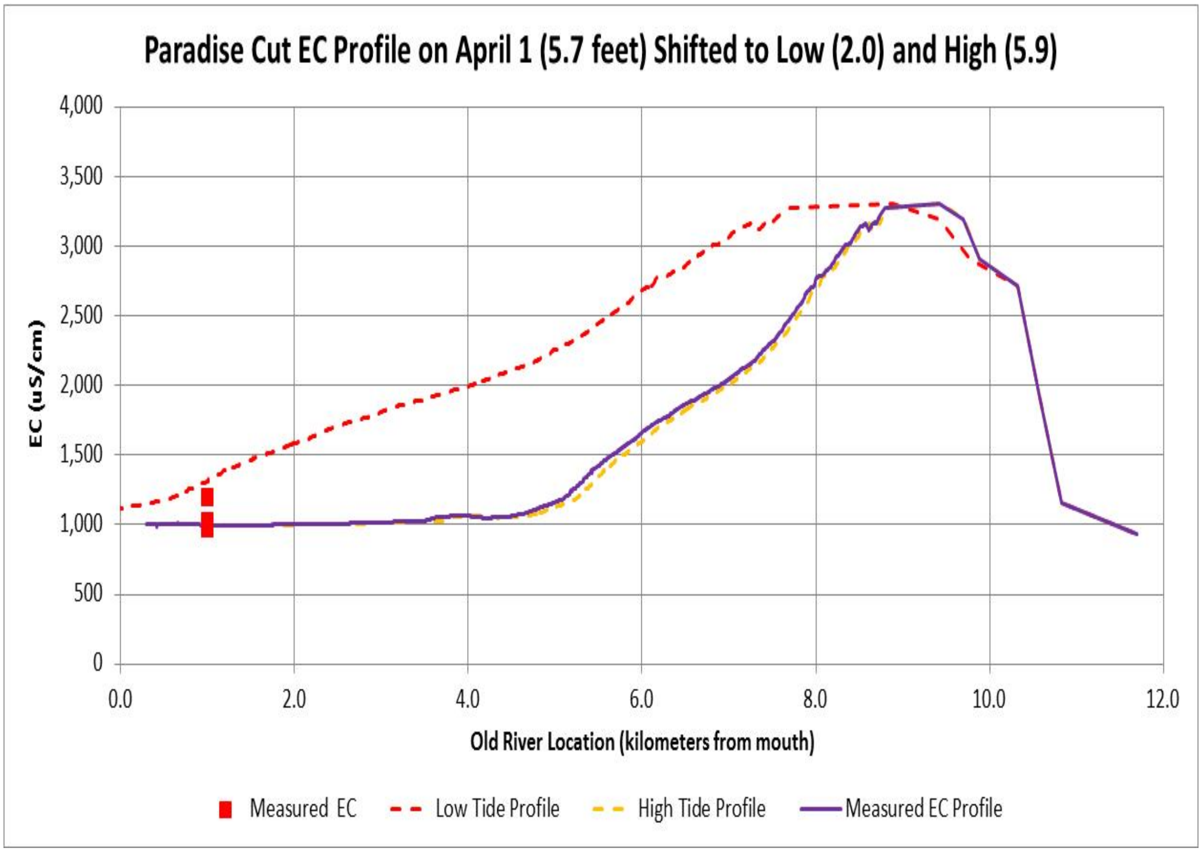


Figure 31c. Measured and Shifted (low and high tide) Paradise Cut EC Profiles on April 1, 2009

Figure 31d shows the measured (4.2 feet) and shifted (low tide at 1.5 feet and high tide at 4.9 feet) Paradise Cut EC profiles on April 16, 2009. The measured EC was 750 µS/cm from the mouth to about 2 km and increased to about 2,500 µS/cm between 7 km and 9 km. The high tide EC shifted slightly (0.7 feet difference). The low tide EC profile shifted by about 4 km (3.5 feet difference), so that the shifted EC profile was 1,500 µS/cm at the mouth and 2,500 µS/cm at 4 km. The maximum EC at the monitoring station was about 1,600 µS/cm, which matched the shifted low tide EC profile (1,700 µS/cm); the mean EC was slightly higher than the minimum of 700 µS/cm, indicating that the higher EC was measured for only a short period.

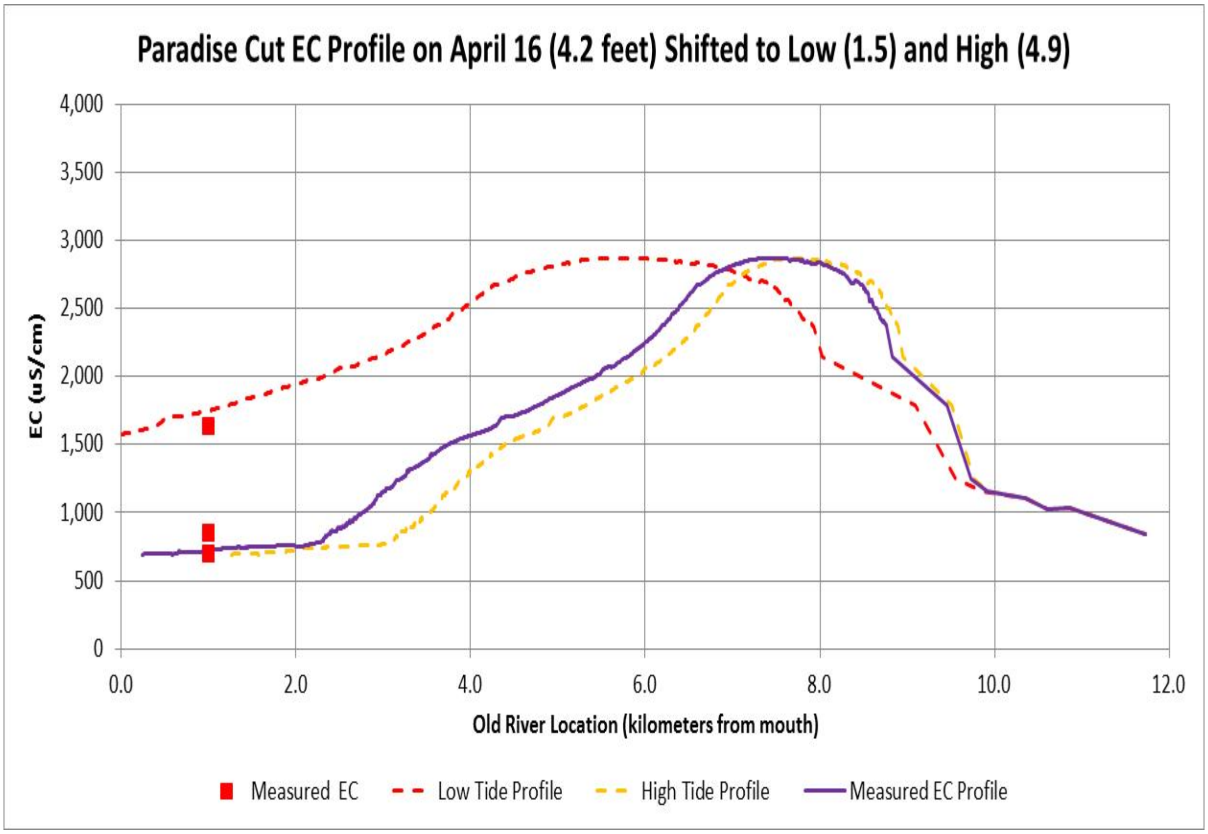


Figure 31d. Measured and Shifted (low and high tide) Paradise Cut EC Profiles on April 16, 2009

Figure 31e shows the measured (5.7 feet) and shifted (low tide at 2.4 feet and high tide at 6.4 feet) Paradise Cut EC profiles on April 28, 2009. The measured EC was 500 µS/cm from the mouth to about 3 km and increased to about 2,500 µS/cm between 8 km and 9 km. The high tide EC shifted slightly (0.5 feet difference). The low tide EC profile shifted by about 5 km (3.3 feet difference), so that the shifted EC profile was 1,400 µS/cm at the mouth and 2,500 µS/cm at 5 km. The maximum EC at the monitoring station was about 1,100 µS/cm, which was less than the shifted low tide EC profile; the minimum EC and mean EC were both about 500 µS/cm, indicating that the higher EC was measured for only a small part of the day.

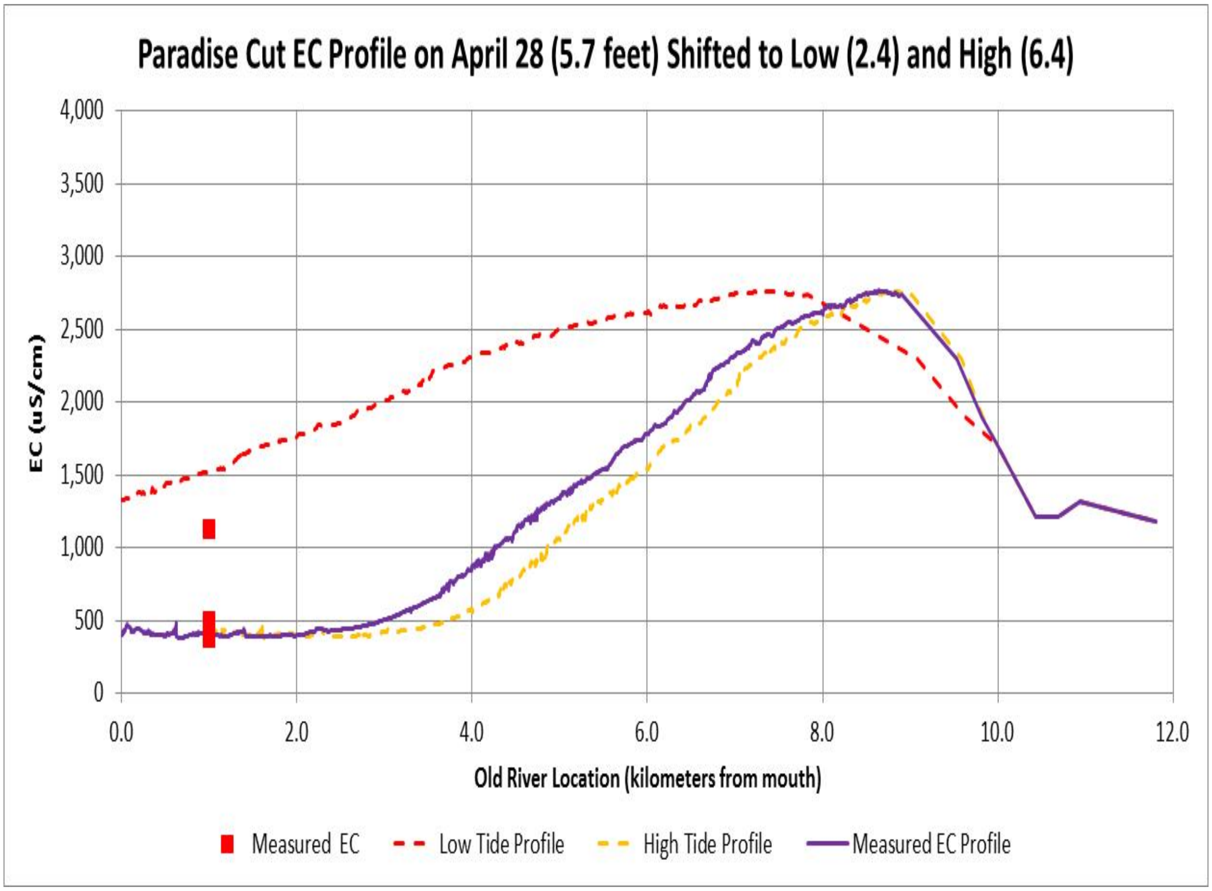


Figure 31e. Measured and Shifted (low and high tide) Paradise Cut EC Profiles on April 28, 2009

Figure 31f shows the measured (5.3 feet) and shifted (low tide at 2.1 feet and high tide at 5.7 feet) Paradise Cut EC profiles on May 14, 2009. The measured EC was 300 µS/cm from the mouth to about 3 km and increased to about 2,500 µS/cm between 8 km and 9 km. The high tide EC shifted slightly (0.4 feet difference). The low tide EC profile shifted by about 5 km (3.2 feet difference), so that the shifted EC profile was 1,000 µS/cm at the mouth and 2,500 µS/cm at 6 km. The maximum EC at the monitoring station matched the shifted low tide EC profile.

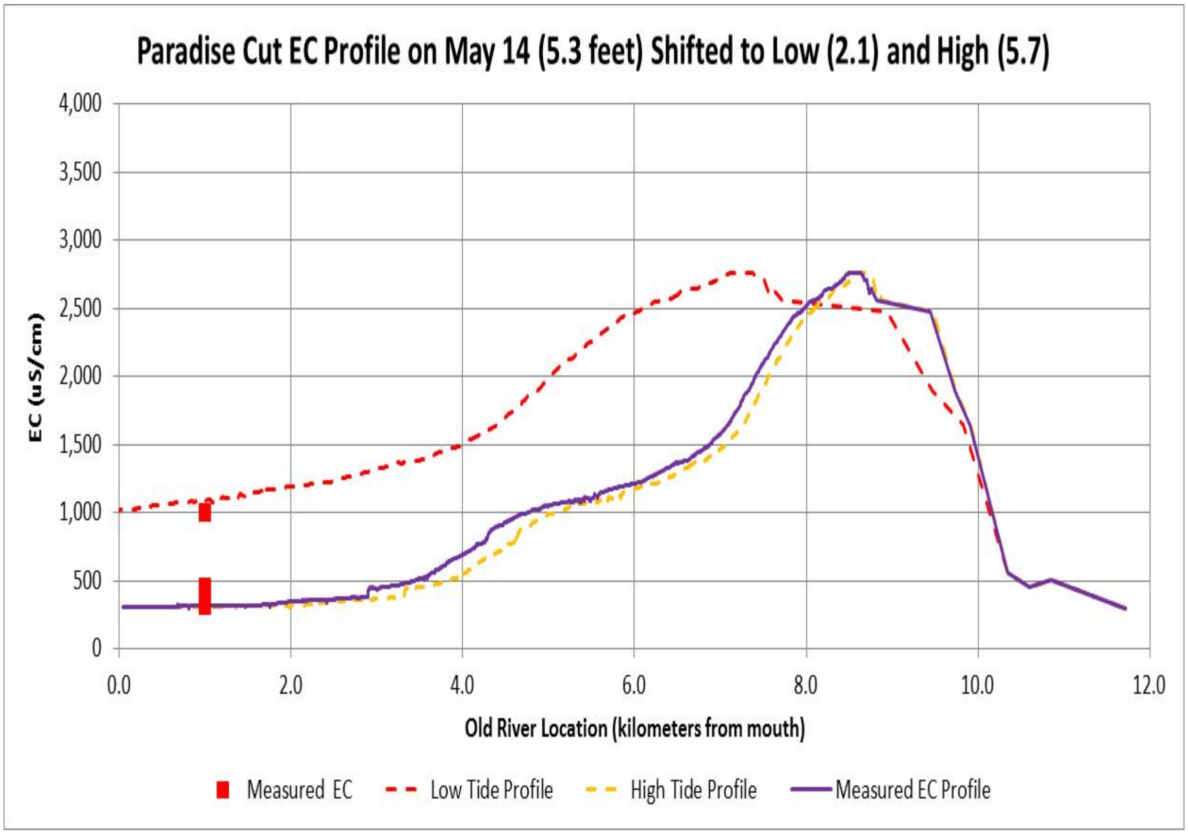


Figure 31f. Measured and Shifted (low and high tide) Paradise Cut EC Profiles on May 14, 2009

The EC profiles in Paradise Cut that were measured from January through June 2009 indicated tidal conditions without the temporary barriers, which were fully operational (with flap gates) in early July. The tidal range was generally 4 feet, and the downstream portion of Paradise Cut EC always was the same as the Old River EC because of the full tidal filling with Old River water. The maximum EC at the upstream end of Paradise Cut decreased in April, May, and June (3,500 µS/cm on April 1 and 2,000 µS/cm on June 23). The reduction in the peak EC likely was the result of a combination of flushing and tidal mixing with lower EC Old River water during the SJR pulse flow period, and perhaps a reduced inflow of high salinity water at the upstream end of Paradise Cut.

Three EC profiles measured during the period with temporary barriers had much less tidal movement, because the range of tidal elevations was less. The maximum EC in Paradise Cut was about 1,500 µS/cm for these three EC profiles, which was much less than the peak EC of 3,500 µS/cm measured on April 1 before the SJR pulse flow. The EC profiles were more spread out, with slightly higher EC from about 2 km to 8 km at high tide. The reduced peak EC and more spread out EC profiles likely were the result of tidal mixing along Paradise Cut without as much tidal exchange with Old River, and perhaps reduced inflow of higher salinity water to Paradise Cut. If the summer inflow of high salinity water had remained the same as in the winter period, the peak EC in Paradise Cut likely would have remained similar.

Old River EC Profiles

Old River EC profiles were measured by DWR in 2009 and 2010 to identify salinity sources along Old River between the Union Island EC station (Old River at 70 km upstream of the mouth at the SJR) and the DMC intake (Old River at 45 km). Each boat survey took about two hours. Most of the EC profiles identified sources of salinity (EC increases) in the vicinity of Paradise Cut (Old River at 63.5 km), Sugar Cut (Old River at 63 km), and Tracy Boulevard (Old River at 59 km). The Old River EC profiles often showed much lower salinity at the downstream end of the profile in the vicinity of the DMC barrier location. This lower salinity likely was caused by the tidal movement of lower EC water from Old River downstream from Grant Line Canal, which was flowing from the central Delta to the CCF intake (SWP pumping) and the DMC intake (CVP pumping). Tidal movement in Old River upstream from the DMC intake is similar to the tidal movement in Paradise Cut. Very little tidal flow (movement) occurs at Tracy Boulevard, because of the net flow in Old River and because the channel is constricted (shallow) between Tracy Boulevard and Doughty Cut. The tidal shifting of the measured EC profiles assumed that the tidal movement extended from the DMC intake (greatest) to Tracy Boulevard (least).

The volume of the Old River channel between the DMC barrier and Tracy Boulevard is about 1,350 af at low tide and 2,350 af at high tide (DSM2 geometry file). A tidal volume of 1,000 af is sufficient to move water from the DMC intake (45 km) at low tide (2.5 feet NAVD) to about 51 km (6 km upstream) at high tide (6.5 feet NAVD). However, the net flow in Old River causes the ebb-tide flow (downstream movement) to be greater than the flood-tide flow (upstream movement). Therefore, the tidal movement in Old River at the DMC intake was calculated assuming 2.0 km for each 1 feet of tidal elevation change. The movement of water at upstream locations was proportional to the distance remaining to Tracy Boulevard, assuming the Old River channel surface area and volume (depth) was uniform from the DMC to Tracy Boulevard (59 km).

The measured EC profiles, collected at a particular tidal elevation, were shifted downstream to the minimum tide elevation for the day and were shifted upstream to the maximum tide elevation for the day. The shifted low tide EC profile was expected to match the daily maximum EC at the DMC barrier stations. The shifted high tide EC profile was expected to match the daily minimum EC at the downstream stations. The measured EC at the Old River monitoring stations were compared with the EC profiles by showing the minimum, average, and maximum EC for the day (red boxes). The EC profiles started at the head of Middle River (Union Island EC station) at Old River at 70 km with the Doughty Cut EC station located at Old River at 64 km, the Tracy Boulevard EC station located at Old River at 59 km, the EC station upstream from DMC barrier located at Old River at 46.5 km, the EC station downstream from DMC barrier located at Old River at 46.25 km, and the DMC intake EC station located at Old River at 45 km.

Figure 32a shows the measured and shifted Old River EC profiles on February 25, 2009, referenced by the Old River location (km from the mouth). The measured EC profile was collected at 4 feet, while the low tide was 2.3 feet and the high tide was 5.1 feet. The measured EC profile was about 625 µS/cm at 46 km (downstream end of EC profile) and increased to greater than 1,000 µS/cm between 50 km and 53 km. There were some moderate increases in EC (100-250 µS/cm) measured in the EC profile ("EC slugs") near the Tracy Boulevard EC station at 59 km and upstream at 61 km. The EC profile matched the measured Union EC and Doughty Cut EC, with only a small daily range between the minimum EC and maximum EC at these stations. The calculated tidal shift in the low tide EC profile at the DMC intake was about 3 km, so the maximum EC at the DMC barrier was increased to 900 µS/cm. However, the maximum measured EC at the DMC stations was 1,200 µS/cm. The tidal shift would need to be about 0.5 km more to match the maximum EC. The high tide EC profile was shifted about 1.5 km upstream. The green line with boxes indicates the downstream net movement of water from the Tracy Boulevard station, with the corresponding daily average Tracy Boulevard EC from the previous days. The travel time to the DMC intake was about 10 days, and the EC at Tracy was higher on these previous days.

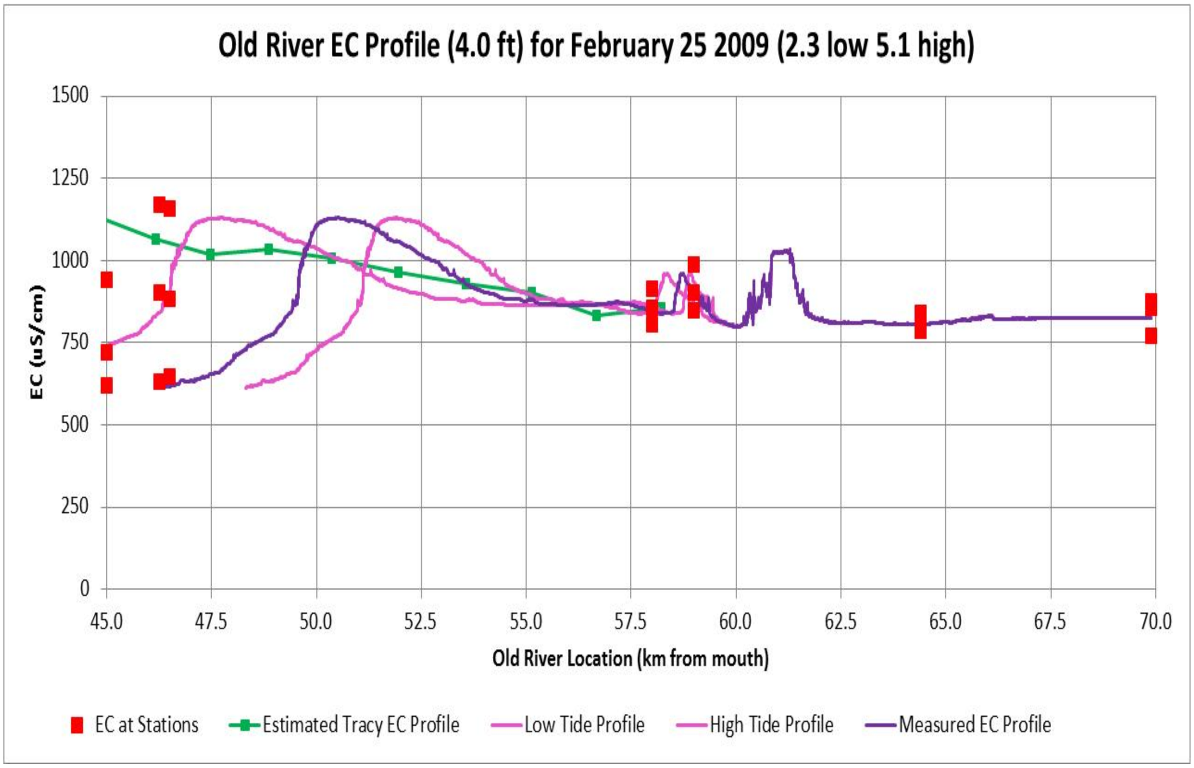


Figure 32a. Measured and Shifted Low Tide and High Tide EC Profiles in Old River between Middle River (70 km) and the DMC Intake (45 km) on February 25, 2009

Figure 32b shows the measured and shifted Old River EC profiles on March 16, 2009. The measured EC profile was collected at 4.9 feet, while the low tide was 1.8 feet and the high tide was 5 feet. The measured EC was about 375 µS/cm at 46 km, 500 µS/cm at 50 km, increased to more than 1,000 µS/cm at 51 km (steep EC gradient), and was 1,100 µS/cm upstream to Union EC station at 70 km. No large increase in Old River EC between Union and Tracy Boulevard was measured by this EC profile. The EC profile matched the measured EC at the three upstream stations. The calculated tidal shift in the low tide EC profile at the DMC intake was about 6 km, so the maximum EC at the DMC barrier was increased to 1,100 µS/cm, which matched the daily maximum EC measured at the DMC stations. The net flow in Old River at Tracy Boulevard increased the downstream movement of the higher EC water during ebb-tides. The DMC diversion is the most likely cause of this very strong EC gradient; the high EC in Old River upstream of the DMC is moving downstream past the DMC intake at low tide and the DMC pumping diverts this water, and also diverts much lower EC water from downstream, as the flood tide begins. Therefore, the salinity gradient is reinforced by the DMC diversion during each low tide period.

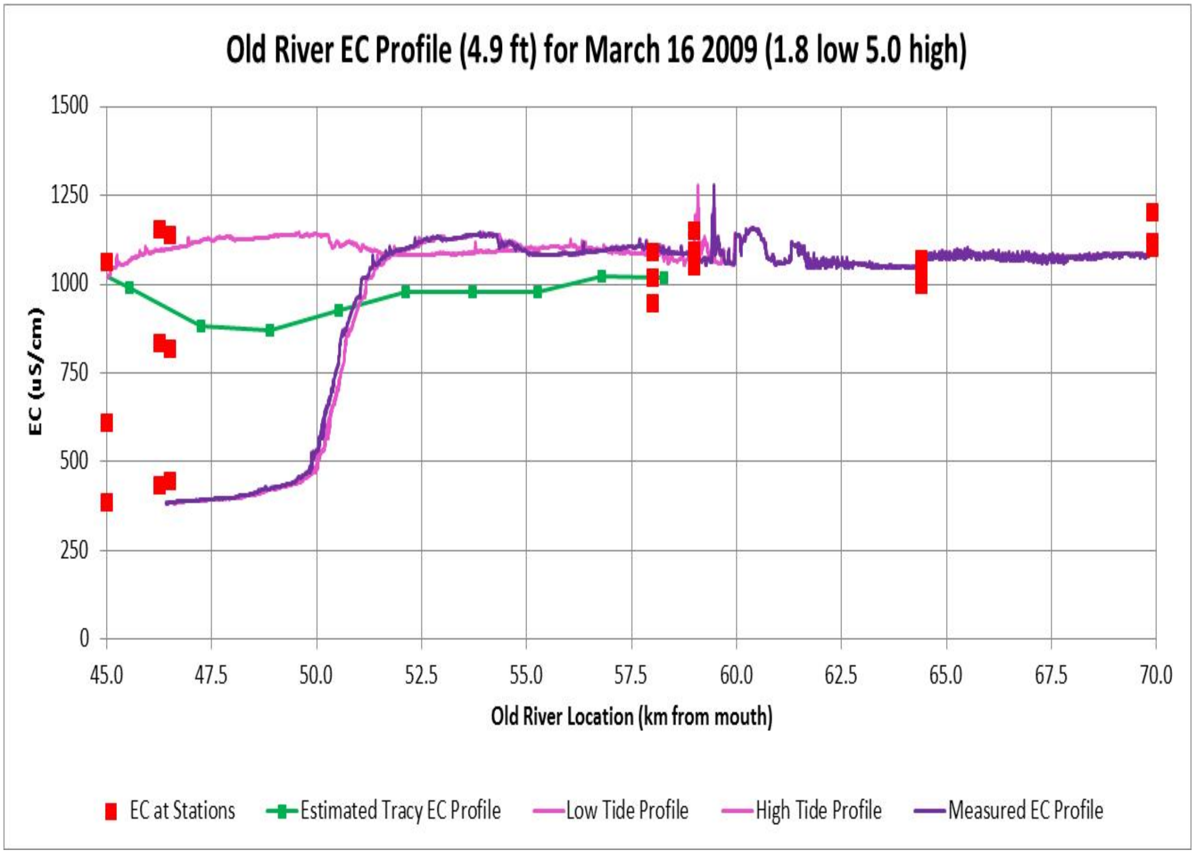


Figure 32b. Measured and Shifted Low Tide and High Tide EC Profiles in Old River between Middle River (70 km) and the DMC Intake (45 km) on March 16, 2009

Figure 32c shows the measured and shifted Old River EC profiles on April 1, 2009. The measured EC profile was collected at 5.1 feet, while the low tide was 1.8 feet and the high tide was 5.7 feet. The measured EC was about 300 µS/cm between 46 km and 50 km, increased to 1,350 µS/cm at 54 km (very steep EC gradient), decreased to 1,000 µS/cm at 62.5 km, and was 1,000 µS/cm upstream to Union EC station at 70 km. No large increase in Old River EC between Union and Tracy Boulevard was measured by this EC profile, but the EC increased substantially downstream from Tracy Boulevard. The green line and boxes indicate that the Tracy EC was higher on previous days, but the measured EC was higher than the green line, suggesting another source of higher EC water downstream of Tracy Boulevard. The EC profile matched the measured EC at the three upstream stations. The calculated tidal shift in the low tide EC profile at the DMC intake was about 7 km and the maximum EC at the DMC barrier increased to 1,000 µS/cm, which almost matched the daily maximum EC of 1,200 µS/cm at the DMC barrier stations. The tidal movement at low tide apparently was a little more than calculated, but the very large tidal movement of water in this section of Old River was verified. The tidal movement was about 5 km upstream during each flood tide and was likely about 6 km downstream during each ebb-tide (the net flow increased the ebb-tide movement).

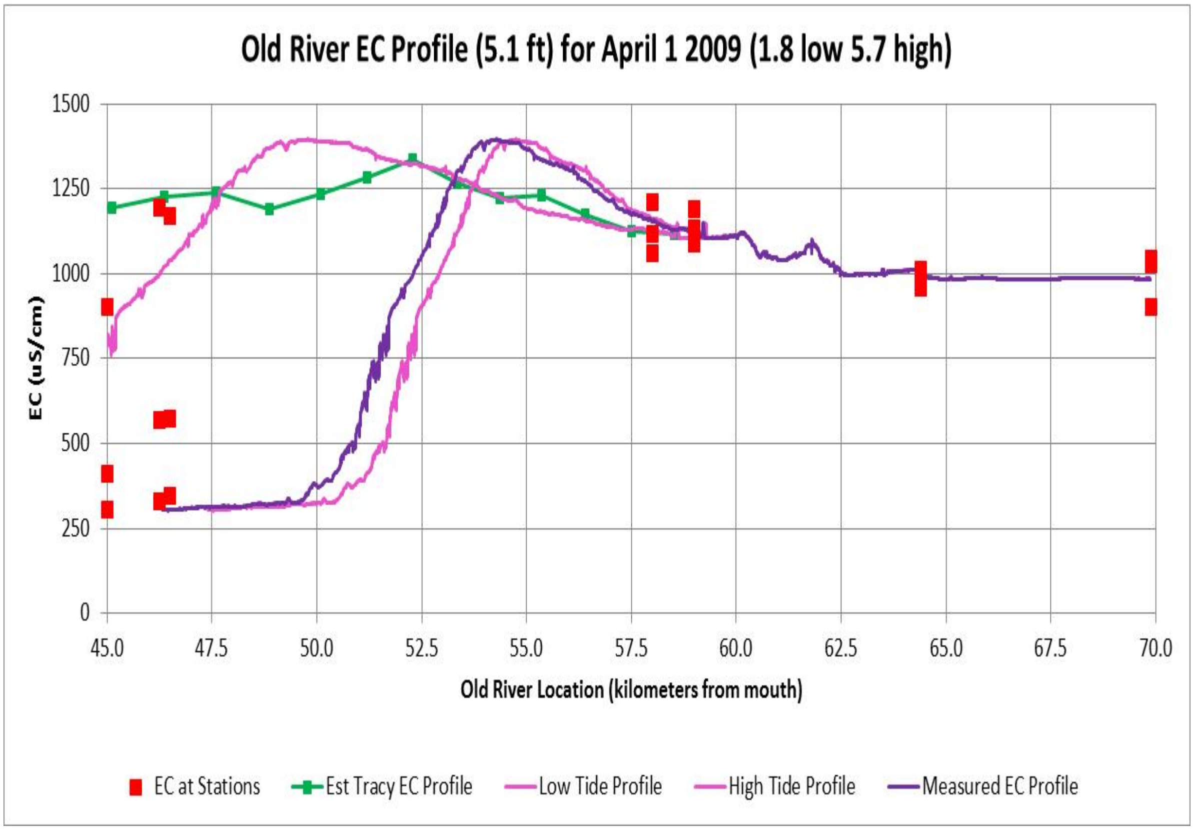


Figure 32c. Measured and Shifted Low Tide and High Tide EC Profiles in Old River between Middle River (70 km) and the DMC Intake (45 km) on April 1, 2009

This large tidal movement in Old River near the DMC barrier and the large EC gradient (high EC upstream, low EC downstream) indicates the potential salinity-reduction benefits in Old River upstream of the DMC (including at Tracy Boulevard) that would likely result from a tidal gate at this location, as was proposed by the SDIP. The large EC differences often observed in Old River upstream and downstream of the DMC intake are likely the result of export pumping that causes a net upstream tidal flow of Sacramento River water in Old River upstream of Franks Tract and in Middle River and Victoria Canal upstream of the SJR. If the proposed Old River at DMC tidal gate was opened at low tide, the flood-tide volume would fill the Old River channel with water from downstream of the DMC, which often has a lower EC. Lower salinity water would move upstream about 5 km during each flood tide. The proposed tidal gate would close at high tide and the ebb-tide flow in Old River would move water upstream another 5 km past Tracy Boulevard, Sugar Cut, and Paradise Cut to Doughty Cut and would flow downstream to Grant Line Canal. This would create a very strong water circulation (upstream in Old River and downstream in Grant Line Canal) that would reduce the salinity measured at Tracy Boulevard to about the Old River EC exported at the DMC and CCF intakes. This likely would be a very effective salinity-reduction alternative.

Sources of Flow and Salinity (EC) in the CVP and SWP Exports

The sources of flow and salinity (EC) in the CVP and SWP exports can be compared and evaluated from the daily average flow and EC data calculated in the Data Atlas files for 2009-13. The seasonal pattern of flow and EC from each water source also provides a framework for understanding potential salinity-reduction alternatives. There are only two basic water sources for the CVP and SWP exports: the Sacramento River at Freeport and the SJR at Vernalis. The Sacramento River at Freeport has the lowest EC, with an EC range of 100-250 μS/cm. The SJR at Vernalis generally has a higher EC, ranging from 250 to 1,250 μS/cm. Agricultural drainage and shallow groundwater seepage from irrigated land in the south Delta, including the salt sources in Paradise Cut and Sugar Cut, will cause the SJR EC to increase as it flows downstream to the head of Old River and downstream in Old River and Grant Line Canal to the exports. The SJR flow usually increases the EC of the CVP and SWP exports, because the SJR EC is usually higher than the Sacramento River EC. The majority of the SJR water diverted into Old River is generally pumped into the DMC, because the SJR water in Old River and Grant Line Canal flows past the DMC intake before reaching the CCF intake, located just downstream from the mouth of Grant Line Canal.

The two major channels that convey Sacramento River water to the exports are Old River and Middle River. Agricultural drainage from irrigated lands within the Delta and seawater intrusion will cause the Sacramento River EC to increase as it is tidally transported across the Delta (i.e., north to south) to the exports. The Old River at Bacon EC and the Middle River at Bacon EC are often 200-250 μS/cm, similar to the Sacramento River EC. But the Old River at Bacon EC is sometimes much higher than the Sacramento River EC, because seawater intrusion causes the Old River at Bacon EC to increase when Delta outflow is less than about 5,000 cfs. The Middle River at Bacon EC can also be increased somewhat by seawater intrusion. Middle River at Bacon EC can also be increased by the SJR EC, because some of the SJR flow continues past the head of Old River to Stockton and some is diverted to Middle River through Turner Cut, Columbia Cut, or at the mouth of Middle River.

The contributions of the three major salt sources (i.e., Sacramento River, SJR, and seawater intrusion) to the EC and total salt load (tons/day) of the CVP and SWP exports can be evaluated by assuming that the lowest possible EC from the Sacramento River (with some agricultural drainage) would be about 250 µS/cm. Any water source with EC greater than 250 µS/cm will contribute an additional (incremental) salt load equal to the flow times the incremental EC of the source (i.e., Source EC – 250 µS/cm) times a conversion factor. Assuming that all of the SJR water was exported, the incremental salt load in the exports from the SJR inflow was calculated as:

SJR Incremental Salt (tons/day) = 0.00175 x SJR Flow (cfs) x [SJR EC (µS/cm) – 250]

The incremental salt load in the exports from seawater intrusion can be estimated by assuming that seawater intrusion will increase the lower SJR at Jersey Point EC and move into Franks Tract through Dutch Slough and False River to increase Old River at Bacon EC and Middle River at Bacon EC. The seawater intrusion incremental salt load in the exports, when the Old and Middle River net flow was reversed (upstream), was calculated as:

Seawater Salt (tons/day) = 0.00175 x {Old River Flow (cfs) x [Old River EC (µS/cm) - 250]
+ Middle River Flow (cfs) x [Middle River EC (µS/cm) – 250]}

The incremental salt loads from each source can also be compared with the export EC increments; the Sacramento River water EC was assumed to be 250 µS/cm. The daily export EC increment from the SJR, when the SJR flow was less than the exports, was calculated as:

EC from SJR (µS/cm) = SJR (cfs) / Exports (cfs) x [SJR EC (µS/cm) – 250]

The daily export EC increment from seawater intrusion, when Old and Middle River flow was reversed, was calculated as:

EC from Seawater (µS/cm) = Old + Middle Flow (cfs) / Exports (cfs) x [Flow-weighted Old
and Middle EC (µS/cm) – 250]

Because some of the SJR flow is mixed with Middle River flow, some of the SJR EC increment was also measured in the Middle River at Bacon EC, so the EC increment from seawater intrusion was likely less than calculated with these simple equations. The daily patterns of calculated EC increments (and salt loads) from the SJR and from seawater intrusion provided an accurate evaluation of the salt sources in the exports.

Because the salt contributions from agricultural drainage and wastewater discharges are distributed throughout the Delta, the total contribution from these salt sources cannot be estimated, because seawater intrusion is likely a larger salt source, which cannot be separately estimated from the Old River at Bacon and Middle River at Bacon EC measurements. However, the general magnitude of the incremental EC from wastewater discharges and agricultural drainage in the CVP and SWP exports can be identified as follows. The combined wastewater discharges to the Delta are about 250 cfs, dominated by the Sacramento Regional discharge of about 180 cfs and the Stockton discharge of about 50 cfs. About 50 percent was assumed to reach the exports (50 percent mixed with the Delta outflow). If the average wastewater EC was 1,250 µS/cm, the wastewater EC increment in the exports would be:

Wastewater EC Increment (µS/cm) = 125 (cfs) / Exports (cfs) x 1,000 (µS/cm)

The estimated wastewater EC increment would therefore be about 25 µS/cm with exports of 5,000 cfs and 12.5 µS/cm with exports of 10,000 cfs.

The combined agricultural drainage EC increment in the exports can be identified in a similar way. The annual average channel depletions (for evaporation and crop transpiration, ET) were estimated (from DAYFLOW) to be about 2,300 cfs; the drainage flow was assumed to be 25 percent of ET

(575 cfs), and about 65 percent (375 cfs) was assumed to reach the exports (35 percent mixed with Delta outflow). The average EC of the drainage water would be about four times the applied EC (e.g., 1,000-2,000 μS/cm). If the average agricultural drainage EC was assumed to be 1,500 μS/cm, the agricultural drainage EC increment in the exports would be:

Agricultural Drainage EC Increment (μS/cm) = 375 (cfs) / Exports (cfs) x 1,500 (μS/cm)

The estimated agricultural drainage EC increment would be about 110 μS/cm with exports of 5,000 cfs and about 55 μS/cm with exports of 10,000 cfs. However, the wastewater and agricultural drainage EC increments cannot be reliably estimated from the measured flow and EC data; they are included in the estimated seawater intrusion EC increments.

The daily incremental salt sources and EC increments from the three major sources were calculated for each of the study years (2009-13) and the daily patterns are illustrated in the daily graphs shown below. The average (export-weighted) EC increments provide a summary of the contributions from the three salt sources for each year. High flow years with higher exports will have a higher total salt load (tons/day), but the majority of the salt load will originate from Sacramento River water with an average EC of 250 μS/cm assumed. During low flow years, the EC increments from the SJR and from seawater intrusion (including wastewater and agricultural drainage) will be greater and will provide a larger fraction of the total exported salt load. For example, if the calculated SJR EC increment was 250 μS/cm, the higher SJR EC would double the export EC and salt load; if the calculated seawater intrusion EC increment was 250 μS/cm, seawater intrusion in Old and Middle Rivers would double the export EC and salt load.

Figure 33a shows a two panel graph of daily EC (top) and daily flow (bottom) for 2009. The daily flows shown in the bottom panel compare the combined CVP and SWP exports with the daily SJR flow at Vernalis and the net upstream (reversed) Old and Middle River flows. The SJR flow and total exports are accurately measured; the Old and Middle River flows are more difficult to measure (high tidal flows) and daily net flows have a strong spring-neap tidal variation. The daily Old and Middle River net (reversed) flows can be estimated as the exports plus the south Delta channel depletions (maximum of about 1,000 cfs in the summer) and Contra Costa Water District (CCWD) diversions from Old River and Victoria Canal intakes (maximum of 250 cfs), minus the head of Old River diversions. The exports were generally low (2,500 cfs to 5,000 cfs) from January to June, and increased to about 10,000 cfs in July and decreased to about 5,000 cfs in November and December of 2009. The SJR flows were less than 2,500 cfs for the entire year. All of the SJR flows were exported in 2009 because the exports were greater than the SJR flows.

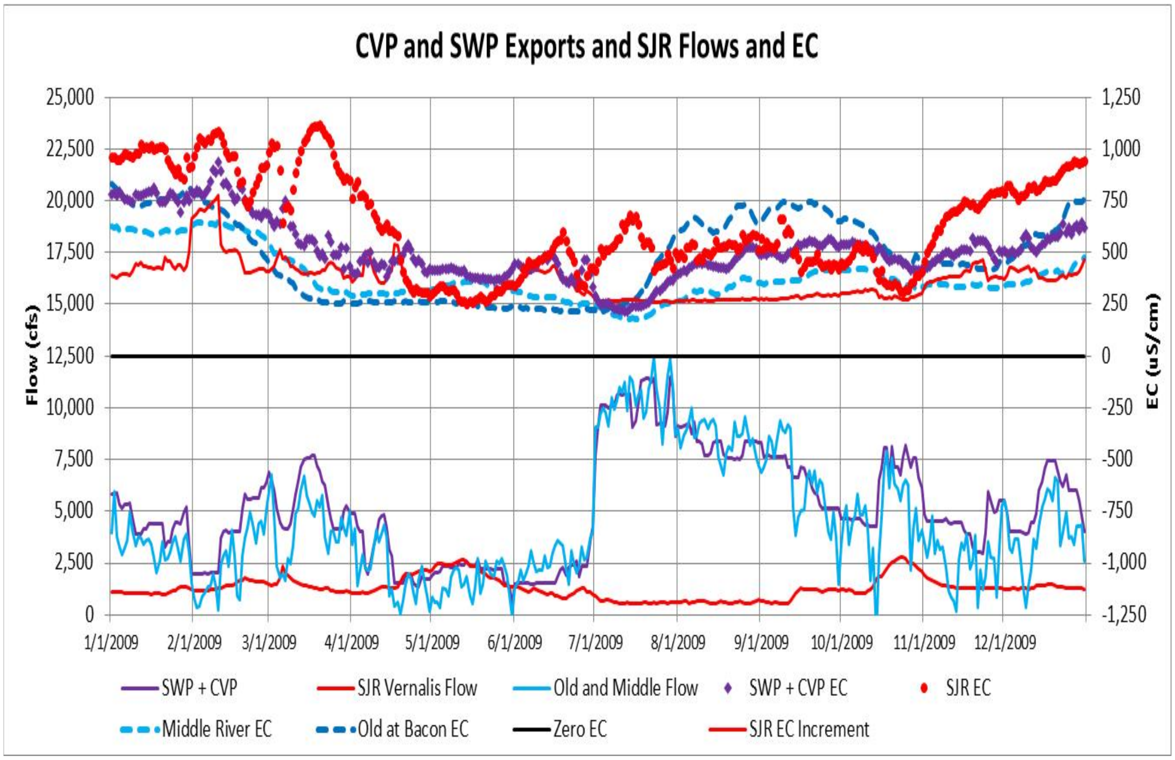


Figure 33a. Measured SJR Flows and EC, CVP and SWP Exports and EC, Old and Middle River Flows and EC, and Calculated Export EC Increments from SJR and Seawater Intrusion for 2009.

The daily measured EC shown in the top panel are SJR EC (red dots), combined export EC (purple diamonds), Old River at Bacon EC (dark-blue dashed-line), and Middle River at Bacon EC (light-blue dashed-line). The Middle River EC was usually the lowest, reflecting the Sacramento River EC (<250 µS/cm) plus some SJR EC and some seawater intrusion EC, when Delta outflow is low (<7,500 cfs). The calculated SJR EC increment (red line) was highest when the SJR was a major fraction of the combined exports and when the SJR EC was high; and the seawater intrusion EC increment (difference between the Export EC and the SJR EC increment) was highest when the Old River at Bacon EC was greater than 500 µS/cm. During the summer and fall months, when the SJR flow was low, most of the exported water originated from the Sacramento River (reversed Old and Middle River flow) and seawater intrusion was a major source of exported salt. The SJR EC increment (above 250 μS/cm) was about 125 μS/cm in January to April, June, and November to December of 2009. The seawater intrusion EC increment (above 250 μS/cm) was about 375 μS/cm in January to February, about 500 μS/cm in August to September, and about 375 μS/cm in October to December of 2009.

For 2009, the average exports were 5,185 cfs and the flow-weighted average EC of the exports was 492 μS/cm. The Sacramento River water with assumed EC of 250 μS/cm contributed 51 percent of exported salt; the average SJR EC increment was 90 μS/cm, contributing 18 percent of the exported salt; and the seawater intrusion EC increment was 152 μS/cm, contributing 31 percent of exported salt. The sum of the calculated daily EC increments was slightly different than the average export EC, because the seawater EC increments in Middle River include some of the SJR EC increment and because the Old and Middle River daily net flows are difficult to estimate because of spring-neap tidal flow variations.

Figure 33b shows a two panel graph of daily EC (top) and daily flow (bottom) for 2010. The daily flows shown in the bottom panel compare the combined CVP and SWP exports with the daily SJR flow at Vernalis and the upstream (reversed) Old and Middle River flows. The exports were 5,000-7,500 cfs in January to March, were reduced to 1,500 cfs in April and May, were 5,000 cfs in June, and were about 10,000 cfs in July to December of 2010. The SJR flows were about 2,500 cfs in January to March, increased to about 5,000 cfs from mid-April to mid-June, and were less than 2,500 cfs from July to November, with major runoff in the second half of December 2010.

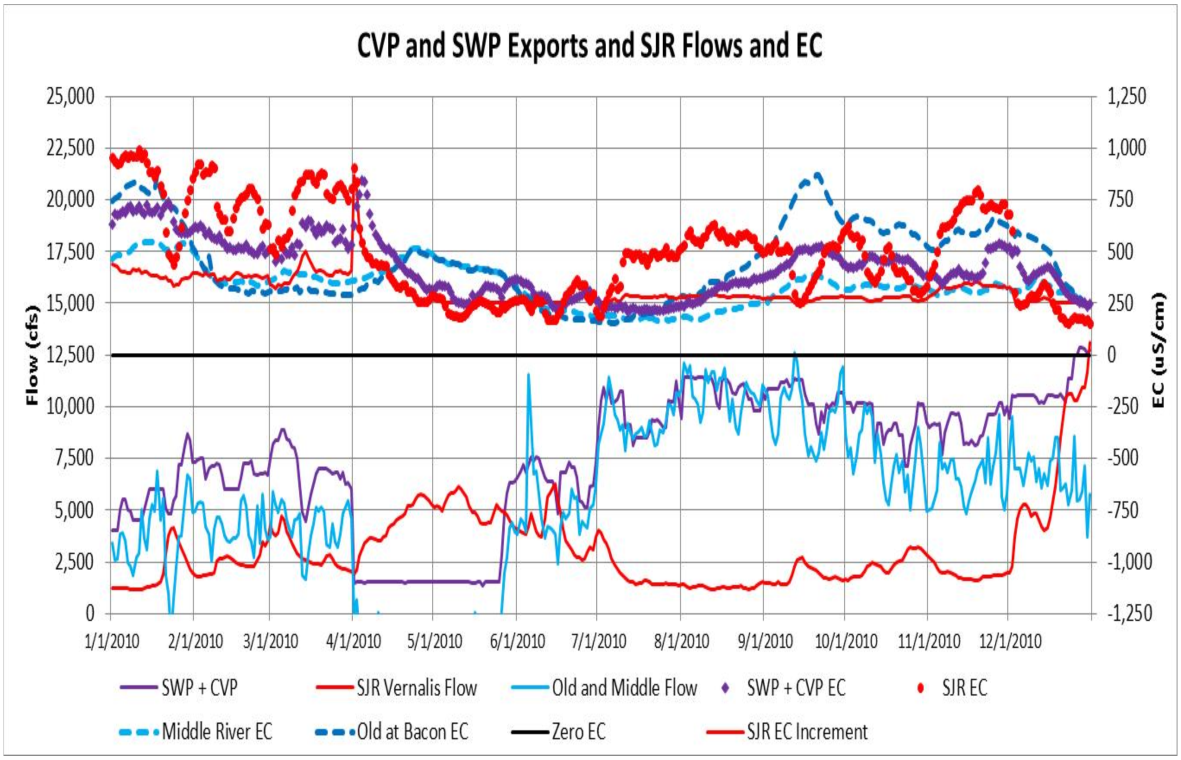


Figure 33b. Measured SJR Flows and EC, CVP and SWP Exports and EC, Old and Middle River Flows and EC, and Calculated Export EC Increments from SJR and Seawater Intrusion for 2010.

The daily measured EC shown in the top panel are SJR EC (red dots), combined export EC (purple diamonds), Old River at Bacon EC (dark-blue dashed-line), and Middle River at Bacon EC (light-blue dashed-line). The calculated SJR EC increment (red line) was highest when the SJR was a major fraction of the combined exports and when the SJR EC was high; and the seawater intrusion EC increment (difference between the export EC and the SJR EC increment) was highest when the Old River at Bacon EC was greater than 500 µS/cm. The EC of the exports was greater than 500 µS/cm from January to mid-April and from mid-September through November of 2010. The SJR EC increment was 125-250 µS/cm in January to mid-April and was low for the remainder of 2010. The seawater intrusion EC increment was about 250 µS/cm in January (Old at Bacon EC was 750 µS/cm), 250 µS/cm in September (Old at Bacon EC was 750 µS/cm), and 125-250 µS/cm in October to December of 2010 (Old at Bacon EC was >500 µS/cm).

For 2010, the average exports were 7,535 cfs and the flow-weighted average EC of the exports was 410 µS/cm. The Sacramento River water, with assumed EC of 250 µS/cm, contributed 61 percent of the exported salt; the average SJR EC increment was 67 µS/cm (16 percent of the exported salt); and the average seawater intrusion EC increment was 93 µS/cm (23 percent of exported salt).

Figure 33c shows a two panel graph of daily EC (top) and daily flow (bottom) for 2011. The daily flows shown in the bottom panel compare the combined CVP and SWP exports with the daily SJR flow at Vernalis and the upstream (reversed) Old and Middle River flows. The SJR flow was about equal to the exports in January to March, much higher than the exports in April and May, equal to the exports in June and July, and less than the exports in August to December 2011. Most of the exports were SJR water through June; exports were about 50 percent SJR water and 50 percent Sacramento River water from July through November and were about 25 percent SJR water and 75 percent Sacramento River water in December. The Old and Middle River reverse flows were equal to the exports minus about 50 percent of the SJR flows in January to March and in June, because only 50 percent of the SJR is diverted at the head of Old River. The reverse Old and Middle River flows were negative in April and May (downstream flow) because of the high SJR flows (greater than exports).

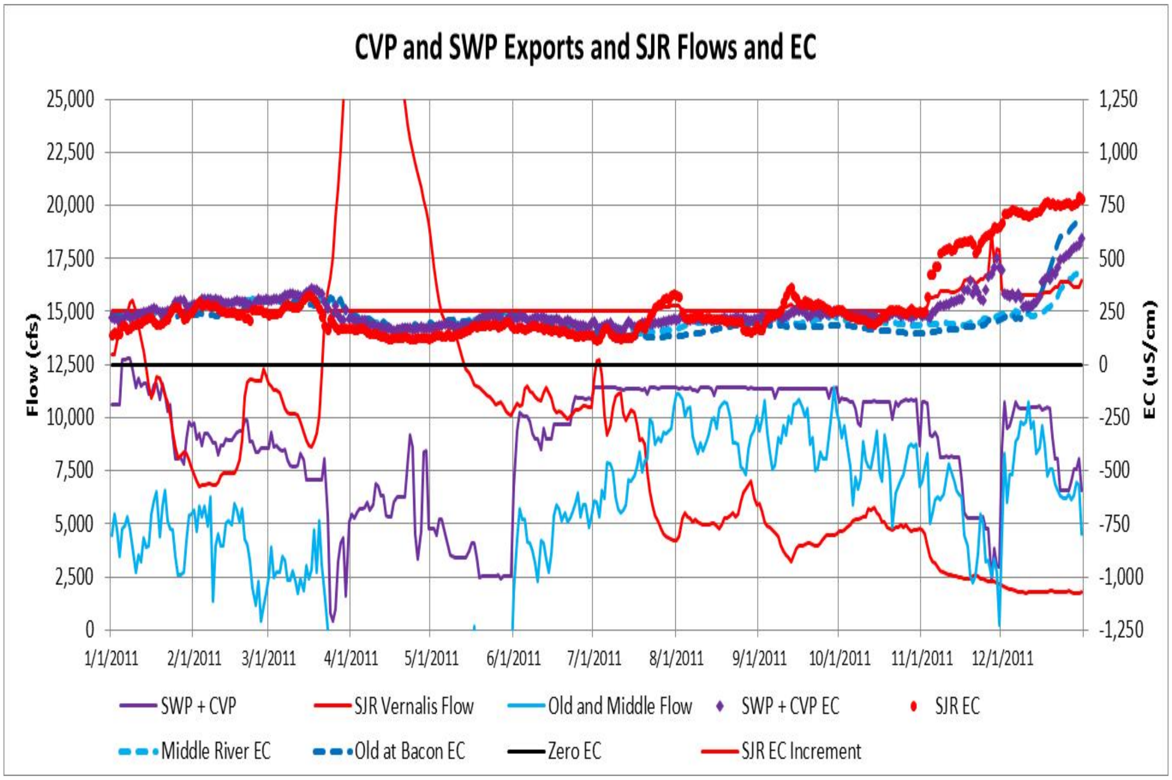


Figure 33c. Measured SJR Flows and EC, CVP and SWP Exports and EC, Old and Middle River Flows and EC, and Calculated Export EC Increments from SJR and Seawater Intrusion for 2011.

The daily measured EC shown in the top panel are SJR EC (red dots), combined export EC (purple diamonds), Old River at Bacon EC (dark-blue dashed-line), and Middle River at Bacon EC (light-blue dashed-line). The calculated SJR EC increment (red line) was 0 through October, because the SJR EC was about 250 μS/cm. The SJR EC increment was about 125 μS/cm in November and December 2011. The seawater intrusion EC increments were 0 μS/cm until the second half of December, when they increased to about 250 μS/cm (Old at Bacon EC > 500 μS/cm). For 2011, the average exports were 8,850 cfs and the average flow-weighted EC of the exports (with minimum EC of 250 assumed) was 275 μS/cm. The Sacramento River water with assumed EC of 250 μS/cm contributed 91 percent of the exported salt. Because of high SJR flows (with low SJR EC), the average calculated SJR

EC increment was 19 µS/cm (7 percent of exported salt in November and December) and the average seawater intrusion EC increment was 6 µS/cm (2 percent of exported salt in December).

Figure 33d shows the daily SJR flow at Vernalis compared to the CVP and SWP exports, along with the daily EC in the SJR at Vernalis, the CVP and SWP exports, in Old River at Bacon, and in Middle River at Bacon for 2012. The exports were 2,500 cfs to 5,000 cfs from January to June, and increased to between 7,500 cfs and 10,000 cfs from July to December 2012. The SJR flows were less than 2,500 cfs for the entire year, so all of the SJR flow was exported in 2012 because the exports were greater than the SJR flows.

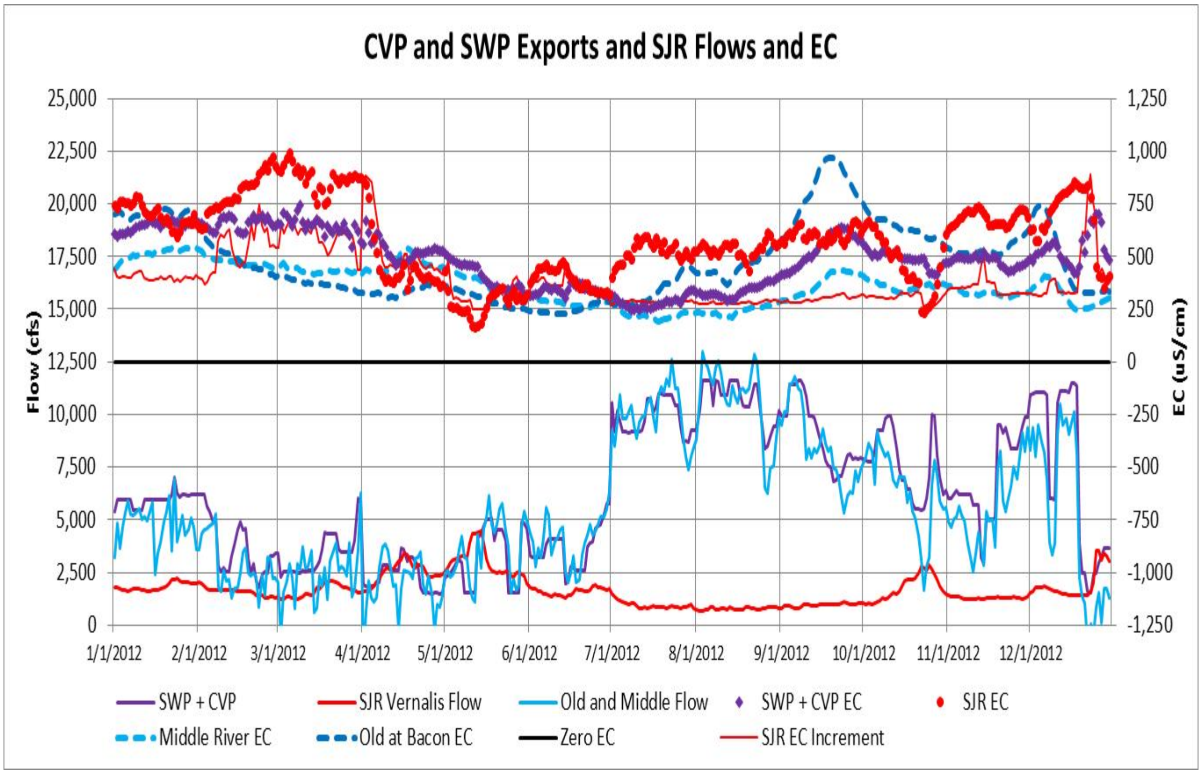


Figure 33d. Measured SJR Flows and EC, CVP and SWP Exports and EC, Old and Middle River Flows and EC, and Calculated Export EC Increments from SJR and Seawater Intrusion for 2012.

The daily measured EC shown in the top panel are SJR EC (red dots), combined export EC (purple diamonds), Old River at Bacon EC (dark-blue dashed-line), and Middle River at Bacon EC (light-blue dashed-line). The calculated SJR EC increment (red line) was highest when the SJR was a major fraction of the combined exports and when the SJR EC was high; and the seawater intrusion EC increment (green line) was highest when the Old River at Bacon EC was greater than 500 µS/cm. The SJR EC increment was 125 µS/cm in January and April, and was 250 µS/cm in February and March. The seawater intrusion EC increment was 125-250 µS/cm in January to April, was greatest in September (250 µS/cm), and was about 125 µS/cm in October and November. For 2012, the average exports were 6,145 cfs and the average flow-weighted EC of the exports was 460 µS/cm. The assumed Sacramento River EC of 250 µS/cm contributed 54 percent of the exported salt; the calculated SJR EC increment was 96 µS/cm (21 percent of exported salt); and the calculated seawater intrusion EC increment was 114 µS/cm (25 percent of exported salt).

Figure 33e shows the daily SJR flow at Vernalis compared to the CVP and SWP exports, along with the daily EC in the SJR at Vernalis, the CVP and SWP exports, in Old River at Bacon, and in Middle River at Bacon for 2013. The exports were about 5,000 cfs from January to March, about 2,500 cfs in April to June, about 10,000 cfs in July to August, and about 2,500 cfs to 5,000 cfs in September to December 2013. The SJR flows were less than 2,500 cfs for the entire year, so all of the SJR flow was exported in 2013.

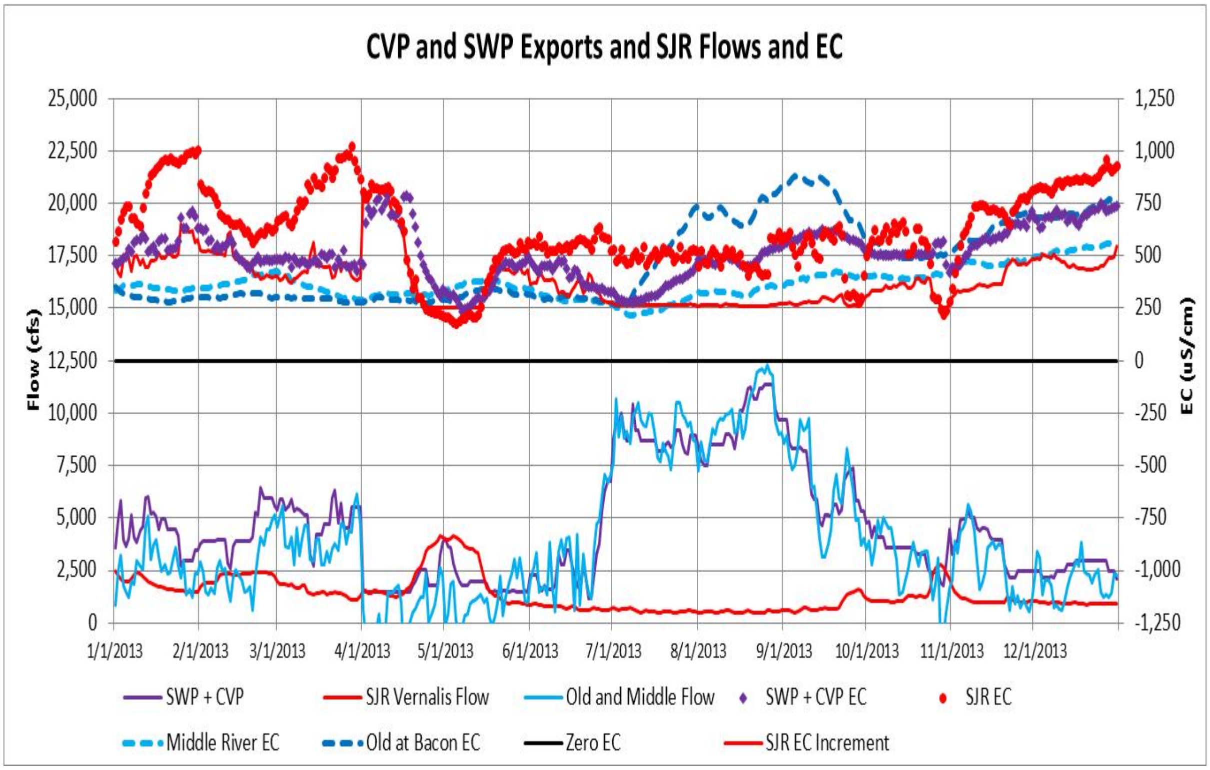


Figure 33e. Measured SJR Flows and EC, CVP and SWP Exports and EC, Old and Middle River Flows and EC, and Calculated Export EC Increments from SJR and Seawater Intrusion for 2013.

The daily measured EC shown in the top panel are SJR EC (red dots), combined export EC (purple diamonds), Old River at Bacon EC (dark-blue dashed-line), and Middle River at Bacon EC (light-blue dashed-line). The two calculated EC increments are also shown in the top panel; the SJR EC increment (red line) was highest when the SJR was a major fraction of the combined exports and when the SJR EC was high; and the seawater intrusion EC increment (green line) was highest when the Old River at Bacon EC was greater than 500 µS/cm. The SJR EC increment was about 250 µS/cm in January to March and about 500 µS/cm in the first half of April. The SJR EC increment was about 125 µS/cm in October to November and was 250 µS/cm in December 2013. The seawater intrusion EC increment was 250 µS/cm in August to September (Old at Bacon EC > 500 µS/cm) and was 125-250 µS/cm in October to December 2013. For 2013, the average exports were 4,610 cfs and the average flow-weighted EC of the exports was 490 µS/cm. The assumed Sacramento River EC of 250 µS/cm contributed 51 percent of the exported salt; the calculated SJR EC increment was 98 µS/cm (20 percent of exported salt); and the calculated seawater intrusion EC increment was 143 µS/cm (29 percent of exported salt).

The salt source tracking for these 5 years demonstrated that the average export EC is influenced by the two water sources (i.e., SJR and Sacramento River) and the three major salt sources (Sacramento River, SJR, and seawater intrusion). The SJR EC was highest when the SJR flow was less than 2,500 cfs and the effects of the SJR EC on the export EC would decrease with higher exports. The effects of seawater intrusion on the export EC increases as Delta outflow is reduced from 10,000 cfs to the minimum outflow of 3,000 cfs (maximum seawater intrusion EC increment of about 500 µS/cm). The annual average export EC would be as low as 250 µS/cm in high flow years, because the Sacramento River EC is always less than 250 µS/cm, the SJR EC would be less than 250 µS/cm if the SJR flows were greater than about 5,000 cfs (e.g., most of 2011), and there would be no seawater intrusion if Delta outflow was greater than 10,000 cfs. For several of the years, the annual average export EC was about 500 µS/cm (e.g., 2009 and 2013), which was twice the minimum possible export EC with 100% Sacramento River water. The incremental EC (and salt load) caused by the higher SJR EC ranged from 20 µS/cm in 2011 to about 100 µS/cm in 2012 and 2013, which was 40 percent more EC and salt load than for Sacramento River water. The incremental EC (and salt load) caused by seawater intrusion ranged from less than 10 µS/cm in 2011 to about 150 µS/cm in 2009 and 2013, which was about 60 percent more EC and salt load than for exports from Sacramento River water.

Summary of Analysis Methods and Equations

The analysis and evaluation of the south Delta tidal data used several basic methods that have been described with examples and results in this report. Table 2 summarizes the various flow and salinity equations that were used for each analysis method, with the coefficients (parameters) that were estimated for each location. The first group of equations is the diversion flow calculations (i.e., flow fractions) for several channel junctions. The net flows in each channel would be reduced by agricultural diversions and increased by agricultural discharges. The second group of equations is the tidal flow estimates, calculated from the elevation changes and the upstream surface areas for several locations. The third group of equations gives the tidal flow calculations from the upstream and downstream elevations for the culverts in each temporary barrier; culvert flow is upstream only when flap gates are operating. The fourth group of equations gives the tidal flow calculations from the upstream and downstream elevations for each temporary barrier weir crest and leakage flow through the rock barriers. The fifth group of equations gives the tidal movement calculations used for shifting the measured longitudinal EC profiles in Paradise Cut and in Old River to estimate low tide EC profiles and high tide EC profiles. These calculations are included in the Data Atlas Excel files for each year. Tidal graphs are provided in the data analysis files to compare the tidal calculations with the measured data. Any of these coefficients or parameters can be changed easily to explore the sensitivity of the flow calculations or improve the calibration (i.e., match) with the measured data.

The primary purpose for these tidal data analysis methods was to identify the likely sources of higher EC water that is often observed at the Old River at Tracy Boulevard EC measurement station. The EC measurements at various locations in Old River, and in Paradise Cut and Sugar Cut, together with the analysis of the tidal movement of water from these tidal sloughs to Old River, has indicated that there are substantial sources of high EC water (excess salt load) originating from the upstream ends of Paradise Cut and Sugar Cut. Although these salt sources are much smaller that the salt load in the SJR at Vernalis, they are sufficient to increase the EC in Old River at Tracy Boulevard by an average of about 100-125 µS/cm (See Figures 30a-30e). Based on these data analysis methods and results, several conceptual salinity-reduction alternatives that might reduce or eliminate the high EC measurements in Old River at Tracy Boulevard were developed and compared; the alternatives are described and evaluated for likely effectiveness, feasibility and approximate cost in the next section.

Table 2. Summary of Flow and Salinity Equations Used to Analyze Tidal Flow and EC Data

Flow Diversions at Channel Junctions:
Paradise Cut Weir Flow (cfs) = 0.5 x [SJR at Vernalis Flow – 17,500]
Head of Old River Flow (cfs) = 0.5 x SJR at Vernalis + 0.05 x [SWP Flow + CVP Flow]
Head of Middle River Flow (cfs) = 0.03 x Head of Old River (HOR) Flow
Grant Line Canal Flow (cfs) = 0.87 x HOR Flow
Old River at Tracy Boulevard Flow (cfs) = 0.10 x HOR Flow
Tidal Channel Flow Volumes:
Old at Tracy Boulevard (af) = -Elevation Change (feet) x 50 acres +10% HOR Flow (cfs) x 0.02
Old at DMC Barrier (af) = -Elevation Change (feet) x 750 acres + 10% HOR Flow (cfs) x 0.02
Old at Bacon (af) = -Elevation Change (feet) x 1,750 acres + 47% [CVP + SWP] Flow (cfs) x 0.02
Middle at Barrier (af) = -Elevation Change (feet) x 150 acres
Middle at Undine Road (af) = -Elevation Change (feet) x 150 acres + 3% HOR Flow (cfs) x 0.02
Middle at Bacon (af) = -Elevation Change (feet) x 2,000 acres + 53% [CVP + SWP] Flow (cfs) x 0.02
GLC at Barrier (af) = - Elevation Change (feet) x 500 acres + 85% HOR Flow (cfs) x 0.02
GLC at Mouth (af) = - Elevation Change (feet) x 750 acres + 85% HOR Flow (cfs) x 0.02
Paradise Cut at Mouth (af) = - Elevation Change (feet) x 170 acres
Sugar Cut at Mouth (af) = - Elevation Change (feet) x 55 acres – Tom Paine Diversion (cfs) x 0.02
Barrier Culvert Flows (upstream only with flap gates):
Tom Paine Slough Diversion (cfs) = -300 x Elevation Difference (feet) $^{0.5}$
Old at DMC Barrier Flow = - 600 x Elevation Difference (feet) $^{0.5}$
Grant Line Canal Barrier Flow = - 450 x Elevation Difference (feet) $^{0.5}$
Middle River Barrier Flow = - 450 x Elevation Difference (feet) $^{0.5}$
Barrier Weir Crest and Leakage Flow (either direction depending on elevations):
Old at DMC Crest Flow = 150 x [Water Elevation – Crest Elevation (4.4 feet)] $^{1.5}$ + Net Flow
Grant Line Canal Crest Flow = 250 x [Water Elevation – Crest Elevation (3.4 feet)] $^{1.5}$ + Net Flow
Middle River Crest Flow = 180 x [Water Elevation – Crest Elevation (4.4 feet)] $^{1.5}$ + Net Flow
Rock Barrier Leakage Flow = 150 x Elevation Difference $^{0.5}$
Longitudinal EC Profile Shifting to High Tide (the measured EC at each location is shifted upstream):
Paradise Cut (km) = Measured (km) + [High Tide – Measured Tide] x 1.5 km/feet x [10 km – Measured km]/10 km
Old River (km) = Measured (km) + [High Tide – Measured Tide] x 2 km/feet x [60 km – Measured km]/15 km
Longitudinal EC Profile Shifting to Low Tide (the Measured EC at each location is shifted downstream):
Paradise Cut (km) = Measured (km) - [Measured Tide- low Tide] x 1.5 km/feet x [10 km – Measured km]/10 km
Old River (km) = Measured (km) - [Measured Tide – Low Tide] x 2 km/feet x [60 km – Measured km]/15 km

Regulatory Options and Physical Alternatives for Reducing Old River at Tracy Boulevard EC

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

Regulatory Options

Based on the results shown in this report, the SWRCB might reconsider using the Old River at Tracy Boulevard EC monitoring station as an EC compliance station, but could retain the Old River at Tracy Boulevard station as an EC monitoring station. The SWRCB could decide to rely on the SJR at Brandt Bridge and the Old River at Union Island 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 some EC increases in the SJR between the Vernalis station and the south Delta stations, the Vernalis EC objectives should be specified as 50 µS/cm or 100 µS/cm less than the south Delta EC objectives. For example, the south Delta EC objectives might be specified to match the D-1641 drinking water EC objectives (1,000 µS/cm, monthly average, year-round). The review of salinity criteria for agricultural uses in the south Delta (Hoffman 2010) indicated that an EC criterion for fully protecting salt-sensitive crops (i.e., beans and alfalfa) would be about 1,000 µS/cm. Therefore, 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 (i.e., agricultural diversions and subsequent drainage of higher EC water) along the SJR and Old River.

The possible need for New Melones Reservoir releases to meet the adjusted Vernalis EC objectives should be evaluated and compared with releases for the existing Vernalis EC objectives. SJR flows might decrease slightly (with lower New Melones releases) during the irrigation season if the Vernalis EC objective were increased from 700 µS/cm to 900 or 950 µS/cm. Changes in the Vernalis flow and EC will have nearly identical effects on the measured EC at the south Delta stations (i.e., same EC increments). Changing the EC objectives at the south Delta EC monitoring stations will not likely have any additional effects on south Delta EC, because the SJR at Vernalis EC controls the south Delta EC. However, adjusting the Vernalis EC objectives to be 50 to 100 µS/cm less than the south Delta EC objectives would likely eliminate future periods of non-compliance with the EC objectives at the SJR at Brandt Bridge and the Old River at Union Island EC monitoring stations. The Old River at Tracy Boulevard station should remain as an EC monitoring station to compare the effectiveness of the selected salinity-reduction physical alternative even if the SWRCB determines that it should no longer be used as an EC compliance station.

Physical Alternatives

Several physical alternatives for reducing the effects of salt sources from Paradise Cut and Sugar Cut in Old River at the Tracy Boulevard EC station were developed and evaluated for likely effectiveness, general feasibility, and approximate cost. Each of the physical alternatives is briefly described and their likely effectiveness and feasibility are discussed from a planning perspective; additional engineering details will be required for the alternative designs. Each of the physical alternatives could be further evaluated with additional engineering design and cost estimates. The likely effectiveness of each alternative could be compared using DSM2 modeling to calculate the changes in Old River at Tracy Boulevard EC that would be achieved by implementing the alternatives. The DSM2 model should be adjusted (to better match historical tidal flows and EC) to include more accurate channel geometry and more accurate representation of salinity sources from agricultural drainage and shallow groundwater seepage. The most promising alternative may be selected by DWR for a salinity-reduction demonstration project. The EC monitoring in south Delta channels might be enhanced (with additional stations) for the salinity-reduction demonstration project and could continue for 2 or 3 years after the demonstration project is implemented (constructed) to provide monitoring records for evaluation of the actual effectiveness of the selected salinity-reduction alternative.

The effectiveness of the selected demonstration alternative could be judged by comparing the future measured EC increments in Old River at Tracy Boulevard with the salinity-reduction alternative to the historical EC increments measured in 2009–13 (evaluated in this report) and the EC increments measured in 2014-16 (not included in this report). The EC increments in Old River for specific SJR flow and EC conditions in 2009–16 (without the demonstration project) could be compared to the future measured EC increments in Old River with the salinity-reduction project for similar SJR flow and EC conditions. Based on the results of the demonstration project EC monitoring and comparisons with previous EC conditions in 2009–16, DWR may decide to modify the demonstration project (for improved salinity-reduction effects) or to construct a permanent south Delta salinity-reduction facility based on the demonstration project performance. The demonstration project would likely be implemented in cooperation with Reclamation, RWQCB, SWRCB, and south Delta stakeholders (e.g., SDWA, San Joaquin County). Funds for the design, construction and monitoring of the salinity-reduction demonstration project might be obtained from water quality improvement funds (State Bonds) or other appropriate sources.

A. Pump Water from the San Joaquin River to Provide Flushing Flows in Paradise Cut and Sugar Cut

This salinity-reduction alternative was based on the general concept that the salinity (EC) could be reduced if the salt source was diluted (flushed) with lower EC water. However, flushing Paradise Cut and Sugar Cut with SJR water (e.g., 10 to 25 cfs pumps) would likely not reduce the excess salt loads entering Old River from Paradise Cut and Sugar Cut (i.e., EC higher than Old River EC at Doughty Cut) that increase the Old River at Tracy Boulevard EC. Although the SJR flushing flow would dilute the EC in the tidal sloughs and the EC entering Old River during ebb-tides, the flushing flows would not reduce the salt loads entering Old River and would not change the EC increments at Tracy Boulevard. Dilution of the higher salinity source water would be more effective if the dilution water had a much lower salinity; because the SJR EC would be the same as the Old River EC, the excess salt load would remain about the same:

Excess salt load (tons/day) = salt source flow x (salt source EC – Old River EC) x 0.0175

Adding SJR water would slightly lower the EC leaving Paradise Cut and Sugar Cut and would reduce the measured EC at Tracy Boulevard slightly, but the effect would be about the same as increasing the Old River flow at Tracy Boulevard by the dilution (pumping) flow. Because a large incremental EC at Tracy Boulevard has been measured for a wide range of Old River flows, increasing the effective flow by 20 to 50 cfs would not change the excess salt load from either Paradise Cut or Sugar

Cut, and would not likely be an effective salinity-reduction alternative. The pipeline from the SJR to the upstream end of Paradise Cut would be about 1 mile long. The construction of the pump and pipeline would be moderately expensive ($5 million, based on the Stockton Deep Water Shipping Channel [DWSC] Aeration Demonstration project cost of $2 million for two 25 cfs pumps and 1,000 feet of pipeline). The pipeline from the SJR to the upstream end of Sugar Cut would be much longer (about 5 miles), and therefore would be considerably more expensive ($20 million). The pumps would also have an annual energy cost.

B. Pump High Salinity Water from the Upstream End of Sugar Cut and Paradise Cut

Pumping the higher salinity water that enters the upstream end of Sugar Cut and Paradise Cut to the SJR or to Old River (upstream from Doughty Cut) may be an effective way to reduce the EC increments in Old River at Tracy Boulevard, because the excess salt loads would be mixed (diluted) with much higher SJR or Old River flows. The EC increment at Tracy Boulevard would be reduced by the ratio of the Old River at Tracy Boulevard flow to the SJR flow (e.g., one-twentieth) or to the head of Old River flow (e.g., one-tenth). The shallow groundwater seepage to Paradise Cut and the surface drainage to Sugar Cut (i.e., Arbor Road Drain) may originate from local infiltration (soil drainage) of applied water in Pescadero Tract, from upslope areas (to the southwest) with irrigation drainage (e.g., some Westside ID tile drainage enters Sugar Cut), or from historical saline groundwater. The high salinity source flows were estimated during this project to be about 5 to 10 cfs with an EC of 2,000 to 3,000 μS/cm (25 to 50 tons/day) from both Paradise Cut and Sugar Cut. Therefore, pumping 5 to 10 cfs from each tidal slough to the SJR or to Old River upstream from Doughty Cut likely would be sufficient to remove the majority of the salt sources from Old River at Tracy Boulevard. The salt source water would be diluted in the full SJR flow (or in the head of Old River flow, about 50 percent of SJR flow), and therefore would cause a smaller EC increment in Old River at Tracy Boulevard. Pumping higher salinity water from the upstream end of Sugar Cut would have the additional benefit of reducing the Tom Paine Slough irrigation diversion salinity. Most of the excess salt load from the upstream end of Sugar Cut is likely diverted into Tom Paine Slough during the irrigation season. Some of the excess salt load from Paradise Cut also may flow into Old River during ebb-tides and enter Sugar Cut during flood tides, and some may be diverted into Tom Paine Slough. Further investigation of this alternative could include the need for water right applications to pump water from Paradise Cut and Sugar Cut.

A future possibility for the Sugar Cut water may be the potential use of the pipeline from the City of Tracy wastewater treatment plant to the diffuser, which is located in Old River just upstream from Doughty Cut. A pump (5 to 10 cfs) might be used to pump water from the upstream end of Sugar Cut into the existing 33-inch-diameter wastewater diffuser pipeline for discharge into Old River (upstream from Doughty Cut). Preliminary discussion with the City of Tracy revealed that the existing pipeline (built in 1976 using concrete–asbestos pipe) is near capacity (9 mgd, 14 cfs) and relatively fragile. The existing pipeline likely could not be pressurized any further to pump additional water from Sugar Cut (pipe sections may crack or burst). The City of Tracy is planning to build a replacement pipeline (16 mgd, 25 cfs) and, after completion, the old pipeline would likely be maintained as a standby pipeline. Construction of the new pipeline currently is on hold because of lack of funding. Pumping water from the upstream end of Sugar Cut may be feasible in the original pipeline after the new pipeline is constructed.

This pumping alternative would also reduce the salinity in the Tom Paine Slough diversion of irrigation water to about the Old River EC. The current salinity of the Tom Paine Slough diversions (EC measurements begun in April 2014) is similar to the measured Sugar Cut EC and generally about 250 µS/cm higher than the Old River EC. By removing the salt source from the upstream end of Sugar Cut with a pipeline, the EC of the irrigation water for Pescadero Tract, and the resulting EC of the drainage or shallow groundwater seepage from these irrigated lands would also be reduced.

A pipeline from the upper end of Paradise Cut to the SJR near the Paradise Cut flood-control (bypass) weir would be about 1 mile long. The construction of a 10 cfs pump and pipeline will be moderately expensive ($5 million, based on the Stockton DWSC Aeration Demonstration project with two 25 cfs pumps and 1,000 feet pipeline constructed at a cost of $2 million). If a pipeline is constructed for pumping water from the upper end of Sugar Cut to Old River (near the City of Tracy diffuser), the length would be about 2.25 miles and the cost likely would be $10 million. The City of Tracy design for a new 16-mgd (25-cfs) pipeline (42-inch-diameter) was estimated to cost about $25 million. The pumps would also require an annual energy cost. Although this conceptual salinity-reduction alternative would likely be very effective, it may be more expensive than the salinity-reduction benefits in Old River at Tracy Boulevard warrant.

C. Increase the Net Flow in Old River at Tracy Boulevard by Dredging the Old River Channel

Dredging the Old River channel immediately downstream from Doughty Cut likely would allow a greater fraction of the Old River flow to remain in Old River, and thereby would reduce the elevated EC at Old River at Tracy Boulevard. This would reduce the EC increments caused by the salt sources from Paradise Cut and Sugar Cut. Because the net flow at Tracy Boulevard is currently about 10 percent of the head of Old River flow (See Figures 5a to 5e), the EC increments can be reduced by half if the Old River at Tracy Boulevard flow was increased to 20 percent of the head of Old River flow. Dredging a 4-mile section (6 km) of Old River between Doughty Cut and Tracy Boulevard would likely increase the net flow at Tracy Boulevard, although the change in the net flows caused by dredging could be accurately determined only after the dredging was completed.

To support the evaluation of this conceptual dredging alternative, a Geographical Information System (GIS) analysis using the 2-m DEM for the south Delta developed by DWR was conducted. The channel bathymetry in sections of Old River, Paradise Cut, Sugar Cut, and connecting channels was created (converted) from the 2-m DEM and graphed as channel elevation contours with 4-feet increments). This channel bathymetry map then was used to determine the amount of dredging that would be required. These channel contour map sheets and tables of proposed dredging volumes are provided in Attachment A of this report.

The existing Old River channel is about 100 feet wide, with a bottom elevation of between -2 feet and-4 feet NAVD, and thus the water depth is about 4 to 6 feet at low tide (2 feet NAVD). Dredging a 4-mile section of Old River with a 100-foot-wide channel to a depth of -8 feet (water depth of 10 feet at low tide) would double the channel cross-section at low tide, but would require the removal of about 275,000 cubic yards of sediment. At an assumed cost of $50 per cubic yard for clam-shell dredging and transport (to use the sediment to reinforce levees), the initial cost estimate would be about $15 million. Although some levee improvement benefits are likely (cost-sharing), this dredging alternative would be moderately expensive. Additional bathymetric surveys, engineering design, and hydraulic modeling studies are needed to refine quantities and cost estimates.

Evaluations of the possible biological effects from dredging (for permit applications) would also likely be required for this alternative.

D. Increase Net Flow in Old River at Tracy Boulevard with the Grant Line Canal Barrier without the Old River at DMC Barrier

If the Grant Line Canal temporary barrier was installed with a slightly (1-feet) higher weir crest (at 4.5 feet NAVD), rather than a weir crest of 3.5 feet as currently designed, and if the Old River at DMC temporary barrier was not installed, a higher net downstream flow in Old River at Tracy Boulevard likely would provide greater dilution of the excess salt loads from Paradise Cut and Sugar Cut. Discontinuing the Old River at DMC barrier also would allow full tidal flows in Old River upstream from the DMC barrier. There may be some evidence (See Figures 5a to 5e) that the Old River at Tracy Boulevard net flow was increased when all of the culverts were closed in the Grant Line Canal barrier and more culverts were opened in the Old River at DMC barrier. However, the change in the net flows caused by these modifications to the temporary barrier program could be accurately determined only after the higher Grant Line Canal weir crest without the Old River at DMC barrier was implemented (i.e., demonstrated for a year or two). The Grant Line Canal barrier was not installed before the Old River at DMC barrier during any of the previous years (2009-13) evaluated in this report, but a demonstration might be possible as part of the Temporary Barrier Program, to further evaluate this conceptual alternative.

This alternative would likely have no additional costs for the Temporary Barriers Program, but the effectiveness could be accurately evaluated only after this modified operation was demonstrated for a year or two. The effects on daily minimum tidal elevations upstream from the Old River at DMC barrier caused by this alternative design of the temporary barriers could have impacts on agricultural diversions in this portion of Old River. The channel elevations (water depths) in the vicinity of the existing irrigation pumps and siphons located upstream from the Old River at DMC barrier should be carefully measured and monitored during the demonstration period. Localized dredging or intake modifications may be needed to maintain all existing irrigation diversions without the installation of the Old River at DMC temporary barrier. There would be no additional costs associated with this alternative; there could be a cost savings by not installing and removing the Old River at DMC temporary barrier each year.

E. Increase the Flood Tide Flows and Create an Upstream Circulation Flow in Old River at Tracy Boulevard with a Tidal Gate at the DMC Barrier Location

A tidal gate could be constructed in Old River at the DMC barrier location that would be opened at low tide to allow the full flood-tide flows (500 af) to fill the Old River channel (5 km upstream) and would be closed at high tide to create an upstream circulation flow past Tracy Boulevard during ebb-tide. A tidal gate in the Old River channel near the DMC barrier location would allow full flood-tide flows in Old River upstream from the DMC barrier location and would eliminate any downstream flow past Tracy Boulevard. This alternative would cause the higher salinity water leaving Sugar Cut and Paradise Cut during ebb-tides to flow upstream in Old River to Doughty Cut and to Grant Line Canal rather than downstream in Old River to Tracy Boulevard.

A possible design for the tidal gate would include pilings with gate panels on either side of the channel, with concrete footings that angle upstream 15 degrees (closure angle) to the center of the channel, where the two gates would meet when closed. This would be similar to the “miter gates” used for many small canal locks. The closed gates would sit on the footings and the open gates would sit on similar concrete footing along the channel levees. The gate panels would be about 100 feet long and 15 feet tall, and could be fabricated from aluminum with lateral chambers (e.g., 2-foot-diameter pipes) for buoyancy. Hydraulic pistons would open the gates (at low tide) and would close the gates (at high tide). The tidal gate design could include a side-channel (wall) with a small boat lock (e.g., 20 feet wide) that could be used by recreational boats during ebb- tide (when the tidal gate would be closed). Additional tidal gate features could be developed and refined during the engineering design and specifications process.

This operable tidal gate would be open during flood-tides and would be closed during ebb-tides to provide a net upstream flushing flow that would transport all excess salt from Paradise Cut and Sugar Cut to Grant Line Canal via Doughty Cut. This would be similar to the “tidal circulation” proposed by DWR in the SDIP (Jones and Stokes 2005). An operable tidal gate would be more effective for salinity control circulation than the temporary barriers with culverts (for upstream flow), because the temporary barriers have provided only a small net upstream circulation flow in Old River and Middle River. The Old River at Tracy Boulevard EC would be reduced considerably, often to less than the SJR EC, because the EC of Old River downstream from the DMC is usually lower than the SJR EC.

The cost of this salinity-reduction alternative has been conceptually estimated at $5 million, but this capital expense (design and fabrication of the tidal gate structure) might be recovered (offset) by the cost savings from not installing and removing the Old River at DMC temporary barrier each year.

F. Block the Mouths of Paradise Cut and Sugar Cut and Dredge a New Channel to Connect Sugar Cut and Paradise Cut with Old River Upstream from Doughty Cut

Blocking the mouth of Paradise Cut and the mouth of Sugar Cut, dredging a 0.25 mile channel from Sugar Cut to Paradise Cut, and enlarging an existing ditch from Paradise Cut to Old River (upstream from Doughty Cut) likely would allow the majority (e.g., 90 percent) of the excess salinity from Paradise Cut and Sugar Cut to flow through Doughty Cut to Grant Line Canal during ebb-tide, and thereby would greatly reduce the elevated EC in Old River at Tracy Boulevard (e.g., 10 percent of the existing EC increments).

The existing mouth of Sugar Cut could be blocked with a “wall” made of prefabricated aluminum sections (e.g., 25 feet wide by 15 feet tall) or pre-stressed concrete panels connected by a line of “H” beam pilings, because there are no large flood flows in Sugar Cut. The existing mouth of Paradise Cut could be blocked with a gate made with aluminum panels connected (hinged) to pilings, so that the gate sections could be opened during major storm events when the Paradise Cut weir was spilling (e.g., April 2011). Sugar Cut could be connected to Paradise Cut with a new dredged channel 0.25 miles long under the power lines, but through the golf course (between fairways with bridges). This would allow the salt loads from Paradise Cut and Sugar Cut to be diluted with the head of Old River flow (like the Tracy Wastewater Treatment Plant discharge) and would reduce the EC increment at Tracy Boulevard to about 10 percent of the existing EC increment, because about 10 percent of the Old River flow would continue to flow downstream in Old River past Tracy Boulevard.

The salinity reduction benefits can be roughly estimated, but the actual salinity reduction effects could accurately be evaluated with a demonstration project.

Although this alternative would reduce the EC in Old River at Tracy Boulevard, it would not reduce the EC in the Tom Paine Slough diversion of irrigation water from Sugar Cut. One additional channel-modification feature could be included in this alternative. A dividing wall could be constructed in the center of the new connecting channel and in the center of Sugar Cut to 0.5 miles upstream of the Tom Paine Slough diversion dam; the total length of the dividing wall would be 1.75 miles. The dividing wall would be about 15 feet tall (extending to 8 feet NAVD) and could be constructed with pre-stressed concrete panels (e.g., 15 feet tall by 25 feet wide) and concrete "H" pilings. A tidal gate could be constructed at the downstream end of the connecting channel and a "flood-tide" gate on one side of the dividing wall would be opened at low tide to allow Old River water to fill Sugar Cut, moving Old River water past the Tom Paine Slough diversion dam. At high tide, the "flood-tide" gate would be closed and the "ebb-tide" gate on the other side of the dividing wall would be opened to allow the high salinity water from the upstream end of Sugar Cut to drain down the other side of the divided Sugar Cut (separated from Tom Paine Slough). The tidal gate with the dividing wall in Sugar Cut would create a tidal circulation in Sugar Cut, providing the lowest possible EC water to Tom Paine Slough and draining the higher salinity water to Doughty Cut and Grant Line Canal rather than to Old River at Tracy Boulevard.

Dredging the existing (remnant) channel between Paradise Cut and Old River and building the connecting levees, and excavating a new channel with levees to connect Sugar Cut with Paradise Cut, would likely require about 50,000 cubic yards of sediment. The Sugar Cut to Paradise Cut channel would be about 1,500 feet long, 50 feet wide, and 12 feet deep, with new levees at 8 feet NAVD. Assuming an excavation and placement cost of $75 per cubic yard, the likely cost for excavation and building new levees would be about $5 million, and the barriers at the mouth of Sugar Cut and Paradise Cut likely would increase the total cost to about $6 million. If the dividing wall in Sugar Cut and tidal gates at the mouth were included in the alternative (to reduce the Tom Paine Slough EC), the cost may approach $8 million. However, this fairly complicated alternative might be very effective for reducing the EC increments in Old River at Tracy Boulevard and also for reducing the Tom Paine Slough EC.

G. Reduce the Fraction of San Joaquin River Flow and EC Reaching the CVP and SWP Exports by Diverting the Entire SJR to Old River and Separating Old River from the Exports and from Middle River

This alternative would reduce the fraction of the SJR flow and EC reaching the CVP and SWP exports by diverting all of the SJR flow to Old River and Grant Line Canal and separating the Old River and Grant Line Canal flow from the exports with a dividing wall and river crossing (culvert) in Victoria Canal. Most of the SJR flow and EC, as well as all of the additional salt sources in the south Delta channels (including Paradise Cut and Sugar Cut) are currently exported at the CVP or SWP pumping plants. Because the higher SJR EC often increases the EC of the CVP and SWP exports (See Figures 33a-33e), the EC at the SWP and CVP pumping plants could be reduced considerably by separating the SJR flow and EC from the exports. This alternative would provide a more comprehensive reduction of the EC of the CVP and SWP exports. The Old River at Tracy Boulevard EC would be reduced along with the EC in the CVP and SWP exports. These general salinity-reduction benefits would be substantial. This alternative was introduced by SDWA and Central Delta Water Agency as the Delta Corridors Plan (ICF Jones & Stokes 2007) during the Delta Vision planning process and was included in the BDCP (California WaterFix) Draft EIS/EIR documents as Alternative 9.

The Delta Corridors alternative would divert the entire SJR flow into the head of Old River using a tidal gate in the SJR immediately downstream from the head of Old River (near Lathrop). This tidal gate would replace the Head of Old River temporary barrier and would be closed during ebb-tides to divert all of the SJR flow into Old River. During low SJR flow (<3,000 cfs), there is a substantial flood-tide (upstream) flow at Lathrop and the tidal gate would be open to allow some downstream SJR water (mixed with the Stockton treated wastewater discharge of 50 cfs) to flow upstream and be diverted into Old River. The alternative would include a 250-cfs pumping plant at the proposed SJR tidal gate to provide a minimum dilution of the wastewater discharge during higher flow conditions (>3,000 cfs). The tidal gate would remain open when SJR flows at Vernalis were greater than 10,000 cfs for SJR flood control operations. The tidal gate and pumping plant would increase the head of Old River flow because the entire SJR flow would be diverted (plus 250 cfs). This would reduce the EC increments in Old River at Tracy Boulevard and in Grant Line Canal by about 50 percent, because the Old River at Tracy Boulevard and Grant Line Canal flows would be twice as high.

The Delta Corridors alternative also would separate the CVP and SWP export pumping from Old River and Grant Line Canal flow so that none of the SJR flow or EC would be exported. A dividing wall would be constructed in the middle of Old River, extending from the DMC intake to the southern end of Coney Island. All of the tidal flows and net flows in Old River and in Grant Line Canal would remain in the Old River channel on the east side of the wall. The water for SWP and CVP export pumping would flow south from the Sacramento River (diverted into the DCC and Georgiana Slough) to the Mokelumne River, south (upstream) in the SJR to Middle River, south (upstream) in Middle River to Victoria Canal and West Canal to the CCF and DMC intakes, on the west side of the dividing wall. Four barriers (walls) also would separate Old River from Middle River at Woodward Cut, Railroad Cut, Connection Slough, and at the mouth of Old River (at Franks Tract). This separation of the SJR flow and EC from the export water flowing in Middle River and Victoria Canal from the Sacramento River, would reduce the SWP and CVP export EC (and salt load) by about 25 percent (See Figures 33a-33e), and eventually could reduce the SJR at Vernalis EC, because most of the SJR at Vernalis salt load originates from agricultural drainage from the irrigation districts located along the DMC to the west of the SJR (ICF Jones & Stokes 2007). The separation of Old River and Middle River could also reduce the seawater intrusion at the exports, because the seawater intrusion in Middle River at Bacon would be much less than the salinity intrusion in Old River at Bacon. (This was the major salinity-reduction benefit from the Emergency Drought Barrier installed in False River in June-October 2015). The full Delta Corridors alternative would involve two major fish screens at the Delta Cross-Channel (DCC) and Georgiana Slough, several miles of dividing walls and other facilities (e.g., tidal gates and pumps), and would require considerable dredging in Middle River and Victoria Canal (estimated 7.5 million yards) to allow full export pumping of 10,000 to 15,000 cfs. A preliminary cost estimate for the entire Delta Corridors Plan (with all facilities and full dredging of Middle River and Victoria Canal) would likely be $500 to $1,000 million dollars.

The salinity-reduction effects of this alternative could be investigated further with a pilot demonstration of the south Delta portions of this alternative, using walls to separate the Old River and Middle River channels (four locations), a tidal gate downstream of the head of Old River, and the 1-mile long dividing wall between the DMC intake and Coney Island. A river bridge (large culvert for Victoria Canal water) could be constructed at the north end of Coney Island to allow water from Victoria Canal to flow under the Old River channel to West Canal and the exports. The demonstration might be conducted during the spring and summer months, when the SJR flow was less than 3,000 cfs and the exports were less than 5,000 cfs (existing capacity of Victoria Canal), without the temporary barriers normally installed by DWR. The south Delta facilities that would be needed for a pilot demonstration of the salinity-reduction effectiveness of this alternative could likely be constructed for approximately $50 to $100 million. The potential salinity-reduction benefits in the south Delta and at the exports would be much greater than could be achieved with the other alternatives.

The salinity-reduction benefits of this alternative could be compatible with the California WaterFix project and could further reduce the salinity of the CVP and SWP exports. The likely salinity-reduction benefits of the Delta Corridors alternative are described here for comparative purposes; however, because this would be a more comprehensive alternative, further investigations or pilot demonstrations would likely require additional planning and coordination efforts (e.g., agency review and permit approvals) and more substantial funding. This alternative could be further investigated with DSM2 modeling and engineering feasibility studies, but a pilot demonstration of the salinity-reduction benefits would likely require more extensive coordination with other State and Federal water management and fish protection agencies.

Additional Data Collection and Salinity Investigations for the Selected Demonstration Project

The DWR DSM2 should be used to evaluate the likely benefits (effectiveness) of each of the salinity-reduction alternatives. DMS2 historical simulations (i.e., using daily measured inflows, exports and SJR EC) for several recent years (e.g., 2009-16) would allow an accurate evaluation of the likely salinity-reduction effects from each alternative. The channel geometry and channel connections should be adjusted to match recent bathymetric data (i.e., widths and depths). Daily estimates of the inflow and EC for the salt sources in Paradise Cut and Sugar Cut should be included in the model formulation; and the wastewater discharges from Lathrop, Tracy, and Stockton should be added to the model. The model calculations of agricultural diversions and drainage flow and drainage EC (i.e., DICU module) might be modified to include soil moisture and EC accounting (e.g., water and salt balances for each island). Once the model was adjusted to match the historical tidal flows and EC data, changes in the channels (e.g., dredging, walls) and in the barrier configurations (e.g., weir crest, tidal gate) would be simulated, and the changes in the EC patterns at several south Delta locations would be compared to determine the effectiveness of each alternative. The DSM2 results would provide a great evaluation tool for guiding the selection of the demonstration project alternative.

One of the alternatives may be selected by DWR to demonstrate an effective permanent solution for reducing the effects of Paradise Cut and Sugar Cut salt sources on the Old River at Tracy Boulevard EC. A pilot demonstration project (e.g., 3 years) may be implemented by DWR in cooperation with SWRCB, SDWA, Central Valley RWQCB, and other stakeholders and agencies to measure the actual effects of the selected alternative and confirm that the selected alternative would be effective in substantially reducing the measured EC increments in Old River at Tracy Boulevard. The demonstration project would be completely reversible (i.e., removable) if EC monitoring showed unexpected, potentially adverse consequences from the channel or barrier modifications. If the demonstration project was successful in reducing the EC increments at Tracy Boulevard, the demonstration project could be permanently implemented with any beneficial modifications that were identified during the demonstration project.

To support the demonstration project, temporary EC stations could be established for a specified period (e.g., 3 years) at a few additional locations to more accurately characterize the existing salt sources along Old River. Temporary EC stations could be added at the two bridges along Paradise Cut, at the upper end of Sugar Cut, in Tom Paine Slough upstream from the Diversion Dam (this EC station was installed in 2014), near the mouth of Sugar Cut (at Old River), in Old River at Lammers Road, and in Wicklund Cut (Westside ID pumping plant diversion) to provide more comprehensive EC measurements for tracking the effects of Paradise Cut and Sugar Cut salt sources on Old River EC during the 3-year demonstration project.

Additional longitudinal EC profiles could be collected (similar to those collected in 2009 and 2010 in Old River) to confirm the salt source locations and tidal movement of salinity in Paradise Cut and Sugar Cut, and in Old River and Grant Line Canal. Additional longitudinal EC profiles could be taken at high tide and low tide on several days to confirm that the assumed tidal shifting of the measured EC profiles (see previous section of report) provides an accurate representation of the tidal flows (volumes) in Old River at the DMC barrier and at the mouth of Grant Line Canal. EC profiles in Old River, Paradise Cut, and Sugar Cut could be obtained periodically during the salinity reduction demonstration project to compare with the Old River EC profiles and Paradise Cut EC profiles that were measured by DWR in 2009 and 2010 (DWR 2012). These longitudinal EC profiles would be particularly important to demonstrate the salinity-reduction effects of a tidal gate in Old River instead of the temporary barrier upstream of the DMC intake.

The compilation and analysis of all available south Delta tidal elevation and EC data (described in this report) could be extended to include 2014 and 2015 data and should continue during the demonstration project monitoring period. This tidal and EC data would provide the basis for accurate evaluation and assessment of the salinity-reduction benefits achieved with the DWR-selected demonstration alternative.

Conclusions and Recommendations

This report provides an integrated assessment of the salinity changes measured between the SJR at Vernalis and the SJR at Brandt Bridge, Old River at Union Island, and Old River at Tracy Boulevard stations. The EC measured in the SJR at Brandt Bridge station and in Old River at Union Island station generally was similar to the measured EC in the SJR at Vernalis, with some EC increases of 25 to 50 µS/cm observed. However, the EC measured in Old River at the Tracy Boulevard station often was much higher than the EC in Old River at Union Island station, although the Tracy Boulevard station is only 6.5 miles downstream from the Old River at Union Island station. The likely sources for the higher salinity water (e.g., groundwater seepage and agricultural discharges) were identified through longitudinal boat surveys (DWR 2012) and additional EC monitoring in Sugar Cut and Paradise Cut (tidal sloughs located on Old River downstream from Doughty Cut and upstream from Tracy Boulevard). The measured EC increments were greatest when the net flows in this section of Old River were lower with less dilution of the higher salinity water. This report presents an integrated assessment of the effects of SJR inflows, CVP and SWP export pumping, and temporary barriers (with weir crests and flap gate culverts) on tidal elevations, tidal flows, net flows, and measured salinity increases in south Delta channels (i.e., Old River, Middle River, and Grant Line Canal). This integrated assessment was based primarily on the extensive tidal data collected by DWR, USGS, and Reclamation.

In 2009, DWR added tidal EC stations in Sugar Cut (just upstream from Tom Paine Slough diversion dam) and near the mouth of Paradise Cut. Both Paradise Cut and Sugar Cut join Old River just downstream from Doughty Cut, which conveys the majority of Old River flow to Grant Line Canal. Because of constricted channel geometry, the measured Old River flow downstream from Doughty Cut is only 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 tide periods, when water from the tidal sloughs is exiting towards Old River. Salinity (EC) monitoring at both Sugar Cut and Paradise Cut has documented many periods when the EC was greater than the Old River at Tracy Boulevard EC, and therefore could be increasing the measured EC at Tracy Boulevard. Because the measured EC increase in Old River at Tracy Boulevard depends on the net river flow and the salt load of higher salinity water (i.e., source flow times source EC), the tidal flow measurements in the south Delta were used to estimate the daily net flows, and the net flows were used to calculate the daily salinity (loads) added to Old River between Union Island and Old River at Tracy Boulevard stations. Because of tidal flows in all of these south Delta channels, and the connection between Old River and Grant Line Canal through Doughty Cut, the movement of the higher salinity water leaving Paradise Cut and Sugar Cut is variable, depending on the tidal fluctuations and the installation of the temporary barriers in Old River near the DMC intake and in Grant Line Canal near the Tracy Boulevard Bridge. This report evaluated the movement of higher salinity water from Sugar Cut and Paradise Cut to the Old River at Tracy Boulevard station and described several possible alternatives for reducing the high measured EC at Tracy Boulevard.

DWR operates (annually installs and removes) three temporary barriers in south Delta channels, which include weir crests and culverts with flap gates, to increase the minimum water elevations during the summer irrigation season to allow full operation of siphons and pumps, and to provide adequate circulation (i.e., net flushing flows) in south Delta channels to reduce the effects of agricultural diversions and discharges on water quality (EC). Although the temporary barriers maintain higher minimum daily water elevations (e.g., 1.0 to 1.5 feet higher) upstream from the barriers, tidal flows are substantially reduced (e.g., 50 percent) by the barriers. A fourth barrier at the head of Old River has been installed by DWR in several years to protect migrating fish in the spring (juvenile Chinook salmon in April and May) and fall (adult Chinook salmon in October and November). The tidal data analysis was presented in five south Delta Tidal Data Atlas Excel files and five south Delta Data Atlas documents to provide a visual framework for evaluating the extensive data collected in south Delta channels. The Data Atlas framework includes the compilation, integration, and analysis of the 15-minute tidal elevation, tidal flow, and tidal EC data from about 25 south Delta stations located on the SJR, Old River, Middle River, Grant Line Canal, Victoria Canal, Paradise Cut, Sugar Cut, and Tom Paine Slough. Excel files with 15-minute and daily average data, tidal flow and salinity calculations, graphical comparisons, and statistical summaries were prepared for calendar years 2009 through 2013. These integrated data files can be used to further explore (by comparisons and calculations) the effects of SJR inflows, 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 and estimate the seasonal patterns of potential salinity sources in the south Delta.

The evaluation of the tidal flow and EC data suggested that both Sugar Cut and Paradise Cut have sources of higher salinity water (e.g., groundwater seepage or tile-drainage) that contribute a substantial portion of the higher EC often measured in Old River at Tracy Boulevard. Low flow conditions in the SJR, relatively high agricultural diversions, and the installation of temporary barriers that reduce the tidal flows in Old River and Middle River likely contribute to the elevated EC measurements in Old River at Tracy Boulevard.

Regulatory options were identified and several physical alternatives for reducing the higher EC measured in Old River at Tracy Boulevard were comparatively evaluated. Based on the results shown in this report, the SWRCB might reconsider using Old River at Tracy Boulevard as an EC compliance station. The SWRCB could decide to retain Old River at Tracy Boulevard as an EC monitoring station and rely on SJR at Brandt Bridge and Old River at Union Island as EC compliance stations for the protection of south Delta agricultural water uses. The physical alternatives for reducing the higher EC in Old River at Tracy Boulevard are summarized here, with recommendations for 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 the high 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.]

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.]

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 would reduce (with greater dilution) the elevated EC in Old River at Tracy Boulevard. A GIS representation of the south Delta channel bathymetry was developed to support the evaluation of dredging volumes for this alternative (See Attachment A). Localized dredging may also be effective for improving minimum water conditions at some existing agricultural diversions (i.e., siphons and pumps). [This alternative could be further investigated with more detailed bathymetric measurements.]

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.]

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 (gates 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. This tidal circulation with tidal-gates was proposed by DWR in the 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 BDCP (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.]

The effects of the salinity-reduction alternatives could be more accurately evaluated using the DSM2 model to compare the effects of each alternative with 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 the further discussions with stakeholders and regulatory agencies, one of the physical salinity-reduction alternatives could be selected by DWR as a recommended demonstration project to actually install (construct) and measure the effectiveness of the selected physical alternative. The demonstration project might be permitted as a modification of the DWR Temporary Barriers Program. The selected demonstration project should 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 2014-16 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 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.

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Attachment A
South Delta Channel Bathymetry

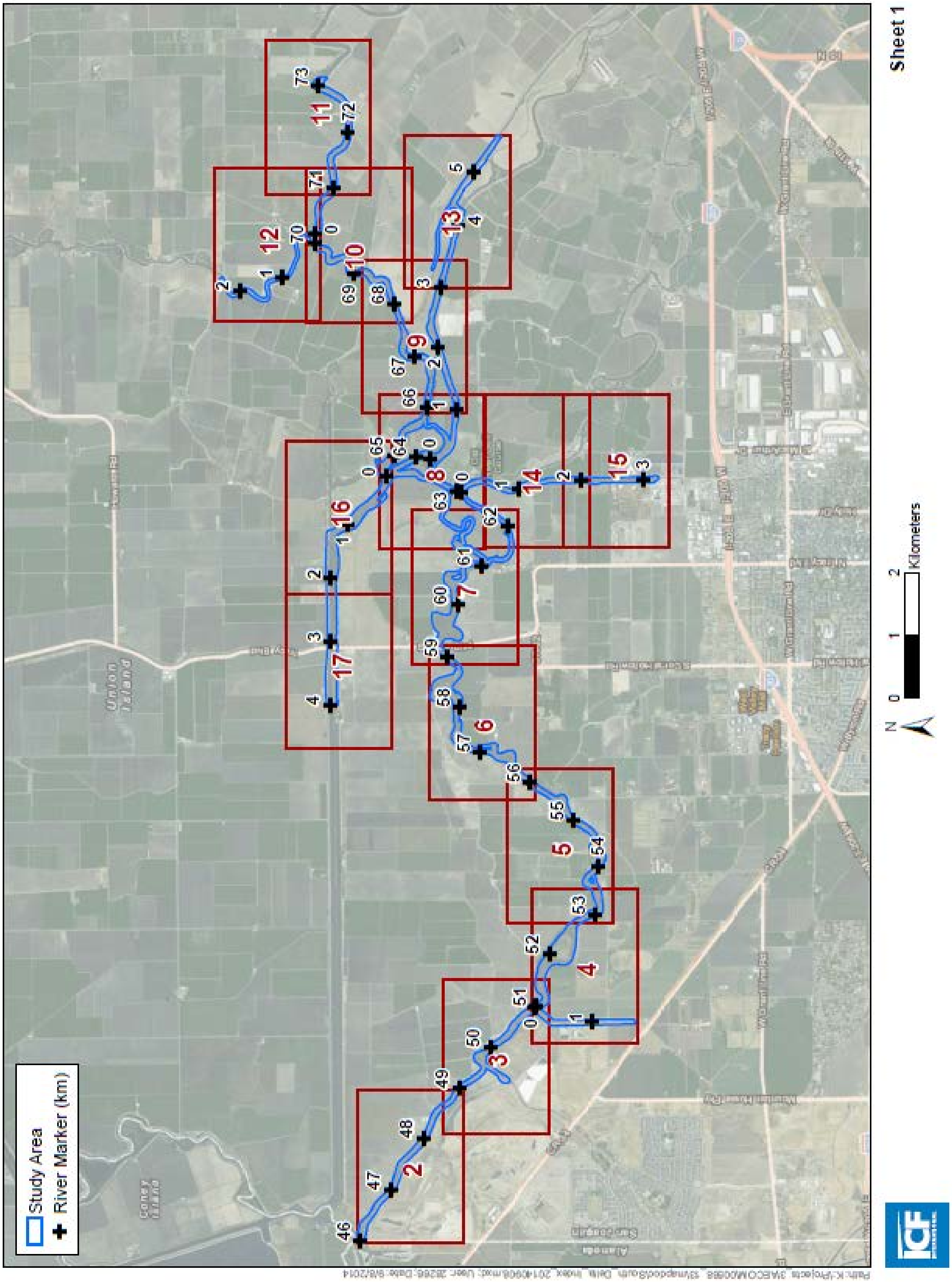
South Delta channel bathymetry (underwater elevations) and topography (land surface elevations) are important for understanding the channel volumes, conveyance areas, water surface areas, levee heights, and irrigated land surface elevations. A set of channel bathymetry maps was created for the south Delta Tidal Data Evaluation Project to show the channel depths and cross-sections along Old River and portions of Grant Line Canal, Paradise Cut, and Sugar Cut. These map sheets are shown in this attachment.

Sheet 1 shows the layout of the bathymetry map sheets, with the Old River kilometer markers (with 0 km corresponding to the mouth of Old River at the San Joaquin River), with a scale of 1 inch equals 2 km. The DMC intake is at Old River km 46, Tracy Boulevard is at Old River km 59, Sugar Cut is at Old River km 63, Paradise Cut is at Old River 64 km, and Doughty Cut is at Old River km 65. Each map sheet shows about 2 to 3 kilometers of channel with a scale of 1 inch equals 250 m. The bathymetric data have been superimposed on a Google Earth image and saved as a KMZ file that is available on the project CD along with the south Delta salinity data.

These bathymetry maps of the south Delta channels were based on digital elevation model (DEM) data files available from DWR. South Delta DEM (Version 3), contained in file "dem_south_delta_2m_v3_20121106.zip," was downloaded from DWR's Delta modeling website (http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/modelingdata/DEM.cfm).

Development of this DEM by the Delta Modeling Section of DWR was described by Wang and Ateljevich (2012). Bed elevation data (bathymetry) is an important input for any hydrodynamics model, and the Delta Modeling Section has maintained a database of bathymetry soundings and levee surveys for decades. In recent years, new data have become available; technology has shifted to very dense multibeam sonar soundings; and the demands for accuracy have increased because of increasingly common multidimensional modeling of the Bay–Delta region. The improvements in recent DEM datasets have been substantial because of improved sonar sounding resolution, more accurate geo-referencing techniques, and denser coverage of areas that were previously interpolated (a 2-m grid rather than a 10-m grid). The Bay–Delta DEM was a composite of multiple sources of elevation data including high-resolution LiDAR and sonar soundings. The horizontal datum was NAD83 and the vertical datum was NAVD88 (also used for tidal elevation monitoring).

The initial release of this DEM dataset (map) was in the form of a 10-m DEM for the entire Bay–Delta, supplemented by a 2-m grid DEM for the south Delta, where the channel features were poorly resolved at 10-m. These data are raster data sets, meaning that they are defined on a rectangular mesh with square cells, some of which may be declared missing. Raster data are compatible with data formats used for modeling and allow a greater variety of GIS analyses. However, in regions where high resolution LiDAR and multibeam sonar coincide, some of the analysis uses ArcGIS Terrain data sets. A Terrain is a collection of dense points, lines, and polygons. It is a form of data that makes good use of disparate data and is efficient for huge clusters of points. However, it is a proprietary data structure, not directly usable by hydrodynamic models.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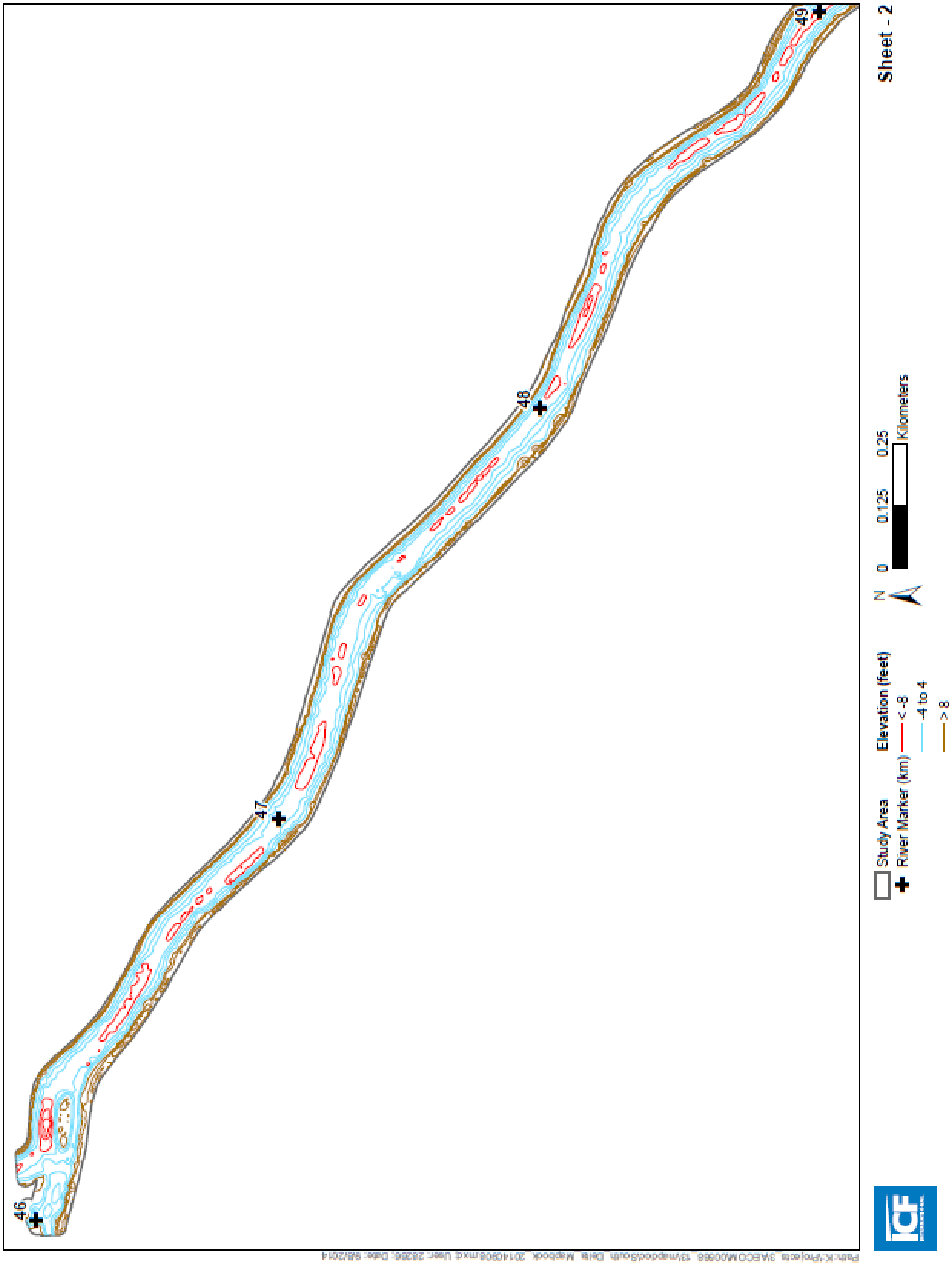
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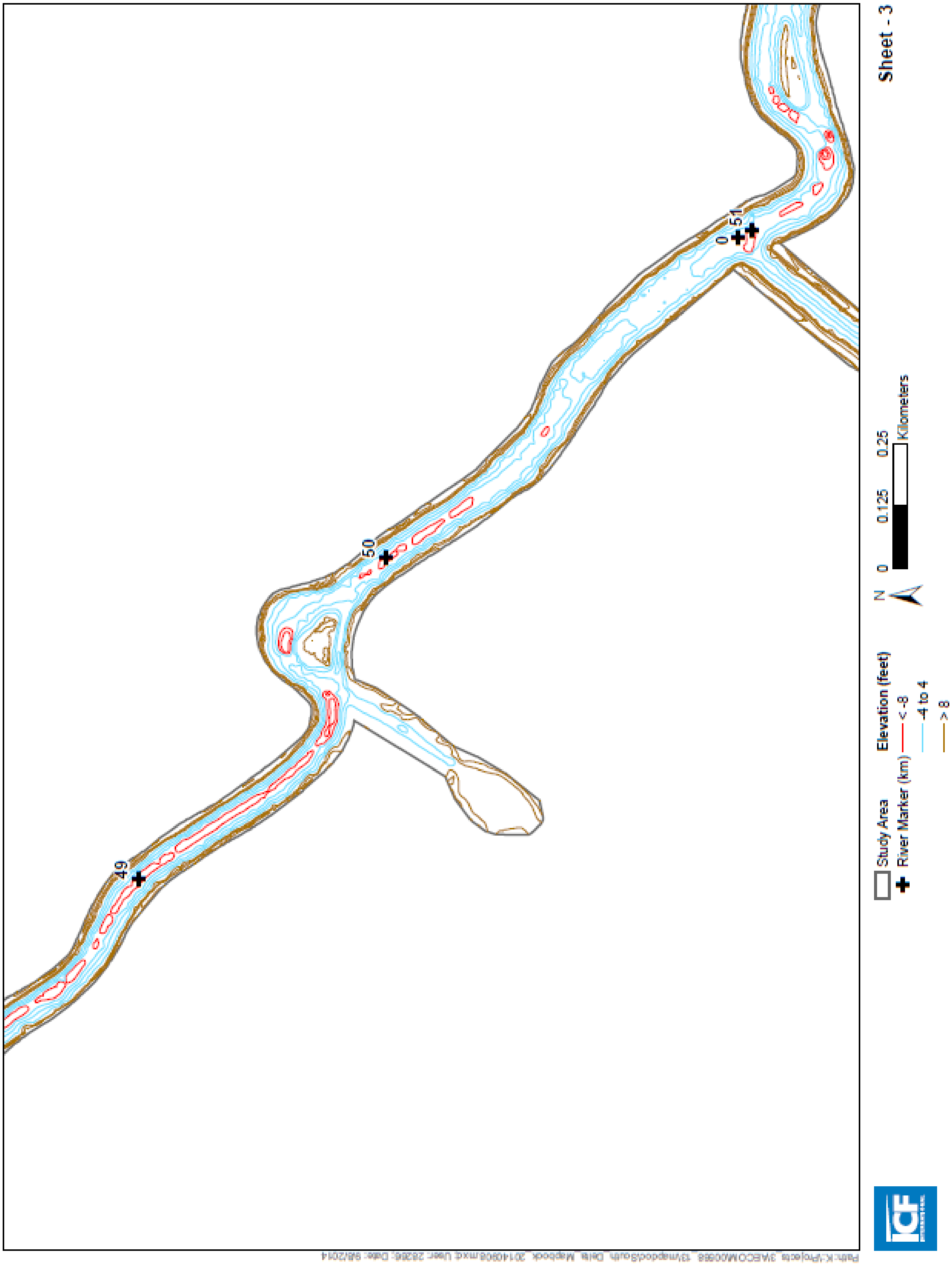
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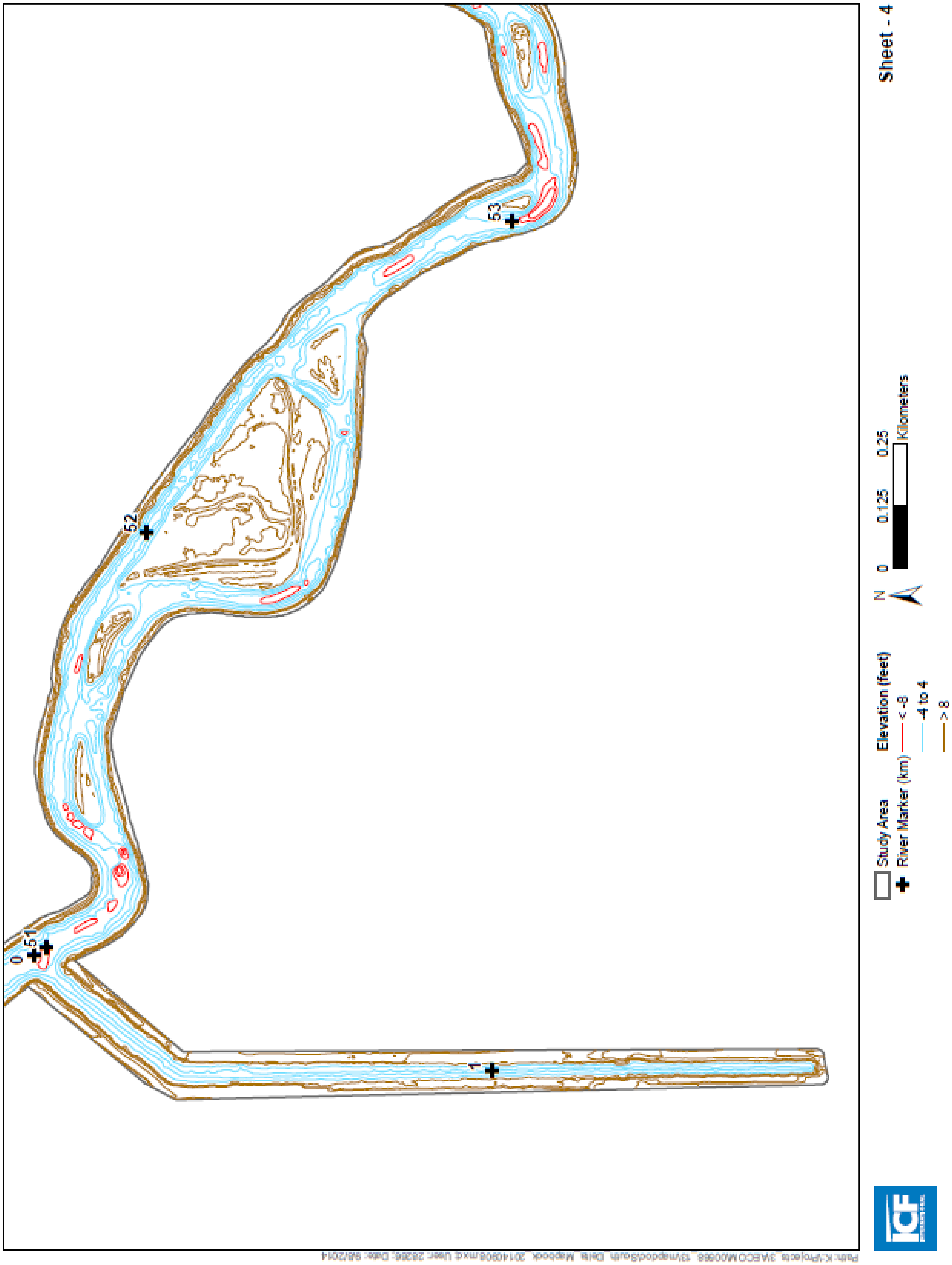
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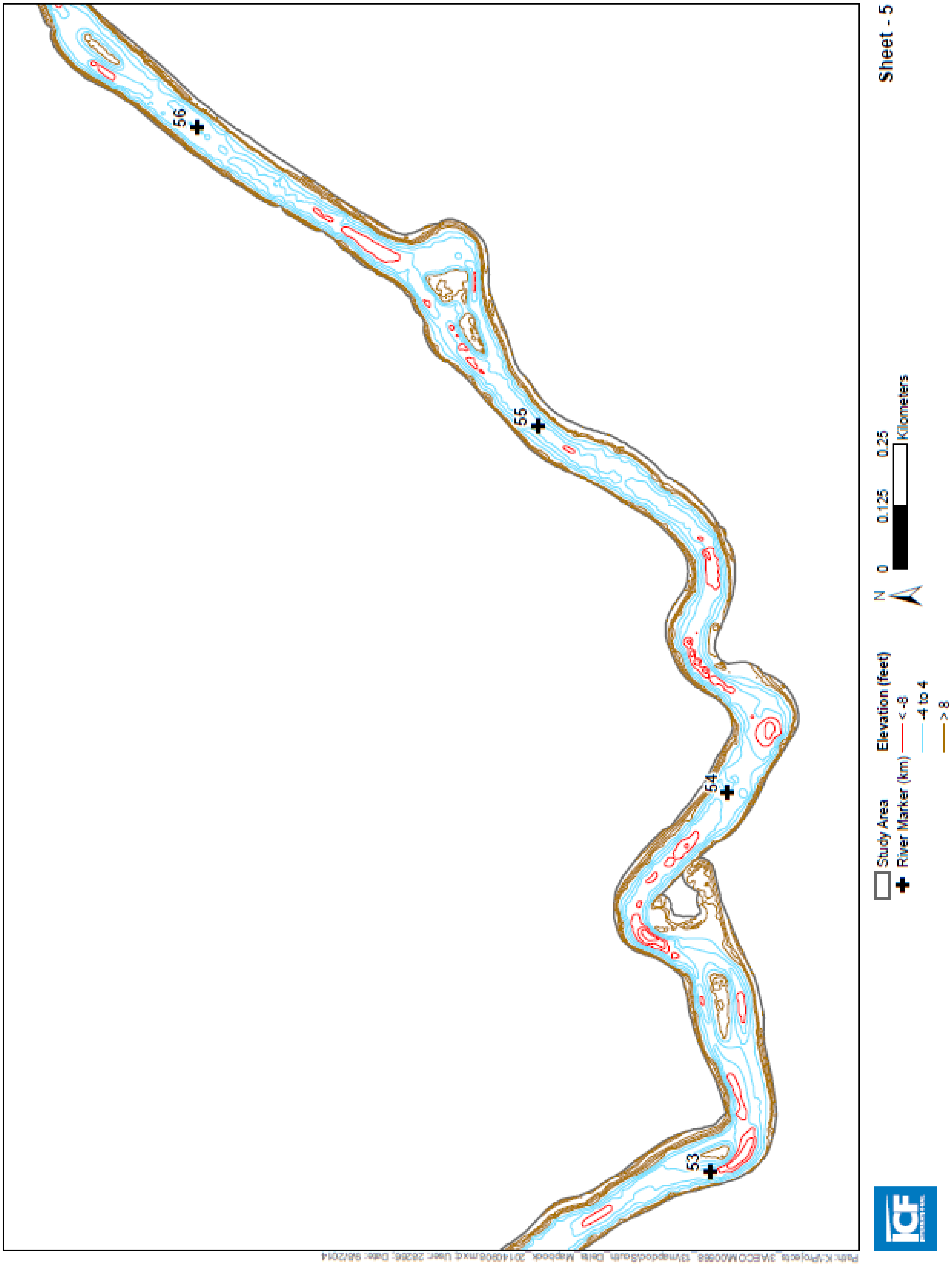
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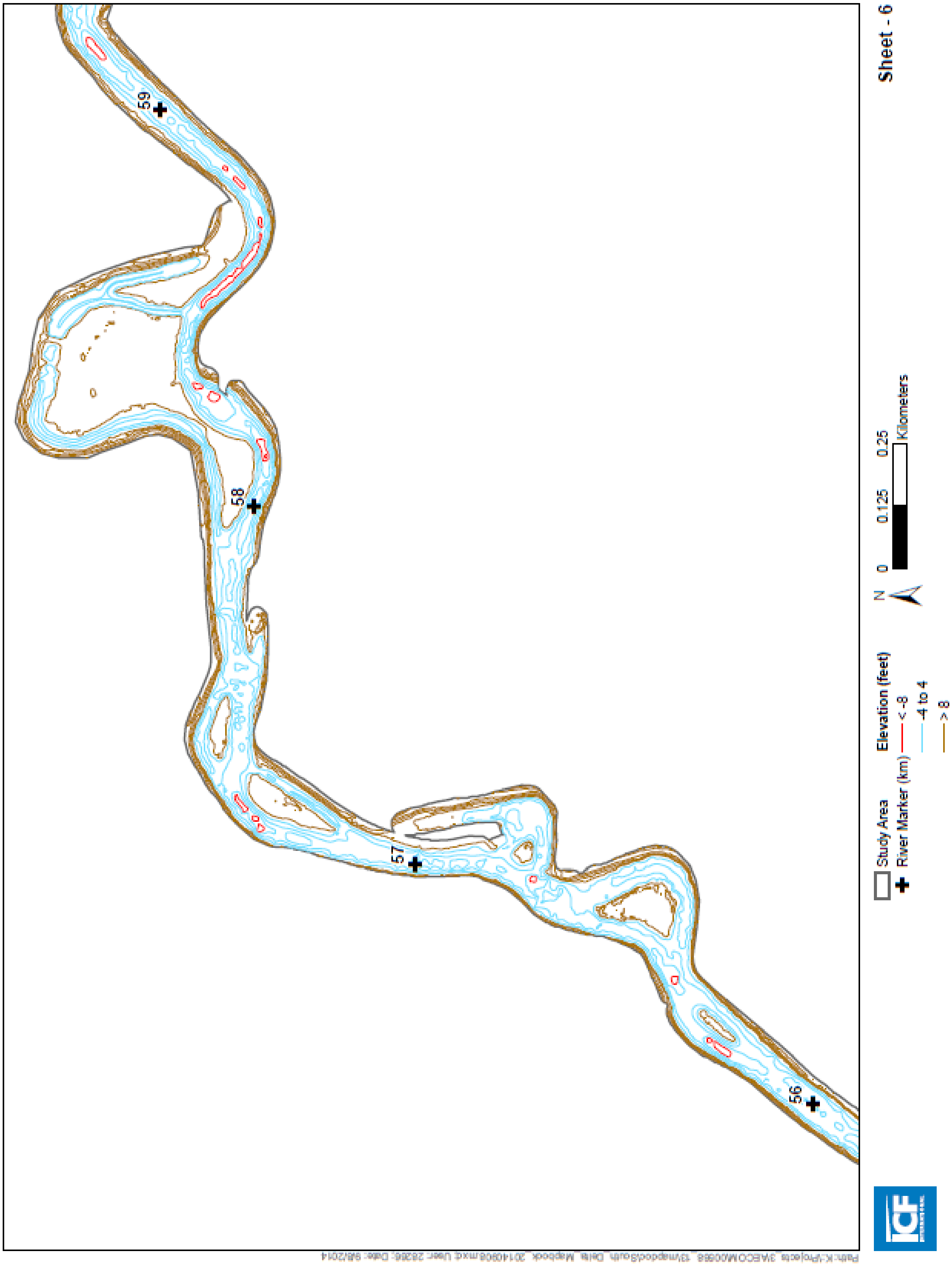
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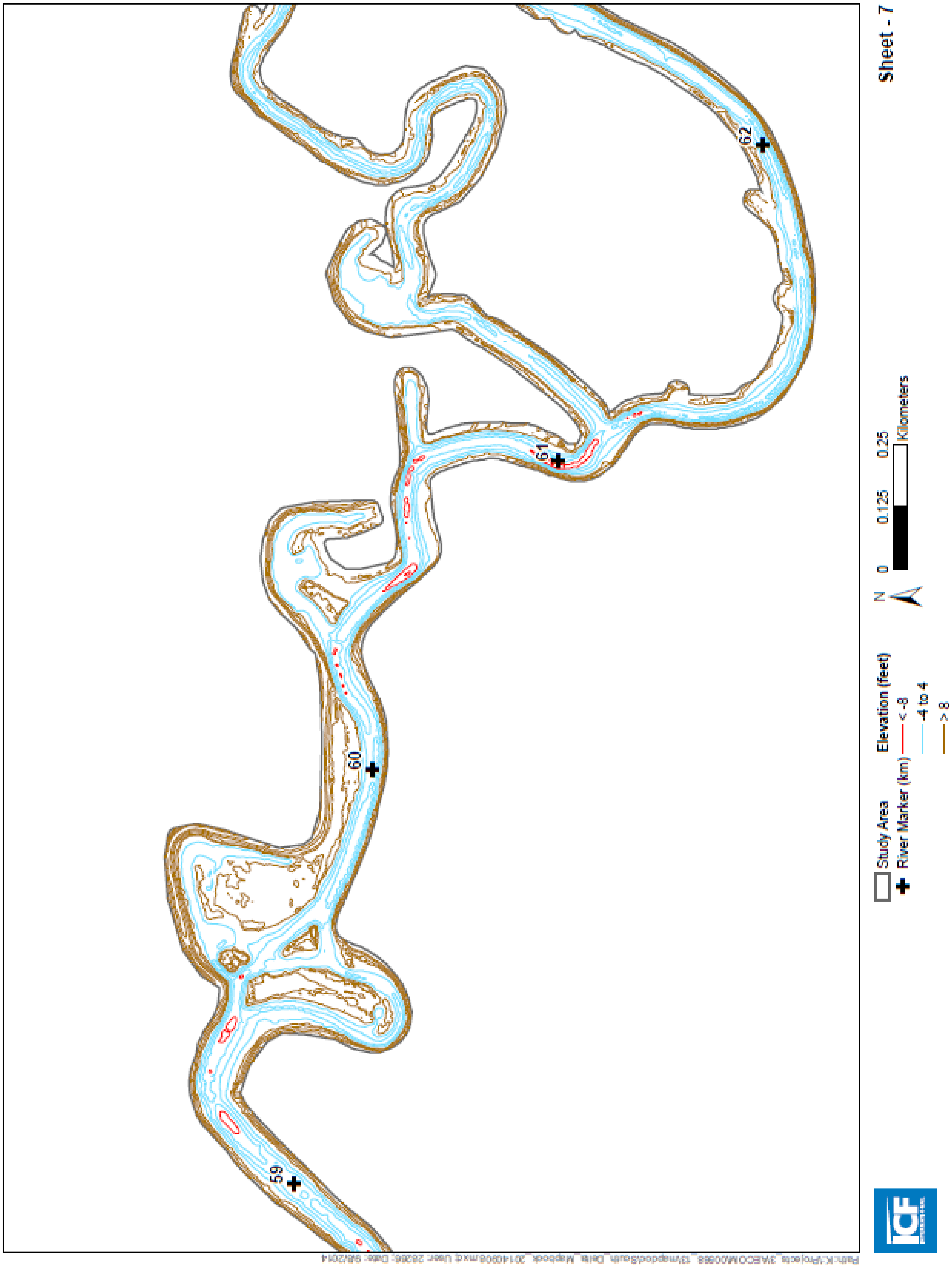
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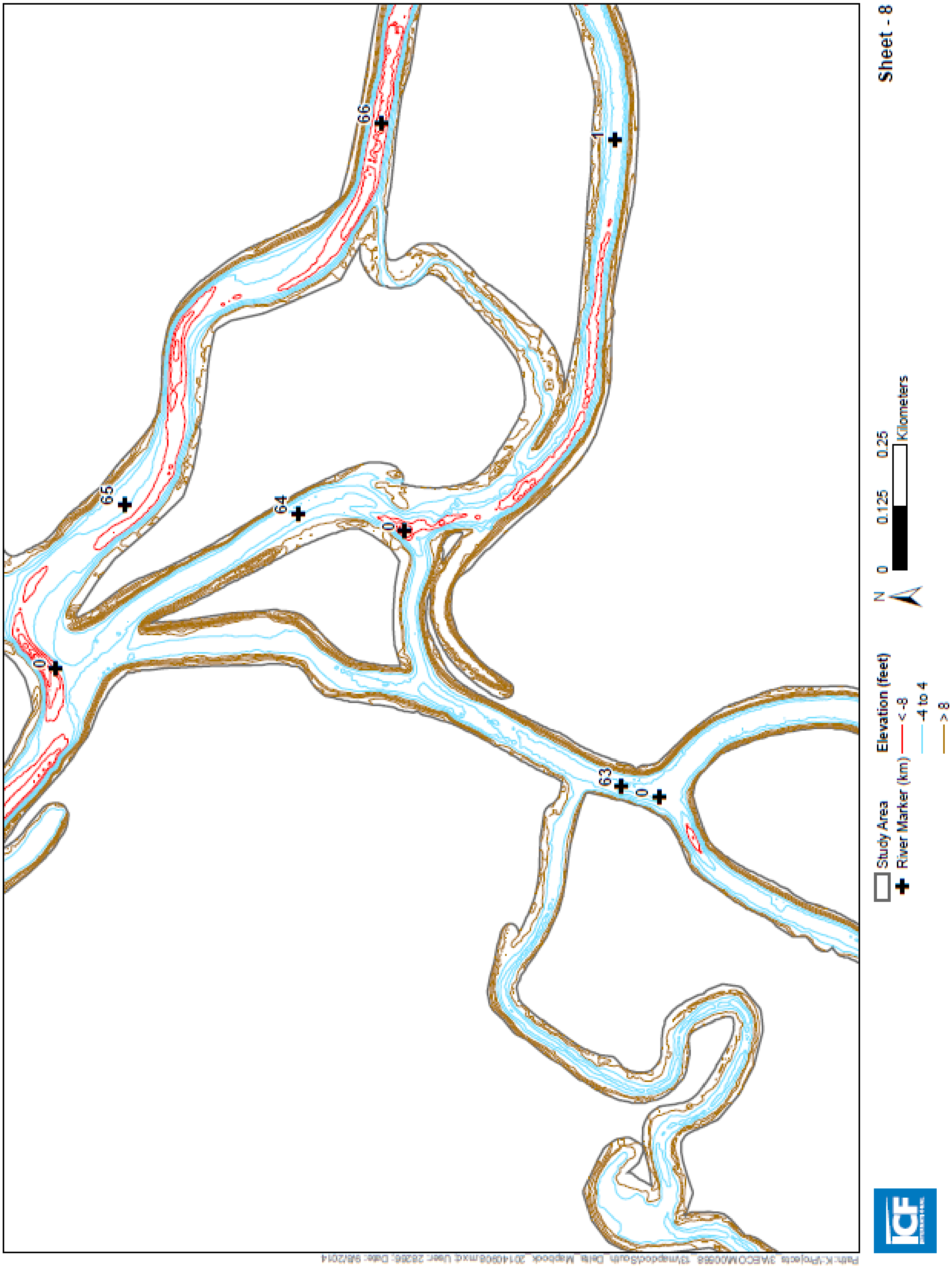
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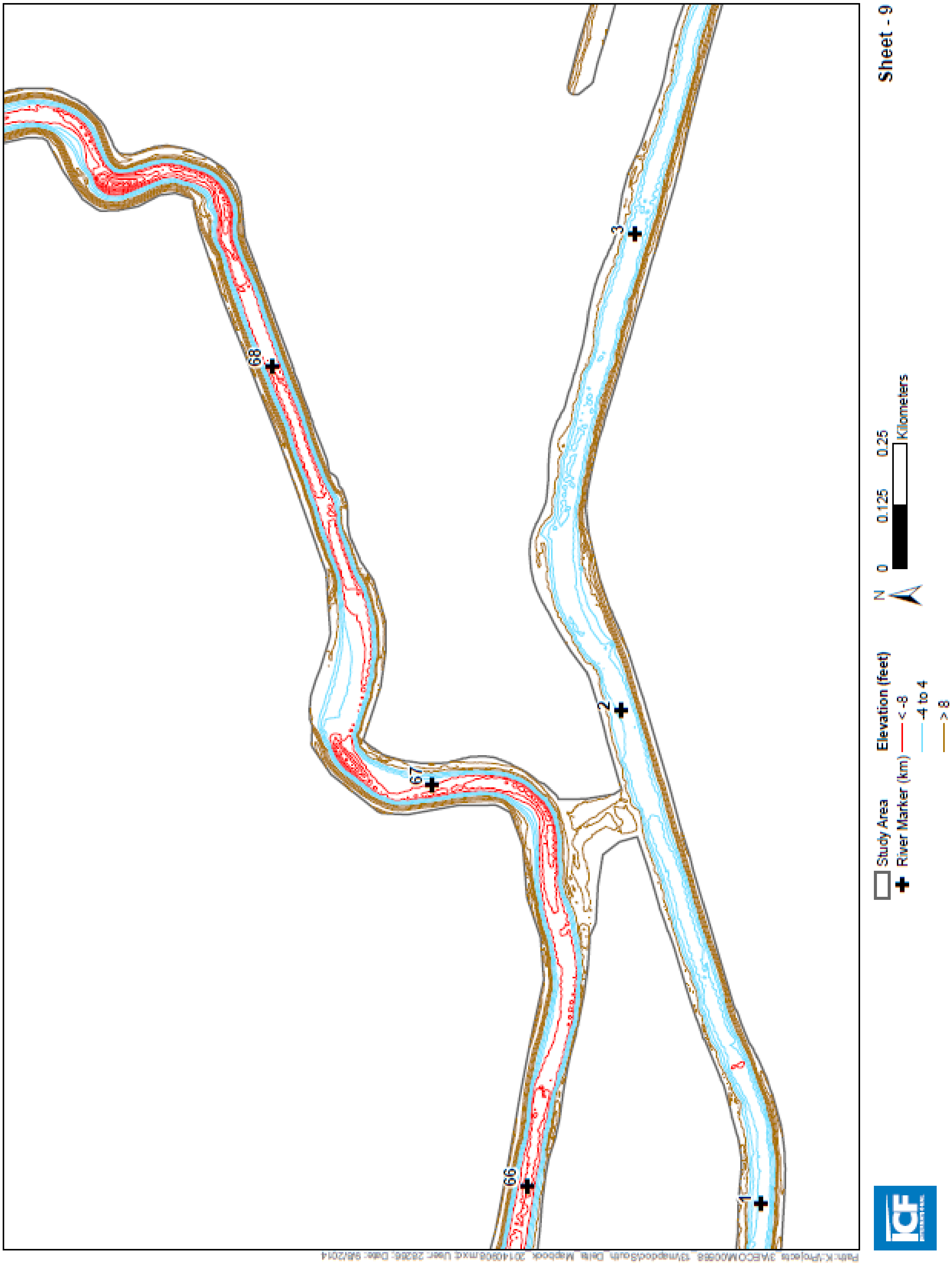
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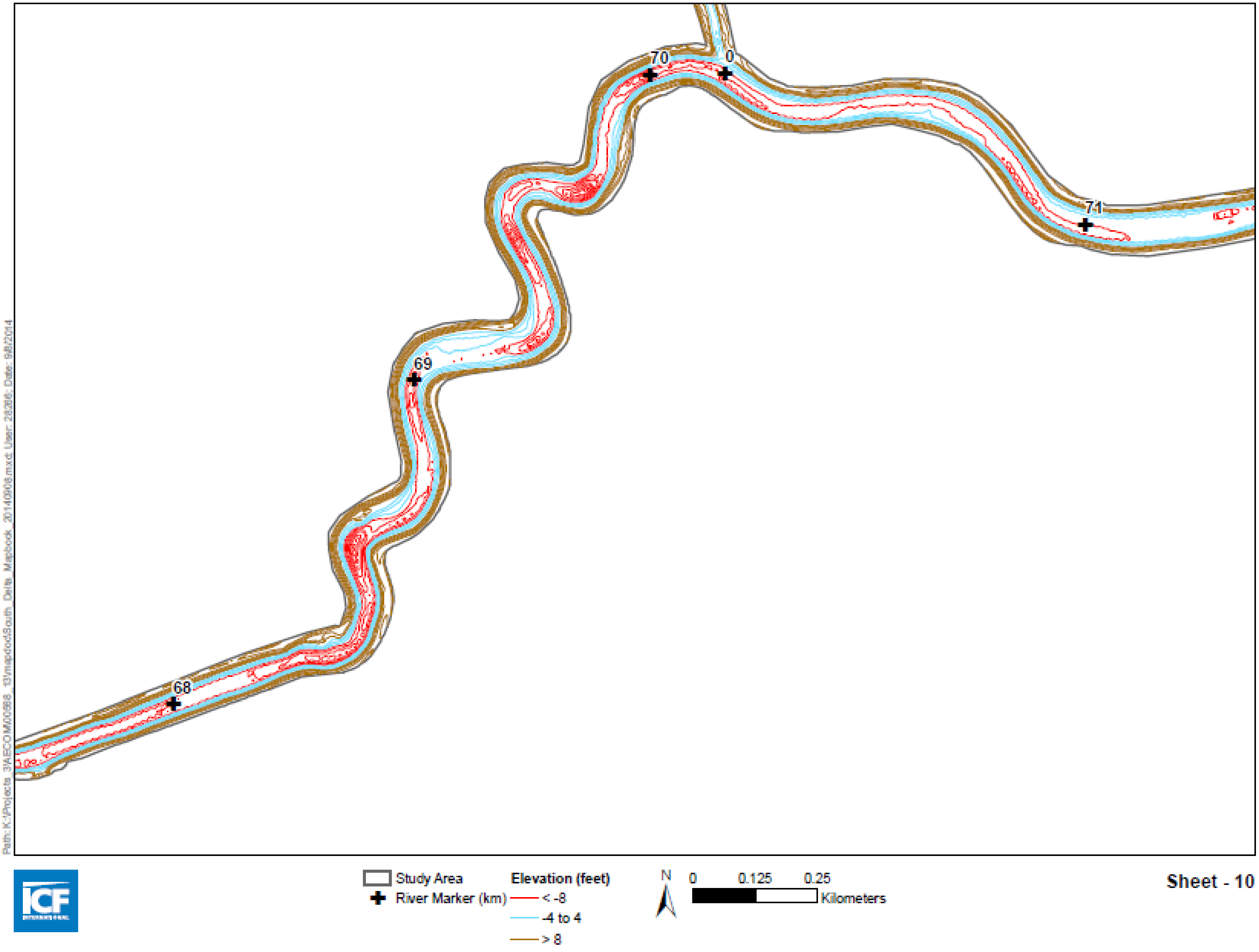
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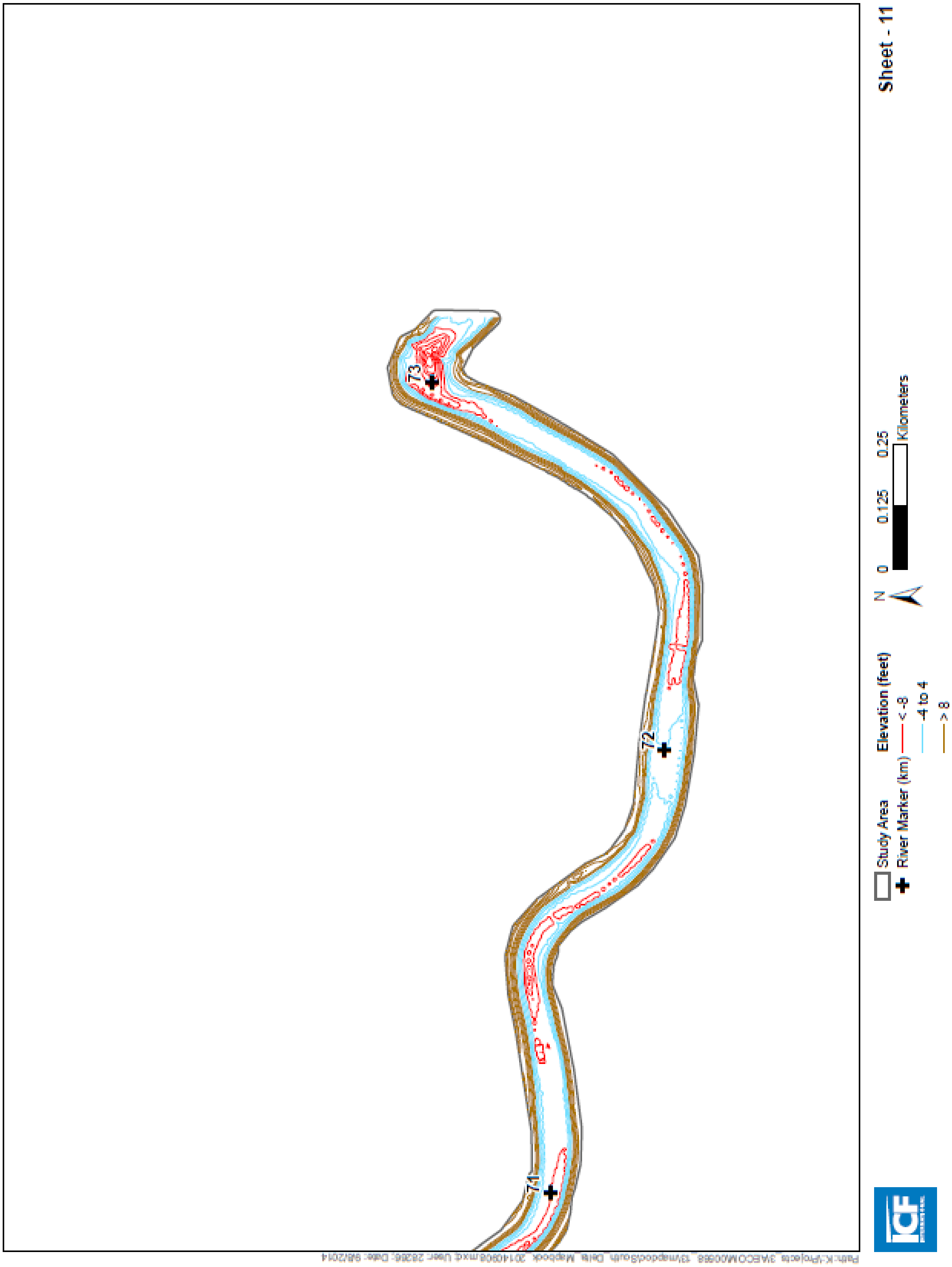
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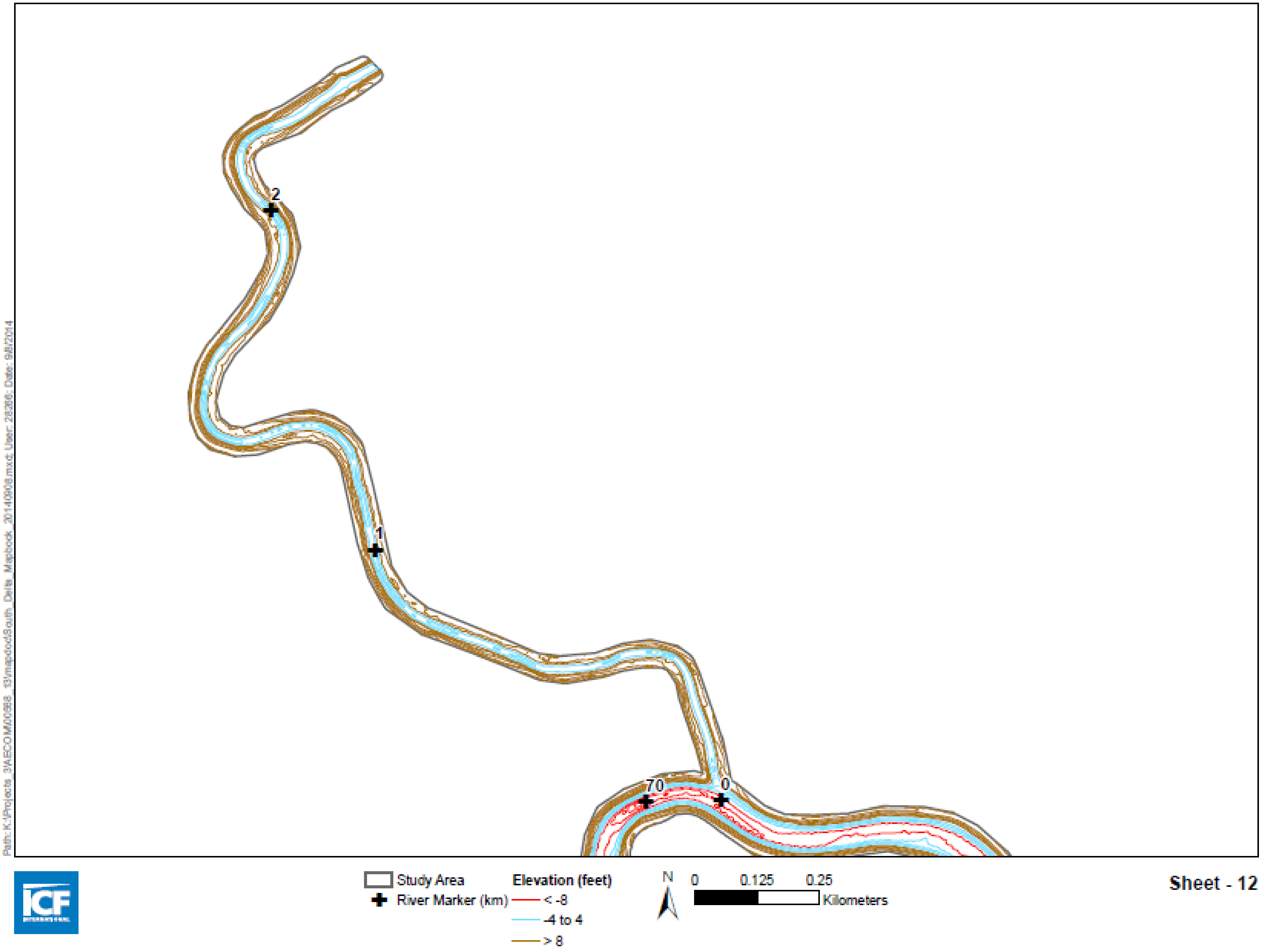
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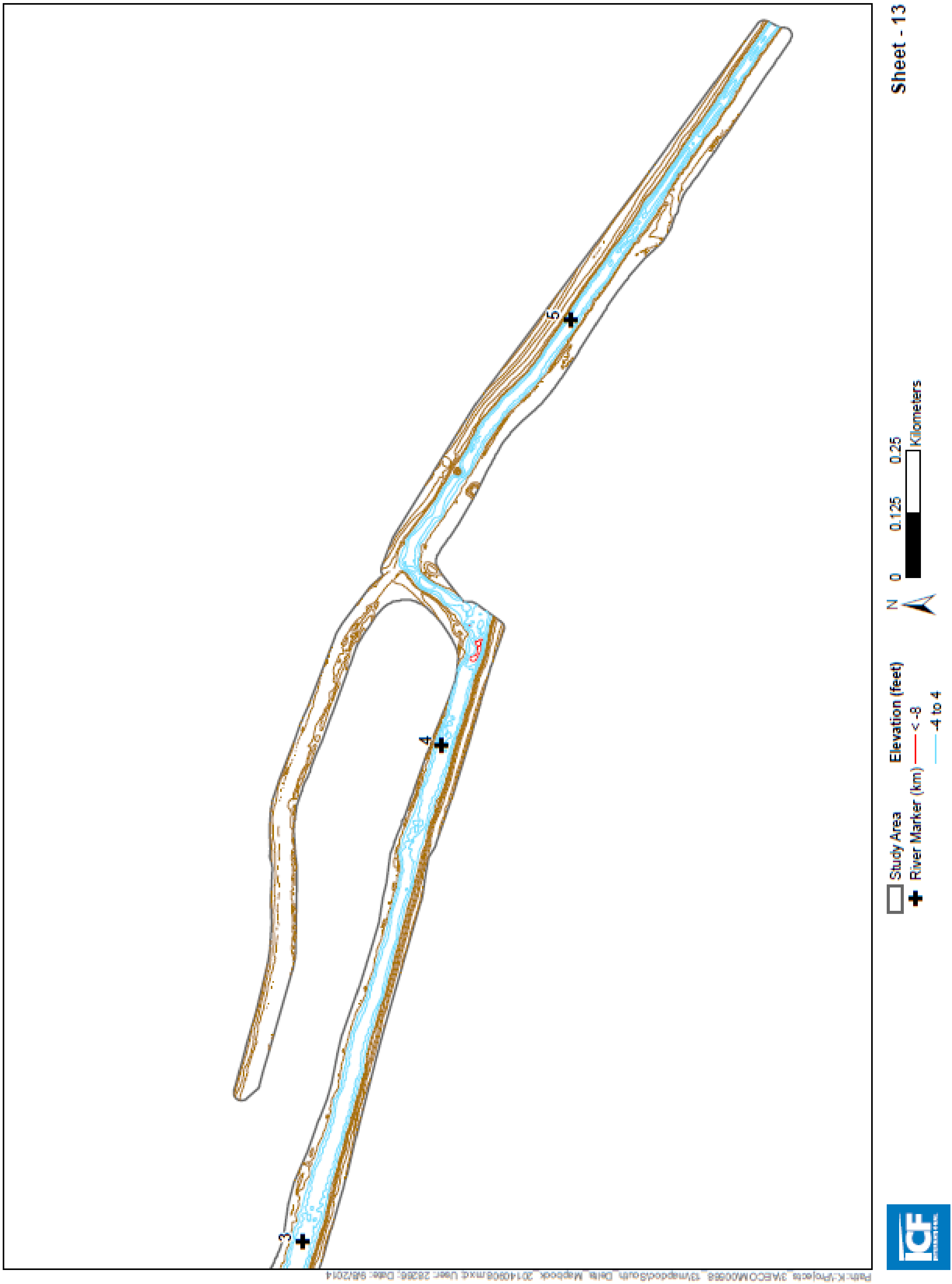
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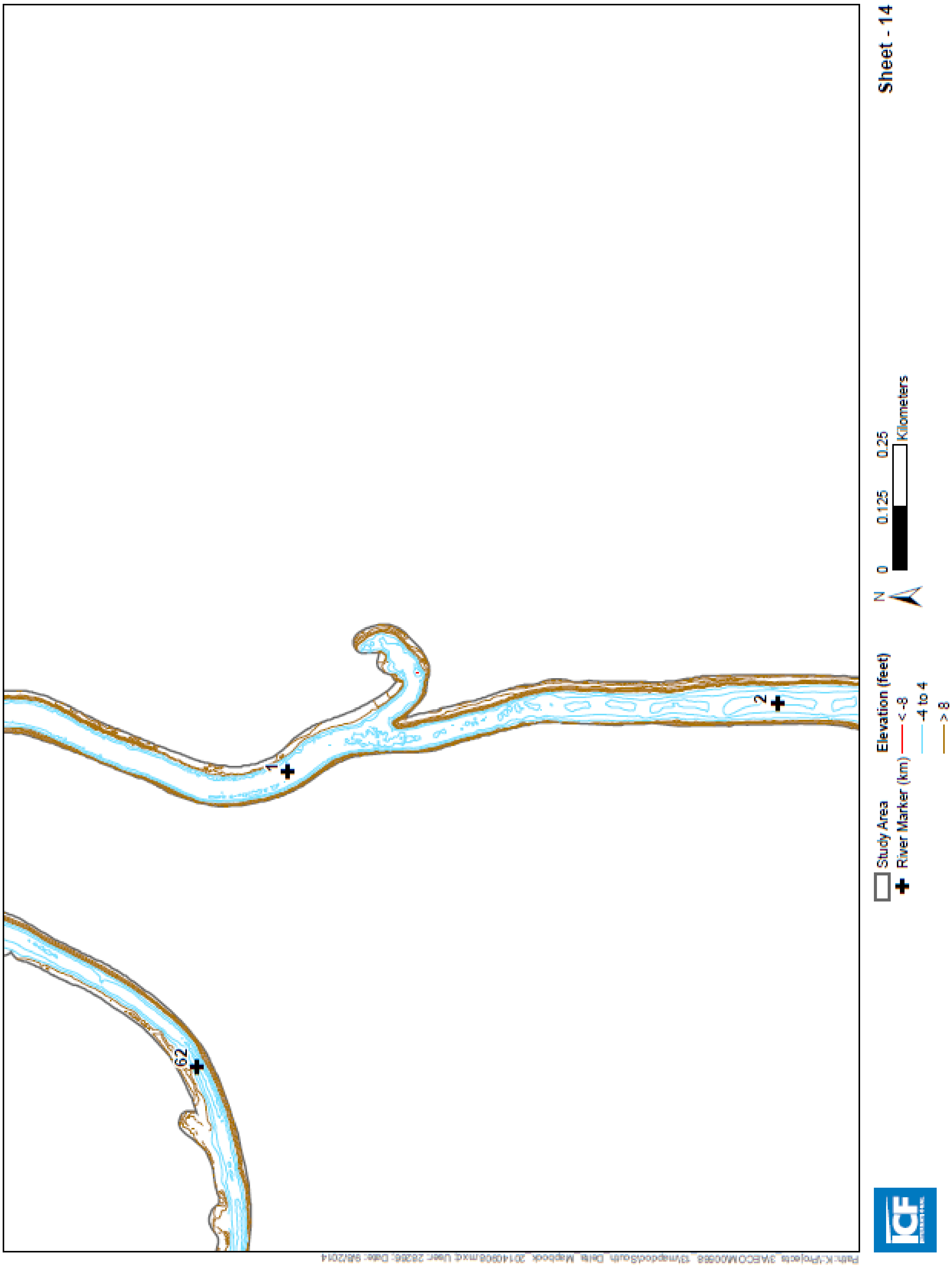
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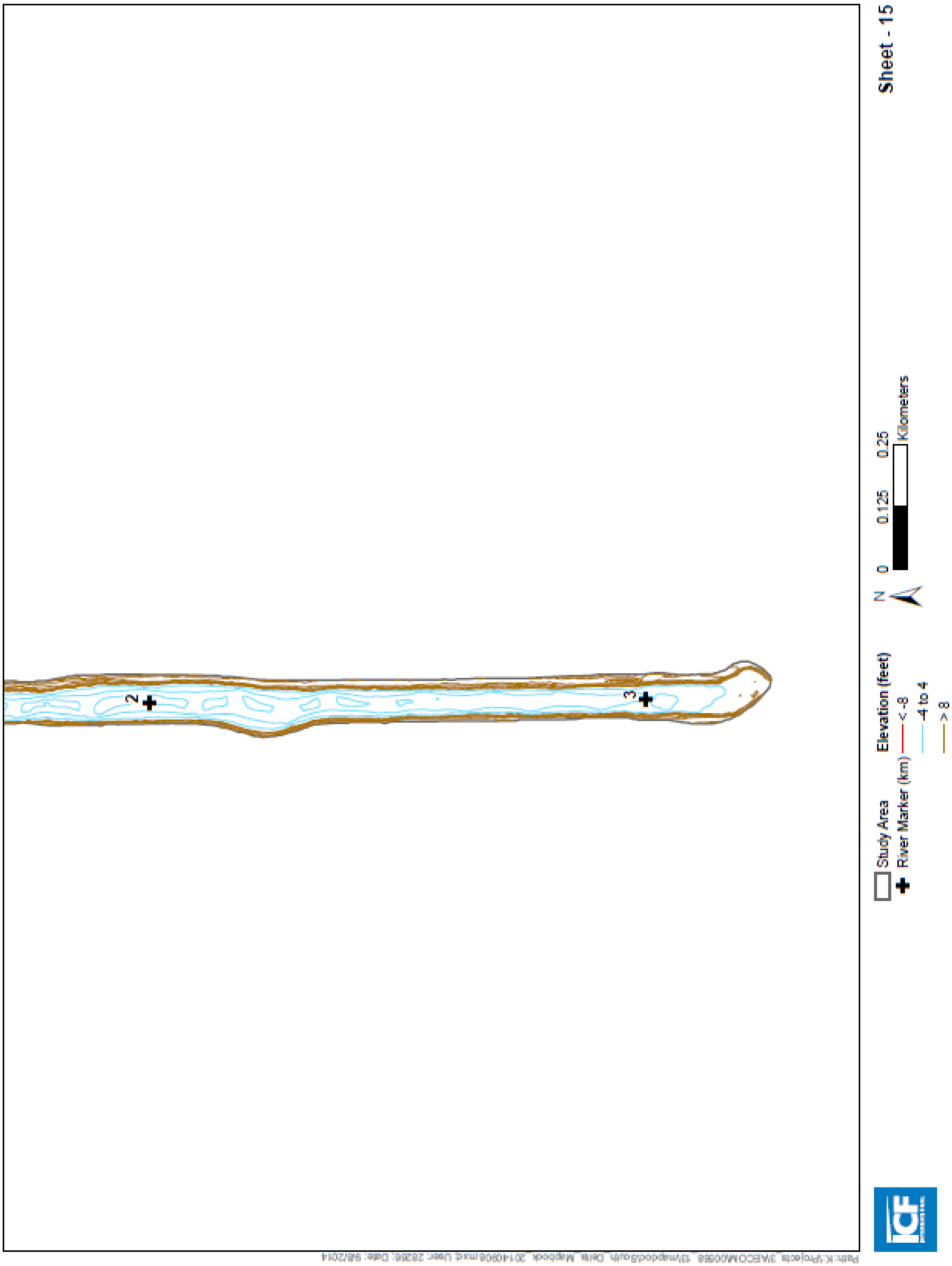
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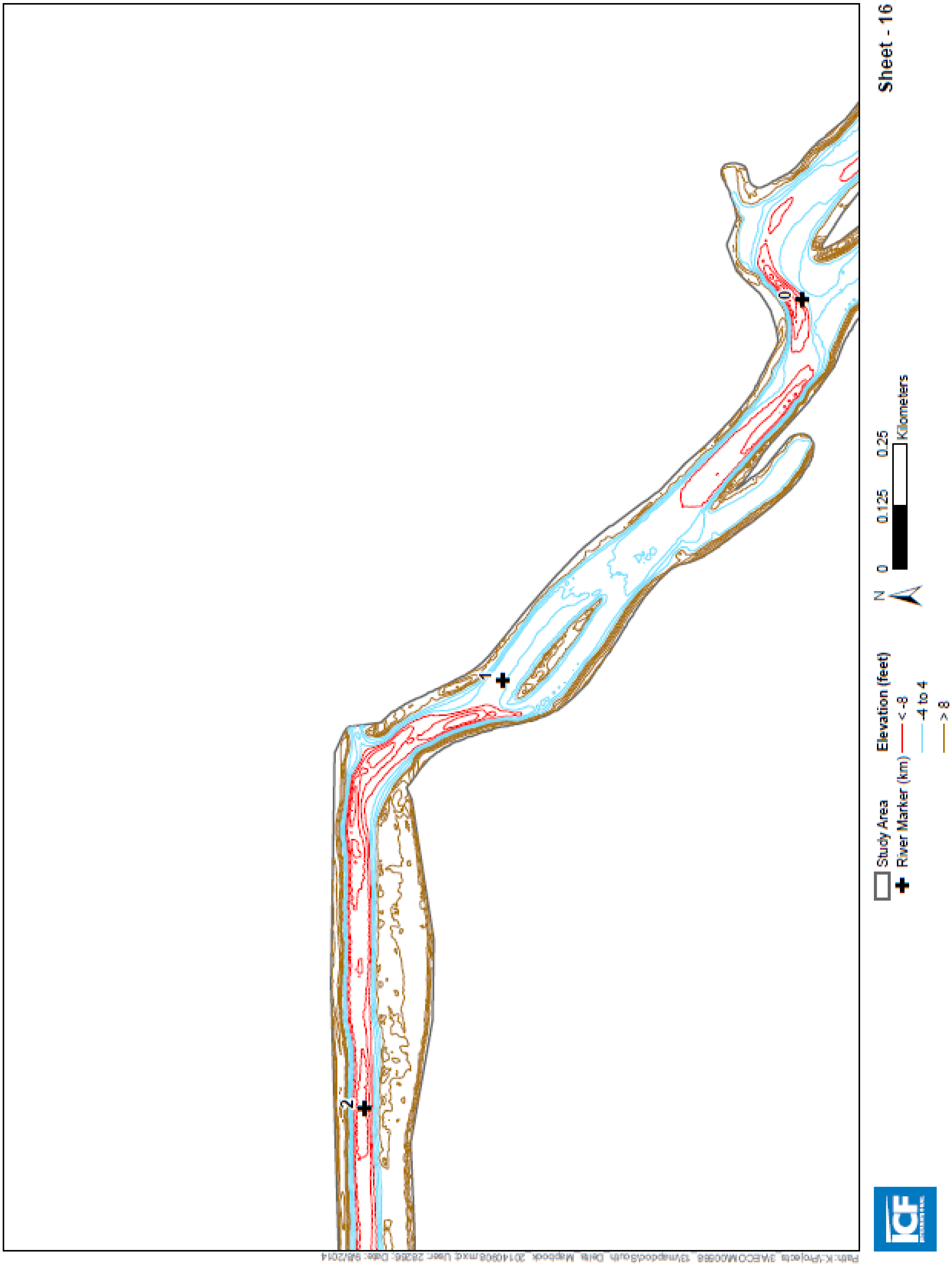
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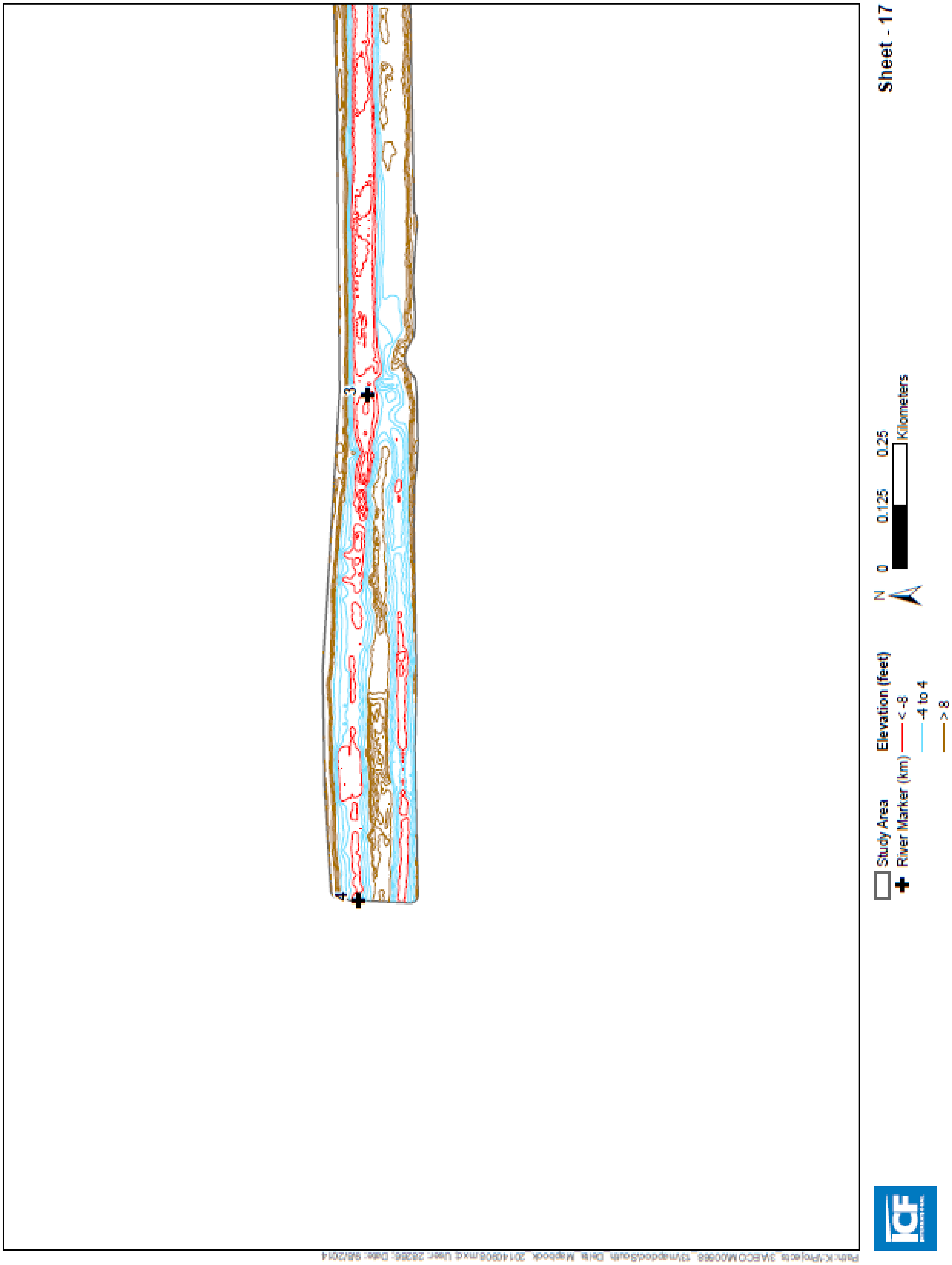
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The DEM was processed by "Clipping" (selecting) a buffer zone that included the channel levees along the south Delta channels, and then using "Spatial Analysis" (ESRI GIS extension) to create contour lines at designated elevations. An elevation interval of 4 feet was selected so that the channels could be well-defined without being cluttered. The +8 feet and higher elevation contours were color-coded brown (levees and banks above water) and the -8 feet and lower elevation contours were color-coded red to identify channels that were at least 10 feet deep at minimum tide elevation (+2 feet NAVD88). The -4 feet, 0 feet, and +4 feet contours were color-coded blue to indicate water. The tidal range in the south Delta is about 2 to 6 feet (NAVD88), with the mean tide at 4 feet; therefore the tidal zone generally can be identified between the 0 and +4 feet blue contours and the +8 feet brown contour. Review of the map sheets indicates that many sections of Old River and other south Delta channels are less than 10 feet deep at low tide (no red contours). For the dredging analysis, depth contours for the sub-tidal elevations (-8 feet to 0 feet with 2-foot intervals) were "connected" with lines at each 1-kilometer section of the south Delta channels to create polygons for each contour elevation within each 1-kilometer channel section. An elevation-area table for each 1-kilometer section provided the channel surface area (acres) at each contour elevation and the corresponding average widths (feet) were calculated.

Table A-1 shows this geometry information for the south Delta channels divided into 1-kilometer sections. The surface area (acres) and the average channel width (feet) are given for each elevation. For example, the downstream section of Old River (from 46 km at the DMC intake to 47 km) shown on sheet 2 had a "bottom" area of 1.8 acres at -8 feet, 4.2 acres at -6 feet, 7.1 acres at -4 feet, 9.5 acres at -2 feet, and 12.3 acres at 0 feet elevation. One "hole" existed with a bottom elevation of -16 feet (three red contour lines), but most of the channel was between -4 feet (blue contour) and -8 feet (red contour). The average channel width at these elevations was about 25 feet wide at -8 feet, about 55 feet wide at -6 feet, about 95 feet wide at -4 feet, about 125 feet wide at -2 feet, and about 165 feet wide at 0 feet elevation.

Dredging volumes can be estimated for each 1-kilometer section of channel if the width and depth of the dredged channel is specified. For example, dredging the 6 km length of Old River between Tracy Boulevard (59 km) and Doughty Cut (65 km) to a width of 100 feet would approximately double the conveyance area below 2 feet (low tide), but would require about 275,000 cubic yards of dredging. This may allow more of the Old River flow to continue past Doughty Cut to Tracy Boulevard and provide more dilution of the higher salinity water from Paradise Cut and Sugar Cut.

Other dredging calculations can be made to provide slightly increased channel depths for irrigation diversion pumps. This may be needed in the future if the Old River at DMC temporary barrier is replaced with a tidal gate; tidal flows would be increased, but minimum water elevations likely would be reduced by 1 or 2 feet. Dredging a 25 feet wide by 2 feet deep channel (to compensate for the reduced minimum water elevations) would require about 6,000 cubic yards of dredged material for each kilometer of dredged channel. Clamshell dredging likely would be the most practical method for these narrow channels with a dredger or crane working from the levees. The material could be trucked for reuse as levee strengthening material (berms) to minimize the environmental effects from the dredging.

Table A-1. Summary of South Delta Channel Bathymetry for 1-km Channel Sections

	Surface Area (acres) at Elevation (feet NAVD88)					Average Width (feet) at Elevation (feet NAVD88)				
	-8 feet	-6 feet	-4 feet	-2 feet	0 feet	-8 feet	-6 feet	-4 feet	-2 feet	0 feet
Grant Line Canal										
0 km (Old) to 1 km (Doughty Cut)	4.7	7.9	12.5	21.4	22.9	63.0	104.4	165.9	283.7	304.0
1 km to 2 km	10.2	11.5	13.2	14.9	15.9	135.5	152.2	175.2	198.4	211.5
2 km to 3 km (Tracy Boulevard)	10.8	11.6	12.5	13.3	14.4	143.0	154.5	165.6	177.2	191.4
3 km to 4 km	6.5	10.1	13.9	17.5	20.3	86.6	134.4	184.0	233.0	270.1
Middle River										
0 km (Old) to 1 km	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	4.6
1 km to 2 km	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.5	8.4
Old River										
46 km (DMC) to 47 km	1.8	4.2	7.1	9.5	12.3	23.5	55.9	94.7	126.2	163.6
47 km to 48 km	1.2	4.9	8.1	10.3	12.0	15.5	64.6	108.1	137.3	159.4
48 km to 49 km	1.9	4.3	6.4	8.2	9.8	24.6	57.2	85.2	108.6	129.7
49 km to 50 km	2.2	3.7	6.2	8.8	12.7	28.9	49.2	82.8	117.4	168.4
50 km to 51 km (Wicklund Cut)	0.7	3.4	6.7	10.8	12.9	9.7	45.3	88.5	143.9	170.8
51 km (Wicklund Cut) to 52 km	0.8	3.3	6.9	11.5	17.2	10.7	44.5	92.2	152.9	228.8
52 km to 53 km	0.5	1.6	5.1	9.7	13.1	6.4	21.4	67.2	128.5	174.5
53 km to 54 km	2.2	4.2	6.4	9.7	12.1	29.3	56.1	85.6	129.4	160.7
54 km to 55 km	1.5	3.5	6.6	9.5	12.0	19.5	47.0	87.8	126.1	159.7
55 km to 56 km	0.9	2.6	5.3	9.0	11.7	12.1	34.3	70.5	119.9	155.9
56 km to 57 km	0.2	0.8	2.5	7.1	13.1	2.7	10.5	33.3	93.9	173.8
57 km to 58 km	0.1	0.4	1.7	4.7	9.1	1.8	5.8	22.5	63.0	121.0
58 km to 59 km (Tracy Boulevard)	0.8	2.0	4.1	6.2	9.1	10.5	26.4	53.9	82.1	121.0
59 km to 60 km Tracy Boulevard)	0.3	1.2	3.3	5.7	8.8	4.5	16.2	43.3	75.1	116.9
60 km to 61 km	0.6	2.1	4.4	6.4	7.9	8.6	27.9	58.9	85.3	104.3
61 km to 62 km	0.2	0.5	1.7	3.8	5.3	2.9	6.4	22.5	50.3	70.5
62 to 63 km (Sugar Cut)	0.1	0.3	0.8	3.7	6.6	1.9	3.5	10.0	48.8	88.1
63 to 64 km (Paradise Cut)	0.3	0.5	1.1	2.9	6.5	3.5	6.2	14.3	38.7	86.9
64 to 65 km (Doughty Cut)	1.4	3.2	5.0	7.8	12.6	19.0	42.9	65.9	104.2	167.8

	Surface Area (acres) at Elevation (feet NAVD88)					Average Width (feet) at Elevation (feet NAVD88)				
	-8 feet	-6 feet	-4 feet	-2 feet	0 feet	-8 feet	-6 feet	-4 feet	-2 feet	0 feet
65 km to 66 km	5.8	8.5	10.9	13.2	14.9	77.4	112.7	144.9	175.4	197.4
66 km to 67 km	8.0	9.4	10.3	11.1	11.8	105.8	124.3	136.8	147.3	157.0
67 km to 68 km	5.7	8.0	9.8	11.2	12.2	75.4	106.6	130.6	148.4	161.4
68 km to 69 km	7.1	8.1	9.0	9.8	10.6	93.9	107.6	119.4	130.6	141.1
69 km to 70 km (Middle River)	5.4	7.5	9.1	10.5	11.7	71.9	99.1	120.2	138.8	155.5
70 km to 71 km	5.5	7.5	9.1	10.2	11.0	72.8	99.8	121.3	135.5	146.6
71 km to 72 km	2.0	5.6	8.8	11.5	12.5	26.9	74.2	117.4	152.9	166.5
72 km to 73 km	1.9	5.4	9.2	11.4	12.4	25.8	72.0	121.8	151.2	164.6
Paradise Cut										
0 km (Old) to1 km	2.6	4.7	6.5	7.8	9.0	34.1	62.3	86.6	103.2	120.0
1 km to 2 km	0.0	0.5	4.9	7.2	9.8	0.5	7.1	65.5	96.1	130.7
2 km to 3 km	0.0	0.0	0.6	5.0	9.1	0.0	0.0	7.5	66.1	120.7
3 km to 4 km	0.0	0.0	0.0	1.2	5.6	0.0	0.0	0.4	15.3	74.5
4 km to 5 km	0.1	0.2	0.6	2.6	4.6	1.1	2.4	7.6	33.9	61.5
5 km to 5.5 km	0.0	0.0	0.7	1.9	2.6	0.0	0.4	8.6	24.8	34.8
Sugar Cut										
0 km (Old)to 1 km (Tom Paine)	0.0	0.0	0.1	4.5	9.6	0.0	0.0	1.5	60.0	127.1
1 km to 2 km	0.0	0.0	1.9	8.2	11.6	0.0	0.3	25.7	109.5	154.3
2 km to 3 km (End)	0.0	0.0	1.1	5.4	8.6	0.0	0.0	14.3	71.9	114.8
Wicklund Cut										
0 km (Old) to 1 km	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.1	25.4
1 km to 2 km (Pump)	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	10.3

Attachment B
South Delta Tidal Data Compilation Methods

The analysis of the south Delta tidal data (15-minute interval) can begin only after all of the available and applicable data is downloaded and time-sequenced (compiled) into a master data file (spreadsheet). Although this may appear to be a fairly basic task, several possible difficulties exist. The recommended procedures for obtaining and compiling the available tidal data from the south Delta are briefly described in this attachment. Future updating of South Delta Tidal Data Atlas files (e.g., adding each year's data) can be facilitated by following these general guidelines and procedures. Table B-1 lists the stations that were accessed and the parameters that were compiled for the South Delta Tidal Data Atlas project for 2009–13. Data for tidal elevation, tidal flow, tidal velocity, and EC were obtained for each station, if available.

The south Delta tidal data (15-minute interval) were obtained (accessed and downloaded) from three basic database systems:

USGS data were obtained from Brad Sullivan of the USGS California Water Science Center in West Sacramento. USGS data also can be obtained from the USGS NWIS. These data generally have been reviewed and checked for errors (with some filling of missing periods with estimated values).

DWR data were obtained mainly from the North Central Regional Office (NCRO), which is part of the Division of Integrated Regional Water Management. This division runs the Hydstra database. Typically, the Hydstra database can be accessed only by personnel from DWR's NCRO, the Division of Environmental Services (DES), and Water Data Library (WDL) staff. For this study, Hydstra data were requested from NCRO and WDL personnel, who set up database queries to output multiple parameters for multiple stations. Data also can be accessed through the online WDL, which makes use of previously prepared data reports. These online reports, which are generated by NCRO, DES, and the WDL (but not necessarily from the Hydstra database), can be accessed only one station and one parameter at a time. The public has access to the online WDL reports, but only DWR personnel can request data from the Hydstra database through personnel in the NCRO, DES, or WDL. Data from the Hydstra database undergo strict quality assurance and quality control (QA/QC) screening. Data from the online WDL may be provisional or QA/QC screened.

Some DWR, Reclamation, and USGS data were obtained from DWR's CDEC. The CDEC is an organized database for real-time measurements that are collected by a variety of agencies and water districts throughout California. The CDEC data generally are collected from remote monitoring stations using satellite and other data network communications; data are reported as received and are not processed to check for errors or missing periods.

Data that already were processed with QA/QC screening procedures (Hydstra or USGS data) were selected when available. Provisional data or data without any QA/QC screening were used only when QA/QC (screened) data were not available. South Delta data available from the Hydstra database were the first choice for accessing data. The non-screened data were obtained primarily from the CDEC. Provisional data included flow measurements obtained from Operations and Maintenance (O&M) personnel for the California SWP and the Federal CVP pumping facilities. Each of the public databases may add or discontinue stations, and the search and retrieval features are improving with time. Often additional stations or variables collected at existing stations will change over time; therefore searching for applicable data from the study area will require iterative data retrievals. The compilation of all available tidal data from the south Delta channels was one of the major goals for the South Delta Data Atlas project.

Data Accessing Procedures

The initial searching for available data within California (study area) should begin with the CDEC, because the CDEC has several map features for locating available data at stations within a region. However, the CDEC may not contain all available stations and parameters, so the other major water resources databases (i.e., USGS NWIS and DWR's WDL) also should be searched for the study area.

CDEC Data Access

The main CDEC website for station information (http://cdec.water.ca.gov/staInfo.html) provides multiple ways to find out about CDEC stations, including a link to search for stations by name, constituent, hydrologic region, and other descriptors, but to search for all stations within the study area, it is best to use the station locator map (http://cdec.water.ca.gov/cdec station). It is better than the prior map search feature which did not allow zoom capability. However, this map search tool is somewhat slow to use over the Internet. After the codes for stations of interest are determined, more station detail can be obtained by looking at the station metadata (http://cdec.water.ca.gov/staMeta.html).

USGS Data Access

To provide data completeness, DWR requested data from local USGS contacts to obtain the USGS data from specified stations in zipped files via e-mail. Most of this data, however, is available from the USGS NWIS web site.

Several websites provide information for finding USGS monitoring stations, as follows:

A national map of USGS stations can be found at:
http://maps.waterdata.usgs.gov/mapper/?state=ca

A map of Bay Delta monitoring stations can be found at:
http://ca.water.usgs.gov/projects/baydelta/

This map is missing some south Delta stations that are on the national map, but has some Bay stations that are not on the national map.

The USGS NWIS provides the capability of searching for site information based on information such as location, site name, and hydrologic region, without the use of a map:
http://waterdata.usgs.gov/nwis/inventory

The USGS NWIS website (http://waterdata.usgs.gov/nwis/) can be used to download USGS data in multiple formats for multiple constituents at a monitoring station. Data downloaded in the "Tab-separated" table format may be imported into Excel.

Hydstra Database and WDL Access

South Delta data available from the Hydstra database were the first choice for accessing data, because this database contains data that have been processed with QA/QC screening procedures unlike the CDEC and online WDL data. However, these data can only be obtained with a request from personnel in specific DWR divisions who contribute data to the database. Data in the Hydstra database came from different DWR sources. Flow, velocity, stage, and EC data came from three separate sections in DWR's Integrated Regional Water Management NCRO. The flow and velocity data came from the Flow Monitoring and Special Studies Section and the stage and EC data came from the Surface Water Data and the Water Quality Evaluation Sections. It later was discovered that a request could be made directly to the WDL staff, although the most recent QA/QC'd data may not be present because the separate DWR divisions may not have uploaded their latest data to the Hydstra database.

The online version of the WDL is available online at http://www.water.ca.gov/waterdatalibrary/. This website provides access to a map that can be used to search for particular monitoring stations based on location and type of measurement. Even with a relatively fast Internet connection, the map search can be slow. It is best to zoom in on a location before selecting the monitoring type of interest.

After a monitoring site is located, clicking on the site takes the user to the data page, where data can be downloaded one year and one parameter at a time. Alternatively, time series data for surface water stations can be accessed without the use of the map by selecting "Continuous Data" in the upper left corner of the home page and then selecting type of data and county. Clicking on the desired station takes the user to the same data page that is accessible using the map.

Delta Exports

Daily CVP Delta exports are estimated based on the number of pumping units in operation and the number of tubes being used to convey the water to the canal. These estimated flows can be obtained from the CDEC website. Flow data from DWR's SWP export facilities were obtained from its operations personnel. The SWP exports are estimated based on estimates of inflow into CCF. The Clifton Court inflow is estimated on an hourly basis using equations that calculate the flow for each of the five radial gates based on the position of each gate and the upstream and downstream water levels. A spreadsheet is used to calculate and sum the total flow.

Downloading Procedures

Hydrologic Engineering Center (HEC) DSSVue Data Retrieval

For most website data sources, data must be downloaded for a single parameter (e.g., flow) from a selected station, although some websites have more advanced options (e.g., multiple stations or multiple variables). Because the goal of the Data Atlas project was to organize the applicable data (several parameters) from all stations in the study area, methods to download multiple parameters from several selected stations were very helpful. The USGS site (NWIS) allows data for all constituents at a selected station to be downloaded at the same time.

One good option for obtaining data from the CDEC is the DSSVue program, created by the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC). Data for multiple CDEC stations and constituents can be downloaded by using a CDEC add-in to the DSSVue program. After being downloaded into DSSVue, the CDEC data then can be exported from DSSVue to Excel. DSSVue also may be used for USGS data, but the data links did not appear to function properly for this project. Most of the CDEC data for this project was downloaded using the DSSVue program, which provided the requested parameters from multiple stations in a time-sequenced format. DSSVue allows the removal of obvious outliers (specified maximum and minimum values) before exporting the data to an Excel spreadsheet. The DSSVue program is available online at http://www.hec.usace.army.mil/software/hec-dssvue/.

Some data-processing issues occurred with the DSSVue data. First, the Excel "text to columns" command had to be used for each column of data in Excel and then it was necessary to make sure the data were spaced properly (15-minute intervals for all data). Many of the CDEC data files had mysterious time-stamp shifts. The time stamp shifted back an hour in the spring and forward in the fall (i.e., opposite of what would be expected, although perhaps what may be expected if trying to convert clock time to constant Pacific Standard Time). Usually one hour of missing data occurred in the spring data (i.e., blanks), near the daylight savings shift. Furthermore, when some of the data were compared to the Hydstra data, the CDEC values appeared to be one hour too early compared to the Hydstra data (i.e., CDEC data for 2300 matched Hydstra data for 2400). CDEC time-stamp issues generally were addressed by shifting the data in the manner needed to match the Hydstra data.

Data Compiling and Processing Procedures

The downloaded data was compiled in a master data file using the following procedures.

Time Sequencing

When some of the 15-minute data are missing, the missing times may be skipped; therefore data must be spaced properly to attain even time increments. This seems to be true of the CDEC and USGS data, but not the Hydstra data. With the CDEC data, much of this trouble can be avoided with the DSSVue bulk download, although missing rows can still occur, and if one of the sites has a time stamp that does not fall precisely on the 15-minute increment, the result of the bulk download is a dataset that has two rows for each 15-minute increment. A master date-time-sequence column was created in column A of the master data file and in each annual data atlas file for checking the time sequence of all downloaded data. This was created in Excel by entering the beginning date and incrementing the rows with one-ninety sixth fractions (i.e., 15-minute increments). Time zone changes in downloaded data should be removed (shifted) to match the master date-time column (Pacific Standard Time).

Metadata

Some of the basic metadata is used to identify the data columns (labels). Generally the station name (location), data collection agency (source), and database record number (i.e., station number or abbreviation, parameter number) are used as column labels at the top of the spreadsheet. However, other information about the station or data parameters may change during the period of record (e.g., station location, elevation datum, or flow-elevation "rating curve"). Some of the identified shifts in data could be added to the index sheet of the master data atlas file.

Data Comparison Checking

Data accuracy and consistency already may have been reviewed for data accessed from some of the databases (e.g., USGS NWIS and Hydstra), but the data also should be checked visually by comparing data parameters from nearby stations. The comparison of data from nearby stations to determine consistency and identify basic patterns with location or relationships with flow (i.e., dilution of salinity with increasing flow) was one of the major goals for the data atlas project. After data were identified (located), obtained from a database, and time-sequenced, the graphical comparison of the tidal data was the first step in the data analysis and evaluation procedures.

Master Data File Description

Data were entered into the master data file (South Delta Master 15-minute File 2009-2013.xlsx) in an upstream to downstream station order for the four major south Delta channels (on separate sheets): San Joaquin River, Old River, Middle River, and Grant Line Canal.

Creating Annual Data Atlas Files

Because the Data Atlas files include the 15-minute data for a calendar year but also have many calculations of daily values (minimum, average, and maximum) and many other calculations of tidal flows and tidal salinity changes, each annual data atlas is created from a template file (2012 Data Atlas, with all available data locations and graphs). The date and time columns on each sheet are updated (2012 was a leap year with 366 days; other years have fewer rows of data) and the 15-minute data for the selected year from the four south Delta channels (i.e., separate sheets) are copied from the Master Data File. The template is “saved as” a Data Atlas file with the selected year of data (e.g., “2013 South Delta Data Atlas”). The 15-minute graphs were created with the 2009 dates, so this “dummy column” (used only for the x-axis of the 15-minute data graphs) in the “Old” sheet remains unchanged. In addition, to create a Data Atlas file for a new year, the DAYFLOW data needs to be updated, and filling of some 15-minute values must be completed for the Paradise Cut and Sugar Cut-Tom Paine Slough tidal flow and EC calculations. Some daily values can be “erased” to eliminate vertical lines on the daily graphs (for missing data periods).

Table B-1. South Delta Tidal Data Stations and Parameters for 2009-2013

Site and Operator	CDEC Code	WDL or USGS Number	Parameter	Data Source1	Notes
San Joaquin River					
SJR at Vernalis: USGS+DWR	VNS	11303500	Elevation	USGS	
SJR at Vernalis: USGS+DWR	VNS	11303500	Flow	USGS	
SJR at Vernalis:			Velocity		No data
SJR at Vernalis: USBR	VER		EC	CDEC	
SJR at McCune: DWR-DES	SJR		EC	CDEC	
New Jerusalem Drain: DWR	NJD		Elevation	CDEC	ends Dec 2010
New Jerusalem Drain: DWR	NJD		EC	CDEC	ends Dec 2010
SJR at DVI Pump		B95880	EC	WDL	
SJR below Paradise Weir		B95850	EC	WDL	
SJR at Mossdale Bridge: DWR-DES	MSD	B95820	Elevation	WDL	
SJR at Mossdale Bridge: DWR-DES	MSD	B95820	Flow	WDL/NCRO	
SJR at Mossdale Bridge: DWR-DES	MSD	B95820	Velocity	NCRO	
SJR at Mossdale Bridge: DWR-DES	MSD	B95820	EC	CDEC	
SJR below Old River at Lathrop	SJL	B95765	Elevation	WDL	
SJR below Old River at Lathrop	SJL	B95765	Flow	WDL/NCRO	
SJR below Old River at Lathrop	SJL	B95765	Velocity	NCRO	
SJR below Old River at Lathrop	SJL	B95765	EC	WDL	
San Joaquin River above Dos Reis: DWR-NCRO			Elevation		no data
San Joaquin River above Dos Reis: DWR-NCRO	SJD	B95760	Flow	NCRO	begins Feb 2013
San Joaquin River above Dos Reis: DWR-NCRO	SJD	B95760	Velocity	NCRO	begins Feb 2013
San Joaquin River above Dos Reis: DWR-NCRO	SJD	B95760	EC	NCRO	begins Jun 2013
SJR at Brandt Bridge: DWR O&M	BDT	B95740	Elevation	WDL	
SJR at Brandt Bridge: DWR O&M	BDT	B95740	Flow	WDL/NCRO	

Site and Operator	CDEC Code	WDL or USGS Number	Parameter	Data Source1	Notes
SJR at Brandt Bridge: DWR O&M	BDT	B95740	Velocity	CDEC/NCRO	
SJR at Brandt Bridge: DWR O&M	BDT	B95740	EC	WDL	
SJR at Garwood Bridge above Stockton RWQCF: USGS	SJG	11304810	Elevation	USGS	
SJR at Garwood Bridge above Stockton RWQCF: USGS	SJG	11304810	Flow	USGS	
SJR at Garwood Bridge above Stockton RWQCF: USGS	SJG	11304810	Velocity	USGS	
SJR at Garwood Bridge above Stockton RWQCF: USGS	SJG	11304810	EC	USGS	Data begin Apr 2010
Rough and Ready Island: DWR-DES	RRI	B95660	Elevation	CDEC/WDL	
Rough and Ready Island: DWR-DES	RRI	B95660	Flow	WDL/NCRO	
Rough and Ready Island: DWR-DES	RRI	B95660	Velocity	NCRO	
Rough and Ready Island: DWR-DES	RRI	B95660	EC	CDEC	
Old River					
Old River at Head: DWR	OH1	B95400	Elevation	WDL	
Old River at Head: DWR	OH1	B95400	Flow	WDL/NCRO	
Old River at Head: DWR	OH1	B95400	Velocity	CDEC/NCRO	
Old River at Head: DWR	OH1	B95400	EC	NCRO	
Old River at Middle River (Union Island): USBR	UNI		EC	CDEC	
Old River above Doughty Cut: DWR-NCRO			Elevation		No data
Old River above Doughty Cut: DWR-NCRO	ORX	B95390	Flow	NCRO	begins Jan 2013
Old River above Doughty Cut: DWR-NCRO	ORX	B95390	Velocity	NCRO	begins Jan 2013
Old River above Doughty Cut: DWR-NCRO			EC		No data
Paradise Cut near Old River: DWR-NCRO	PCO	B95410	EC	WDL	
Tom Paine at Pescadero (upstream end): DWR O&M	TPP	B95425	Elevation	WDL	
Tom Paine Slough (upstream of dam): DWR	TPI	B95421	Elevation	WDL	
Tom Paine Slough (downstream of dam): DWR NCRO	TPS	B95420	Elevation	WDL	
Sugar Cut (upstream of Tom Paine): DWR NCRO	SUR	B95422	EC	WDL	
Old River at Tracy Boulevard: DWR O&M	OLD	B95380	Elevation	WDL	

Site and Operator	CDEC Code	WDL or USGS Number	Parameter	Data Source1	Notes
Old River at Tracy Boulevard: DWR O&M	OLD	B95380	Flow	WDL/NCRO	Data begin Jan 2011
Old River at Tracy Boulevard: DWR O&M	OLD	B95380	Velocity	NCRO	Data begin Jan 2011
Old River at Tracy Boulevard: DWR O&M	OLD	B95380	EC	WDL	
Old River at Tracy Wildlife Area: DWR NCRO	TWA		EC	CDEC/NCRO	begins Jan 2011
Old River at DMC Barrier: USGS	ODM	11312968	Elevation	USGS	Station moved from upstream of the barrier to downstream on Sep 23, 2010.
Old River at DMC Barrier: USGS	ODM	11312968	Flow	USGS	
Old River at DMC Barrier: USGS	ODM	11312968	Velocity	USGS	
Old River at DMC Barrier: USGS	ODM	11312968	EC	USGS	begins Sep 2010
Old River at DMC Barrier upstream: DWR	OAD	B95366	Elevation	WDL	Does not agree with USGS values
Old River at DMC Barrier upstream			Flow		no data
Old River at DMC Barrier upstream			Velocity		no data
Old River at DMC Barrier upstream: DWR	OAD	B95366	EC	WDL/NCRO	Does not agree with USGS values
Old River at DMC Barrier downstream: DWR	OBD	B95365	Elevation	WDL	
Old River at DMC Barrier downstream			Flow		no data
Old River at DMC Barrier downstream			Velocity		no data
Old River at DMC Barrier downstream: DWR	OBD	B95365	EC	CDEC/NCRO	data end July 2010 but then NCRO data beginning in 2013
DMC Headworks: USBR	DMC		EC	CDEC	
Old River at Clifton Court Intake (south of intake)		B95340	Elevation	WDL	
Old River at Clifton Court Intake (south of intake): DWR NCRO	ORI	B95341	Flow	WDL/NCRO	

Site and Operator	CDEC Code	WDL or USGS Number	Parameter	Data Source1	Notes
Old River at Clifton Court Intake (south of intake): DWR NCRO	ORI	B95341	Velocity	NCRO	
Old River at Clifton Court Intake (south of intake)			EC		No data
Clifton Court Forebay: DWR O&M			Downstream level	DWR O&M	Hourly Data
Clifton Court Forebay: DWR O&M			Upstream level	DWR O&M	Hourly Data
Clifton Court Forebay: DWR O&M			CCF inflow	DWR O&M	Hourly Mapper flows from DWR
Clifton Court Forebay: DWR O&M	CLC		EC	CDEC	Hourly Data
West Canal at Clifton Court Intake (north of intake)	WCI	B95338	Elevation	WDL	
West Canal at Clifton Court Intake (north of intake): DWR NCRO	WCI	B95338	Flow	WDL/NCRO	
West Canal at Clifton Court Intake (north of intake): DWR NCRO	WCI	B95338	Velocity	NCRO	
West Canal at Clifton Court Intake (north of intake)			EC		No data
Old River at Highway 4: USGS	OH4	11313315	Elevation	USGS	
Old River at Highway 4: USGS	OH4	11313315	Flow	USGS	
Old River at Highway 4: USGS	OH4	11313315	Velocity	USGS	
Old River at Highway 4: USGS	OH4	11313315	EC	USGS	Data start Dec 2009
Old River at Byron (Highway 4): DWR	ORB	B95270	Elevation	WDL	
Old River at Bacon Island: USGS	OBI	11313405	Elevation	USGS	
Old River at Bacon Island: USGS	OBI	11313405	Flow	USGS	
Old River at Bacon Island: USGS	OBI	11313405	Velocity	USGS	
Old River at Bacon Island: USGS	OBI	11313405	EC	USGS	
Old River at Bacon Island: DWR O&M	BAC	B95250	Elevation	WDL	
Old River at Bacon Island: DWR O&M			Flow		no data
Old River at Bacon Island: DWR O&M			Velocity		no data

Site and Operator	CDEC Code	WDL or USGS Number	Parameter	Data Source1	Notes
Old River at Bacon Island: DWR O&M	BAC	B95250	EC	WDL	
Rock Slough near CCC intake		B95218	Elevation	WDL	
Rock Slough near CCC intake			Flow		no data
Rock Slough near CCC intake			Velocity		no data
Rock Slough near CCC intake		B95218	EC	WDL	
Middle River					
Middle River at Mowry Bridge		B95540	Elevation	WDL	
Middle River @ Undine Road: DWR NCRO	MRU	B95541	Flow	WDL/NCRO	
Middle River @ Undine Road: DWR NCRO	MRU	B95541	Velocity	NCRO	
Middle River @ Undine Road: DWR NCRO	MRU	B95541	EC	NCRO	begins Jan 2013
Middle R. at Howard Road Bridge: DWR	MHR	B95530	Elevation	WDL	
Middle R. at Howard Road Bridge: DWR	MHR	B95530	EC	CDEC	ends Jul 2010
Middle R. near Howard Road Bridge (near head): DWR NCRO	MHO	B9553100	EC	CDEC/NCRO	begins Oct 2010
Middle River at Tracy Road: DWR	MTB	B95503	Elevation	WDL	
Middle River at Tracy Road			Flow		No data
Middle River at Tracy Road			Velocity		No data
Middle River at Tracy Road: DWR	MTB	B95503	EC	WDL	
Middle River at Borden (Highway 4): DWR NCRO		B95500	Elevation	WDL	
Middle River at Union Point: DWR NCRO	MUP		EC	CDEC/NCRO	begins Mar 2010
Middle River at Victoria Canal: USBR	VIC		EC	CDEC	
Victoria Canal bl CCWD Intake: USGS	VCU	11312672	Elevation	USGS	
Victoria Canal bl CCWD Intake: USGS	VCU	11312672	Flow	USGS	
Victoria Canal bl CCWD Intake: USGS	VCU	11312672	Velocity	USGS	
Victoria Canal bl CCWD Intake: USGS	VCU	11312672	EC	USGS	begins Jun 2009
Middle River at Jones Tract: DWR NCRO	JTR	B95480	Elevation	CDEC	begins Feb 2012

Site and Operator	CDEC Code	WDL or USGS Number	Parameter	Data Source1	Notes
Middle River at Jones Tract: DWR NCRO	JTR	B95480	Flow	CDEC	Data appear to be erroneous
Middle River at Middle River: USGS	MDM	11312676	Elevation	USGS	
Middle River at Middle River: USGS	MDM	11312676	Flow	USGS	
Middle River at Middle River: USGS	MDM	11312676	Velocity	USGS	
Middle River at Middle River: USGS	MDM	11312676	EC	USGS	begins Dec 2009
Middle River at Middle River		B95468	Elevation	WDL	
Middle River at Middle River			Flow		no data
Middle River at Middle River			Velocity		no data
Middle River at Middle River		B95468	EC	WDL	
Grant Line Canal					
Doughty Cut at Grant Line: DWR	DGL	B95325	Elevation	WDL	
Doughty Cut at Grant Line			Flow		no data
Doughty Cut at Grant Line			Velocity		no data
Doughty Cut at Grant Line: DWR	DGL	B95325	EC	WDL/NCRO	
Grant Line Canal East			Elevation		no data
Grant Line Canal East: DWR NCRO	GLE	B95320	Flow	NCRO	begins Jan 2013
Grant Line Canal East: DWR NCRO	GLE	B95320	Velocity	NCRO	begins Jan 2013
Grant Line Canal East	GLE	B95320	EC	NCRO	begins Feb 2013
Grant Line above barrier (upstream)		B95310	Elevation	WDL	begins Jun 2011 There may also be some EC data for this site
Grant Line at Tracy Blvd (downstream): DWR	GCT	B95300	Elevation	WDL	
Grant Line at Tracy Blvd (downstream)			Flow		no data
Grant Line at Tracy Blvd (downstream)			Velocity		no data
Grant Line at Tracy Blvd (downstream): DWR	GCT	B95300	EC	CDEC/NCRO	

Site and Operator	CDEC Code	WDL or USGS Number	Parameter	Data Source1	Notes
Grant Line Canal (west end): USGS	GLC	11313200	Elevation	USGS	Station moved to this location in 2005
Grant Line Canal (west end): USGS	GLC	11313200	Flow	USGS	
Grant Line Canal (west end): USGS	GLC	11313200	Velocity	USGS	
Grant Line Canal (west end): USGS	GLC	11313200/B95295	EC	USGS/NCRO	

Note:

[1] In some instances, CDEC data were used to fill in information that was not available from other sources for the end of the evaluation period (November and December 2013). For these short periods, CDEC is not listed as a source in this table.

Attachment C

Monthly Water and Salt Budgets for the South Delta

This attachment gives a summary of the monthly average flow and salinity (EC) measurements in the south Delta channels for 2009-13. Monthly water and salt budgets are described from the SJR at Vernalis to the head of Old River to Old River at Tracy Boulevard to the CVP and SWP exports, including the net (reverse) flow and EC in Old River at Bacon Island and in Middle River at Bacon Island. The increases in EC measured downstream from Vernalis are used to identify inflow sources of higher salinity water. The magnitudes of these salt sources (between measurement stations) were estimated by the changes in EC times the net flow times a conversion factor.

This report suggests that the south Delta salinity (EC) patterns are largely controlled by the SJR at Vernalis flow and salinity (EC) patterns. This report, however, does not determine the sources of water and salt (EC) in the SJR at Vernalis. During the summer and fall months with little surface runoff from rainfall, the SJR at Vernalis flow and EC are the combination of tributary inflows (reservoir releases) from the Stanislaus, Tuolumne, and Merced Rivers and agricultural sub-surface drainage and shallow groundwater inflow (seepage) from irrigated areas along these tributaries (east-side of SJR), as well as agricultural sub-surface drainage and groundwater seepage from the west-side of the SJR. Because the east-side agricultural areas are irrigated with Sierra Nevada runoff with a low salinity (EC of 50 to 100 µS/cm), the sub-surface drainage and shallow groundwater salinity is also relatively low. But the west-side SJR agricultural areas are irrigated primarily with water from the DMC with a relatively high salinity (EC of 250 to 750 µS/cm) and the agricultural soils have a higher salt content (i.e., marine sediments) so that the sub-surface drainage and shallow groundwater seepage salinity is considerably higher. The salt loading of the applied water from the DMC is seasonal, but the salinity discharge to the SJR from sub-surface drainage and shallow groundwater may be more uniform. During winter and spring months with surface runoff and occasional reservoir spills, the Vernalis flows are higher and the salinity (EC) is generally lower, although the total salt load (tons/month) can be higher, because the surface runoff has a background salinity (EC of 50 to 100 µS/cm).

Summary of the SJR at Vernalis Salt and Boron TMDL Studies

The SWRCB established the SJR at Vernalis water quality objectives (WQO) for EC in the 1995 WQCP (implemented in D-1641 in 2000) and has required Reclamation to release water (in addition to minimum fish habitat flows) from New Melones Reservoir to meet the Vernalis EC objectives. Although the Vernalis EC objectives have been met since 1995, the Central Valley RWQCB developed a Total Maximum Daily Load (TMDL) allocation in 2004 to control the salt (and boron) loads (i.e., sources) that are discharged as sub-surface drainage or shallow groundwater inflows to the lower SJR, primarily from west-side agricultural areas downstream of the Mendota Pool. Because most of the irrigation water for these areas is supplied from the DMC, which exports water from the south Delta near Tracy, the TMDL Technical Report determined that Reclamation was responsible for the majority of this higher salt loading (in the irrigation water) applied to the Grasslands and northwest watersheds. The TMDL control plan also determined that the SJR at Vernalis EC objectives must be met by Reclamation with increased releases from New Melones Reservoir.

The Draft Technical Report and Staff Report were prepared in 2004 and the Basin Plan Amendments were adopted in 2008. The TMDL proposed a total maximum monthly load (TMML) approach and determined that Reclamation was responsible for the excess loading of DMC salt applied to the watershed and for the additional releases from New Melones Reservoir. The Basin Plan amendment required Reclamation to prepare a Management Agency Agreement (MAA) and adopt a plan to manage (reduce or "offset") the excess salt loading from the DMC. A cooperative effort between Central Valley RWQCB and Reclamation was developed from 2008 to 2014 to achieve compliance with the Vernalis EC objectives through a real-time management program (e.g., shifting the timing of drainage discharges from wetlands and irrigation/reclamation districts). The Central Valley RWQCB website for the SJR at Vernalis Salt and Boron TMDL, with the adopted Basin Plan Amendment, supporting documents, agreements, studies and quarterly monitoring reports is at: http://www.waterboards.ca.gov/centralvalley/water_issues/tmdl/central_valley_projects/vernalis_salt_boron/.

A Draft MAA was submitted by Reclamation in 2008, and a revised MAA was updated in 2014. The TMML approach recognized that the allocation of salt loads should increase with SJR flows to allow a maximum monthly discharge (outflow) of salt loads from the lower SJR watershed while meeting the Vernalis WQO for EC. The revised Real Time Salinity Management Program description prepared by Reclamation (2014) is available from the TMDL website. Reclamation is now responsible to submit annual reports and annual work plans to provide water and salt accounting for normal DMC and New Melones Reservoir operations and provide updates on several salt reduction programs within the watershed.

The TMDL Technical Report (2004) determined that about 50 percent of the DMC salt load pumped from the Delta was delivered to the SJR watershed between Mendota Pool and Vernalis; the other half of the DMC salt load was delivered to CVP contractors outside of the lower SJR watershed. The TMDL Technical Report also determined that the DMC loading to the SJR watershed (about 500,000 tons/year) accounted for about 50 percent of the total SJR at Vernalis salt load (about 1,100,000 tons/year); the applied DMC salt load was assumed to reach the SJR in order for the agricultural soil salinity to remain in balance. Therefore, the TMML identified a goal for Reclamation to offset at least 25 percent of the annual excess salt load that was applied from the DMC to areas draining to the lower SJR. Reclamation receives dilution credits (i.e., assimilative capacity for salinity) based on their releases from New Melones Reservoir, which provide low salinity water that dilutes the SJR salinity to meet the Vernalis WQO for EC. The MAA includes several salinity control projects that may reduce the SJR at Vernalis EC, and which may reduce the need for additional releases from New Melones Reservoir. Implementation of the Grasslands Drainage Area (GDA) selenium TMDL through the SJR Improvement Project (SJRIP), which diverts the majority of the GDA drainage flow to high-salinity irrigated lands (with salt-tolerant crops) has had a large effect on the Vernalis EC, reducing the GDA drainage salt load by 100,000 tons/year in recent years (documented in the quarterly reports prepared by Reclamation). Other factors that may change the future Vernalis flow and EC include increased fish habitat flows below Friant Dam and in the Merced, Tuolumne, and Stanislaus Rivers. Because Reclamation is solely responsible for meeting the SJR at Vernalis EC objectives, they do not agree that they should have additional responsibility for meeting the south Delta EC objectives.

Monthly Water and Salt Budgets for the South Delta and Exports

This report suggests that the south Delta salinity patterns are largely determined by the SJR flow and salinity (EC) at Vernalis. In months when the SJR at Vernalis EC is almost equal to the EC objective, Reclamation likely released additional New Melones Reservoir water to provide dilution of the SJR (i.e., EC measured upstream at Maze) to meet the Vernalis WQO for EC. When the Vernalis EC is almost equal to the WQO, there is little remaining assimilative capacity for salinity in the SJR downstream of Vernalis, because the south Delta EC objectives are identical to the Vernalis EC objectives (i.e., 700 µS/cm in April to August, 1,000 µS/cm in other months). The daily average flow and EC data that were calculated from the tidal measurements in the south Delta channels were summarized as monthly average flows, monthly average salinity (EC) and monthly salt loads (tons/month). These monthly values can be used to describe and evaluate the monthly water and salt budgets for the south Delta channels from the SJR at Vernalis to the CVP and SWP exports. The measured increases in EC at downstream stations (compared to the Vernalis EC), and the calculated increases in salt loads between measurement stations are of particular interest for this project.

Monthly Data for 2009

Table C-1 gives the monthly average flows (cfs), EC (µS/cm) and salt loads (tons/month) for the south Delta channels for 2009. The annual averages or totals are given in the last column. The monthly average flows at Vernalis are given in the first row; the flows were generally low, with an average annual flow of 1,284 cfs (931 TAF/yr). The second row gives the EC objectives for each month and the third row gives the measured monthly Vernalis EC; the measured EC was close to the EC objectives in January to March, but was considerably less than the EC objectives for the remainder of the year. The 2009 annual average Vernalis EC was 639 µS/cm. The calculated monthly salt loads are given in the fourth row; the annual Vernalis salt load was 512,000 tons. The fifth row gives the unused salt load (i.e., assimilative capacity for salt) calculated from the flow and the difference between the EC objective and the measured EC; additional salt loads could have been transported from the SJR without exceeding the EC objective at Vernalis. For 2009, the unused salt load was 210,000 tons, about 29 percent of the maximum possible SJR salt load for the monthly flows and EC objectives. The sixth row gives the measured EC in the SJR downstream at Brandt Bridge and the seventh row indicates the increased EC (increment) from Vernalis; the average annual increase was 32 µS/cm, and the average EC at Brandt Bridge was 105 percent of the average Vernalis EC.

The head of Old River monthly flows, EC values, EC increments, and salt loads are given in rows 8-11. Because the Old River diversion is about 50 percent of the SJR flow plus 5 percent of the exports, the majority of the SJR flow and salt was diverted into Old River during 2009; the average annual flow was 946 cfs, which was almost 75 percent of the Vernalis flow. The annual average EC at the head of Old River was 690 µS/cm, about 50 µS/cm higher than the average Vernalis EC; the highest EC increments were measured in March to October. The annual salt load diverted to Old River was about 420,000 tons (82 percent of the Vernalis salt load). The monthly Old at Union EC and the EC increments from the Vernalis EC are given in rows 12 and 13; the annual average Old at Union EC was 713 µS/cm (112 percent of the Vernalis EC), with an average EC increment of 74 µS/cm. The monthly EC at Doughty Cut (connecting Old River to Grant Line Canal) and the EC increments from Vernalis are given in rows 14 and 15; the annual average Doughty Cut EC was 735 µS/cm (115 percent of the Vernalis EC), with an average EC increment of 95 µS/cm. These three Old

River EC measurement stations are located upstream of Paradise Cut and Sugar Cut; the Doughty Cut EC was used as the baseline Old River EC for calculating the EC increments and salt loads added to Old River from Paradise Cut and Sugar Cut.

The monthly Paradise Cut EC and monthly Sugar Cut EC are given in rows 16 and 17. These EC values were considerably higher than the EC measured at the head of Old River, at Union Island, and at Doughty Cut. The Paradise Cut EC measurement station is near the mouth, and although there is considerable tidal exchange with Old River, the average EC was 846 µS/cm, about 200 µS/cm higher than the Vernalis EC. The Sugar Cut EC measurement station is about a mile upstream from the mouth and also upstream of the Tom Paine diversion for irrigation water; the annual average EC was 1,094 µS/cm, about 450 µS/cm higher than the Vernalis EC. The higher EC measurements in Paradise Cut and Sugar Cut indicate there are sources of higher salinity water upstream in each of these tidal sloughs, but the added salt loads from these tidal sloughs cannot be directly estimated from the EC measurements.

The monthly average Old River flows at Tracy Boulevard for 2009 are given in row 18; the average Old River at Tracy flow was estimated as 10 percent of the head of Old River (plus Paradise Weir) flow, based on tidal flow measurements (in 2011-2013). The monthly average EC, EC increments from Vernalis, and the calculated salt load (tons) from Paradise Cut and Sugar Cut are given in rows 19-21 for Tracy Boulevard EC station and in rows 22-24 for Tracy Wildlife EC station (located 0.5 miles downstream). The monthly EC at Tracy Boulevard and Tracy Wildlife were considerably higher than the Doughty Cut EC, suggesting an added salt load between these two stations. The added salt load was calculated from the measured EC increment from Doughty Cut times the estimated Old River flow at Tracy Boulevard. The monthly EC at these two nearby stations were usually the same, but the Tracy Boulevard EC was much higher than the Tracy Wildlife from June to December of 2009 (the Tracy Wildlife EC was subsequently determined to be likely more accurate). The annual average EC at Tracy Wildlife was 845 µS/cm (132 percent of the Vernalis EC) and the average EC increment was 206 µS/cm. The average EC increment from Doughty Cut EC was 110 µS/cm and the estimated flow was used to estimate the added salt load from Paradise Cut, Sugar Cut and other drainage sources between Doughty Cut and Tracy Boulevard. The annual salt load increment calculated from the Tracy Wildlife EC was about 7,000 tons. The monthly salt load increments were smallest during the irrigation season, when a majority of the salt sources in Sugar Cut and Paradise Cut were likely diverted into Tom Paine Slough. Although the calculated salt load added to Old River at Tracy Wildlife was less than 2 percent of the Vernalis salt load, the much lower flow in Old River caused a much higher EC increment. The measured EC at Tracy Wildlife was higher than the EC objectives in several (8 of 12) of the months in 2009.

The monthly flow, EC, and salt loads for 2009 are given in rows 25-27 for the CVP pumping, in rows 28-30 for the SWP pumping, in rows 31-33 for Old River at Bacon Island, and in rows 34-36 for Middle River at Bacon Island stations. The CVP and SWP pumping represent the major outflows from the south Delta, while the Old River and Middle River stations represent the two major inflows for the south Delta channels (in addition to the head of Old River diversion). A monthly water budget and salt budget for the south Delta channels can be calculated from these four stations and the head of Old River station. The 2009 annual average CVP flow was 2,679 cfs (1,943 TAF) and the average EC was 542 µS/cm with a total salt load of 889,000 tons. The 2009 annual average SWP flow was 2,506 cfs (1,817 TAF) and the average EC was 488 µS/cm with a total salt load of 743,000 tons. The average CVP EC was about 10 percent higher than the SWP EC because the majority of the SJR salt diverted to the head of Old River is pumped at the CVP. Because about half of the DMC water and salt load is applied to the Grasslands and west-side SJR watersheds, a large fraction of the SJR at

Vernalis salt load (about 512,000 tons in 2009) may originate from the half of the DMC load that is applied within the SJR watershed (445,000 tons in 2009). These salt load measurements at Vernalis and at the CVP exports may indicate that most of the SJR at Vernalis salt load was diverted to Old River and pumped into the DMC, and that about half of the DMC salt load was applied as irrigation water from the DMC and may eventually recycle back to the SJR at Vernalis. The 2009 annual average Old River at Bacon flow was 1,779 cfs (1,290 TAF) and the average EC was 479 µS/cm with a total salt load of 581,000 tons. The 2009 annual average Middle River at Bacon flow was 2,674 cfs (1,939 TAF) and the average EC was 380 µS/cm with a total salt load of 610,000 tons. The Middle River at Bacon EC was considerably lower than the Old River at Bacon, because there was less seawater intrusion reaching Middle River than Old River (i.e., from Jersey Point through False River to Franks Tract).

The overall monthly water budget for the South Delta channels is calculated in rows 38-40. The measured inflows are the head of Old River flow, the Old River at Bacon net (upstream) flow, and the Middle River at Bacon net (upstream) flow. The measured outflows are the CVP and SWP pumping flows. The unmeasured net diversions or inflows (i.e., runoff from rainfall) were estimated from the difference between the inflows and the exports. For 2009, the annual inflows were 3,915 TAF; the annual exports were 3,759 TAF; and the calculated net diversions were 156 TAF (4 percent of inflows). The net diversions from the south Delta channels (and CCWD) were likely larger than this estimate for 2009; nevertheless, there was a reasonable comparison (match) between the measured inflows and outflows. The overall monthly salt budget for the South Delta channels is calculated in rows 41-43. The same inflows and outflows were used to compare the salt loads. The monthly estimated salt sources (or salt load diversions) are given in row 43. The overall salt load source in the south Delta channels for 2009 was calculated to be about 20,000 tons (4 percent of the SJR at Vernalis salt load). These monthly calculations indicate a remarkable salt balance (export salt load was just 1 percent higher than measured salt inflow loads) with a seasonal pattern of salt sources (salt drainage) in the fall and winter months, and a seasonal diversion of salts during the irrigation season (May to September).

Monthly Data for 2010

Table C-2 gives the monthly average flows (cfs), EC (µS/cm) and salt loads (tons) for the south Delta channels for 2010. The annual averages or totals are given in the last column. The monthly average flows at Vernalis are given in the first row; the flows were generally high, with an average annual flow of 3,085 cfs (2,237 TAF/year). The second row gives the EC objectives for each month and the third row gives the measured monthly Vernalis EC; because of the higher flows, the measured EC values were much less than the EC objectives. The 2010 annual average Vernalis EC was 501 µS/cm. The calculated monthly salt loads are given in the fourth row; the 2010 annual Vernalis salt load was 846,000 tons. The fifth row gives the unused salt load (i.e., assimilative capacity for salt); for 2010, the unused salt load was 850,000 tons, about 50 percent of the maximum possible SJR salt load for the monthly flows and EC objectives. The sixth row gives the measured EC in the SJR downstream at Brandt Bridge and the seventh row indicates the EC increment from the Vernalis EC; the average EC at Brandt Bridge was 539 µS/cm, about 108 percent of the average Vernalis EC, and the average EC increment was 38 µS/cm.

The head of Old River monthly flows, EC values, EC increments, and salt loads are given in rows 8-11. The average annual head of Old River flow was 1,993 cfs, which was about 65 percent of the Vernalis flow. The annual average EC at the head of Old River was 546 µS/cm, about 45 µS/cm higher than the average Vernalis EC; the highest EC increments were measured in March and July to September. The annual salt load diverted to Old River was about 607,000 tons (72 percent of the Vernalis salt load). The monthly Old at Union EC and the EC increments from the Vernalis EC are given in rows 12 and 13; the annual average Old at Union EC was 555 µS/cm (111 percent of the Vernalis EC), with an average EC increment of 54 µS/cm. The monthly EC at Doughty Cut and the EC increments from Vernalis are given in rows 14 and 15; the annual average Doughty Cut EC was 561 µS/cm (112 percent of the Vernalis EC), with an average EC increment of 60 µS/cm. The monthly Paradise Cut EC and monthly Sugar Cut EC are given in rows 16 and 17. These EC values were considerably higher than the EC measured at the head of Old River, at Union Island, and at Doughty Cut. The Paradise Cut annual average EC was 699 µS/cm, about 200 µS/cm higher than the Vernalis EC. The Sugar Cut annual average EC was 1,017 µS/cm, about 515 µS/cm higher than the Vernalis EC.

The monthly average Old River flows at Tracy Boulevard for 2010 are given in row 18; the average Old River at Tracy flow was estimated as 10 percent of the head of Old River (plus Paradise weir) flow, based on tidal flow measurements (in 2011-13). The monthly average EC, EC increments from Vernalis, and the calculated salt load (tons) from Paradise Cut and Sugar Cut are given in rows 19-21 for Tracy Boulevard EC station and in rows 22-24 for Tracy Wildlife EC station (located 0.5 miles downstream). The added salt load was calculated from the measured EC increment from Doughty Cut times the estimated Old River flow at Tracy Boulevard. The monthly EC at these two nearby stations were usually about the same. The annual average EC at Tracy Boulevard was 682 µS/cm (136 percent of the Vernalis EC) and the average EC increment was 181 µS/cm. The annual average EC at Tracy Wildlife was 664 µS/cm (133 percent of the Vernalis EC) and the average EC increment was 163 µS/cm. The average EC increment from Doughty Cut to Tracy Boulevard was 121 µS/cm and the average EC increment to Tracy Wildlife was 103 µS/cm. The estimated flow at Tracy Boulevard was used to estimate the added salt load from Paradise Cut, Sugar Cut, and other drainage sources between Doughty Cut and Tracy Boulevard. The annual salt load increment calculated from the Tracy Boulevard EC was about 14,500 tons and the annual salt load increment calculated from the Tracy Wildlife EC was about 13,000 tons. The monthly salt load increments were smallest during the irrigation season when a majority of the salt sources in Sugar Cut and Paradise Cut were likely diverted into Tom Paine Slough. Although the calculated salt load added to Old River at Tracy Boulevard or Tracy Wildlife was less than 2 percent of the Vernalis salt load, the much lower flow in Old River caused a much higher EC increment. The measured EC at Tracy Boulevard was higher than the EC objective in 3 months; Tracy Wildlife EC was higher than the EC objective in just 1 month in 2010.

The monthly flow, EC and salt loads for 2010 are given in rows 25-27 for the CVP pumping, in rows 28-30 for the SWP pumping, in rows 31-33 for Old River at Bacon Island, and in rows 34-36 for Middle River at Bacon Island stations. A monthly water budget and salt budget for the south Delta channels can be calculated from these four stations and the head of Old River station. The 2010 annual average CVP flow was 3,239 cfs (2,349 TAF) and the average EC was 442 µS/cm with a total salt load of 861,000 tons. The 2010 annual average SWP flow was 4,296 cfs (3,115 TAF) and the average EC was 412 µS/cm with a total salt load of 1,112,000 tons. The average CVP EC was about 7 percent higher than the SWP EC because the majority of the SJR salt diverted to the head of Old River is pumped at the CVP. Because about half of the DMC water and salt load is applied to the Grasslands and west-side SJR watersheds, a large fraction of the SJR at Vernalis salt load (about 846,000 tons in 2010) may originate from the half of the DMC load that is applied within the SJR watershed (430,000 tons in 2010). These salt load measurements at Vernalis and at the CVP exports may indicate that most of the SJR at Vernalis salt load was diverted to Old River and pumped into the DMC, and that about half of the DMC salt load was applied as irrigation water from the DMC and may eventually recycle back to the SJR at Vernalis. The 2010 annual average Old River at Bacon flow was 2,424 cfs (1,758 TAF) and the average EC was 448 μS/cm with a total salt load of 705,000 tons. The 2010 annual average Middle River at Bacon flow was 3,073 cfs (2,228 TAF) and the average EC was 345 μS/cm with a total salt load of 592,000 tons.

The overall monthly water budget for the South Delta channels in 2010 is calculated in rows 38-40. For 2010, the annual inflows were 5,431 TAF; the annual exports were 5,463 TAF; and the calculated net diversions were -32 TAF (-0.5 percent of inflows). The calculated diversions were highest in June to August, but the diversions cannot be separated from the runoff; nevertheless, there was a reasonable comparison (match) between the measured inflows and outflows. The overall monthly salt budget for the South Delta channels is calculated in rows 41-43. The same inflows and outflows were used to compare the salt loads. The monthly estimated salt sources (or salt load diversions) are given in row 43. The overall salt load source in the south Delta channels for 2010 was calculated to be about 68,000 tons (8 percent of the SJR at Vernalis salt load). These monthly calculations indicate a remarkable salt balance (export salt load was just 3.5 percent higher than measured salt inflow loads) with a seasonal pattern of salt sources (salt drainage) in the fall and winter months and a seasonal diversion of salts during the irrigation season (June to October).

Monthly Data for 2011

Table C-3 gives the monthly average flows (cfs), EC (μS/cm) and salt loads (tons) for the south Delta channels for 2011. The annual averages or totals are given in the last column. The monthly average flows at Vernalis are given in the first row; the flows were very high, with an average annual flow of 9,291 cfs (6,736 TAF/year). The second row gives the EC objectives for each month and the third row gives the measured monthly Vernalis EC; because of the higher flows, the measured EC values were much less than the EC objectives. The 2011 annual average Vernalis EC was 280 μS/cm. The calculated monthly salt loads are given in the fourth row; the 2011 annual Vernalis salt load was 1,278,000 tons. The fifth row gives the unused salt load (i.e., assimilative capacity for salt); for 2011, the unused salt load was 3,673,000 tons, about 74 percent of the maximum possible SJR salt load for the monthly flows and EC objectives. The sixth row gives the measured EC in the SJR downstream at Brandt Bridge and the seventh row indicates the EC increment from the Vernalis EC; the average EC at Brandt Bridge was 304 μS/cm, about 109 percent of the average Vernalis EC and the average EC increment was 25 μS/cm.

The head of Old River monthly flows, EC values, EC increments, and salt loads are given in rows 8-11. The average annual head of Old River flow was 4,545 cfs, which was about 49 percent of the Vernalis flow. Because the SJR at Vernalis flows were greater than 17,500 cfs in April, some of the SJR flow was diverted at the Paradise Weir to Paradise Cut. The annual average EC at the head of Old River was 302 μS/cm, about 22 μS/cm higher than the average Vernalis EC. The annual salt load diverted to Old River was about 670,000 tons (52% of the Vernalis salt load). The calculated Paradise Weir salt load diverted to Old River was about 44,000 tons in late March and April (3.5 percent of the annual Vernalis salt load). The monthly Old at Union EC and the EC increments from the Vernalis EC are given in rows 12 and 13; the annual average Old at Union EC was 298 μS/cm (106 percent of the Vernalis EC), with an average EC increment of 18 μS/cm. The monthly EC at Doughty Cut and the EC increments from Vernalis are given in rows 14 and 15; the annual average Doughty Cut EC was 306 μS/cm (109 percent of the Vernalis EC), with an average EC increment of

26 µS/cm. The monthly Paradise Cut EC and monthly Sugar Cut EC are given in rows 16 and 17. These EC values were considerably higher than the EC measured at the head of Old River, at Union Island, and at Doughty Cut. The Paradise Cut annual average EC was 516 µS/cm, about 235 µS/cm higher than the Vernalis EC. The Sugar Cut annual average EC was 940 µS/cm, about 660 µS/cm higher than the Vernalis EC.

The monthly average Old River flows at Tracy Boulevard for 2011 are given in row 18; the average Old River at Tracy flow was measured in 2011 and the annual average flow was 709 cfs (about 15 percent of the head of Old River plus Paradise Weir flow). The monthly average EC, EC increments from Vernalis, and the calculated salt load (tons) from Paradise Cut and Sugar Cut are given in rows 19-21 for Tracy Boulevard EC station and in rows 22-24 for Tracy Wildlife EC station (located 0.5 miles downstream). The added salt load was calculated from the measured EC increment from Doughty Cut times the measured Old River flow at Tracy Boulevard. The annual average EC at Tracy Boulevard was 382 µS/cm (136 percent of the Vernalis EC) and the average EC increment was 102 µS/cm. The annual average EC at Tracy Wildlife was 372 µS/cm (133 percent of the Vernalis EC) and the average EC increment was 92 µS/cm. The average EC increment from Doughty Cut to Tracy Boulevard was 76 µS/cm and the average EC increment to Tracy Wildlife was 66 µS/cm. The annual salt load increment calculated from the Tracy Boulevard EC was about 18,000 tons and the annual salt load increment calculated from the Tracy Wildlife EC was about 14,000 tons. The monthly salt load increments were smallest during the irrigation season, when a majority of the salt sources in Sugar Cut and Paradise Cut were likely diverted into Tom Paine Slough. Although the calculated salt load added to Old River at Tracy Boulevard or Tracy Wildlife was less than 2 percent of the Vernalis salt load, the lower flow in Old River caused a higher EC increment. Because of high SJR flows, the measured EC was much less than the EC objectives in 2011.

The monthly flow, EC, and salt loads for 2011 are given in rows 25-27 for the CVP pumping, in rows 28-30 for the SWP pumping, in rows 31-33 for Old River at Bacon Island, and in rows 34-36 for Middle River at Bacon Island stations. A monthly water budget and salt budget for the south Delta channels can be calculated from these four stations and the head of Old River station. The 2011 annual average CVP flow was 3,460 cfs (2,509 TAF) and the average EC was 271 µS/cm with a total salt load of 602,000 tons. The 2011 annual average SWP flow was 5,387 cfs (3,906 TAF) and the average EC was 239 µS/cm with a total salt load of 805,000 tons. The average CVP EC was about 13 percent higher than the SWP EC because the majority of the SJR salt diverted to the head of Old River is pumped at the CVP. Because about half of the DMC water and salt load is applied to the Grasslands and west-side SJR watersheds, a large fraction of the SJR at Vernalis salt load (about 1,278,000 tons in 2011) may originate from the half of the DMC load that is applied within the SJR watershed (300,000 tons in 2010). These salt load measurements at Vernalis and at the CVP exports may indicate that most of the SJR at Vernalis salt load was diverted to Old River and pumped into the DMC, and that about half of the DMC salt load is applied as irrigation water from the DMC and may eventually recycle back to the SJR at Vernalis. The 2011 annual average Old River at Bacon flow was 1,748 cfs (1,267 TAF) and the average EC was 217 µS/cm, with a total salt load of 224,000 tons. The 2011 annual average Middle River at Bacon flow was 2,424 cfs (1,757 TAF) and the average EC was 224 µS/cm with a total salt load of 345,000 tons. The Middle River at Bacon EC was similar to the Old River at Bacon, because there was much less seawater intrusion (i.e., higher Delta outflows) in 2011.

The overall monthly water budget for the South Delta channels in 2011 is calculated in rows 38-40. For 2011, the annual inflows were 6,319 TAF plus 300 TAF from Paradise Weir; the annual exports were 6,414 TAF; and the calculated net diversions were 200 TAF (3 percent of inflows). The calculated diversions were highest in May to September, but the diversions cannot be separated from the runoff; nevertheless, there was a reasonable comparison (match) between the measured inflows and outflows. The overall monthly salt budget for the South Delta channels is calculated in rows 41-43. The same inflows and outflows were used to compare the salt loads. The monthly estimated salt sources (or salt load diversions) are given in row 43. The Paradise Weir added about 44,000 tons to the inflows. The overall salt load source in the south Delta channels for 2011 was calculated to be about 123,000 tons 10 percent of the SJR at Vernalis salt load). These monthly calculations indicate a remarkable salt balance (export salt load was just 10 percent higher than measured salt inflow loads) with salt sources (salt drainage) in all months except December.

Monthly Data for 2012

Table C-4 gives the monthly average flows (cfs), EC (µS/cm) and salt loads (tons) for the south Delta channels for 2012. The annual averages or totals are given in the last column. The monthly average flows at Vernalis are given in the first row; the flows were generally low, with an average annual flow of 1,651 cfs (1,197 TAF/year). The second row gives the EC objectives for each month and the third row gives the measured monthly Vernalis EC; the 2012 annual average Vernalis EC was 584 µS/cm. The calculated monthly salt loads are given in the fourth row; the 2012 annual Vernalis salt load was 613,000 tons. The fifth row gives the unused salt load (i.e., assimilative capacity for salt); the unused salt load was 323,000 tons in 2012, about 35 percent of the maximum possible SJR salt load for the monthly flows and EC objectives. The sixth row gives the measured EC in the SJR downstream at Brandt Bridge and the seventh row indicates the EC increment from the Vernalis EC; the average EC at Brandt Bridge was 651 µS/cm, about 112 percent of the average Vernalis EC, and the average EC increment was 67 µS/cm.

The head of Old River monthly flows, EC values, EC increments, and salt loads are given in rows 8-11. The average annual flow was 1,023 cfs, which was about 62 percent of the Vernalis flow. The annual average EC at the head of Old River was 657 µS/cm, about 74 µS/cm higher than the average Vernalis EC; the highest EC increments were measured in April and June to September. The annual salt load diverted to Old River was about 441,000 tons (72 percent of the Vernalis salt load). The monthly Old at Union EC and the EC increments from the Vernalis EC are given in rows 12 and 13; the annual average Old at Union EC was 634 µS/cm (109 percent of the Vernalis EC), with an average EC increment of 51 µS/cm. The monthly EC at Doughty Cut and the EC increments from Vernalis are given in rows 14 and 15; the annual average Doughty Cut EC was 677 µS/cm (116 percent of the Vernalis EC), with an average EC increment of 93 µS/cm. The monthly Paradise Cut EC and monthly Sugar Cut EC are given in rows 16 and 17. The Paradise Cut annual average EC was 852 µS/cm in 2012, about 268 µS/cm higher than the Vernalis EC. The Sugar Cut annual average EC was 1,057 µS/cm in 2012, about 473 µS/cm higher than the Vernalis EC.

The monthly average Old River flows at Tracy Boulevard for 2012 are given in row 18; the annual average measured Old River at Tracy flow was 145 cfs, about 14 percent of the head of Old River flow. The monthly average EC, EC increments from Vernalis, and the calculated salt load (tons) from Paradise Cut and Sugar Cut are given in rows 19-21 for Tracy Boulevard EC station and in rows 22-24 for Tracy Wildlife EC station (located 0.5 miles downstream). The added salt load was calculated from the measured EC increment from Doughty Cut times the measured Old River flow at Tracy Boulevard. The 2012 annual average EC at Tracy Boulevard was 847 µS/cm (145 percent of the Vernalis EC) and the average EC increment was 264 µS/cm. The annual average EC at Tracy Wildlife was 863 µS/cm (148 percent of the Vernalis EC) and the average EC increment was 280 µS/cm. The average EC increment from Doughty Cut to Tracy Boulevard was 170 µS/cm and the average EC increment to Tracy Wildlife was 186 µS/cm. The annual salt load increment calculated from the Tracy Boulevard EC was about 10,000 tons and the annual salt load increment calculated from the Tracy Wildlife EC was about 11,000 tons. The monthly salt load increments were smallest during the irrigation season, when a majority of the salt sources in Sugar Cut and Paradise Cut were likely diverted into Tom Paine Slough. Although the calculated salt load added to Old River at Tracy Boulevard or Tracy Wildlife was less than 2 percent of the Vernalis salt load, the lower flow in Old River caused a higher EC increment. The measured EC at Tracy Boulevard was higher than the EC objective in 4 months; Tracy Wildlife EC was also higher than the EC objective in 4 months in 2012.

The monthly flow, EC, and salt loads for 2010 are given in rows 25-27 for the CVP pumping, in rows 28-30 for the SWP pumping, in rows 31-33 for Old River at Bacon Island, and in rows 34-36 for Middle River at Bacon Island stations. The 2012 annual average CVP flow was 2,851 cfs (2,067 TAF) and the average EC was 505 µS/cm with a total salt load of 862,000 tons. The 2012 annual average SWP flow was 3,301 cfs (2,393 TAF) and the average EC was 475 µS/cm with a total salt load of 944,000 tons. The average CVP EC was about 6 percent higher than the SWP EC because the majority of the SJR salt diverted to the head of Old River is pumped at the CVP. Because about half of the DMC water and salt load is applied to the Grasslands and west-side SJR watersheds, a large fraction of the SJR at Vernalis salt load (about 613,000 tons in 2012) may originate from the half of the DMC load that is applied within the SJR watershed (430,000 tons in 2012). These salt load measurements at Vernalis and at the CVP exports may indicate that most of the SJR at Vernalis salt load was diverted to Old River and pumped into the DMC, and that about half of the DMC salt load was applied as irrigation water from the DMC and may eventually recycle back to the SJR at Vernalis. The 2012 annual average Old River at Bacon flow was 2,260 cfs (1,639 TAF) and the average EC was 475 µS/cm with a total salt load of 725,000 tons. The 2012 annual average Middle River at Bacon flow was 3,244 cfs (2,352 TAF) and the average EC was 345 µS/cm with a total salt load of 681,000 tons. The Middle River at Bacon EC was considerably lower than the Old River at Bacon, because there was less seawater intrusion reaching Middle River than Old River.

The overall monthly water budget for the South Delta channels in 2012 is calculated in rows 38-40. For 2012, the annual inflows were 4,732 TAF; the annual exports were 4,460 TAF; and the calculated net diversions were 272 TAF (6 percent of inflows). The calculated diversions were highest in May to August, but the diversions cannot be separated from the runoff; nevertheless, there was a reasonable comparison (match) between the measured inflows and outflows. The overall monthly salt budget for the South Delta channels is calculated in rows 41-43. The same inflows and outflows were used to compare the salt loads. The monthly estimated salt sources (or salt load diversions) are given in row 43. The overall salt load source in the south Delta channels for 2012 was calculated to be about -40,000 tons (-6.5 percent of the SJR at Vernalis salt load). These monthly calculations indicate a remarkable salt balance (export salt load was just 2.5 percent lower than measured salt inflow loads) with a seasonal pattern of salt diversions during the irrigation season (June to September).

Monthly Data for 2013

Table C-5 gives the monthly average flows (cfs), EC (µS/cm) and salt loads (tons) for the south Delta channels for 2013. The annual averages or totals are given in the last column. The monthly average flows at Vernalis are given in the first row; the flows were generally low, with an average annual flow of 1,347 cfs (976 TAF/year). The second row gives the EC objectives for each month and the third row gives the measured monthly Vernalis EC; the 2013 annual average Vernalis EC was 617 µS/cm. The calculated monthly salt loads are given in the fourth row; the 2013 annual Vernalis salt load was 542,000 tons. The fifth row gives the unused salt load (i.e., assimilative capacity for salt); the unused salt load was 225,000 tons in 2013, about 29 percent of the maximum possible SJR salt load for the monthly flows and EC objectives. The sixth row gives the measured EC in the SJR downstream at Brandt Bridge and the seventh row indicates the EC increment from the Vernalis EC; the average EC at Brandt Bridge was 689 µS/cm, about 111 percent of the average Vernalis EC and the average EC increment was 69 µS/cm.

The head of Old River monthly flows, EC values, EC increments, and salt loads are given in rows 8-11. The average annual flow was 999 cfs, which was about 74 percent of the Vernalis flow. The annual average EC at the head of Old River was 699 µS/cm (113 percent of the Vernalis EC), about 82 µS/cm higher than the average Vernalis EC; the highest EC increments were measured in June to September. The annual salt load diverted to Old River was about 425,000 tons (78 percent of the Vernalis salt load) in 2013. The monthly Old at Union EC and the EC increments from the Vernalis EC are given in rows 12 and 13; the annual average Old at Union EC was 674 µS/cm (109 percent of the Vernalis EC),\ with an average EC increment of 57 µS/cm. The monthly EC at Doughty Cut and the EC increments from Vernalis are given in rows 14 and 15; the annual average Doughty Cut EC was 729 µS/cm (118 percent of the Vernalis EC) with an average EC increment of 112 µS/cm. The monthly Paradise Cut EC and monthly Sugar Cut EC are given in rows 16 and 17. The Paradise Cut annual average EC was 880 µS/cm in 2013, about 263 µS/cm higher than the Vernalis EC. The Sugar Cut annual average EC was 1,111 µS/cm in 2013, about 494 µS/cm higher than the Vernalis EC.

The monthly average Old River flows at Tracy Boulevard for 2013 are given in row 18; the annual average measured Old River at Tracy flow was 108 cfs, about 11 percent of the head of Old River flow. The monthly average EC, EC increments from Vernalis, and the calculated salt load (tons) from Paradise Cut and Sugar Cut are given in rows 19-21 for Tracy Boulevard EC station and in rows 22-24 for Tracy Wildlife EC station (located 0.5 miles downstream). The added salt load was calculated from the measured EC increment from Doughty Cut times the measured Old River flow at Tracy Boulevard. The 2013 annual average EC at Tracy Boulevard was 870 µS/cm (141 percent of the Vernalis EC) and the average EC increment was 253 µS/cm. The annual average EC at Tracy Wildlife was 878 µS/cm (142 percent of the Vernalis EC) and the average EC increment was 261 µS/cm. The average EC increment from Doughty Cut to Tracy Boulevard was 141 µS/cm and the average EC increment to Tracy Wildlife was 149 µS/cm. The annual salt load increment calculated from the Tracy Boulevard EC was about 9,500 tons and the annual salt load increment calculated from the Tracy Wildlife EC was about 11,500 tons. Although the calculated salt load added to Old River at Tracy Boulevard or Tracy Wildlife was less than 2 percent of the Vernalis salt load, the lower flow in Old River caused a higher EC increment. The measured EC at Tracy Boulevard was higher than the EC objective in 6 months; Tracy Wildlife EC was also higher than the EC objective in 6 months in 2012.

The monthly flow, EC, and salt loads for 2010 are given in rows 25-27 for the CVP pumping, in rows 28-30 for the SWP pumping, in rows 31-33 for Old River at Bacon Island, and in rows 34-36 for Middle River at Bacon Island stations. The 2013 annual average CVP flow was 2,065 cfs (1,497 TAF) and the average EC was 527 µS/cm with a total salt load of 666,000 tons. The 2013 annual average SWP flow was 2,547 cfs (1,847 TAF) and the average EC was 493 µS/cm with a total salt load of 779,000 tons. The average CVP EC was about 7 percent higher than the SWP EC because the majority of the SJR salt diverted to the head of Old River is pumped at the CVP. Because about half of the DMC water and salt load is applied to the Grasslands and west-side SJR watersheds, a large fraction of the SJR at Vernalis salt load (about 542,000 tons in 2013) may originate from the half of the DMC load that is applied within the SJR watershed (330,000 tons in 2013). These salt load measurements at Vernalis and at the CVP exports may indicate that most of the SJR at Vernalis salt load was diverted to Old River and pumped into the DMC, and that about half of the DMC salt load was applied as irrigation water from the DMC and may eventually recycle back to the SJR at Vernalis. The 2013 annual average Old River at Bacon flow was 1,536 cfs (1,113 TAF) and the average EC was 471 µS/cm with a total salt load of 540,000 tons. The 2013 annual average Middle River at Bacon flow was 2,408 cfs (1,746 TAF) and the average EC was 363 µS/cm with a total salt load of 538,000 tons. The Middle River at Bacon EC was considerably lower than the Old River at Bacon, because there was less seawater intrusion reaching Middle River than Old River (Jersey Point through False River to Franks Tract).

The overall monthly water budget for the South Delta channels in 2013 is calculated in rows 38-40. For 2013, the annual inflows were 3,584 TAF; the annual exports were 3,344 TAF; and the calculated net diversions were 240 TAF (7 percent of inflows). The calculated diversions were highest in May to August, but the diversions cannot be separated from the runoff; nevertheless, there was a reasonable match between the measured inflows and outflows. The overall monthly salt budget for the South Delta channels is calculated in rows 41-43. The same inflows and outflows were used to compare the salt loads. The monthly estimated salt sources (or salt load diversions) are given in row 43. The overall salt load source in the south Delta channels for 2013 was calculated to be about -57,000 tons (-10 percent of the SJR at Vernalis salt load). These monthly calculations indicate a remarkable salt balance (export salt load was just 4 percent lower than measured salt inflow loads) with a seasonal pattern of salt diversions during the irrigation season (May to September).

Table C-1. Monthly Water and Salt Budgets for the South Delta in 2009

Row	Station	Variable	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual		Compare
1	Vernalis	Flow	(cfs)	1,104	1,428	1,421	1,516	2,128	1,098	606	609	948	1,846	1,394	1,317	1,284	931	TAF
2	Vernalis	EC Objective	(µS/cm)	1,000	1,000	1,000	700	700	700	700	700	1,000	1,000	1,000	1,000			
3	Vernalis	EC	(µS/cm)	961	945	951	552	302	454	532	526	502	415	691	851	639		
4	Vernalis	Load	(tons)	58,619	66,214	73,037	39,654	34,796	26,967	18,099	17,685	25,224	40,907	49,785	61,084	512,072		
5	Vernalis	Unused Load	(tons)	2,309	3,853	3,785	11,816	45,906	14,212	5,519	5,753	24,794	58,586	22,582	10,675	209,789	29%	SJR Vernalis
6	SJR Brandt	EC	(µS/cm)	998	939	936	670	345	531	601	521	529	471	680	838	670	105%	SJR Vernalis
7	SJR Brandt	EC Increase	(µS/cm)	36	(5)	(14)	119	43	78	69	(5)	26	56	(12)	(13)	32		
8	Old Head	Flow	(cfs)	900	1,112	1,208	1,054	1,309	809	712	585	610	727	1,175	1,167	946	74%	SJR Vernalis
9	Old Head	EC	(µS/cm)	990	948	1,002	634	362	541	615	595	570	464	694	880	690	108%	SJR Vernalis
10	Old Head	EC Increase	(µS/cm)	29	3	51	83	60	87	83	69	68	49	3	30	51		
11	Old Head	Load	(tons)	48,164	50,710	64,706	33,127	25,531	22,424	23,705	18,863	18,079	16,891	42,367	55,695	420,260	82%	SJR Vernalis
12	Old Union	EC	(µS/cm)	1,008	979	1,032	658	367	568	672	597	591	482	722	891	713	112%	SJR Vernalis
13	Old Union	EC Increase	(µS/cm)	47	34	81	106	65	115	139	71	89	68	30	40	74		
14	Old Doughty	EC	(µS/cm)	1,012	948	981	693	404	606	700	705	633	510	741	900	735	115%	SJR Vernalis
15	Old Doughty	EC Increase	(µS/cm)	50	3	30	141	101	152	168	179	131	95	50	50	96		
16	Paradise Cut	EC	(µS/cm)	1,086	1,036	1,071	773	482	728	870	865	806	719	799	929	846		
17	Sugar Cut	EC	(µS/cm)	1,338	1,255	1,296	988	759	983	917	908	969	1,060	1,373	1,301	1,094		
18	Old Tracy	Est. Flow	(cfs)	90	111	121	105	131	81	71	58	61	73	117	117	95	10%	HOR
19	Old Tracy	EC	(µS/cm)	1,178	1,091	1,123	850	531	819	994	997	936	755	1,119	1,252	970	152%	SJR Vernalis
20	Old Tracy	EC Increase	(µS/cm)	217	147	172	299	228	365	462	471	433	340	428	402	331		
21	Old Tracy	Added Load	(tons)	820	782	892	815	880	924	1,111	920	943	878	2,326	2,197	13,490	2.6%	SJR Vernalis
22	Old Wildlife	EC	(µS/cm)	1,170	1,060	1,104	871	540	748	735	732	717	569	887	1,023	845	132%	SJR Vernalis
23	Old Wildlife	EC Increase	(µS/cm)	209	115	153	320	237	295	203	207	215	154	195	172	206		
24	Old Wildlife	Added Load	(tons)	776	604	758	962	960	601	132	82	264	221	888	748	6,998	1.4%	SJR Vernalis
25	CVP	Flow	(cfs)	2,097	1,935	2,898	1,424	1,052	1,326	3,957	4,163	4,143	3,997	2,868	2,192	2,679	1,943	TAF
26	CVP	EC	(µS/cm)	827	835	620	496	410	433	298	449	512	487	527	629	542		
27	CVP	Load	(tons)	93,554	76,766	96,069	36,277	23,270	29,591	63,852	101,317	111,320	105,533	77,449	74,297	889,294		
28	SWP	Flow	(cfs)	2,372	1,977	2,814	1,365	1,079	635	6,223	4,110	2,463	2,036	1,512	3,301	2,506	1,817	TAF
29	SWP	EC	(µS/cm)	722	732	517	407	382	396	257	461	534	482	466	518	488		
30	SWP	Load	(tons)	92,844	69,176	78,721	28,586	22,396	12,871	85,384	102,405	68,166	51,911	36,351	94,259	743,071		
31	Old Bacon	Flow	(cfs)	1,178	700	1,607	602	392	779	4,534	3,698	2,718	2,080	1,145	1,756	1,779	1,290	TAF
32	Old Bacon	EC	(µS/cm)	765	651	311	260	249	224	337	652	713	551	438	604	479		
33	Old Bacon	Load	(tons)	48,956	20,025	26,483	8,198	5,161	9,112	83,749	131,102	102,377	61,101	26,484	57,953	580,701		
34	Middle Bacon	Flow	(cfs)	2,213	1,823	2,703	1,431	1,177	1,802	5,847	4,914	3,697	2,657	1,469	2,205	2,674	1,939	TAF
35	Middle Bacon	EC	(µS/cm)	606	620	394	305	340	275	213	324	382	384	339	391	380		
36	Middle Bacon	Load	(tons)	72,826	54,563	57,774	22,756	21,718	25,907	67,398	86,241	73,130	54,912	26,179	47,233	610,636		
37	SJR Jersey Point	EC	(µS/cm)	1,335	730	267	266	215	253	762	1,239	1,465	1,063	944	1,677	854		
			Water Balance														TAF	
38	Measured		Inflows	4,291	3,635	5,518	3,087	2,878	3,390	11,093	9,196	7,025	5,463	3,788	5,128	5,400	3,915	
39	Measured		Exports	4,469	3,913	5,712	2,788	2,132	1,961	10,180	8,273	6,606	6,033	4,379	5,493	5,185	3,759	
40	Estimated		Diversions (Runoff)	(179)	(278)	(193)	299	746	1,429	913	923	420	(570)	(591)	(365)	215	156	
			Salt Load Balance															
41	Measured		Inflows	169,945	125,298	148,963	64,081	52,409	57,443	174,852	236,207	193,586	132,904	95,029	160,881	1,611,598		
42	Measured		Exports	186,398	145,942	174,790	64,863	45,666	42,462	149,236	203,722	179,486	157,444	113,800	168,556	1,632,365		
43	Estimated		Source (Diversion)	16,453	20,644	25,826	782	(6,744)	(14,981)	(25,616)	(32,485)	(14,100)	24,539	18,771	7,676	20,768	4.1%	SJR Vernalis

Table 2010. Monthly Water and Salt Budgets for the South Delta in 2010

Row	Station	Variable	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Compare	
1	Vernalis	Flow	(cfs)	1,954	2,426	2,934	4,280	5,063	3,999	1,928	1,289	1,842	2,392	1,900	6,943	3,085	2,237	TAF
2	Vernalis	EC Objective	(µS/cm)	1,000	1,000	1,000	700	700	700	700	700	1,000	1,000	1,000	1,000			
3	Vernalis	EC	(µS/cm)	814	760	745	408	234	261	425	568	448	434	671	262	501		
4	Vernalis	Load	(tons)	77,959	91,139	120,758	86,562	67,590	55,870	42,852	42,157	45,277	56,947	69,222	90,054	846,388		
5	Vernalis	Unused Load	(tons)	19,767	28,469	40,541	65,637	127,987	92,106	28,793	9,238	53,364	73,438	32,804	278,070	850,216	50%	Vernalis
6	SJR Brandt	EC	(µS/cm)	851	789	798	446	254	298	483	589	519	484	666	303	539	108%	Vernalis
7	SJR Brandt	EC Increase	(µS/cm)	37	29	53	38	20	36	58	22	71	50	(5)	42	38		
8	Old Head	Flow	(cfs)	1,511	1,795	2,028	2,345	2,750	2,596	1,513	1,137	1,167	1,421	1,746	3,888	1,993	65%	Vernalis
9	Old Head	EC	(µS/cm)	855	796	807	438	258	304	487	644	511	477	697	296	546	109%	Vernalis
10	Old Head	EC Increase	(µS/cm)	42	35	62	30	24	43	62	76	63	43	26	34	45		
11	Old Head	Load	(tons)	64,950	69,029	86,153	50,324	38,135	39,888	37,105	39,692	30,478	34,153	62,729	55,010	607,646	72%	Vernalis
12	Old Union	EC	(µS/cm)	867	812	827	452	260	304	490	665	524	489	691	299	555	111%	Vernalis
13	Old Union	EC Increase	(µS/cm)	54	51	82	44	26	43	66	97	76	55	20	37	54		
14	Old Doughty	EC	(µS/cm)	858	799	811	473	286	338	501	654	525	503	693	305	561	112%	Vernalis
15	Old Doughty	EC Increase	(µS/cm)	44	39	66	65	52	76	76	86	76	69	21	43	60		
16	Paradise Cut	EC	(µS/cm)	920	881	972	553	390	489	695	845	717	711	830	400	699		
17	Sugar Cut	EC	(µS/cm)	1,156	1,333	1,472	780	595	698	741	940	895	1,218	1,335	1,064	1,017		
18	Old Tracy	Est. Flow	(cfs)	151	180	203	234	275	260	151	114	117	142	175	389	199	10%	HOR
19	Old Tracy	EC	(µS/cm)	1,142	976	1,043	559	341	430	558	723	598	588	821	423	682	136%	Vernalis
20	Old Tracy	EC Increase	(µS/cm)	328	215	298	152	107	169	134	155	150	154	150	161	181		
21	Old Tracy	Added Load	(tons)	1,998	1,557	2,535	988	834	1,304	512	422	455	765	1,218	1,981	14,569	1.7%	Vernalis
22	Old Wildlife	EC	(µS/cm)	967	939	974	564	343	448	560	722	608	623	812	427	664	133%	Vernalis
23	Old Wildlife	EC Increase	(µS/cm)	153	179	229	156	109	186	135	154	160	189	141	165	163		
24	Old Wildlife	Added Load	(tons)	896	1,248	1,730	1,046	874	1,547	553	417	519	1,011	1,152	2,073	13,065	1.5%	Vernalis
25	CVP	Flow	(cfs)	1,623	3,794	3,364	822	1,254	3,138	4,176	4,187	4,125	4,167	4,156	4,099	3,239	2,349	TAF
26	CVP	EC	(µS/cm)	776	602	616	543	319	295	239	360	406	414	386	353	442		
27	CVP	Load	(tons)	64,368	111,813	110,602	23,352	22,227	48,752	54,110	81,796	87,938	93,571	84,170	78,864	861,561		
28	SWP	Flow	(cfs)	4,039	3,028	3,653	712	1,025	3,443	5,439	6,679	6,403	5,112	4,947	6,893	4,296	3,115	TAF
29	SWP	EC	(µS/cm)	640	463	502	478	288	279	216	285	507	468	456	368	412		
30	SWP	Load	(tons)	140,050	69,575	98,535	17,855	17,270	50,568	63,884	102,498	168,887	129,460	118,976	134,073	1,111,631		
31	Old Bacon	Flow	(cfs)	1,529	1,731	1,775	(684)	(335)	2,440	4,173	4,882	4,409	3,477	2,796	2,810	2,424	1,758	TAF
32	Old Bacon	EC	(µS/cm)	747	351	307	413	415	209	200	370	713	616	587	448	448		
33	Old Bacon	Load	(tons)	61,314	29,921	29,503	(15,591)	(8,742)	28,009	45,327	97,633	163,877	116,737	86,633	70,927	705,548		
34	Middle Bacon	Flow	(cfs)	2,074	2,542	2,517	(702)	(173)	2,661	5,042	5,801	5,294	4,007	3,749	3,968	3,073	2,228	TAF
35	Middle Bacon	EC	(µS/cm)	538	381	384	448	423	244	182	215	347	339	319	321	345		
36	Middle Bacon	Load	(tons)	60,992	47,895	52,474	(17,063)	(5,449)	33,983	49,740	67,422	96,052	73,796	62,844	69,482	592,168		
37	SJR Jersey	EC	(µS/cm)	1,213	280	273	273	247	171	347	703	1,428	1,247	1,484	613	690		
		Water Balance															TAF	
38	Measured	Inflows		5,114	6,068	6,320	959	2,242	7,697	10,727	11,821	10,870	8,905	8,291	10,666	7,491	5,431	
39	Measured	Exports		5,662	6,822	7,017	1,534	2,279	6,582	9,614	10,866	10,527	9,279	9,103	10,993	7,535	5,463	
40	Estimated	Diversions (Runoff)		(548)	(753)	(696)	(575)	(37)	1,115	1,113	954	343	(374)	(812)	(327)	(45)	(32)	
		Salt Load Balance																
41	Measured	Inflows		187,256	146,845	168,130	17,670	23,944	101,880	132,173	204,746	290,407	224,686	212,206	195,419	1,905,362		
42	Measured	Exports		204,418	181,388	209,137	41,206	39,497	99,320	117,994	184,293	256,824	223,031	203,146	212,937	1,973,192		
43	Estimated	Source (Diversion)		17,162	34,543	41,007	23,536	15,552	(2,560)	(14,178)	(20,453)	(33,583)	(1,655)	(9,060)	17,517	67,830	8.0%	Vernalis

Table 2011. Monthly Water and Salt Budgets for the South Delta in 2011

Row	Station	Variable	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Compare	
1	Vernalis	Flow	(cfs)	11,797	8,699	13,668	26,360	12,642	10,655	8,572	5,393	4,270	5,026	2,754	1,817	9,291	6,736	TAF
2	Vernalis	EC Objective	(µS/cm)	1,000	1,000	1,000	700	700	700	700	700	1,000	1,000	1,000	1,000			
3	Vernalis	EC	(µS/cm)	205	256	245	139	166	161	194	214	270	235	532	738	280		
4	Vernalis	Load	(tons)	140,018	115,548	181,523	216,444	110,109	86,071	81,926	65,430	63,274	66,145	75,610	76,444	1,278,542		
5	Vernalis	Unused Load	(tons)	508,555	316,954	560,038	775,923	366,311	301,689	235,526	142,114	163,654	208,577	67,727	25,845	3,672,914	74%	Vernalis
6	SJR Brandt	EC	(µS/cm)	221	273	263	161	186	164	215	251	309	258	552	794	304	109%	Vernalis
7	SJR Brandt	EC Increase	(µS/cm)	16	17	18	21	20	3	22	37	39	23	21	56	25		
8	Old Head	Flow	(cfs)	5,524	3,884	5,535	11,512	6,383	5,895	4,720	2,649	2,136	2,771	1,944	1,623	4,545	49%	Vernalis
9	Old Head	EC	(µS/cm)	230	273	265	158	167	160	216	246	304	254	556	787	302	108%	Vernalis
10	Old Head	EC Increase	(µS/cm)	24	17	20	19	1	(1)	22	32	34	19	24	49	22		
11	Old Head	Load	(tons)	66,780	51,353	74,648	96,124	57,078	49,534	45,533	34,411	33,072	38,182	54,587	69,258	670,562	52%	Vernalis
12	Old Union	EC	(µS/cm)	222	275	265	160	170	164	216	264	327	290	502	718	298	106%	Vernalis
13	Old Union	EC Increase	(µS/cm)	17	18	21	20	4	3	23	49	57	55	(30)	(20)	18		
14	Old Doughty	EC	(µS/cm)	224	279	262	152	170	172	218	259	320	266	558	790	306	109%	Vernalis
15	Old Doughty	EC Increase	(µS/cm)	19	22	17	13	4	11	24	45	50	31	26	52	26		
16	Paradise Cut	EC	(µS/cm)	412	370	395	182	293	394	526	735	747	630	727	976	516		
17	Sugar Cut	EC	(µS/cm)	760	962	1,121	716	709	716	661	754	883	1,271	1,439	1,292	940		
18	Old Tracy	Flow	(cfs)	610	513	871	2,188	825	594	875	764	388	581	171	121	709	16%	HOR
19	Old Tracy	EC	(µS/cm)	292	353	352	175	229	234	265	307	386	386	696	901	382	136%	Vernalis
20	Old Tracy	EC Increase	(µS/cm)	86	96	107	36	63	74	71	93	116	151	164	163	102		
21	Old Tracy	Added Load	(tons)	2,163	1,248	2,728	1,346	2,015	1,930	1,145	682	730	1,867	1,485	1,006	18,342	1.4%	Vernalis
22	Old Wildlife	EC	(µS/cm)	182	347	345	178	227	240	265	309	390	377	687	914	372	133%	Vernalis
23	Old Wildlife	EC Increase	(µS/cm)	(24)	90	101	39	61	79	71	94	120	142	155	176	92		
24	Old Wildlife	Added Load	(tons)	(1,959)	1,147	2,598	1,528	1,977	2,111	1,142	699	784	1,737	1,339	1,115	14,217	1.1%	Vernalis
25	CVP	Flow	(cfs)	4,002	3,065	3,016	2,237	1,680	3,504	4,227	4,206	4,183	4,038	3,367	3,941	3,460	2,509	TAF
26	CVP	EC	(µS/cm)	258	317	312	188	212	191	206	230	263	266	375	441	271		
27	CVP	Load	(tons)	55,745	47,508	53,750	22,270	18,456	34,817	47,153	52,559	57,868	58,304	60,524	93,035	601,990		
28	SWP	Flow	(cfs)	6,748	5,915	3,409	3,906	1,699	6,269	7,162	7,172	7,159	6,562	3,477	5,198	5,387	3,906	TAF
29	SWP	EC	(µS/cm)	246	288	291	176	189	215	179	206	220	211	280	374	239		
30	SWP	Load	(tons)	88,453	83,405	55,668	35,906	17,280	70,573	69,682	80,209	82,692	75,281	47,037	99,419	805,605		
31	Old Bacon	Flow	(cfs)	1,639	1,605	(461)	(3,417)	(1,220)	1,935	3,395	4,187	4,201	3,502	2,184	3,346	1,748	1,267	TAF
32	Old Bacon	EC	(µS/cm)	230	257	291	195	214	186	135	166	183	164	174	409	217		
33	Old Bacon	Load	(tons)	20,387	19,490	(6,576)	(35,433)	(14,223)	18,488	24,678	37,562	40,388	31,150	19,155	69,407	224,472		
34	Middle Bacon	Flow	(cfs)	2,855	2,459	258	(4,255)	(1,372)	2,759	4,270	5,280	5,180	4,348	2,887	4,315	2,424	1,757	TAF
35	Middle Bacon	EC	(µS/cm)	242	292	295	183	211	208	160	204	208	202	190	290	224		
36	Middle Bacon	Load	(tons)	37,452	34,971	6,480	(41,587)	(15,717)	29,898	37,037	58,231	56,560	47,837	28,249	65,815	345,224		
37	SJR Jersey Point	EC	(µS/cm)	189	227	207	179	147	143	129	235	216	179	329	931	260		
		Water Balance															TAF	
38	Measured	Inflows		10,019	7,948	5,332	3,840	3,792	10,589	12,385	12,116	11,517	10,621	7,015	9,285	8,716	6,319	
39	Measured	Exports		10,751	8,980	6,425	6,143	3,379	9,773	11,389	11,378	11,341	10,600	6,844	9,139	8,847	6,414	
40	Estimated	Diversions (Runoff)		(732)	(1,032)	(1,093)	(2,303)	413	817	996	738	175	21	171	146	(131)	(95)	
		Salt Load Balance																
41	Measured	Inflows		124,620	105,814	74,552	19,104	27,138	97,920	107,248	130,204	130,021	117,169	101,990	204,479	1,240,258		
42	Measured	Exports		144,199	130,913	109,418	58,176	35,736	105,391	116,835	132,767	140,560	133,585	107,561	192,454	1,407,594		
43	Estimated	Source (Diversion)		19,579	25,099	34,866	39,072	8,598	7,471	9,587	2,563	10,539	16,415	5,571	(12,025)	167,336	13.1%	Vernalis

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Table 2012. Monthly Water and Salt Budgets for the South Delta in 2012

Row	Station	Variable	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Compare	
1	Vernalis	Flow	(cfs)	1,821	1,585	1,615	2,500	2,991	1,592	951	778	956	1,790	1,294	1,934	1,651	1,197	TAF
2	Vernalis	EC Objective	(µS/cm)	1,000	1,000	1,000	700	700	700	700	700	1,000	1,000	1,000	1,000			
3	Vernalis	EC	(µS/cm)	702	803	873	463	280	395	524	537	606	470	685	675	584		
4	Vernalis	Load	(tons)	71,884	64,114	79,976	62,426	46,797	36,108	28,593	25,336	33,789	44,756	48,905	70,556	613,250		
5	Vernalis	Unused Load	(tons)	29,458	15,323	11,090	31,070	68,217	25,463	9,069	6,885	19,780	51,434	21,383	34,145	323,315	35%	Vernalis
6	SJR Brandt	EC	(µS/cm)	770	842	964	567	339	509	561	670	698	519	707	672	651	112%	Vernalis
7	SJR Brandt	EC Increase	(µS/cm)	68	39	90	103	60	113	37	134	92	48	22	(3)	67		
8	Old Head	Flow	(cfs)	1,496	1,285	1,169	651	594	833	820	668	698	1,157	1,241	1,676	1,023	62%	Vernalis
9	Old Head	EC	(µS/cm)	753	844	939	549	330	493	615	665	699	525	751	733	657	113%	Vernalis
10	Old Head	EC Increase	(µS/cm)	51	42	65	86	51	97	91	128	93	55	66	59	74		
11	Old Head	Load	(tons)	60,753	52,443	59,172	18,923	10,225	21,174	26,897	24,064	25,581	29,552	48,873	64,057	441,521	72%	Vernalis
12	Old Union	EC	(µS/cm)	738	804	926	554	327	438	611	607	642	516	731	723	634	109%	Vernalis
13	Old Union	EC Increase	(µS/cm)	36	2	53	91	47	42	87	71	36	46	46	48	51		
14	Old Doughty	EC	(µS/cm)	750	722	892	680	405	533	640	700	728	566	753	760	677	116%	Vernalis
15	Old Doughty	EC Increase	(µS/cm)	48	(80)	18	217	125	138	115	163	122	96	68	85	93		
16	Paradise Cut	EC	(µS/cm)	933	971	1,053	849	590	727	845	934	899	701	855	868	852		
17	Sugar Cut	EC	(µS/cm)	997	1,089	1,122	1,145	1,003	895	870	931	1,057	1,183	1,134	1,121	1,057		
18	Old Tracy	Flow	(cfs)	120	116	130	2	93	176	286	259	193	147	97	120	145	14%	HOR
19	Old Tracy	EC	(µS/cm)	882	962	1,085	1,242	624	667	713	764	808	687	851	896	847	145%	Vernalis
20	Old Tracy	EC Increase	(µS/cm)	180	159	211	779	345	271	189	227	202	217	166	221	264		
21	Old Tracy	Added Load	(tons)	892	1,312	1,265	(170)	742	1,000	1,103	902	564	934	486	904	9,951	1.6%	Vernalis
22	Old Wildlife	EC	(µS/cm)	902	993	1,129	1,302	639	676	715	774	813	674	850	910	863	148%	Vernalis
23	Old Wildlife	EC Increase	(µS/cm)	201	190	256	839	359	281	191	237	207	204	165	235	280		
24	Old Wildlife	Added Load	(tons)	1,029	1,483	1,412	(133)	835	1,152	1,122	1,051	607	820	480	1,010	10,889	1.8%	Vernalis
25	CVP	Flow	(cfs)	2,308	1,921	1,901	933	1,470	2,076	4,132	4,404	4,157	3,929	3,937	2,977	2,851	2,067	TAF
26	CVP	EC	(µS/cm)	663	680	700	564	416	356	295	338	511	480	494	575	505		
27	CVP	Load	(tons)	82,786	62,973	70,449	27,343	32,068	38,773	65,880	80,769	110,403	102,978	101,472	87,128	862,461		
28	SWP	Flow	(cfs)	3,668	1,804	1,459	1,359	1,698	1,590	5,719	6,221	4,904	3,725	3,026	4,295	3,301	2,393	TAF
29	SWP	EC	(µS/cm)	637	634	588	506	397	318	272	336	557	498	457	509	475		
30	SWP	Load	(tons)	126,497	55,742	46,164	35,551	35,470	26,222	84,617	112,117	138,847	100,339	71,188	113,348	944,435		
31	Old Bacon	Flow	(cfs)	1,964	1,141	1,014	700	1,501	1,741	4,285	4,546	3,501	2,573	2,179	1,864	2,260	1,639	TAF
32	Old Bacon	EC	(µS/cm)	701	495	369	336	296	252	336	454	811	635	537	477	475		
33	Old Bacon	Load	(tons)	74,633	28,398	20,012	12,237	23,558	23,239	77,765	110,386	146,457	89,928	62,354	56,650	724,804		
34	Middle Bacon	Flow	(cfs)	2,796	1,668	1,451	1,183	2,034	2,260	5,678	6,127	4,971	3,870	3,396	3,354	3,244	2,352	TAF
35	Middle Bacon	EC	(µS/cm)	507	471	429	465	362	275	217	240	367	353	322	312	360		
36	Middle Bacon	Load	(tons)	77,055	38,880	33,655	29,289	39,297	32,816	66,448	79,099	93,553	74,260	57,382	59,525	680,728		
37	SJR Jersey Point	EC	(µS/cm)	1,184	467	316	239	225	400	631	829	1,421	1,164	1,533	620	753		
		Water Balance															TAF	
38	Measured	Inflows		6,256	4,094	3,635	2,535	4,129	4,834	10,784	11,341	9,169	7,600	6,816	6,894	6,527	4,732	
39	Measured	Exports		5,976	3,725	3,360	2,293	3,168	3,666	9,851	10,625	9,061	7,654	6,963	7,271	6,152	4,460	
40	Estimated	Diversions (Runoff)		280	369	274	242	961	1,168	933	716	108	(54)	(147)	(378)	375	272	
		Salt Load Balance																
41	Measured	Inflows		212,441	119,721	112,839	60,448	73,081	77,230	171,111	213,549	265,591	193,740	168,609	180,232	1,847,053		
42	Measured	Exports		209,283	118,715	116,613	62,894	67,538	64,995	150,498	192,885	249,251	203,317	172,660	200,476	1,806,896		
43	Estimated	Source (Diversion)		(3,158)	(1,005)	3,773	2,445	(5,543)	(12,235)	(20,613)	(20,664)	(16,340)	9,578	4,050	20,244	(40,157)	-6.5%	Vernalis

Table 2013. Monthly Water and Salt Budgets for the South Delta in 2013

Row	Station	Variable	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Compare	
1	Vernalis	Flow	(cfs)	1,840	2,229	1,510	2,165	2,316	737	576	525	850	1,459	1,086	935	1,347	976	TAF
2	Vernalis	EC Objective	(µS/cm)	1,000	1,000	1,000	700	700	700	700	700	1,000	1,000	1,000	1,000			
3	Vernalis	EC	(µS/cm)	848	677	835	555	364	560	505	491	506	514	683	865	617		
4	Vernalis	Load	(tons)	87,396	77,344	71,649	58,492	37,476	23,054	17,146	15,224	22,833	41,327	42,359	47,447	541,747		
5	Vernalis	Unused Load	(tons)	15,125	35,290	13,509	16,493	42,174	5,410	6,103	5,964	22,055	38,492	18,065	6,830	225,511	29%	Vernalis
6	SJR Brandt	EC	(µS/cm)	860	691	811	661	374	640	702	713	617	577	677	906	686	111%	Vernalis
7	SJR Brandt	EC Increase	(µS/cm)	12	14	(24)	106	9	80	197	222	112	64	(6)	41	69		
8	Old Head	Flow	(cfs)	1,528	1,787	1,351	1,475	1,563	500	548	556	542	599	880	719	999	74%	Vernalis
9	Old Head	EC	(µS/cm)	886	677	869	638	404	678	696	685	595	587	741	926	699	113%	Vernalis
10	Old Head	EC Increase	(µS/cm)	38	0	34	84	40	118	191	194	89	74	58	61	82		
11	Old Head	Load	(tons)	72,094	58,540	62,599	41,760	27,153	17,676	20,592	20,724	16,551	17,283	33,519	36,083	424,573	78%	Vernalis
12	Old Union	EC	(µS/cm)	868	673	782	638	384	632	672	659	585	574	715	902	674	109%	Vernalis
13	Old Union	EC Increase	(µS/cm)	19	(4)	(53)	84	20	72	167	168	80	61	32	36	57		
14	Old Doughty	EC	(µS/cm)	887	688	849	685	427	778	738	722	660	620	736	953	729	118%	Vernalis
15	Old Doughty	EC Increase	(µS/cm)	38	11	13	130	63	218	234	231	154	106	53	88	112		
16	Paradise Cut	EC	(µS/cm)	1,067	910	1,029	856	526	928	853	884	813	779	842	1,070	880		
17	Sugar Cut	EC	(µS/cm)	1,559	1,292	1,031	1,073	695	1,006	931	972	1,092	1,381	1,085	1,230	1,111		
18	Old Tracy	Flow	(cfs)	102	133	122	151	165	20	116	132	97	97	90	71	108	11%	HOR
19	Old Tracy	EC	(µS/cm)	1,088	902	961	881	490	962	851	841	822	764	828	1,051	870	141%	Vernalis
20	Old Tracy	EC Increase	(µS/cm)	239	225	126	326	126	401	346	350	316	250	145	186	253		
21	Old Tracy	Added Load	(tons)	1,095	1,358	731	1,442	533	365	705	828	797	864	431	366	9,515	1.8%	Vernalis
22	Old Wildlife	EC	(µS/cm)	1,105	927	1,004	884	507	877	877	847	830	782	839	1,059	878	142%	Vernalis
23	Old Wildlife	EC Increase	(µS/cm)	256	250	169	330	142	317	373	356	324	268	156	194	261		
24	Old Wildlife	Added Load	(tons)	1,188	1,527	1,007	1,444	648	274	868	870	848	957	477	400	11,372	2.1%	Vernalis
25	CVP	Flow	(cfs)	1,649	2,605	2,463	455	1,039	783	3,664	3,811	3,297	2,273	1,740	983	2,065	1,497	TAF
26	CVP	EC	(µS/cm)	643	540	512	537	366	443	336	472	582	522	607	767	527		
27	CVP	Load	(tons)	54,718	68,241	68,225	13,818	19,833	18,315	66,783	97,708	100,277	63,701	53,842	40,879	666,340		
28	SWP	Flow	(cfs)	2,655	1,743	2,591	1,374	900	2,048	5,173	5,821	3,378	1,171	1,931	1,659	2,547	1,847	TAF
29	SWP	EC	(µS/cm)	532	490	440	580	357	392	340	499	597	490	550	653	493		
30	SWP	Load	(tons)	75,809	41,259	61,905	41,219	16,860	40,045	94,333	157,887	105,679	31,090	54,493	58,917	779,495		
31	Old Bacon	Flow	(cfs)	795	820	1,470	84	338	1,193	3,815	4,249	2,676	1,151	1,061	671	1,536	1,113	TAF
32	Old Bacon	EC	(µS/cm)	301	309	292	288	323	297	465	719	795	512	625	714	471		
33	Old Bacon	Load	(tons)	12,864	12,371	23,258	1,243	5,994	18,367	96,063	166,341	112,506	32,340	33,465	25,889	540,700		
34	Middle Bacon	Flow	(cfs)	1,780	1,716	2,573	472	754	1,984	5,361	5,666	3,813	1,686	1,680	1,294	2,408	1,746	TAF
35	Middle Bacon	EC	(µS/cm)	341	376	341	309	350	287	249	328	394	397	457	523	363		
36	Middle Bacon	Load	(tons)	33,535	32,565	48,073	7,865	14,656	30,274	73,958	102,611	79,533	36,459	40,820	37,289	537,638		
37	SJR Jersey Point	EC	(µS/cm)	230	254	308	288	336	382	932	1,261	1,189	1,170	1,598	1,743	811		
		Water Balance															TAF	
38	Measured	Inflows		4,103	4,324	5,394	2,031	2,655	3,677	9,724	10,471	7,030	3,437	3,622	2,684	4,943	3,584	
39	Measured	Exports		4,304	4,348	5,054	1,829	1,939	2,831	8,837	9,632	6,675	3,444	3,671	2,642	4,612	3,344	
40	Estimated	Diversions (Runoff)		(201)	(25)	340	202	716	846	886	839	355	(7)	(49)	42	332	240	
		Salt Load Balance																
41	Measured	Inflows		118,492	103,475	133,930	50,868	47,803	66,317	190,613	289,675	208,590	86,082	107,803	99,261	1,502,910		
42	Measured	Exports		130,527	109,500	130,130	55,037	36,693	58,359	161,116	255,594	205,956	94,791	108,335	99,796	1,445,835		
43	Estimated	Source (Diversion)		12,035	6,025	(3,800)	4,169	(11,110)	(7,958)	(29,497)	(34,081)	(2,634)	8,709	532	535	(57,075)	-10.5%	Vernalis