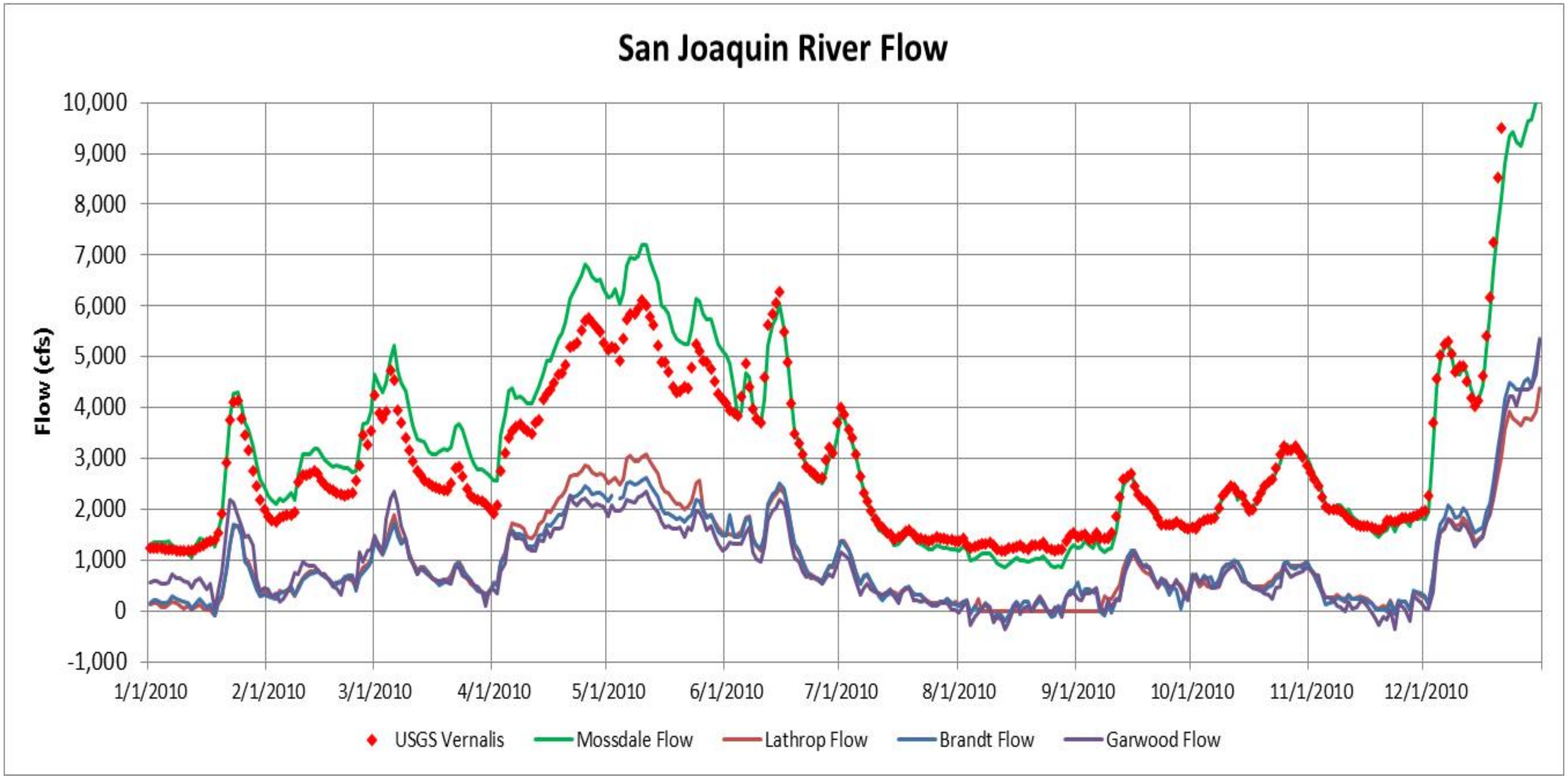
South Delta Tidal Data Atlas Graphs for Calendar Year 2010

This South Delta Data Atlas for 2010 includes several graphs of 15-minute tidal data (shown with quarterly graphs) and several graphs of daily average data from the south Delta channels for 2010. The goal of this flow and salinity data analysis task is to describe and better understand (i.e., identify and quantify relationships) the effects of SJR flows, export pumping, tidal elevations, and temporary barrier installation (weirs with flap-gate culverts) on salinity (EC) between Vernalis and the south Delta EC compliance stations (SJR at Brandt Bridge, Old River at Union Island and Old River at Tracy Boulevard). Because most of the water for exports comes into the south Delta through Old and Middle Rivers, the data analysis includes data from Old and Middle River downstream to the stations near Bacon Island used for computing the OMR combined flow.

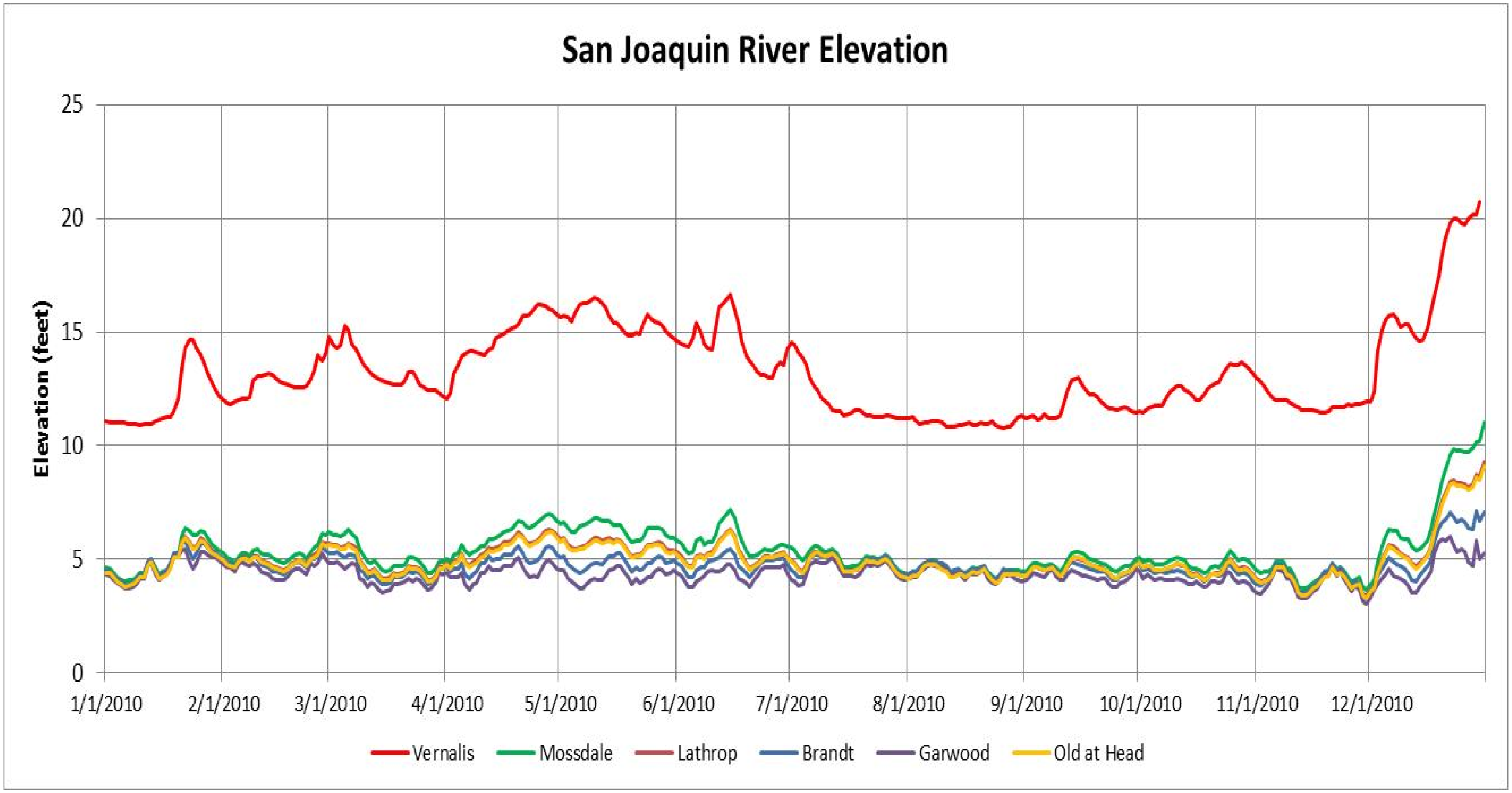
South Delta Data Atlas excel files have been compiled to support the review and summary of data patterns and relationship for 2009-2013. This year (2010) included moderately high SJR flows (1,000-5,000 cfs) with moderate exports (4,000-8,000 cfs) in the January-March period, sustained SJR spring flows (3,000-6,000 cfs) in April-June with low exports for SJR fish protection in April and May, and June exports of about 6,000 cfs, low SJR flow (1,000-2,000 cfs) with very high exports (10,000 cfs) in July-September, moderate SJR flows of about 2,000 cfs in October and November with a late-October pulse flow of 3,000 cfs, and high SJR flows (increasing to 10,000 cfs) in December. The exports remained high (8,000-10,000 cfs) in the September-December period.

Several daily data graphs are shown and briefly described (below each graph) to provide an introduction and summary of the flows, elevations, and EC conditions in the SJR and south Delta channels during calendar year 2010. The basic 15-minute data graphs of tidal elevation, tidal flow, and tidal variation in EC (at several locations), along with calculated EC for Paradise Cut and Sugar Cut and calculated EC for Old River at Tracy Boulevard are shown in four quarterly (3-month) graphs.

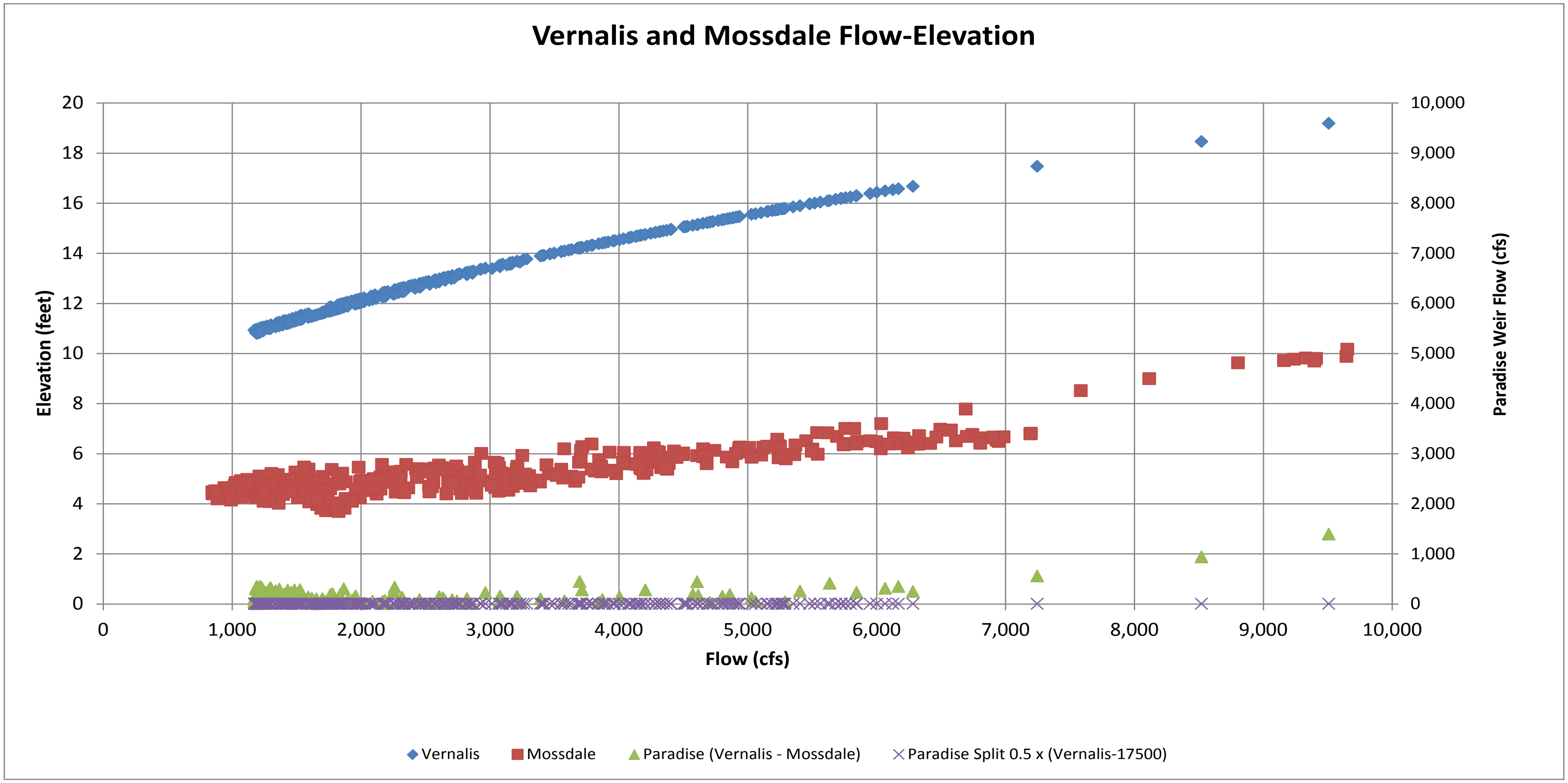
The basic flow splits in the south Delta are evaluated, and the effects of the temporary barriers on tidal elevations, tidal flows, and net downstream flows are described in the graphs. The tidal elevations and tidal flows in Old River at Tracy Boulevard provide the framework for evaluating the effects of salt loads from Paradise Cut and Sugar Cut on the observed EC at Tracy Boulevard. The salt loads from these tidal sloughs are tidally flushed to Old River during ebb tides (declining elevations, tidal outflow) and are mixed and transported downstream about 1.5 miles to Tracy Boulevard. Several factors contribute to the periods of high EC measured at Tracy Boulevard. The review and evaluation of the tidal elevation, tidal flow, and tidal variation in EC has led to the formulation of several alternatives that might be implemented to reduce the high EC at Tracy Boulevard.



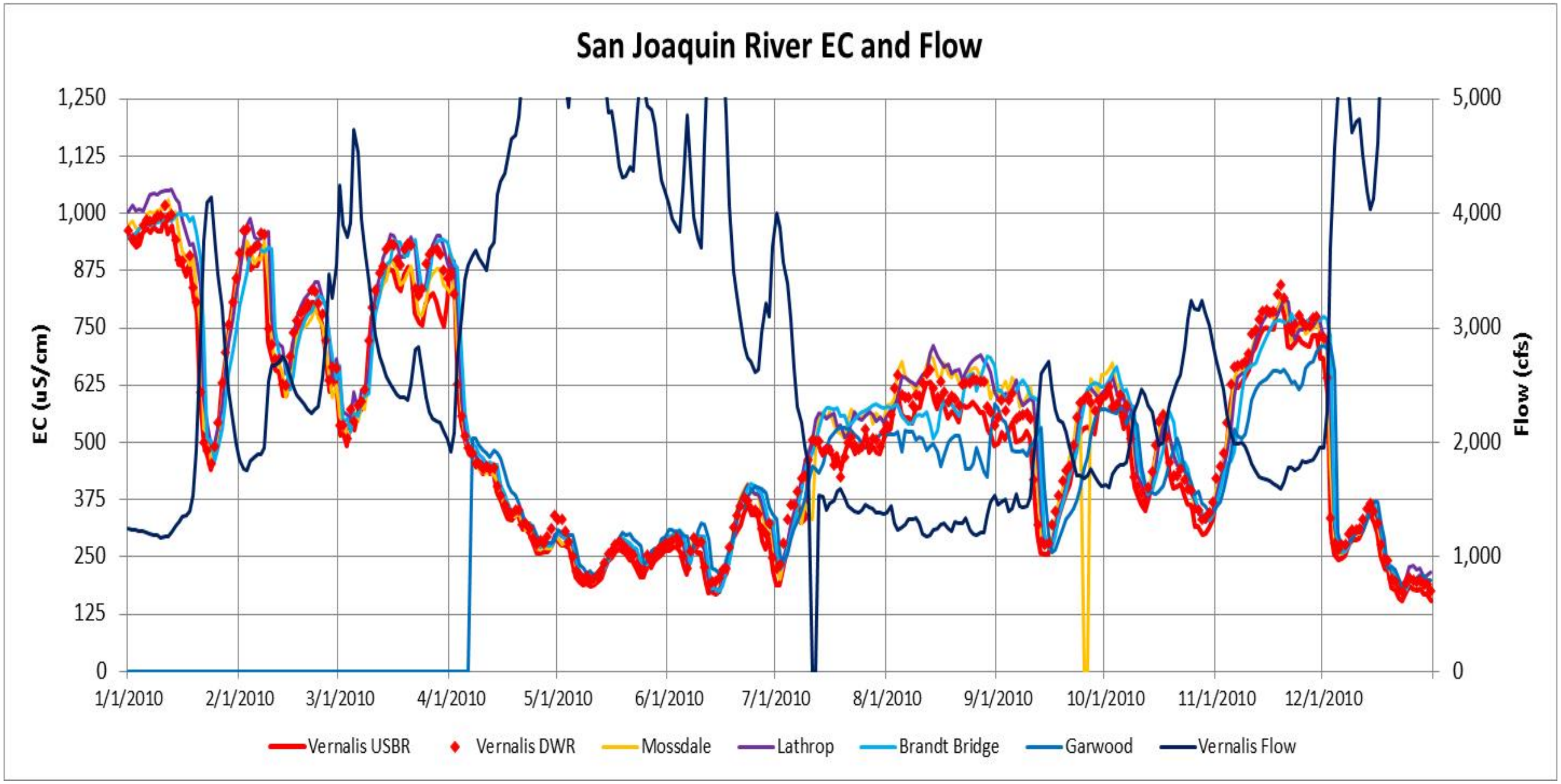
San Joaquin River flows in 2010 in the January-June period were moderately high (1,000-5,000 cfs) with an April-May pulse flow of 7,000 cfs. The exports were moderately high (4,000-8,000 cfs) except the exports were reduced to 1,500 cfs in April and May for SJR fish protection (2009 NMFS RPA). The SJR flows were 1,000-2,000 cfs in July-November with a 2,500 cfs pulse flow in mid-September (water transfer) and a 3,000 cfs pulse flow in late October (fish attraction). Exports were 8,000-12,000 cfs for July-December. Two major storms in December increased the SJR flow to 10,000 cfs at the end of the year. The Mossdale flows were greater than the Vernalis flows in the February-May period, and were slightly less in the summer months. The SJR flows downstream of Old River were much lower than the flow at Vernalis or Mossdale, because most of the SJR was diverted into Old River. The SJR flow downstream of Old River was near zero or negative (i.e., upstream) in early January, August, and November.



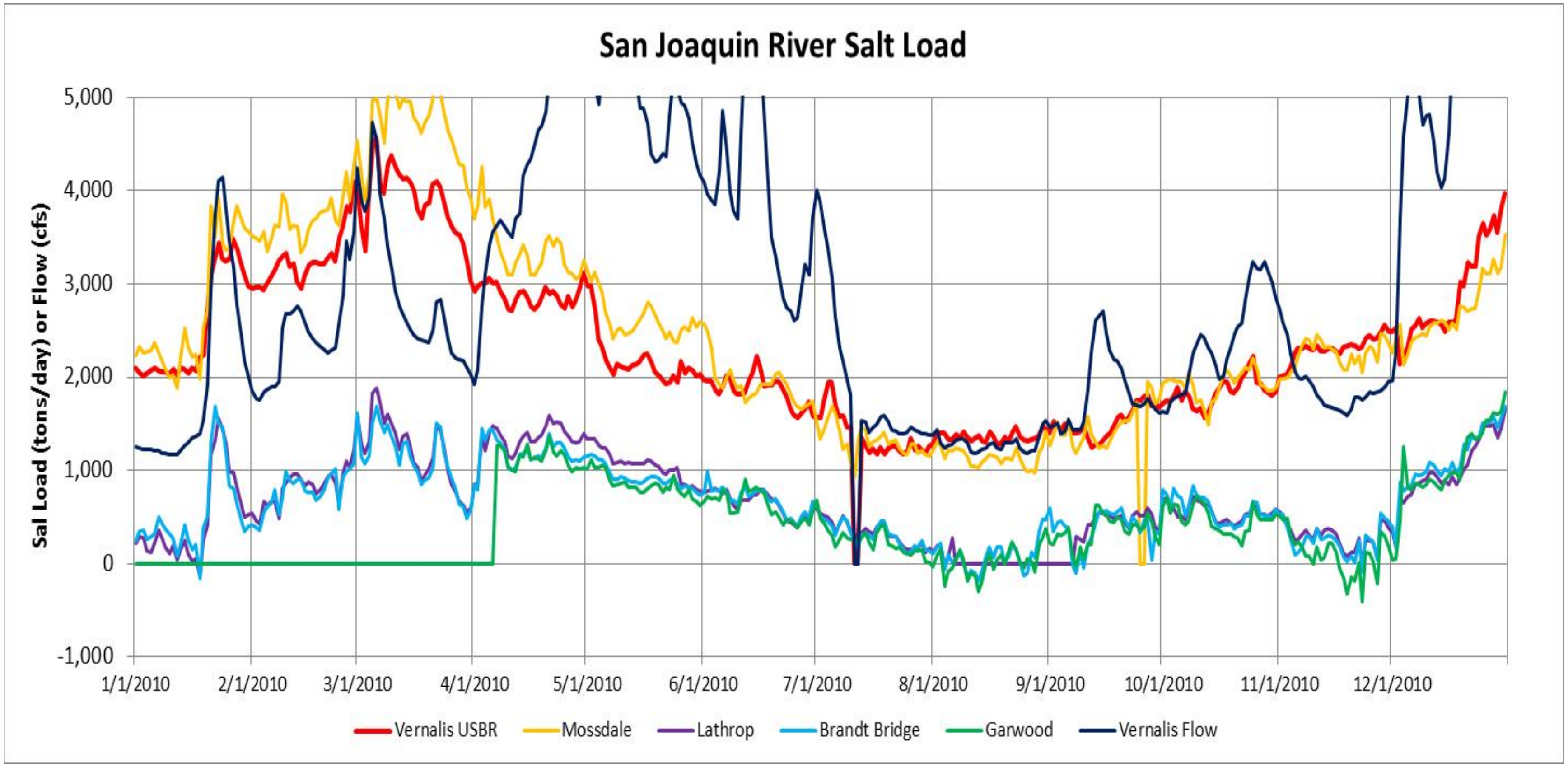
During periods of increased flow at Vernalis (>5,000 cfs) the elevations at Mossdale and other locations were increased slightly above the normal tidal elevations of about 5 feet. Elevations at Mossdale, Lathrop, Brandt Bridge, and Garwood indicate a slight elevation gradient (slope) when flows are greater than 2,500 cfs at Vernalis (elevation of greater than 12.5 feet). Average daily tidal elevations in the SJR downstream of Mossdale were about 4 to 5 feet throughout the year.



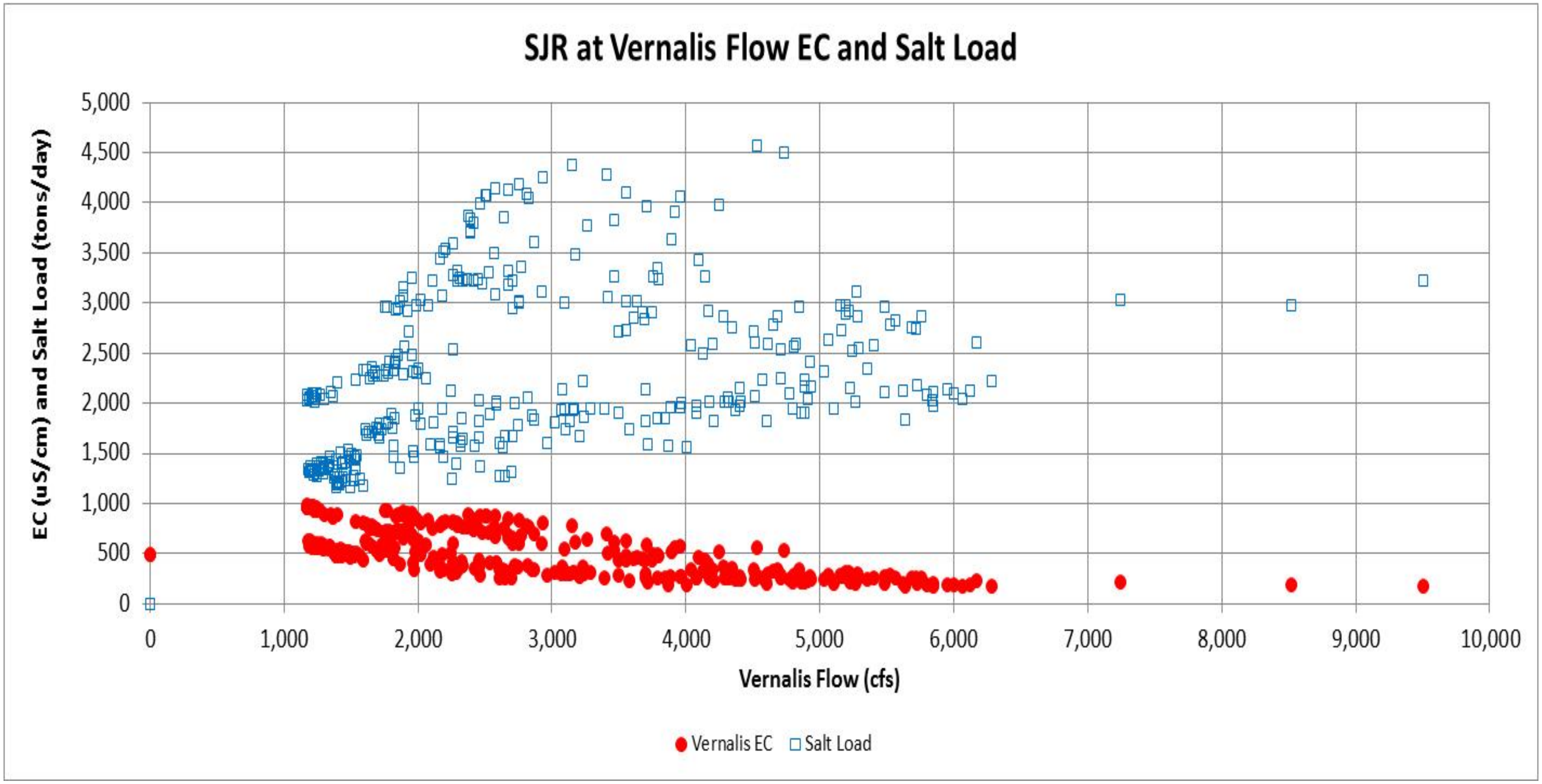
The flow-elevation relationships (rating curves) at Vernalis and Mossdale are quite different because Vernalis is riverine while Mossdale is tidal. The rating curve at Mossdale indicates that the river elevations are increased (above the tidal average of 5 feet) when flows are greater than about 2,000 cfs. The rating curve at Vernalis was stable (no changes) throughout 2010. The reductions between Vernalis and Mossdale flows (green triangles- right scale) were briefly substantial (greater than 500 cfs) during the high December flows. However this reduction was likely caused by rating curve discrepancies because there were no Paradise Cut spills during 2010 (estimated Paradise Weir flow, shown with “X”s is 0 cfs).



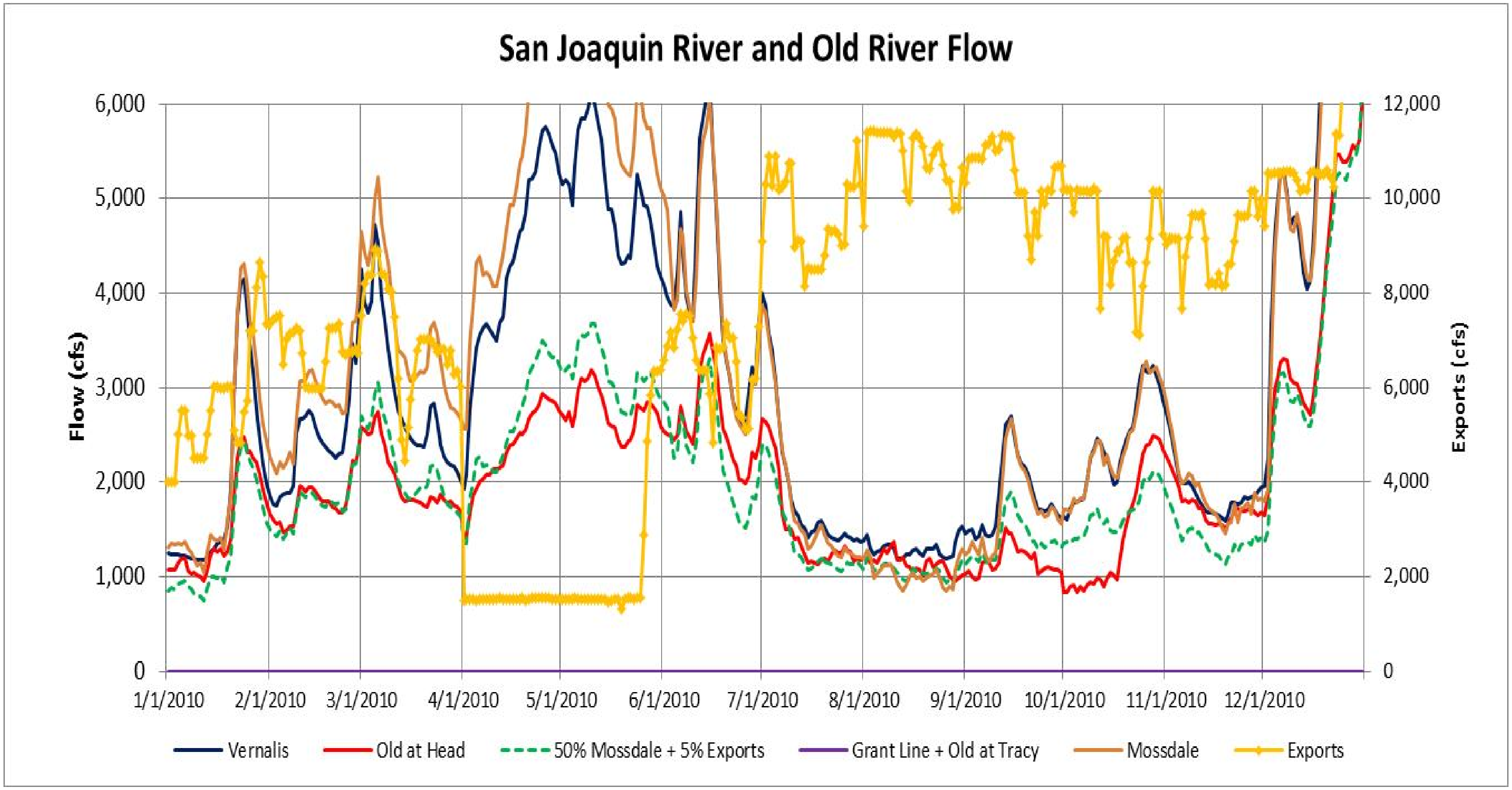
The SJR EC in 2010 was reduced to less than 250 uS/cm during the sustained spring flows (5,000 cfs) and in December. The SJR EC was less than 500 uS/cm during storms in January and March, and during the October pulse flow for fish attraction and in September (reservoir releases). The Vernalis EC objectives (monthly average) are 700 uS/cm for April-August and 1,000 uS/cm for September-March. The highest SJR EC in 2010 was about 1,000 uS/cm in January, about 900 uS/cm in March, and about 750 uS/cm in November. The Vernalis EC was about 500-650 uS/cm in July and August when the SJR flow was 1,500 cfs. The changes in the SJR EC measured at downstream locations was relatively small (<50 uS/cm) during 2010.



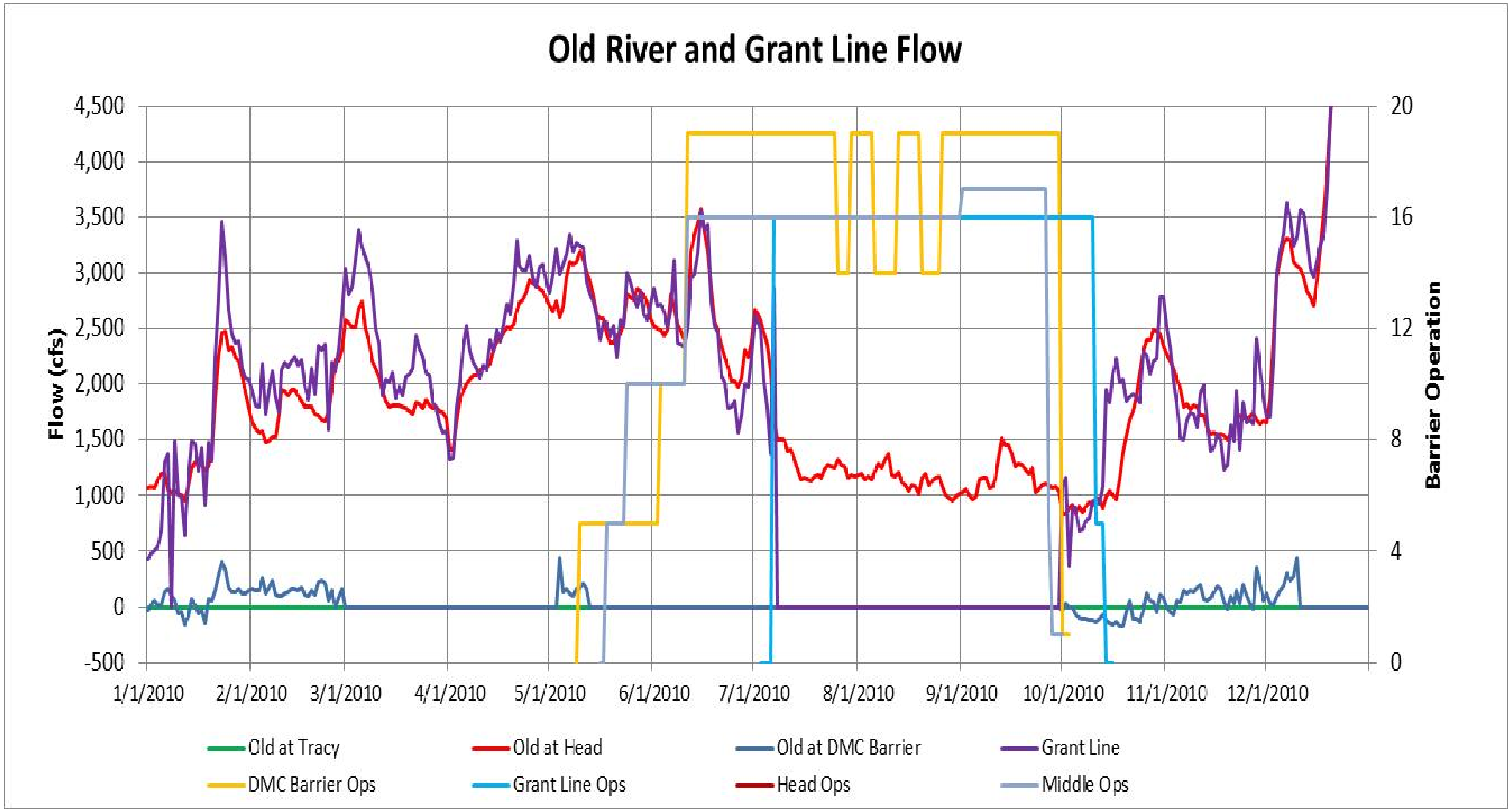
The SJR salt load was estimated as: Salt Load (tons/day) = flow (cfs) x EC (uS/cm) x 0.00175. The SJR salt load at Vernalis was highest (2,000 to 4,000 tons/day) during the highest flow months of January-May and December. The SJR salt load declined to a minimum of about 1,500 tons/day in July-September, and increased to about 2,500 tons/day in November. The EC at Vernalis and Mossdale were similar; the measured SJR flow at Mossdale was higher than the Vernalis flow (likely erroneous). The SJR salt load at Lathrop, Brandt Bridge, and Garwood was reduced by more than half because more than half of the river was diverted into Old River.



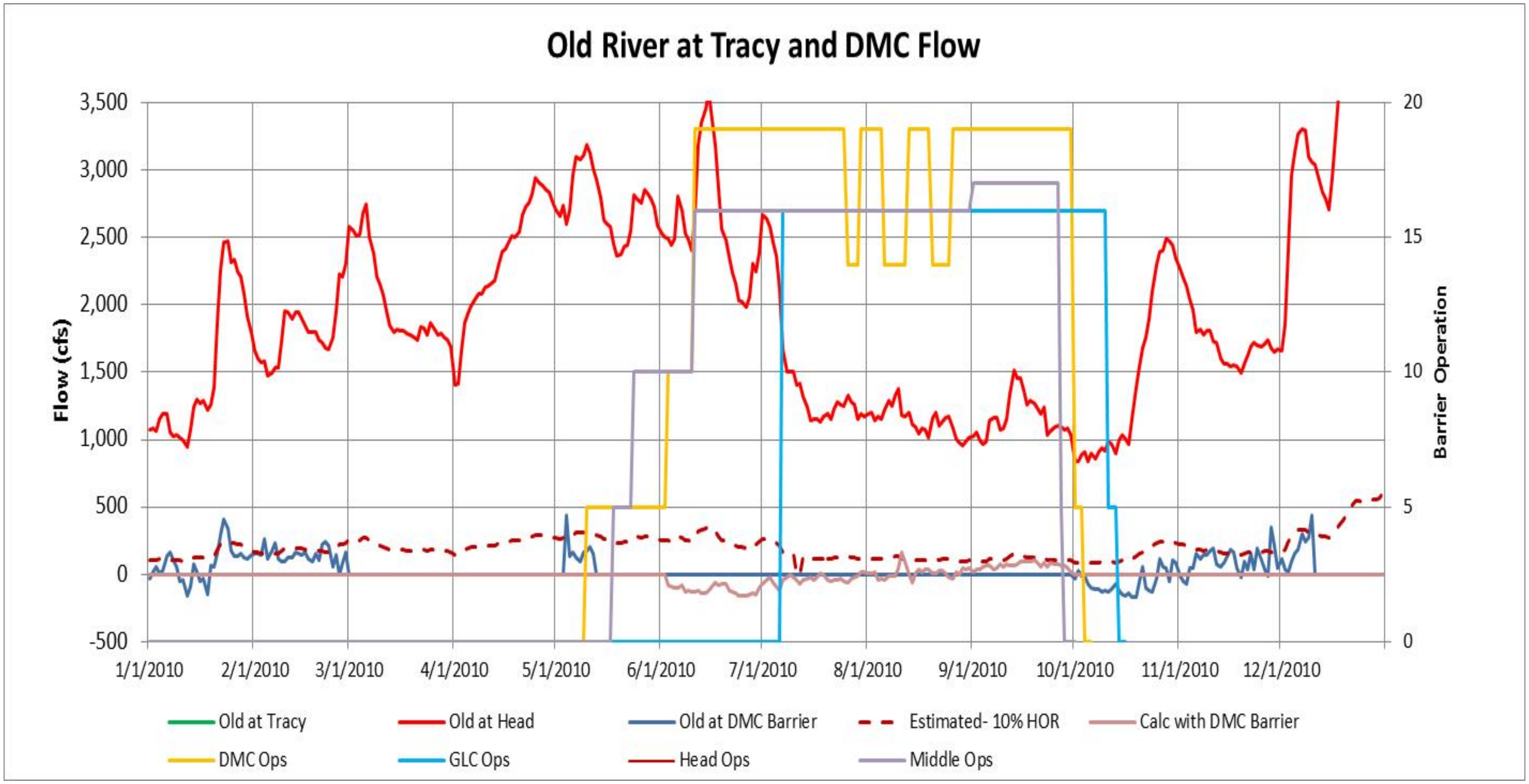
The relationship between the SJR at Vernalis flow and the Vernalis EC depends on the upstream salt loads. There is a general pattern of salt load dilution with higher flows released from the tributary reservoirs, but there are seasonal changes in the salt loads, and higher flows from rainfall-runoff will generally increase the SJR salt load. These different seasonal patterns of flow and EC (and salt load) can be identified in the previous graph showing the sequence of flows and salt loads. The salt load was greatest in the January-May period and was quite low during the summer months. The salt load slowly increased in the October-December period, without a direct relationship between flows and loads.



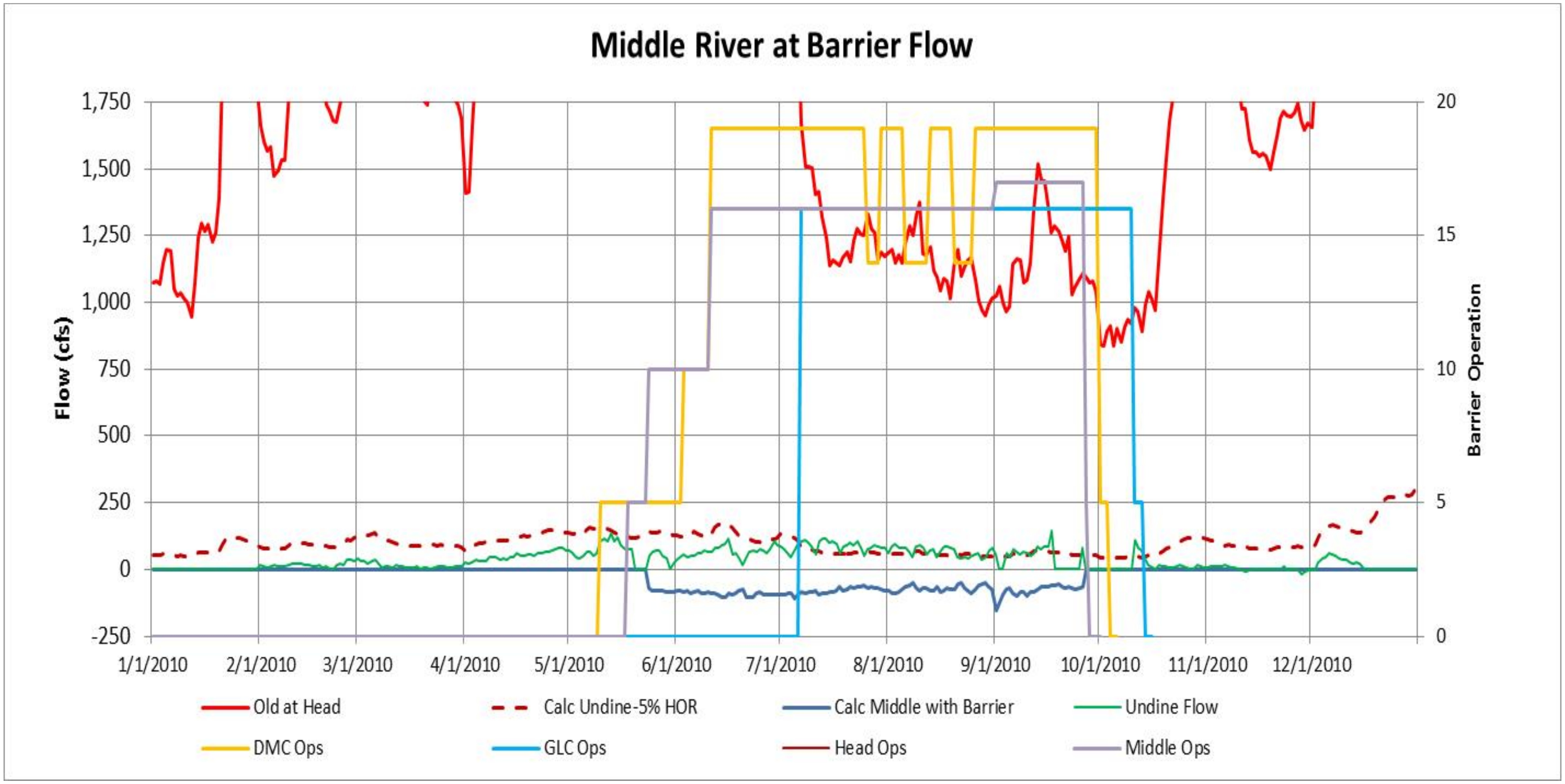
The SJR flow diverted to Old River in 2010 was measured at the head of Old River (red line) and estimated (dashed green line) with the basic relationship for Old River Diversion = 50% Mossdale + 5% of the CVP and SWP exports (gold line, right-hand scale). The Old River flow was generally less than the flow estimated from the Mossdale flow and exports in January-May (because the Mossdale flow was high). The Grant Line Canal flow (next graph) was very similar to the measured Old River at head flow (good confirmation). The Old River flow was a large fraction of the SJR flow during the summer months when the exports were high.



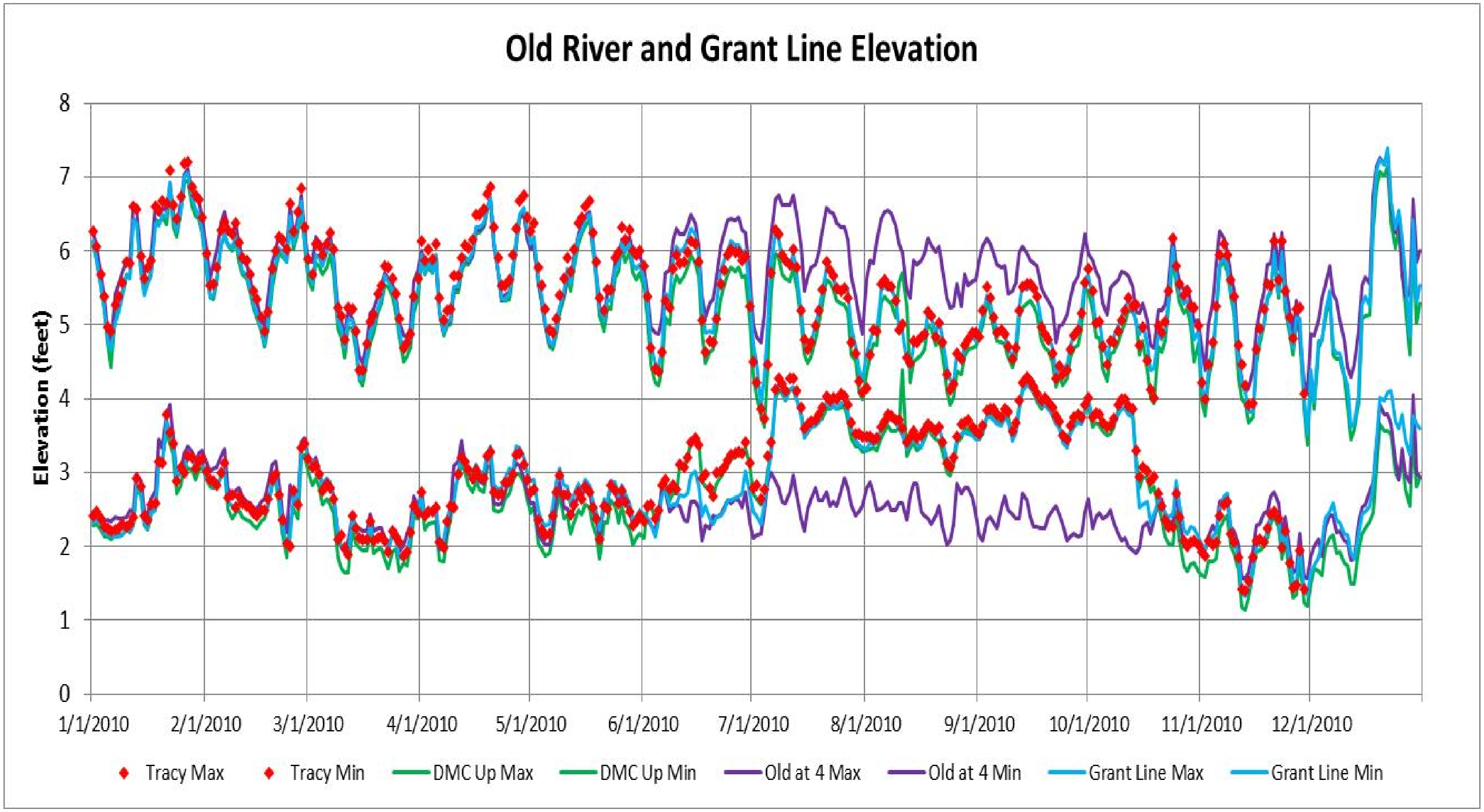
A barrier operation value of 5 (right scale) indicates barrier installation was initiated, a value of 10 indicates the weir was closed but the culverts were open, and higher values indicate the number of flap gates that were operational (10 + flap gates). The Old River flow at the head (red line) in 2010 was generally confirmed by the Grant Line Canal flow (purple line) in January-June and in October-December. The Old River flow at Tracy Boulevard was not measured in 2010, and must be estimated to evaluate the Old River at Tracy Boulevard salinity (EC). The fraction of the Old River flow not diverted to Grant Line Canal was about 10% (based on other years of data). The Old River flow at the DMC barrier was generally less than 150 cfs during the periods of measurements in 2010.



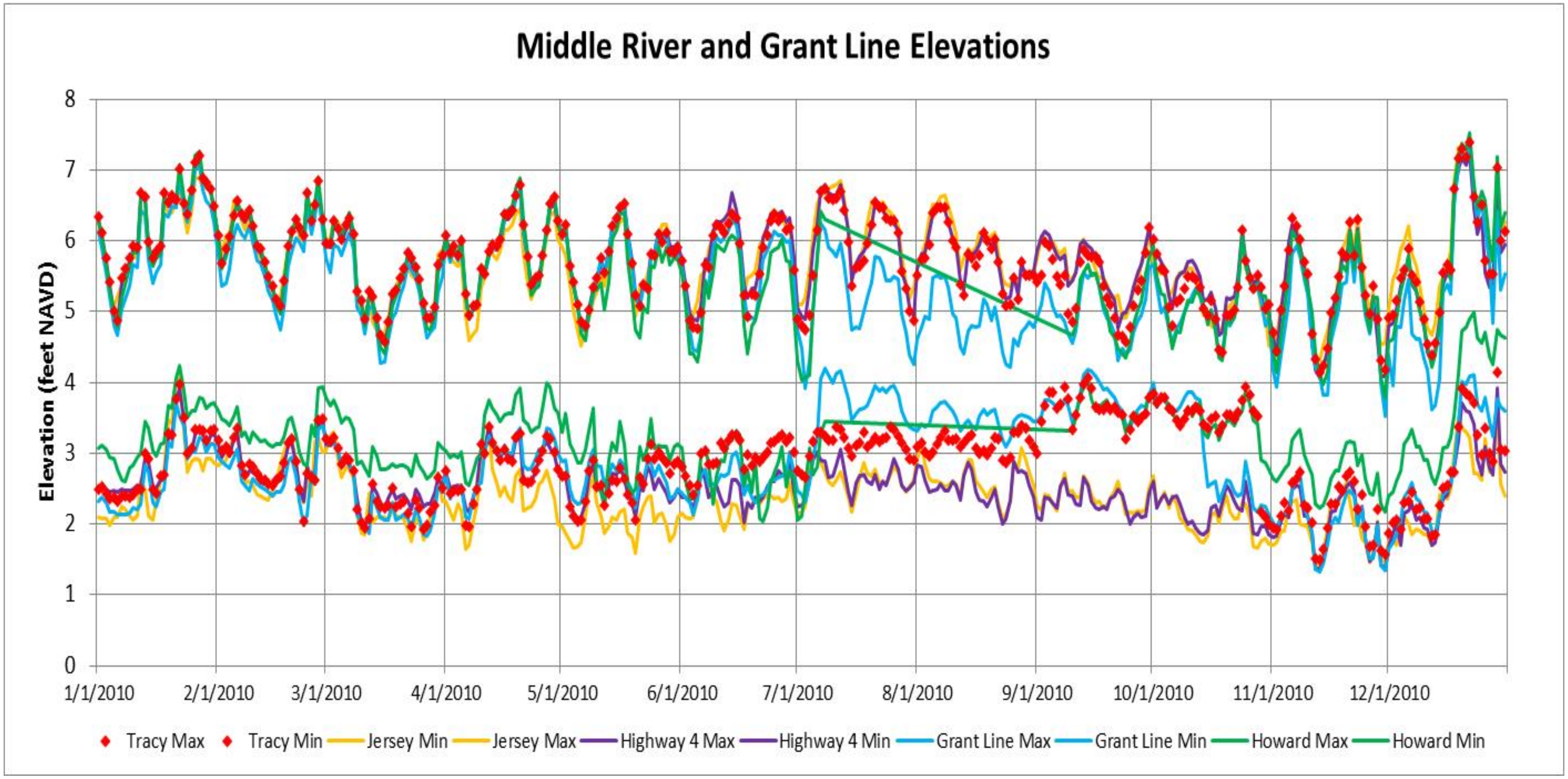
There were no flow measurements in Old River at Tracy Boulevard in 2010; the flow at the DMC barrier was measured in January, February, October, and November when the DMC barrier was not installed. From other years it has been determined that the Old River at Tracy Boulevard flow is about 10% of the head of Old River flow when temporary barriers are not installed, and is generally less with barriers. The Old River at Tracy Boulevard flow is important for evaluating the EC increments measured at Tracy Boulevard; the flow estimate of 10% of the head of Old River flow (dashed red line) may be higher than the actual flow when the DMC barrier was installed from mid-May until the Grant Line Canal barrier was installed in early July.



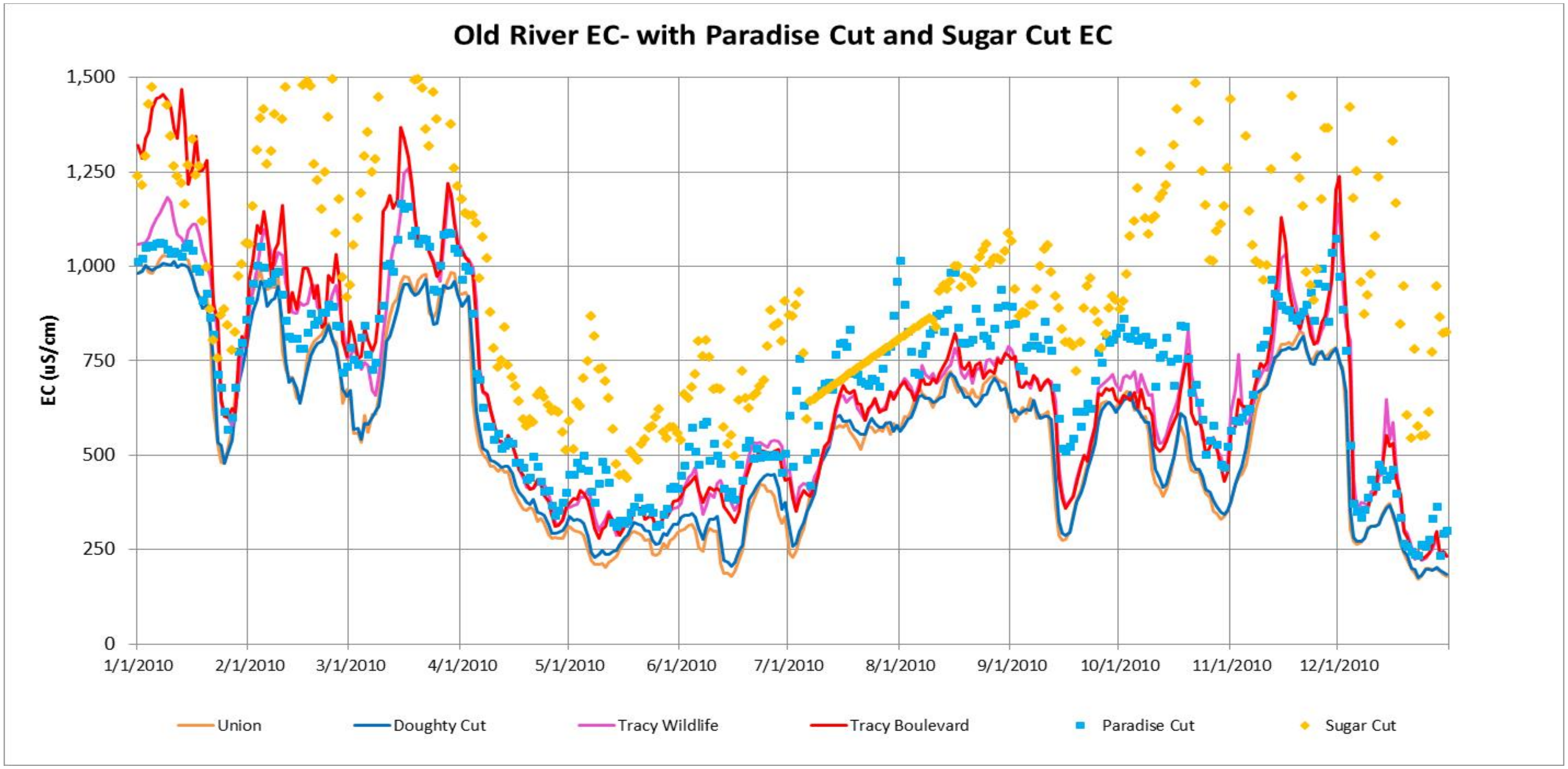
The Middle River flows were measured at Undine Road near the upstream end (head). Based on previous DSM2 modeling with the temporary barriers installed, about 5% of the Old River flow was diverted into Middle River. This estimated flow (brown dashed line) was similar to the measured daily average flow at Undine Road (green line) during the period with barriers. The calculated net daily upstream flow at the Middle River barrier (based on drop in elevation over the barrier) is shown (blue line). The tidal flow through the flap gates (or over the weir) gives an average daily upstream flow of about 75-100 cfs. The seasonal irrigation diversions along Middle River are generally higher, so inflows to Middle River come from both upstream and downstream with the barrier.



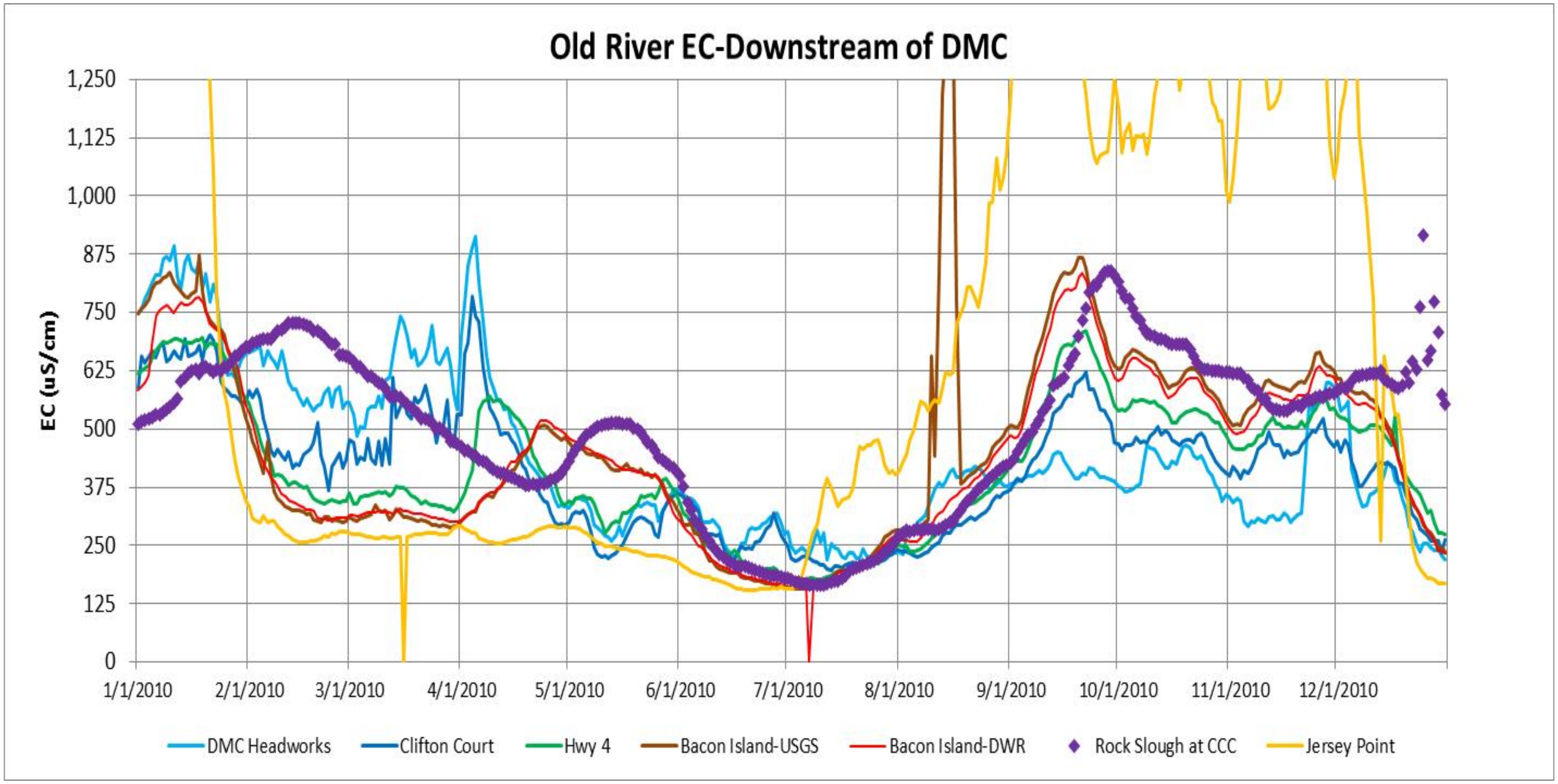
The Old River at Highway 4 minimum and maximum elevations (purple lines) indicate that the tidal elevations generally ranged from 2 feet to 6 feet. The minimum and maximum elevations at Jersey Point (gold Lines) demonstrate that the full tidal range is observed in Old River at Highway 4. The minimum elevations in Old River at Tracy Boulevard and in Grant Line Canal at Tracy Boulevard were increased slightly in June when the DMC barrier was installed, and were increased to between 3 feet and 4 feet in July when the Grant Line Canal barrier was installed. The tidal elevation range in Old River and in Grant Line Canal was reduced to less than 2 feet (with reduced tidal flows) from June through October. The reduction in the maximum daily tide elevations upstream of the DMC and Grant Line Canal barriers reduces the ability to siphon water into Tom Paine Slough.



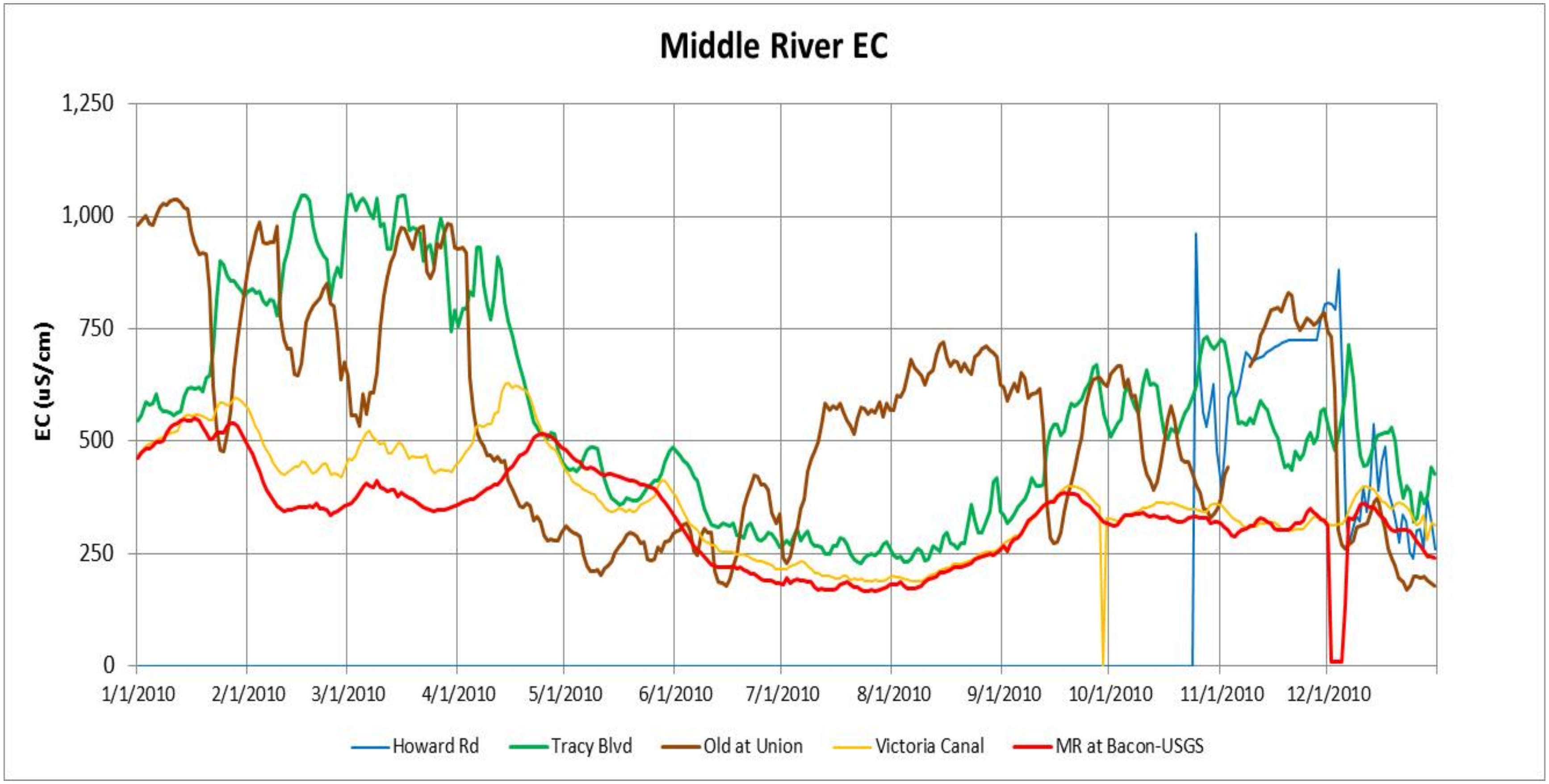
The Middle River Barrier, with a weir crest of about 3.5 feet, was installed at the end of May (culverts open) and flap gates were operated beginning on June 11. The Grant Line Canal barrier was installed with a weir crest of 4.5 feet on July 7, and the Middle River barrier weir crest was raised to 4.5 feet on September 1. The minimum elevations in Middle River at Tracy Boulevard (red diamonds) were slightly increased compared to the Highway 4 elevations in June-August, and were increased by another 0.5 feet in September and October (higher weir crest). The high tides in Middle River were not reduced at Tracy Boulevard and were reduced slightly at Howard Road with the barrier installed. The minimum elevations in Middle River at Howard Road (green line) were increased slightly in May and June, and were increased by 1.5 feet in September and October (higher weir crest and lower irrigation diversions). The Howard Road tide elevations were not available for July and August. The tidal range in Middle River at Howard Road was greater than the tidal range in Grant Line Canal with the temporary barriers installed.



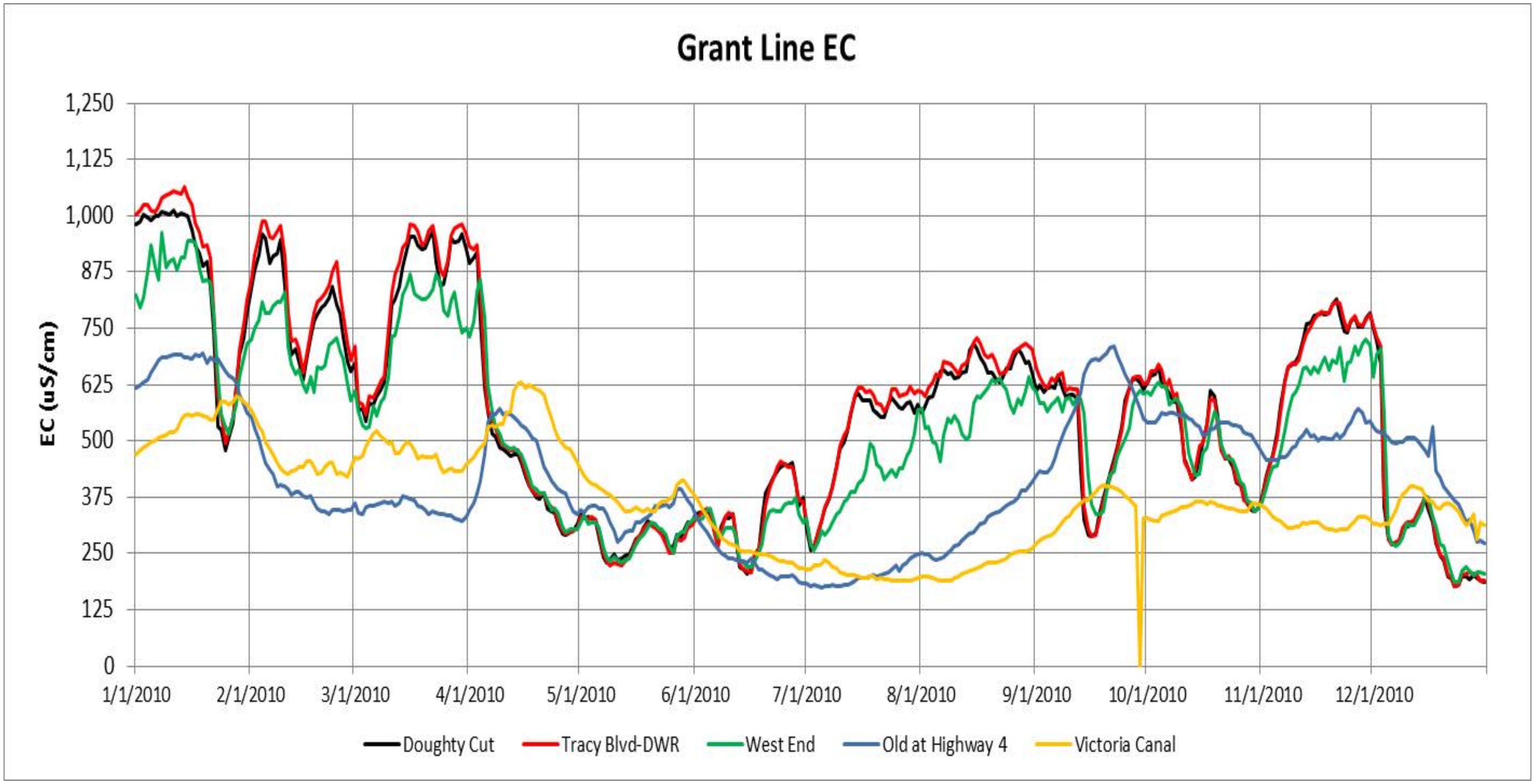
The Old River EC was measured at Union (gold line) and at Doughty Cut (dark blue line). The City of Tracy treated wastewater discharge (diffuser) is located between the two stations, and the EC increase would be greater with lower Old River flows. The most dramatic EC increases were measured in Old River between Doughty Cut and Tracy Boulevard (a distance of about 2 miles). The EC in Old River at Tracy Boulevard (red line) was highest (1,250 uS/cm) in January, and moderately high (1,000 uS/cm) in February, March, and November (low SJR and Old River flows). However, the Old River at Tracy Wildlife EC (located 0.25 km downstream of Tracy Boulevard) was much less than the Tracy Boulevard EC in January; the Tracy Boulevard EC and Tracy Wildlife EC were the same after March (Tracy Boulevard EC was 250 uS/cm higher than the Tracy Wildlife from July 2009 to January 2010). The EC at Tracy Boulevard was generally 50-150 uS/cm higher than the EC at Doughty Cut. The higher EC measured in Sugar Cut (500 to 1,750 uS/cm-gold diamonds) and in Paradise Cut (250 to 1,000 uS/cm-bright blue squares) throughout the year indicate possible sources of higher salinity water.



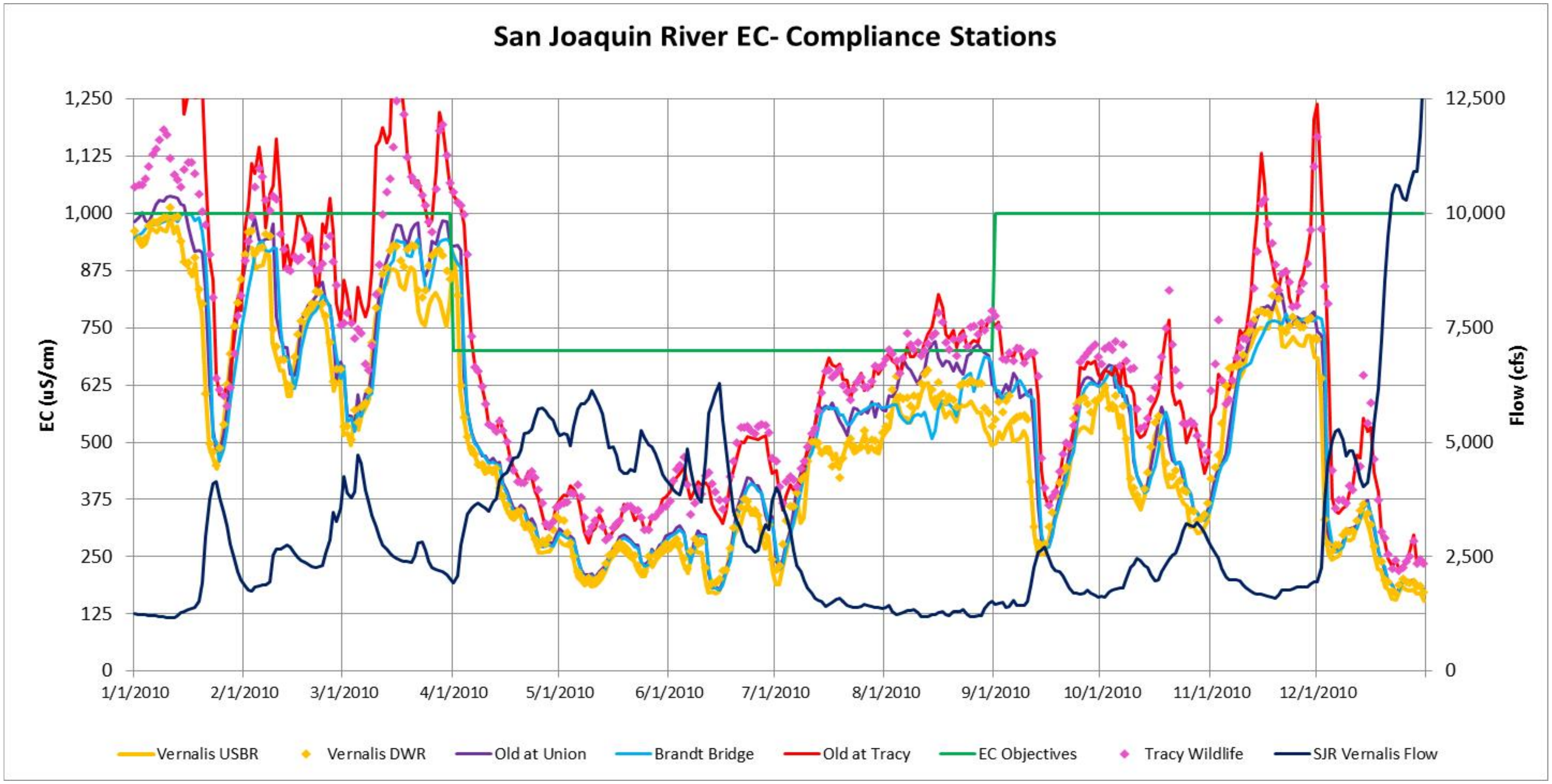
The Old River EC downstream of the DMC intake may have an increasing salt gradient when seawater intrusion is high during periods of low Delta outflow. The SJR at Jersey Point EC (gold line) is highest when seawater intrusion is greatest. False River, located just upstream of Jersey Point, connects the SJR to Franks Tract and Old River; when the Jersey Point EC is higher than about 750 uS/cm, the Old River at Bacon EC and the Rock Slough EC also increases. During periods of high Delta outflow, the SJR at Jersey Point EC was about 250 uS/cm (February-June X2 period) and the Old River EC gradient will decrease downstream of the DMC. The CVP and SWP export EC patterns are influenced by the Delta outflow and Jersey Point EC, and by the SJR at Vernalis flow and corresponding EC.



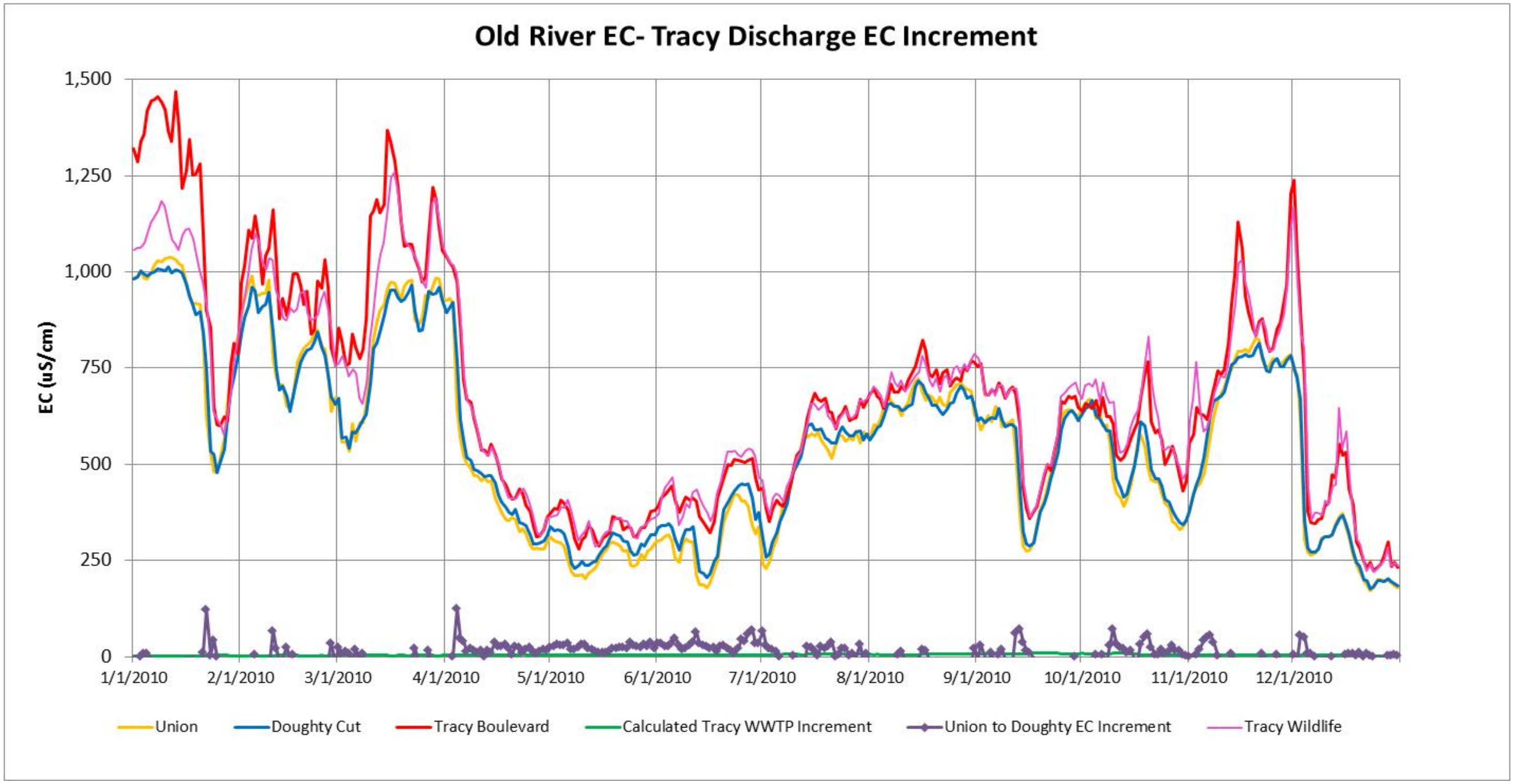
The Middle River EC downstream of the barrier at Victoria Canal or at the USGS station at Bacon Island was 250 to 500 uS/cm in 2010. The EC in Old River at Union (brown line) was 500 to 1,000 uS/cm from January through March, when the SJR pulse flow reduced the EC to 250 uS/cm in April, May, and June. The Middle River EC at Tracy Boulevard was similar to the downstream EC (Victoria Canal or Bacon Island) in January and from May through August (100-200 uS/cm higher), suggesting an upstream flow or tidal mixing with the downstream portion of Middle River. The Tracy Boulevard EC was similar to the Old River at Union EC in February, March, and September-November when the barrier was not installed, suggesting downstream flow in this portion of Middle River.



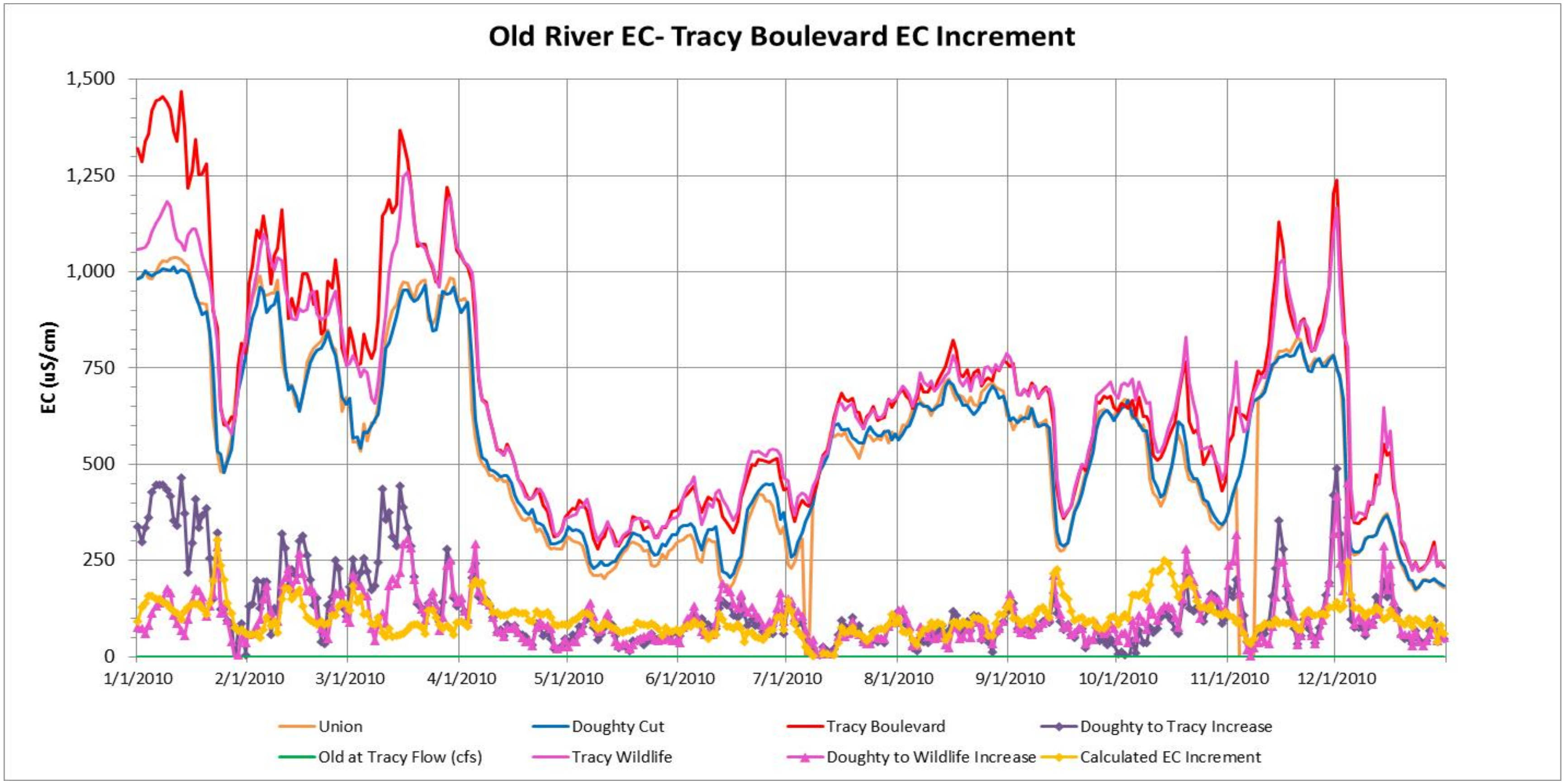
The Grant Line Canal EC at Doughty Cut and at Tracy Boulevard followed the SJR EC pattern that was controlled by SJR flow (EC dilution effect). The Grant Line Canal EC at the western end (green line) was usually less than the EC at Doughty Cut and at Tracy Boulevard because of the high tidal flows at the downstream end of Grant Line Canal. The water from Victoria Canal and from Old River at Highway 4 was tidally mixed into Grant Line Canal during flood tides. The salinity (EC) in Victoria Canal and in Old River at Highway 4 was influenced by seawater intrusion into the lower SJR during periods of low Delta outflow (January and September-November) and also controlled the EC at the Clifton Court Forebay (CCF) and at the DMC intake.



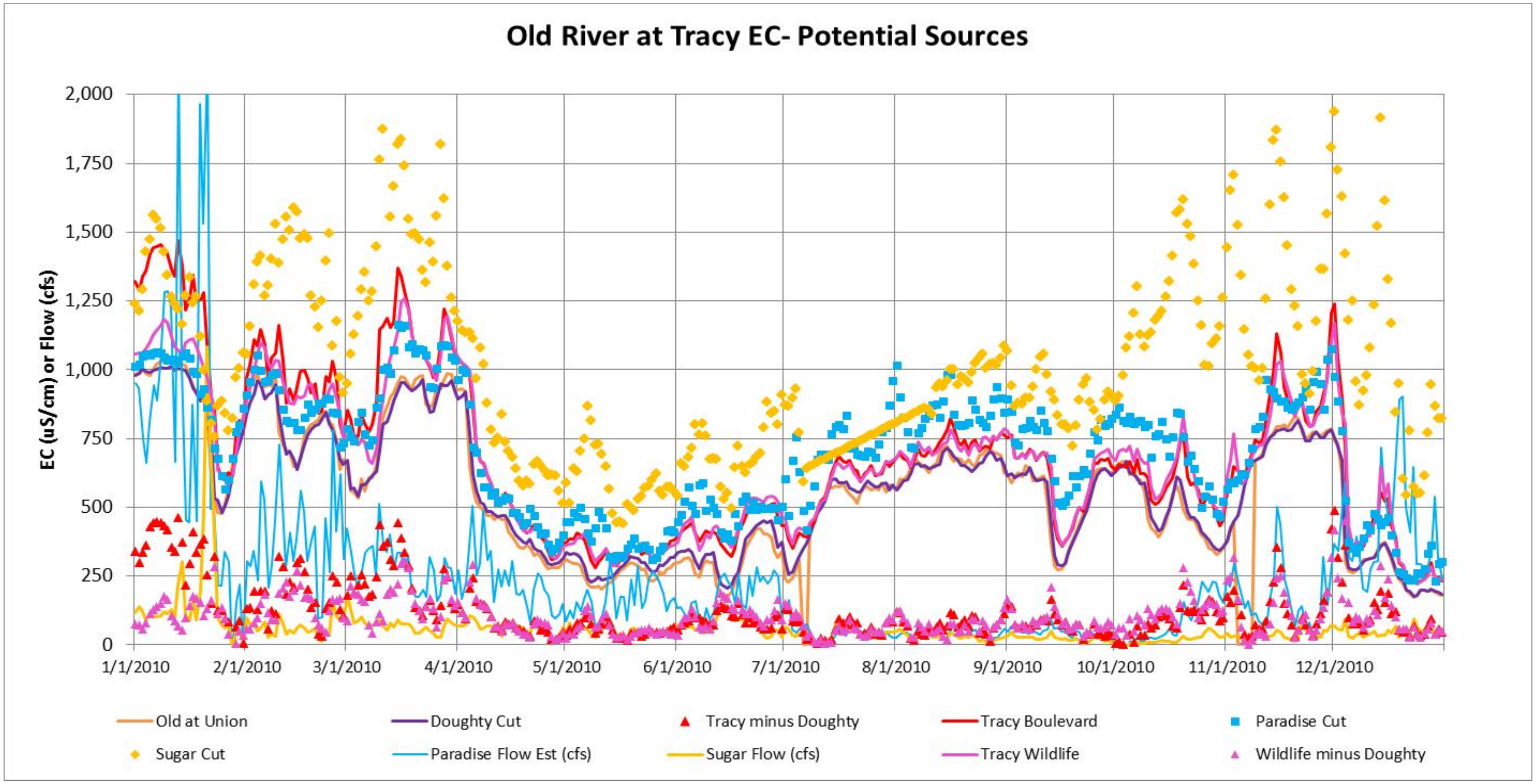
The San Joaquin River at Vernalis EC Objective is 700 uS/cm from April through August and is 1,000 uS/cm from September through March (30-day running average). The south Delta EC objectives are the same as the Vernalis EC objectives at the three compliance locations: SJR at Brandt Bridge, Old River at Union, and Old River at Tracy Boulevard. The EC at Vernalis and at Brandt Bridge and at Union stations are generally similar; however, the Old River at Tracy Boulevard EC was often 125 uS/cm higher than the Old at Union EC, located 7 miles upstream. There appears to be a major source of higher EC water in the vicinity of Old River at Tracy Boulevard. The Old at Tracy Wildlife EC generally confirms the Old at Tracy Boulevard EC; however the July 2009-January 2010 Tracy Boulevard EC was 250 uS/cm higher (data error). The higher EC at Tracy Boulevard and Tracy Wildlife was measured both during periods with the temporary barriers installed (June-September 2010) and during periods without barriers (January-May and October-December 2010).



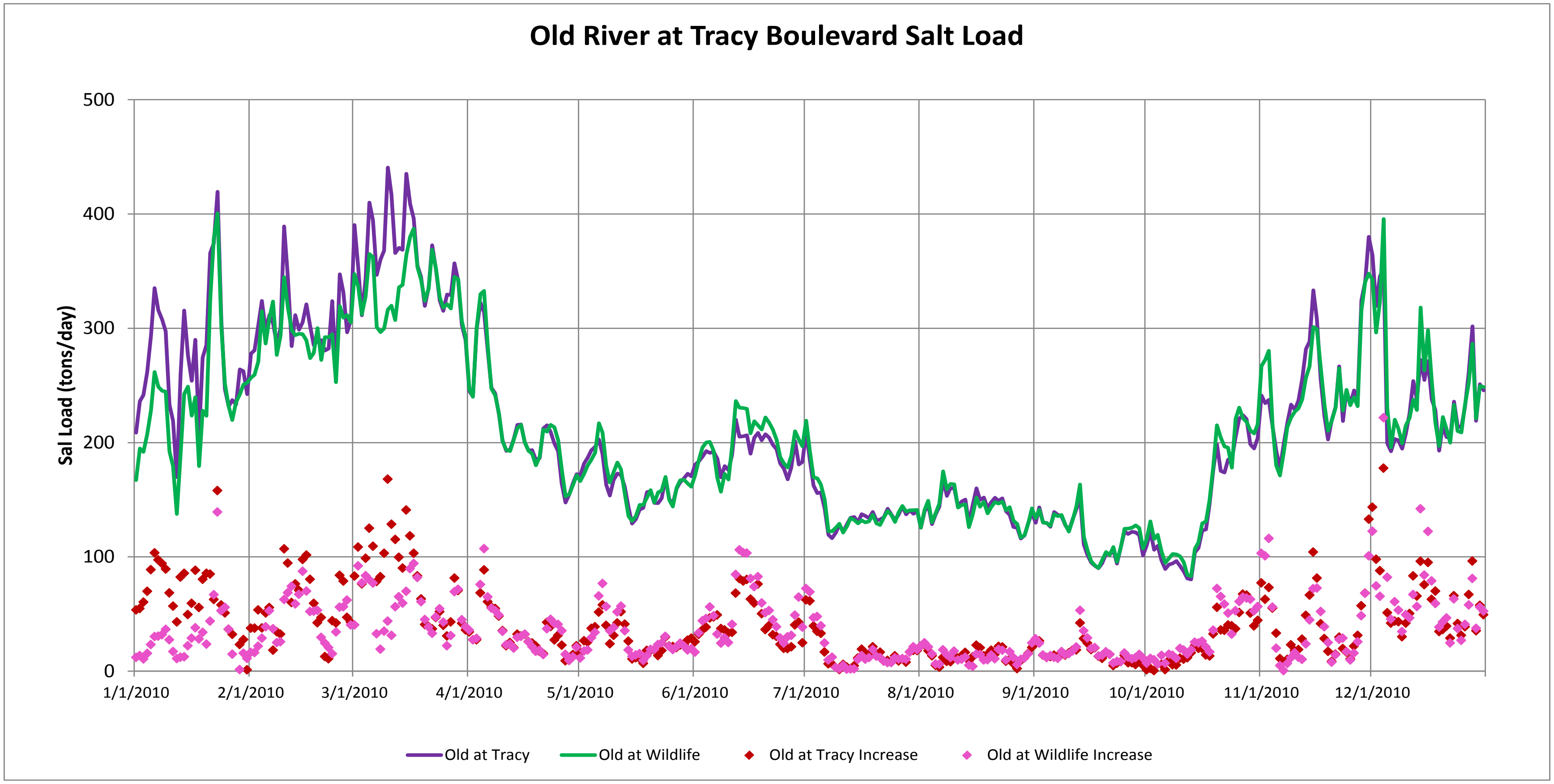
The measured daily EC increment between any two locations along Old River can be approximated with a specified source discharge (cfs) and a specified source EC. The expected EC increment between Union (gold line) and Doughty Cut (blue line) caused by the Tracy Wastewater Discharge (green line) was calculated as: EC increment (uS/cm) = (Tracy Discharge EC – River EC) x Tracy Discharge / (River Flow + Tracy Discharge). The measured daily Old River EC increments between Union and Doughty (purple line) were compared to the daily calculated Tracy Discharge EC increments for the daily Tracy Discharge and EC measurements. The measured and calculated EC increments were relatively small in 2010 because the Old River flows were greater than 1,000 cfs (average excess salt load of 14 tons/day and average EC increment of 4 uS/cm). The Union EC and the Doughty Cut EC were generally the same; the EC increment fluctuated and was often negative, indicating the difficulty of measuring small changes in EC along a river.



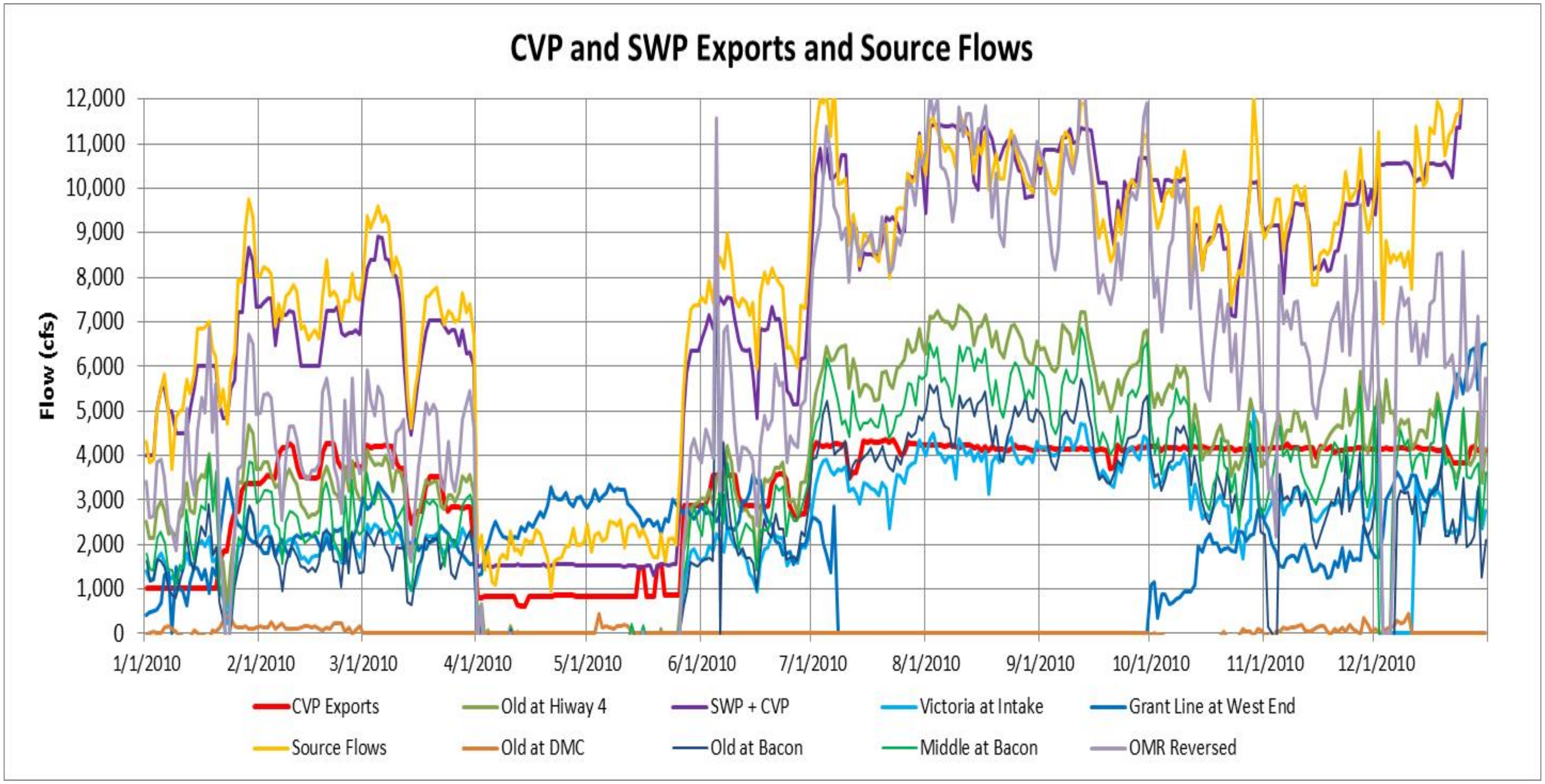
The measured Old River EC increments between Doughty Cut and Tracy Boulevard (purple diamonds) were compared with the calculated EC increments from Paradise Cut and Sugar Cut (gold diamonds), assuming the Old River at Tracy Boulevard flow was 10% of the head of Old River flow. The Old River at Tracy Wildlife EC (pink line) was much lower that the EC at Tracy Boulevard in January and March and is considered to be more accurate. The calculated EC increments depend on the assumed average Old River flow at Tracy Boulevard, and on the tidal movement of salt from Paradise Cut and Sugar Cut. The measured EC increments were highest in January-March and in November-December. The calculated EC increments of 50-200 uS/cm were similar to the measured EC increments and were relatively constant in 2010 (100 uS/cm average), with head of Old River flows of greater than 1,000 cfs.



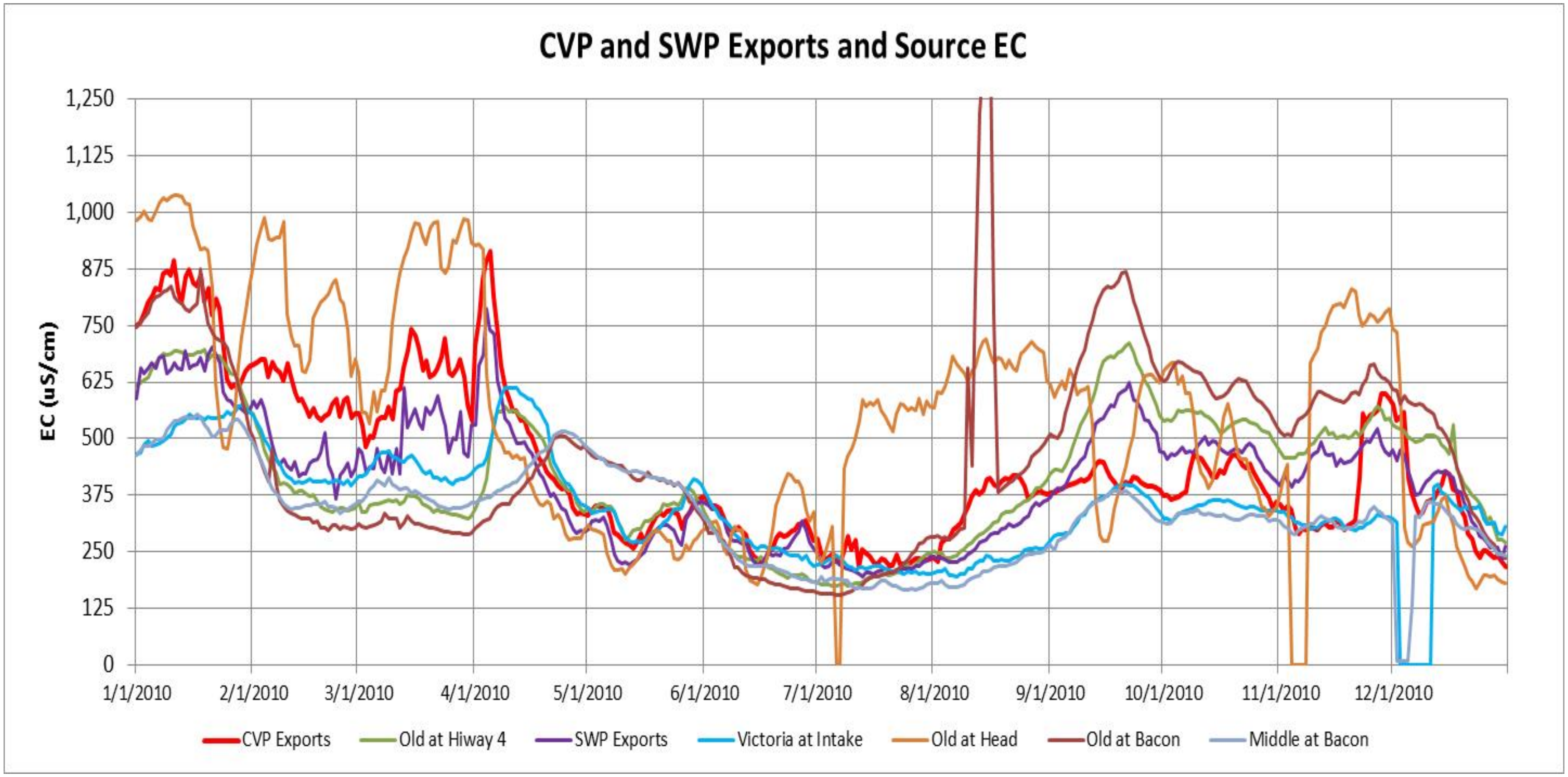
The salt source that would match the measured daily EC increment between Doughty Cut and Tracy Boulevard (or Tracy Wildlife) can be calculated as: EC increment (uS/cm) = (Source EC – River EC) x Source Discharge / (River Flow + Source Discharge). The daily Old River at Tracy Boulevard EC increments (red triangles) and Tracy Wildlife (pink triangles) were matched with the daily average Paradise Cut EC (blue squares) or Sugar Cut EC (gold diamonds) to estimate the "source discharge" for Paradise Cut (blue line) and Sugar Cut (gold line). A larger source discharge is indicated when the EC increment is large and when the flow in Old River at Tracy Boulevard is higher. If Paradise Cut were the only salt source, the estimated salt discharge would have been greater than 100 cfs (a very high discharge) for several months, because the average Paradise EC was not much higher than the Old River at Tracy EC. If Sugar Cut were the only salt source, the calculated source discharge (gold line) would be about 25 cfs to 50 cfs (moderately high).



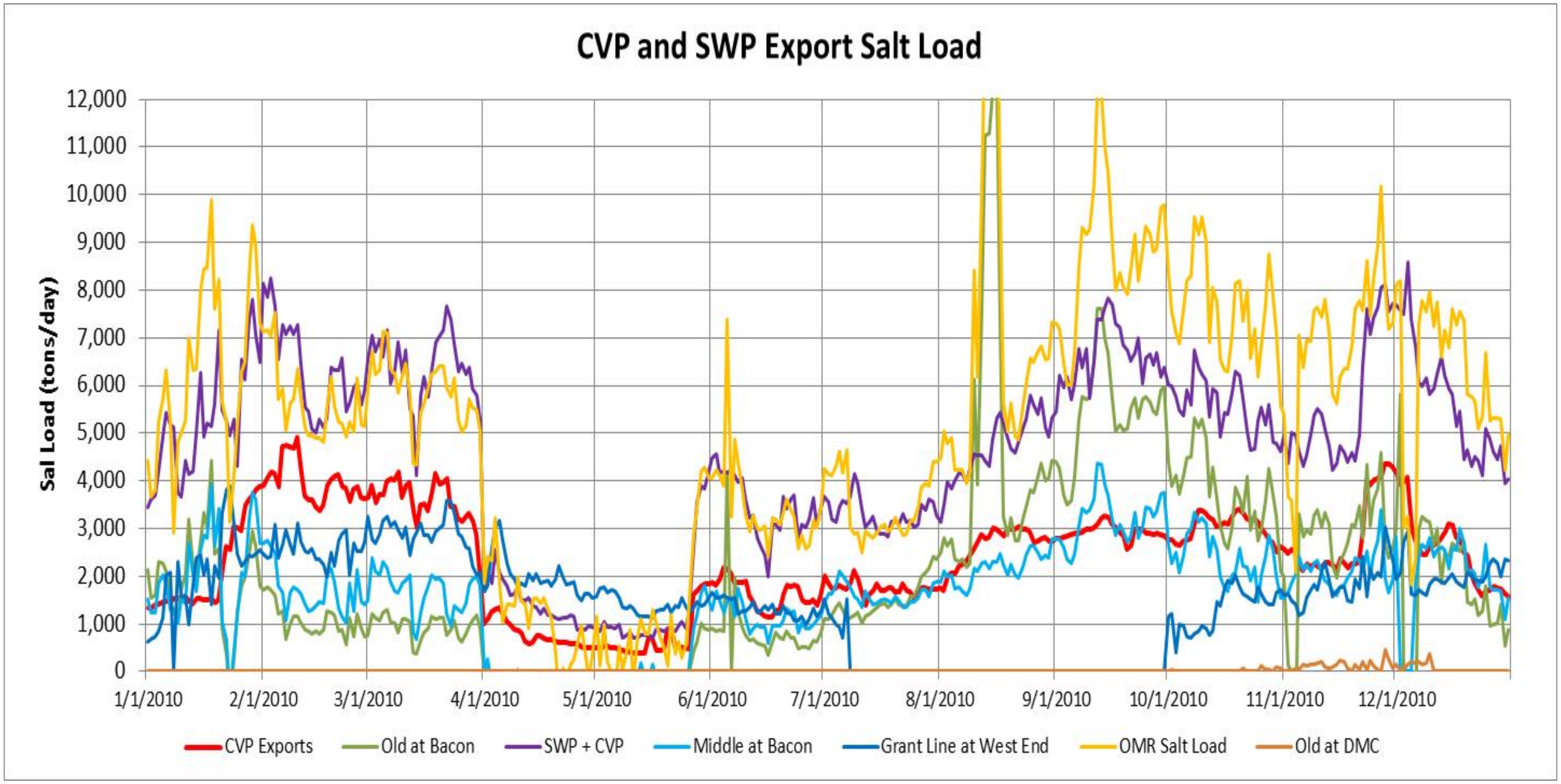
The measured salt loads in Old River at Tracy Boulevard and Tracy Wildlife (purple and green lines, respectively) were calculated from the Old River EC at these locations and estimated flow at Tracy Boulevard (the Tracy Boulevard flow was not measured in 2010, but was estimated as 10% of the head of Old River flow). The salt load increments between Doughty Cut and Tracy Boulevard and Doughty Cut and Tracy Wildlife (red and pink diamonds, respectively) were calculated from the EC increment and the Old River flow at Tracy Boulevard. The measured salt load increments for Tracy Boulevard and Tracy Wildlife were 10-50 tons/day most of the year, but were sometimes 50-100 tons/day. The EC at Tracy Boulevard and the EC at Tracy Wildlife were very similar in 2010 (replicate EC stations), so the salt load increments calculated for these two locations were about the same, except for during the very beginning of the year when the Tracy Boulevard EC was significantly higher than the Tracy Wildlife EC.



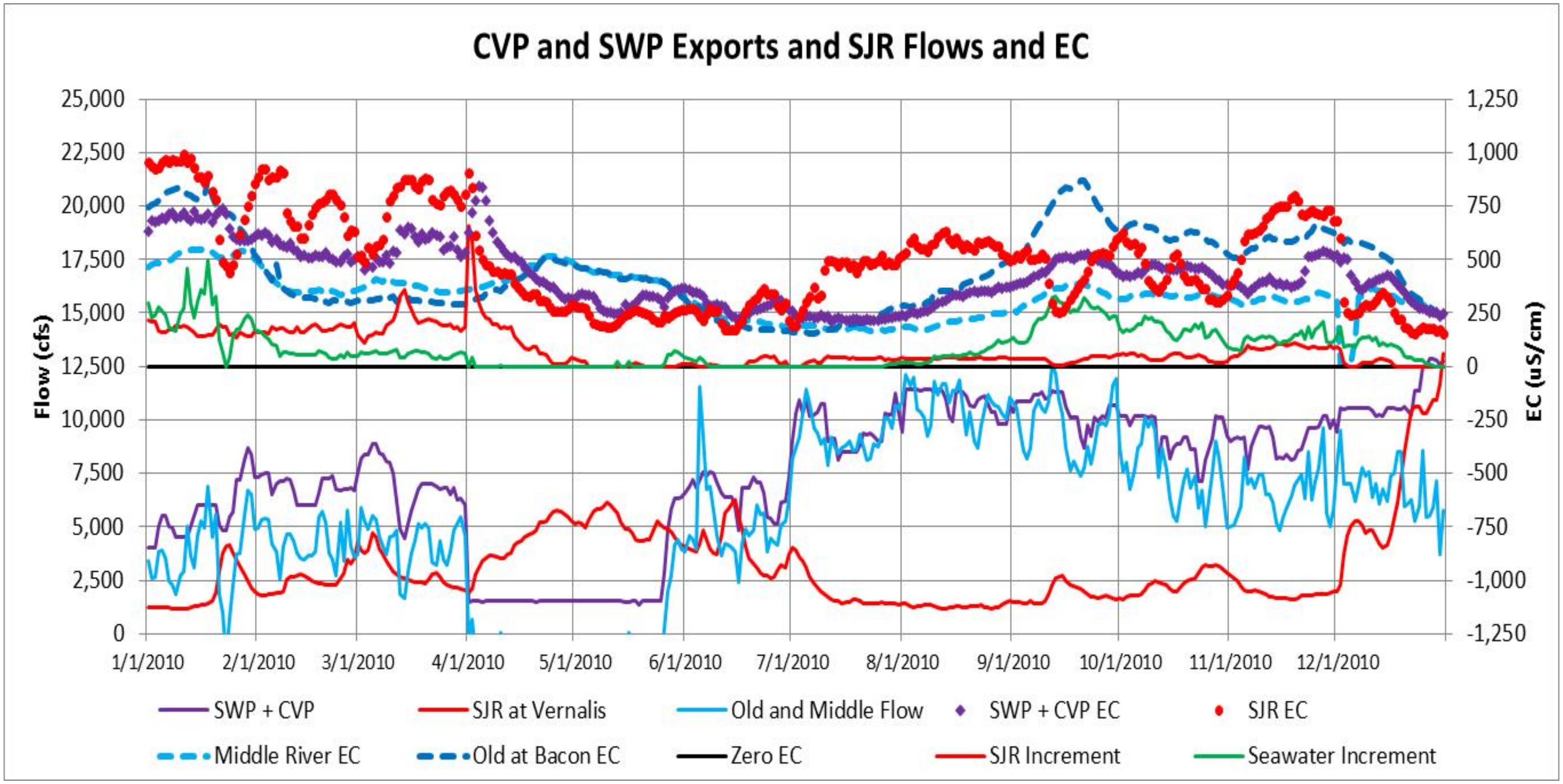
The average tidal flows in the south Delta channels (Old at Highway 4 and Victoria, gold line) provided an accurate match with the CVP and SWP export flows. The Old River at Highway 4 flow was the largest source of water for CVP and SWP exports; when pumping was near the maximum (permitted) of about 11,000 cfs, the Old River at Highway 4 flow was about 7,000 cfs and the Victoria Canal flow (from Middle River) was about 4,000 cfs. The Old River at Bacon flow is slightly lower than the flow at Highway 4 during periods of high pumping; some water (500 cfs) from Middle River is diverted to Old River through Railroad Cut (between Bacon and Woodward Islands) and Woodward Canal (between Woodward Island and Victoria Island). During periods when all four flow stations were operating, the match with CVP and SWP exports (purple line) was very accurate (within 10%).



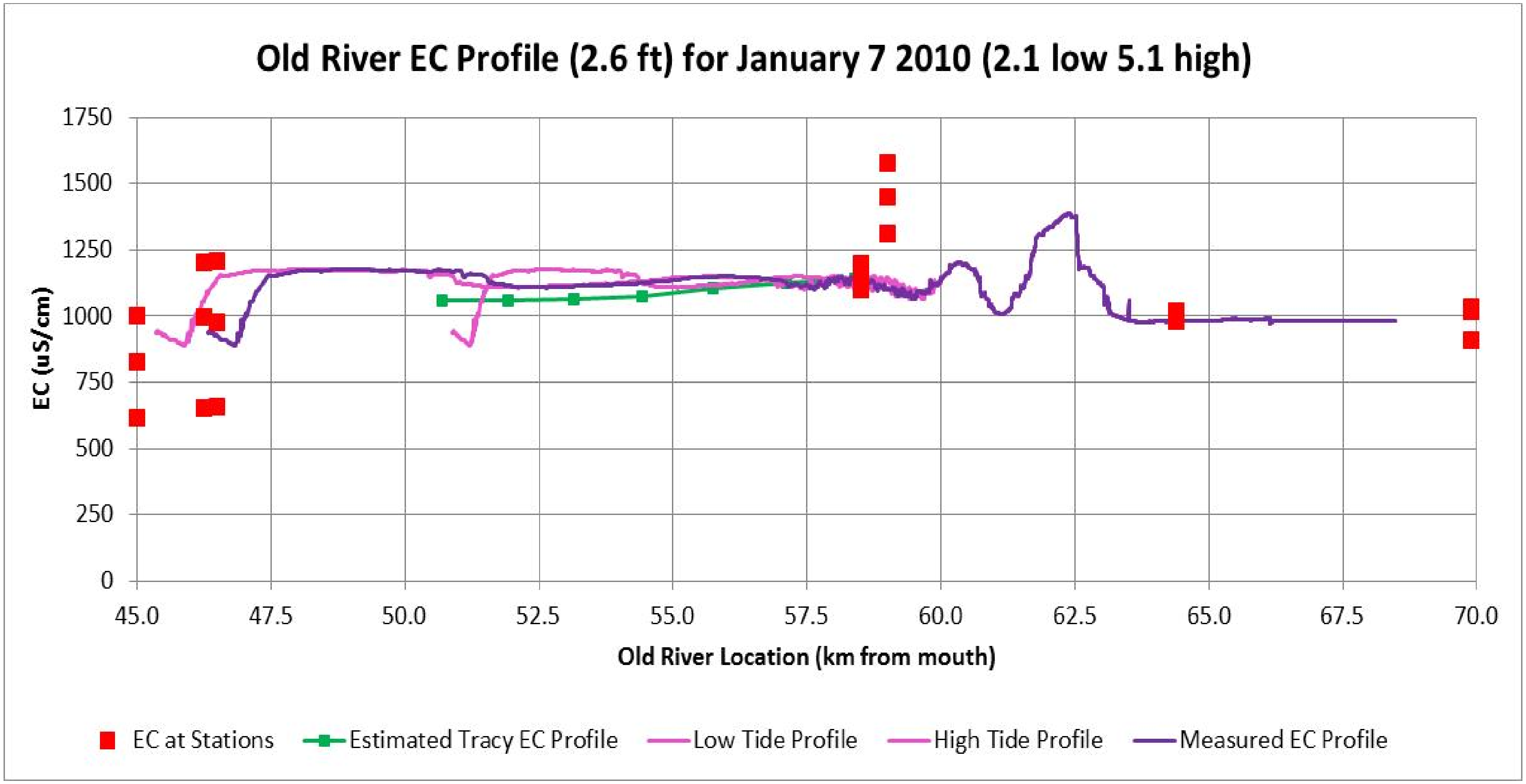
The salinity (EC) of the CVP and SWP exports are slightly different during most of the year. The CVP intake is located just 1 mile south of the SWP intake, but Grant Line Canal enters Old River between the two intakes. The EC in Old River at the head (light brown line) was the highest and the EC in the CVP exports was often higher than the EC in the SWP exports. The EC in Old River at Bacon Island (dark brown line) was higher than the EC in Victoria Canal (light blue line) in January and in September-November because of seawater intrusion into Old River during periods of low Delta outflow.



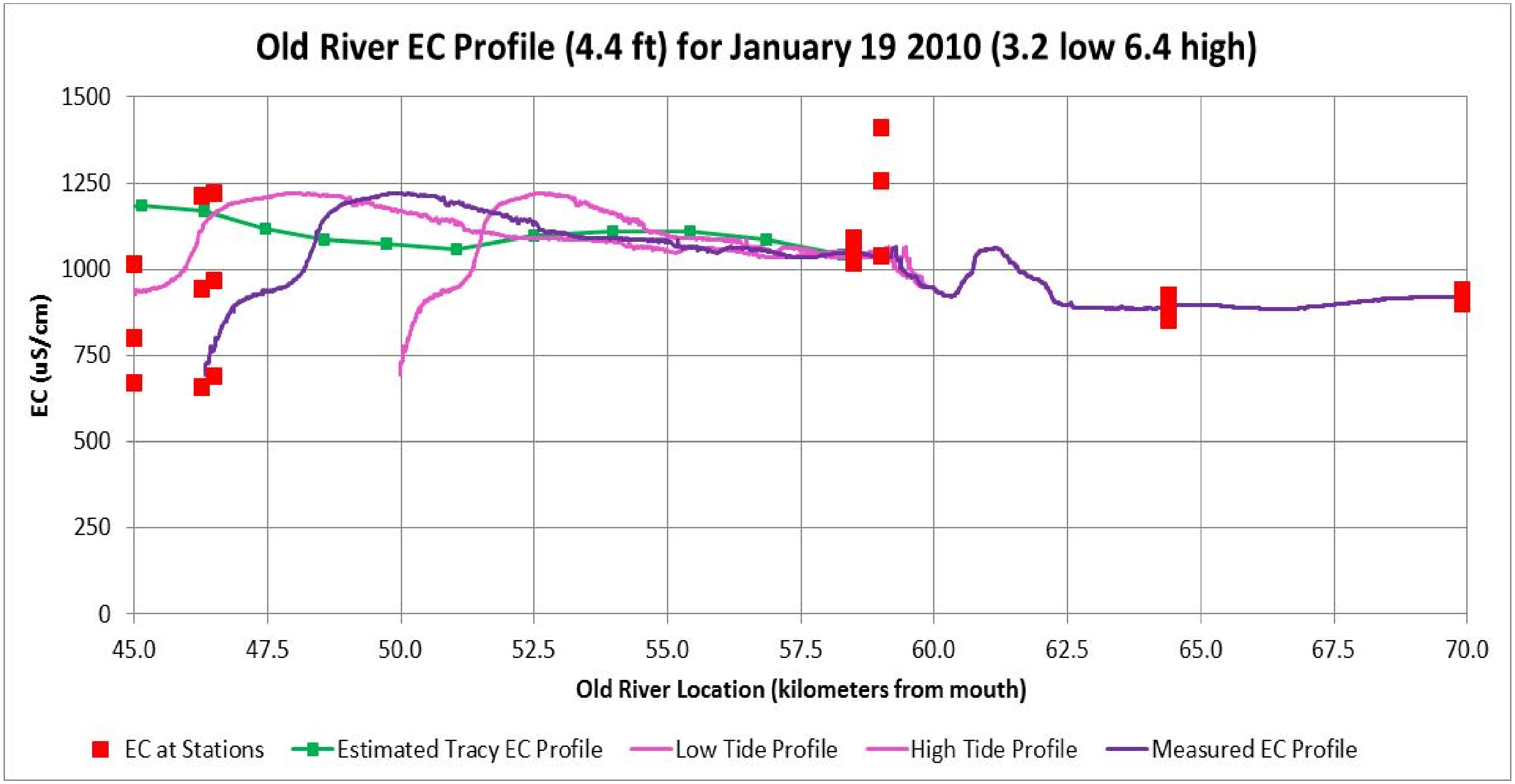
The salt load at the CVP and SWP exports increases with pumping flow and with salinity (EC). The net tidal flows and the daily average EC values were used to calculate the CVP and combined CVP and SWP salt loads (tons/day) as well as the source salt loads (gold line) from Old River at Bacon, Middle River at Bacon, Grant Line Canal at the west end, and Old River at the DMC barrier. The match between the source salt loads and the exported salt loads was generally within 10%; but a much higher source salt load was calculated for the September-November period.



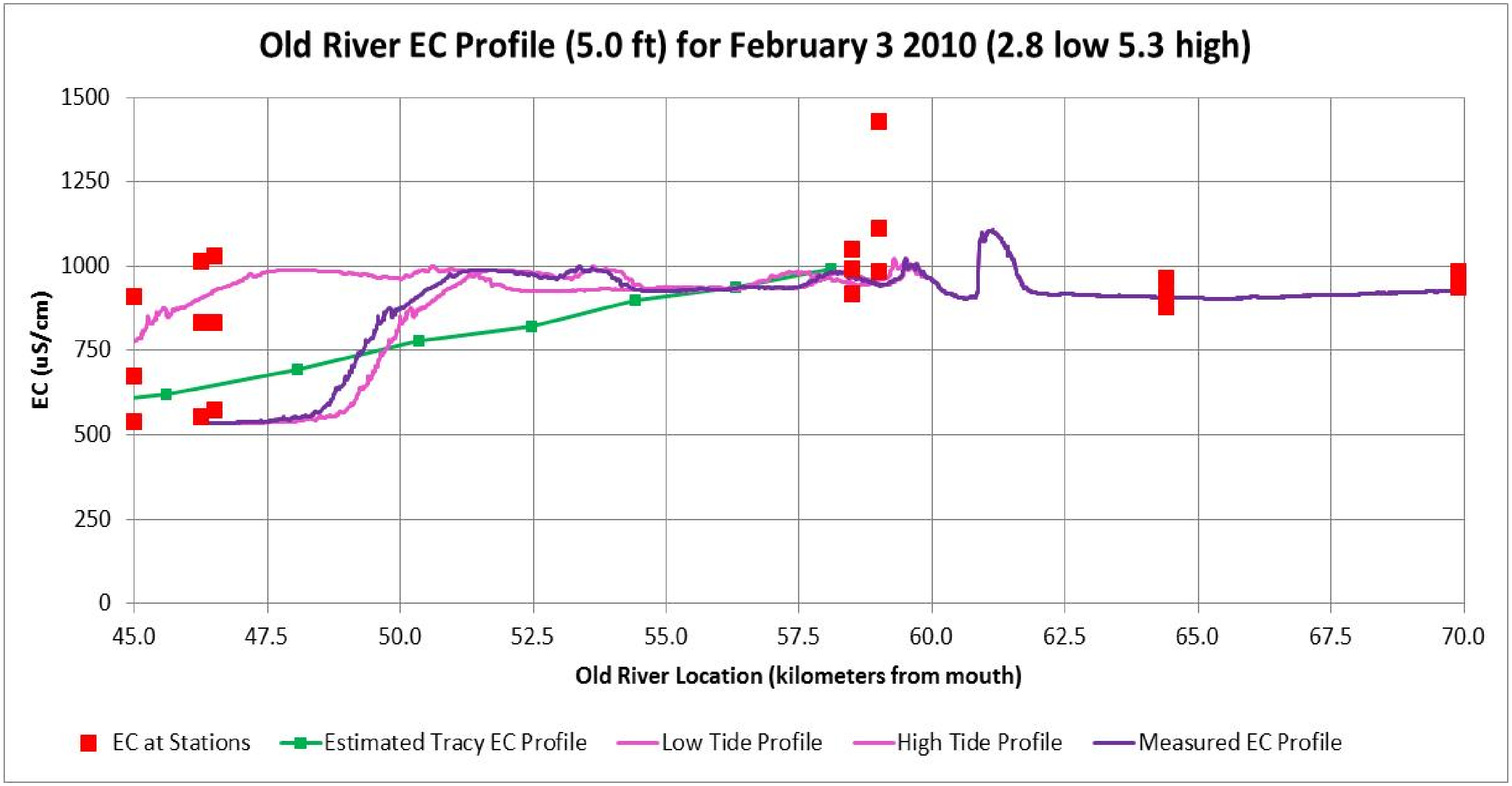
The water sources for the SWP and CVP exports can be estimated from the SJR flow at Vernalis and the Old and Middle River reversed flows. The salt sources in the exports can be estimated from the EC increments, with 250 µS/cm assumed from the Sacramento River water. All of the SJR flow was exported except in April and May of 2010. The SJR EC increment is calculated as the SJR flow fraction (SJR flow/exports) times the SJR EC (minus 250 µS/cm). The seawater intrusion EC increment is calculated as the Old and Middle River flow fraction times the average Old and Middle River EC (minus 250 µS/cm). Seawater intrusion was greatest in January and September-November. For 2010, the average (flow-weighted) export EC was 410 µS/cm; the Sacramento River EC increment was 250 µS/cm (61%), the SJR EC increment was 80 µS/cm (19%), and the seawater EC increment was 100 µS/cm (24%).



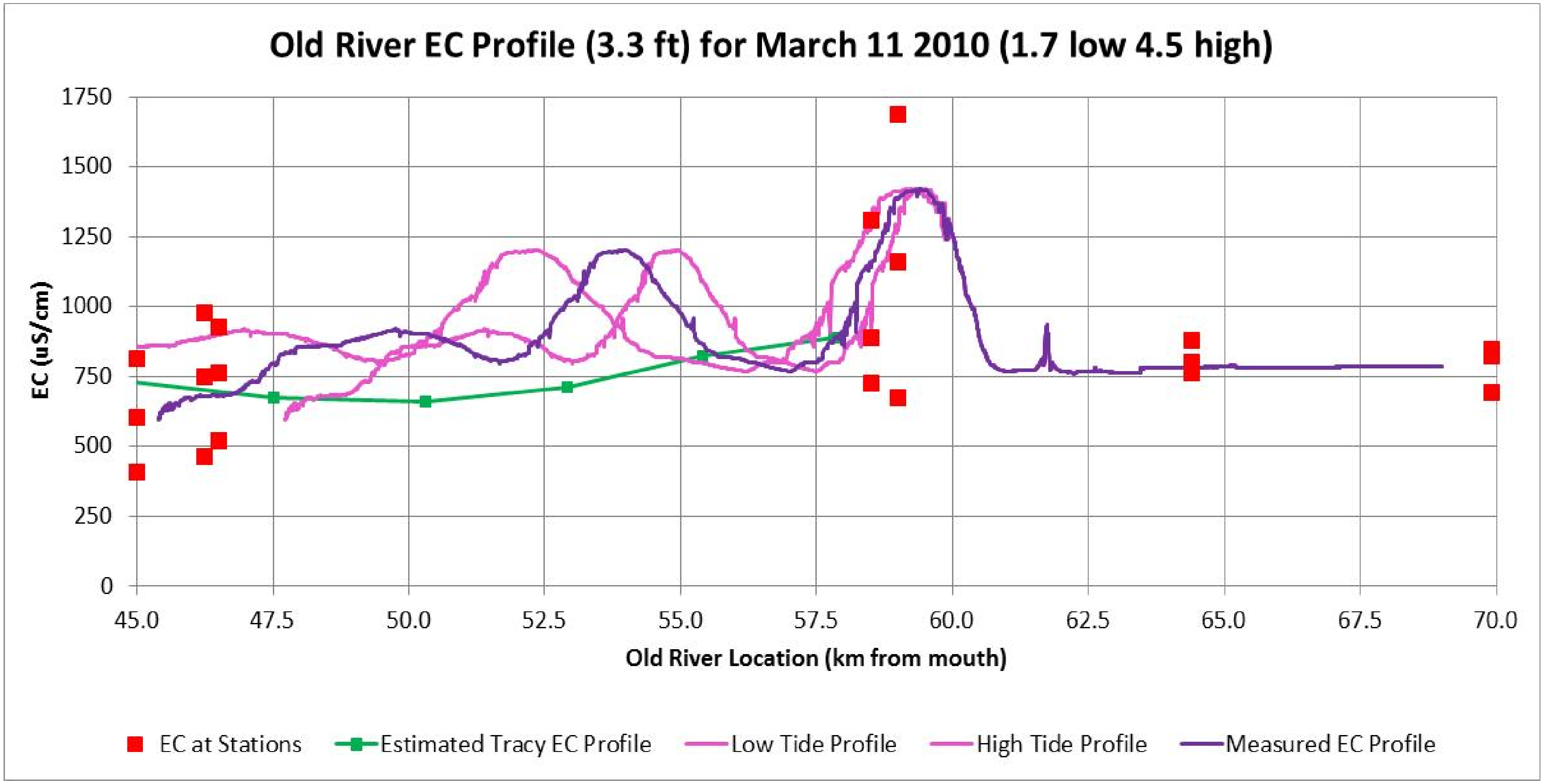
The boat-survey measured Old River EC Profile (purple line) on January 7, 2010 from the DMC barrier (46.5 km) to the head of Middle River (70 km) indicated two salt pulses between Doughty Cut (64 km) and Tracy Boulevard (59 km), with elevated EC downstream to the DMC barrier. The tide elevation was 2.6 feet when the EC profile was measured, the low tide was 2.1 feet and the high tide was 5.1 feet, so the high tide EC profile (pink line) was shifted about 4 km upstream of the measured EC profile. The measured EC at each of the EC stations matched the EC profile, except the measured EC at Tracy Boulevard was more than 250 uS/cm higher than the Tracy Wildlife EC and the profile EC. Higher EC at Tracy Boulevard than at Tracy Wildlife in the second half of 2009 suggests that the Tracy Boulevard EC was reading 250 uS/cm high. The estimated EC profile (green line) was calculated assuming the Tracy Wildlife average EC from previous days was moved downstream with the estimated Old River flow (10% of the head of Old River flow).



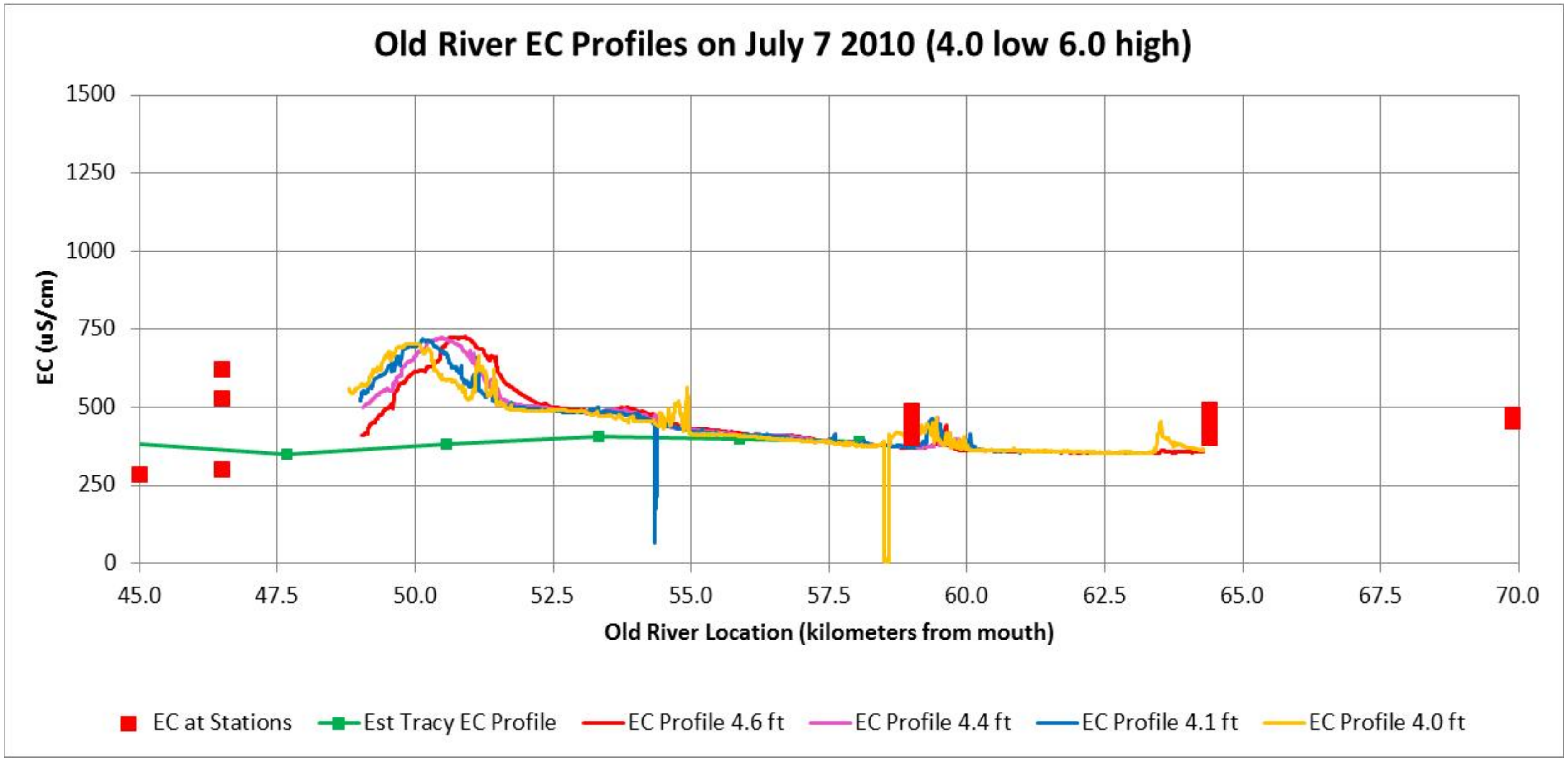
The boat-survey measured Old River EC Profile (purple line) on January 19, 2010 from the DMC barrier to the head of Middle River (70 km) indicated one salt pulse between Doughty Cut (64 km) and Tracy Boulevard (59 km), with elevated EC downstream to the DMC barrier (46.5 km). The tide elevation was 4.4 feet when the EC profile was measured, the low tide was 3.2 feet and the high tide was 6.4 feet, so the high tide and low tide EC profiles were shifted a total of 6 km from the measured EC profile (2 km for each foot of tide elevation change). The measured EC at each of the EC stations matched the EC profile, except the measured EC at Tracy Boulevard was about 250 uS/cm higher than the Tracy Wildlife EC and the profile EC. The estimated EC profile (green line) was calculated assuming the Tracy Wildlife average EC from previous days was moved downstream with the estimated Old River flow (10% of the head of Old River flow). Measured profile EC higher than the estimated EC profile (48.5 to 52.5 km) indicates additional salt sources downstream of Tracy Boulevard.



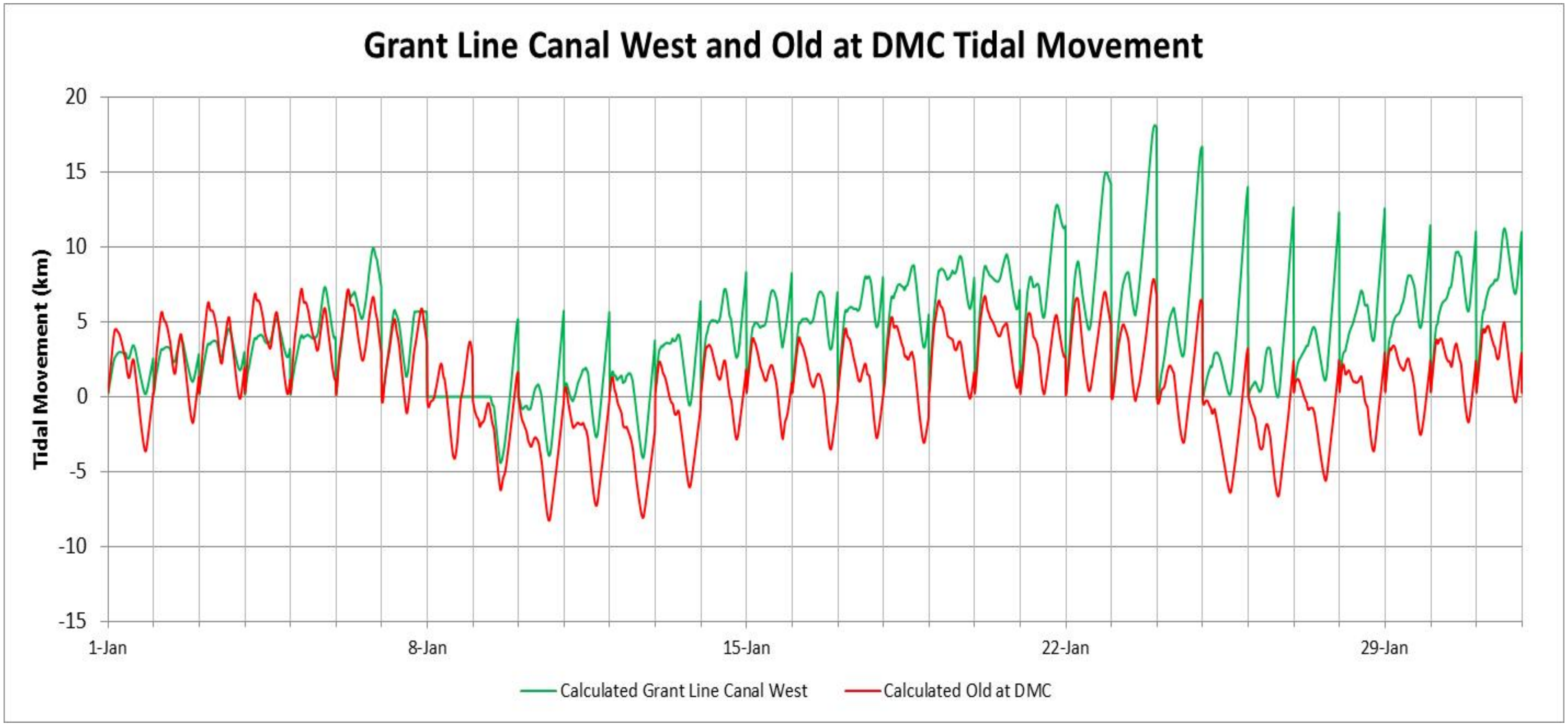
The boat-survey measured Old River EC Profile (purple line) on February 3, 2010 from the DMC barrier to the head of Middle River (70 km) indicated one salt pulse between Doughty Cut (64 km) and Tracy Boulevard (59 km), with elevated EC downstream to the DMC barrier (46.5 km). The tide elevation was 5.0 feet when the EC profile was measured, the low tide was 2.8 feet and the high tide was 5.3 feet, so the low tide EC profile was shifted downstream about 4 km from the measured EC profile. The measured EC at each of the EC stations matched the EC profile, except the EC at Tracy Boulevard was higher than the Tracy Wildlife EC and the profile EC. The maximum EC measured at the downstream stations indicate that Old River water from upstream reaches these stations at low tide. The estimated EC profile (green line) was calculated assuming the Tracy Wildlife average EC from previous days was moved downstream with the estimated Old River flow (10% of the head of Old River flow).



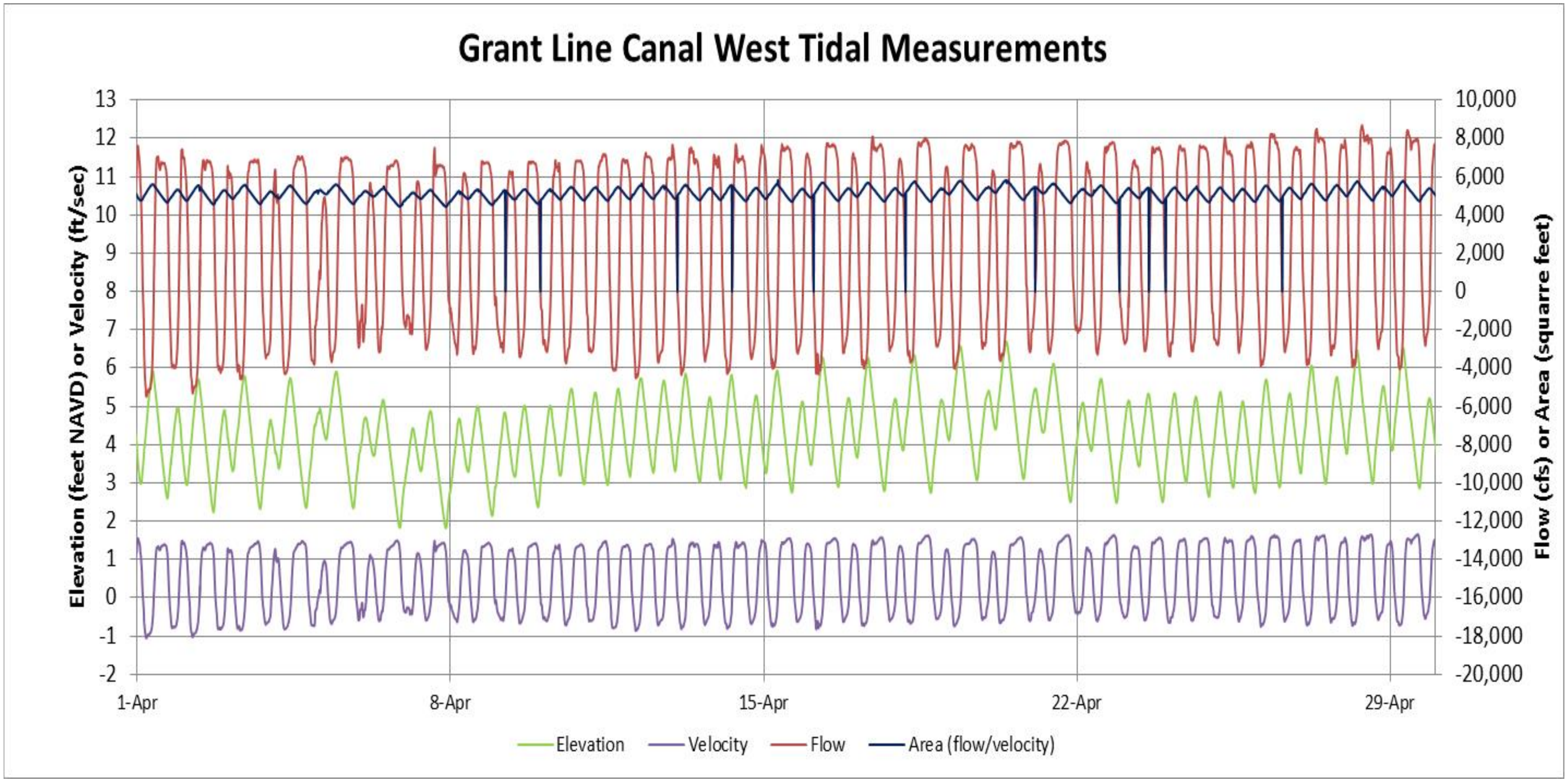
The boat-survey measured Old River EC Profile (purple line) on March 11, 2010 from the DMC barrier to the head of Middle River (70 km) indicated one very large salt pulse at Tracy Boulevard (59 km), and another large salt pulse downstream of Tracy Boulevard. The tide elevation was 5.0 feet when the EC profile was measured, the low tide was 2.8 feet and the high tide was 5.3 feet, so the low tide EC profile was shifted downstream about 3 km from the measured EC profile (50 km to 47 km). The EC bulge near Tracy Boulevard was not shifted by much because the tidal flows at Tracy Boulevard are assumed to be small; the EC bulge between Tracy and the DMC stations was shifted about 2 km (half the tidal flows). The measured EC at each of the stations matched the EC profile, except the EC at Tracy Boulevard was higher than the Tracy Wildlife EC and the profile EC. The estimated EC profile (green line) indicates that the Old at Tracy Boulevard EC had been lower on previous days. The green boxes indicate the secondary EC peak (5 km downstream) was about 2 days of flow downstream (relatively high flow).



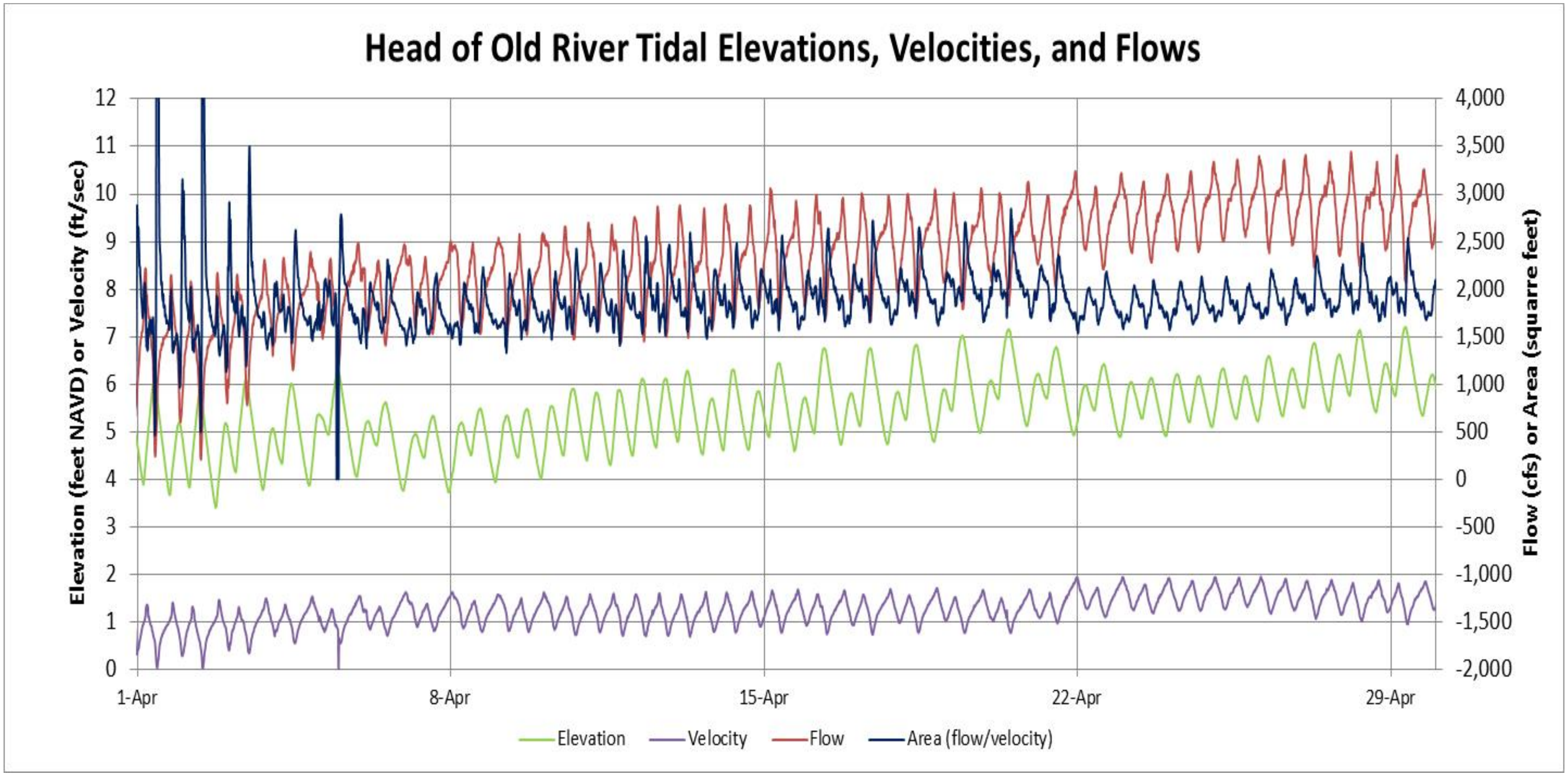
Old River EC Profiles were measured on July 7 (barriers installed with flap gates) at four different elevations, starting at an elevation of 4.6 feet and ending at an elevation of 4.0 feet. The Old River EC profile was less than 400 uS/cm at upstream of Tracy Boulevard (59 km) and matched the measured EC at Union, Doughty, and Tracy Boulevard. The low SJR EC was the result of moderately high SJR flow (4,000 cfs). A moderate salt bulge in the EC Profile was located upstream of Wicklund Cut at 51 km. As the tide elevation decreased from 4.6 feet to 4.0 feet there was a slight downstream movement (1 km) of the salt bulge, although the DMC barrier weir crest is about 4.4 feet, so most of the ebb tide flow was expected to move upstream to Grant Line Canal. There may be some leakage through the rock barrier.



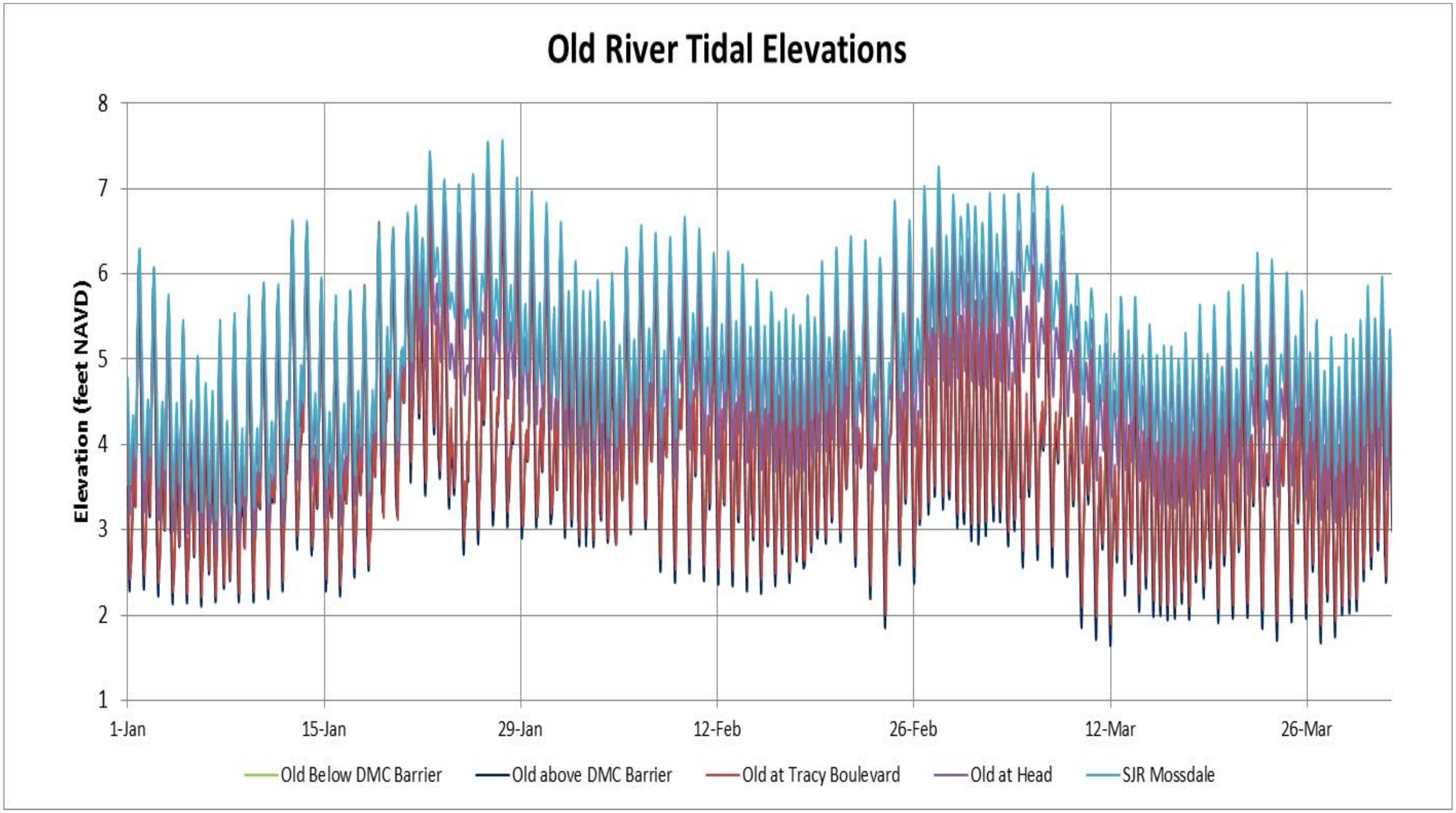
The tidal movement was calculated for each day using the velocity data. The velocity (ft/sec) x 900 seconds / 3281 ft/km gives the movement for each 15-minute period. The cumulative movement through the tidal cycle shows the downstream (positive) and upstream (negative) movement. The upstream movement for each day at the DMC station (red line) can be identified as the difference between the maximum movement value and the minimum movement value. Because the DMC intake is diverting Old River water that moves downstream of the intake on ebb-tide, the salinity gradient between upstream Old River (high EC) and downstream Old River (low EC) is always located just upstream of the DMC intake at low tide. The observed EC gradient location depends on the upstream movement from the previous low tide (which may have been on the previous day). For example, the Old River EC profile measured on January 7 had an upstream movement of about 5.5 km; and the Old River EC profile measured on January 19 had an upstream movement of about 6 km.



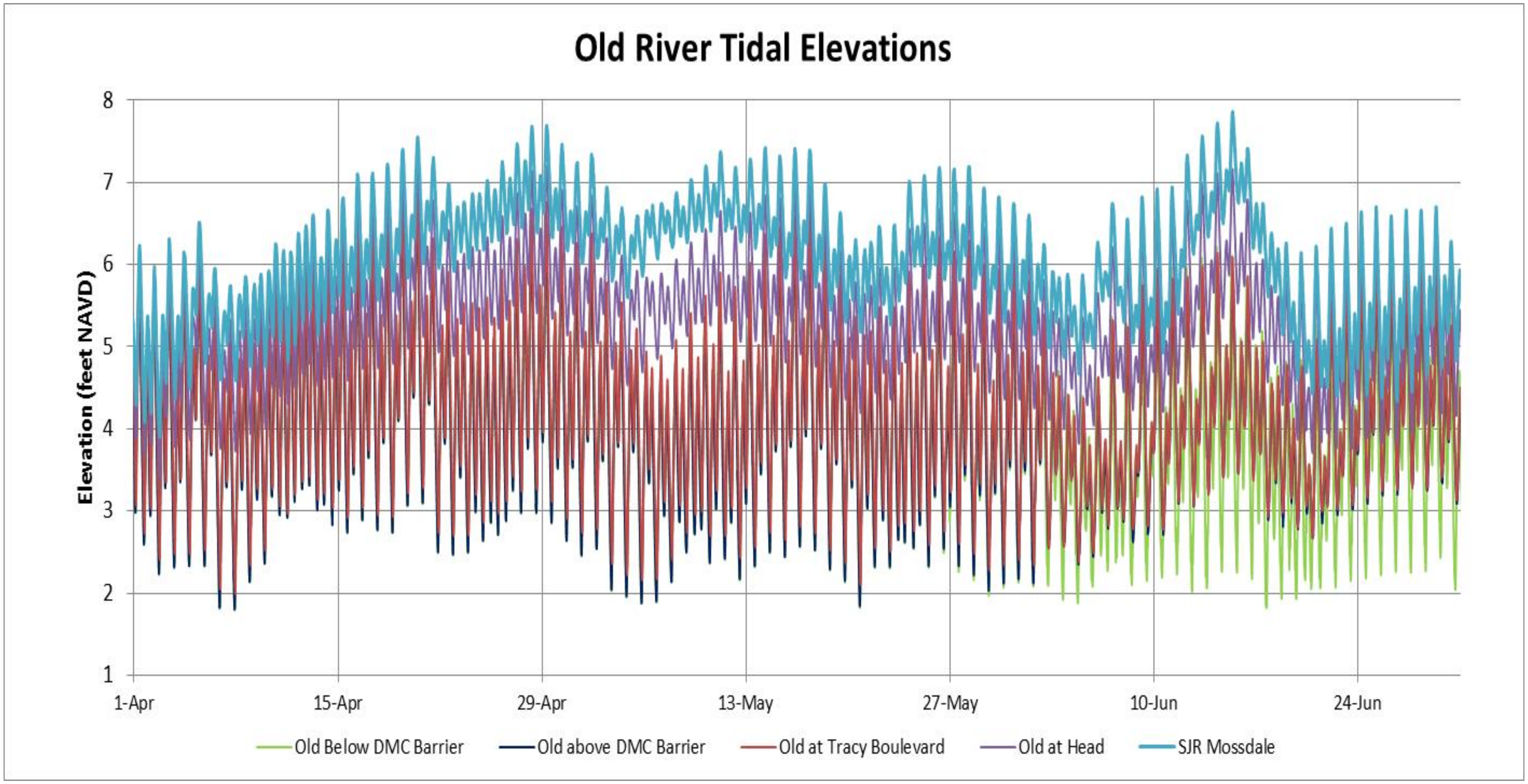
The tidal flow measurements in the south Delta channels are collected with a 15-minute interval. The primary measurements are the water elevations (green line, left scale) and the tidal velocity (purple line, left scale). The cross-section area, which is measured independently as a function of the water elevation, is multiplied by the velocity at the measurements station as part of the data processing. The fluctuation of the area with water elevation is shown on the graph (dark blue line, right scale). The Grant Line Canal cross-section area is about 5,000 ft^2 and varies about 10% between 2 feet and 6 feet. The tidal velocity is only about 1 ft/sec in Grant Line Canal, and the tidal flow fluctuates between about 5,000 cfs and -5,000 cfs during ebb-tide and flood-tide. The ebb-tide flow (positive) is higher than the flood-tide flow because of the net downstream flow from the head of Old River. The tidal measurements are generally quite accurate and consistent.



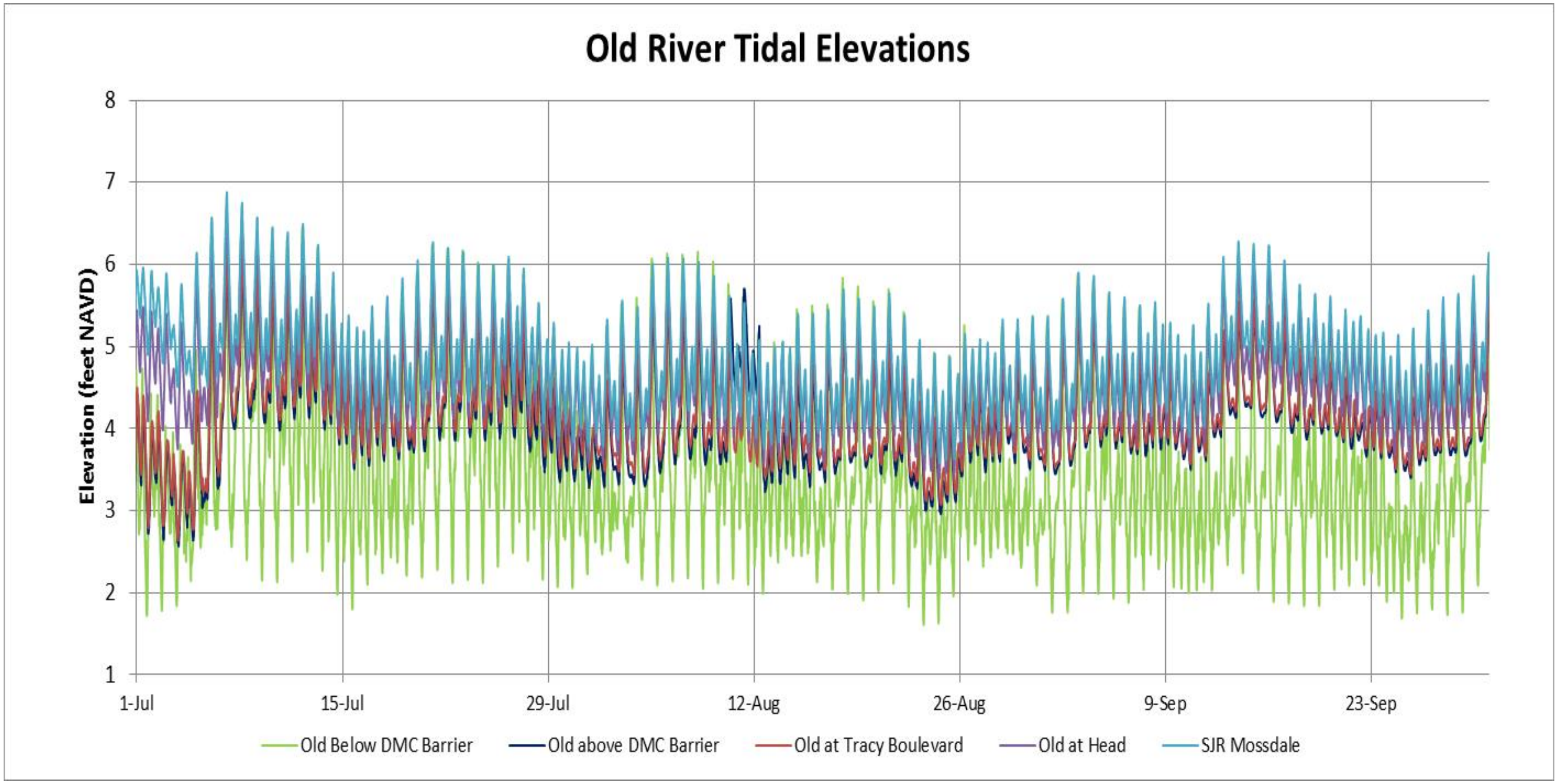
The head of Old River tidal flow measurements have a wider range of elevation and velocity than the Grant Line Canal measurements. The primary measurements are the water elevations (green line, left scale) and the tidal velocity (purple line, left scale). The cross-section area appears to fluctuate more than the elevation. The fluctuation of the area with water elevation is shown on the graph (dark blue line, right scale). The head of Old River cross-section area is about 1,500 ft^2 at low tide (4 feet) and increases to about 2,500 ft^2 at high tide (7 feet). The tidal velocity ranges from is often less than 1 ft/sec, and varies with the flow and the elevation. Tidal elevation measurements are relatively easy and reliable. Tidal velocity is much more difficult and tidal flow requires an accurate relationship between elevations and area.



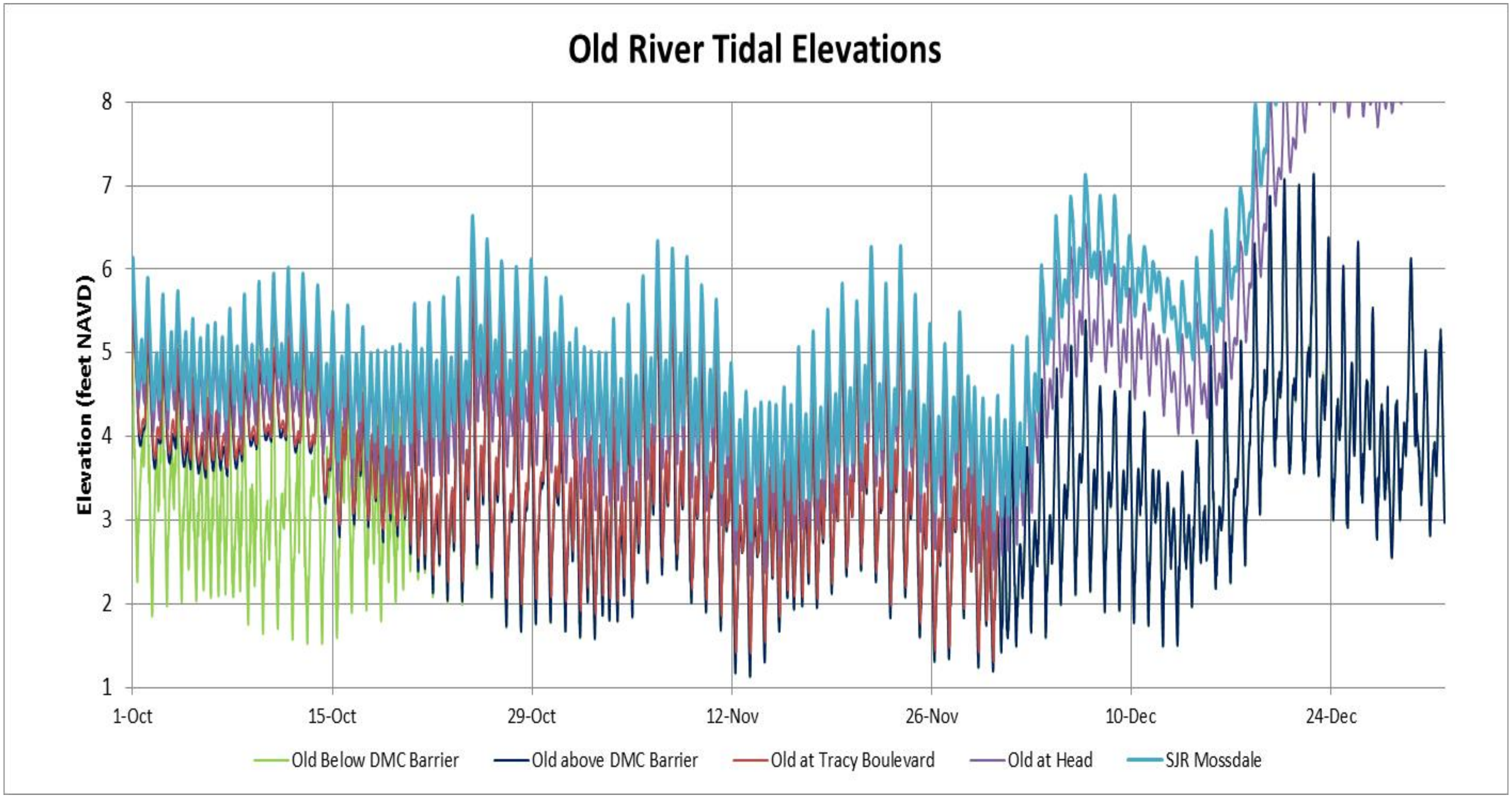
The tidal elevations in Old River were increased during periods of increased SJR flow in the January-March period, before the temporary barriers were installed. The spring-neap tidal cycle can be detected with a tidal range of 2 feet to 5 feet during neap tides and a tidal range of 2 feet to 6 feet during spring tides. High tide elevations of greater than 6 feet indicate higher SJR flows (>2,500 cfs). The graphs have a 14-day vertical grid, so there is a spring-neap cycle within each grid. The minimum elevations at Mossdale and at the head of Old River remain about 1-2 feet higher than the minimum elevations at the other Old River stations.



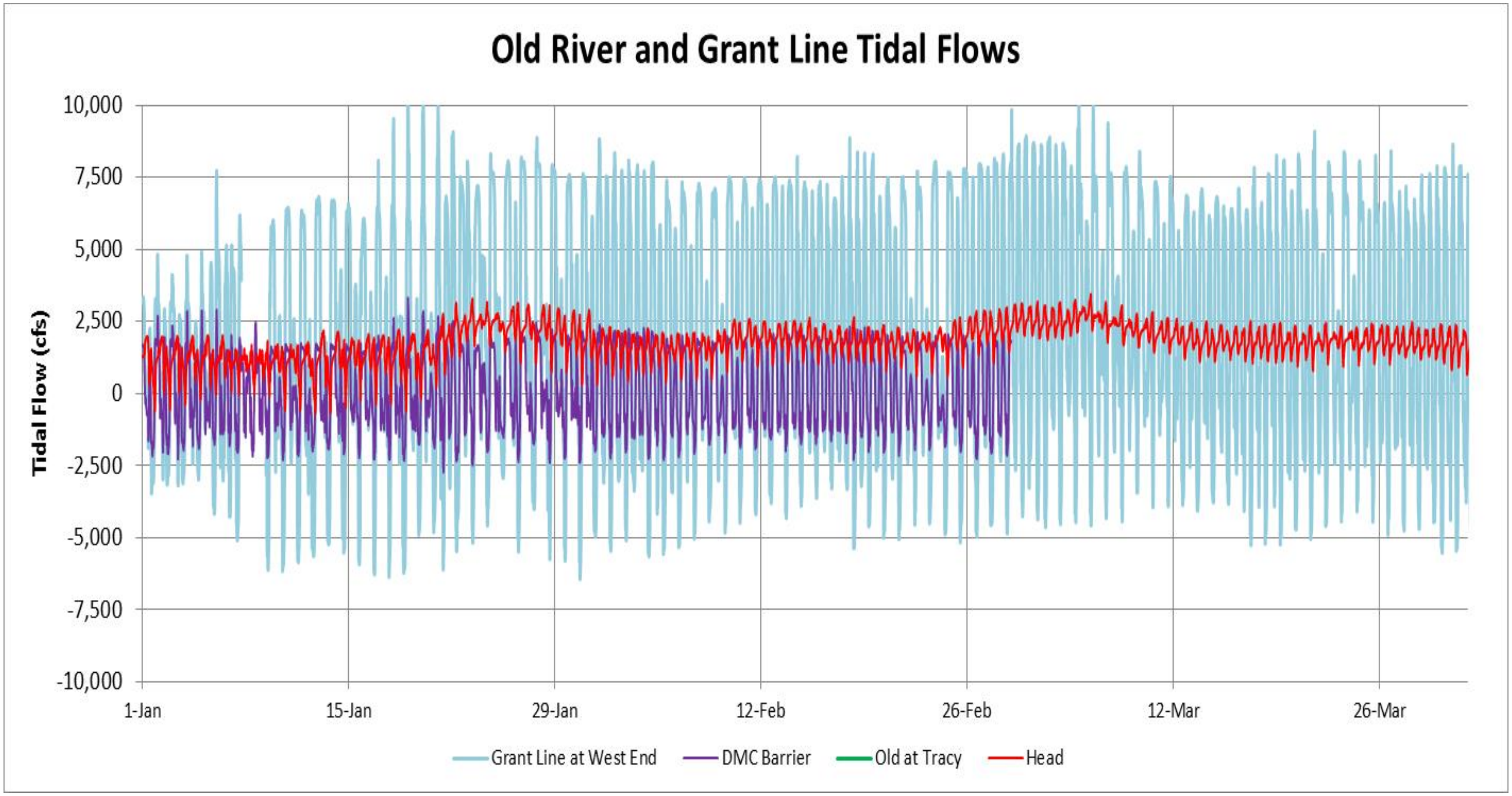
The higher SJR flows in April, May and June (>3,000 cfs) increased the minimum tide elevations at Mossdale and the head of Old River 2-4 feet. The minimum daily tidal elevations in Old River were increased by about 1 foot in June when the DMC barrier was installed. The Old River elevations downstream of the DMC barrier (light green line) remained at about 2 feet, and provide a good reference for the effects of the DMC and Grant Line Canal temporary barriers on the tidal elevations upstream of the barriers.



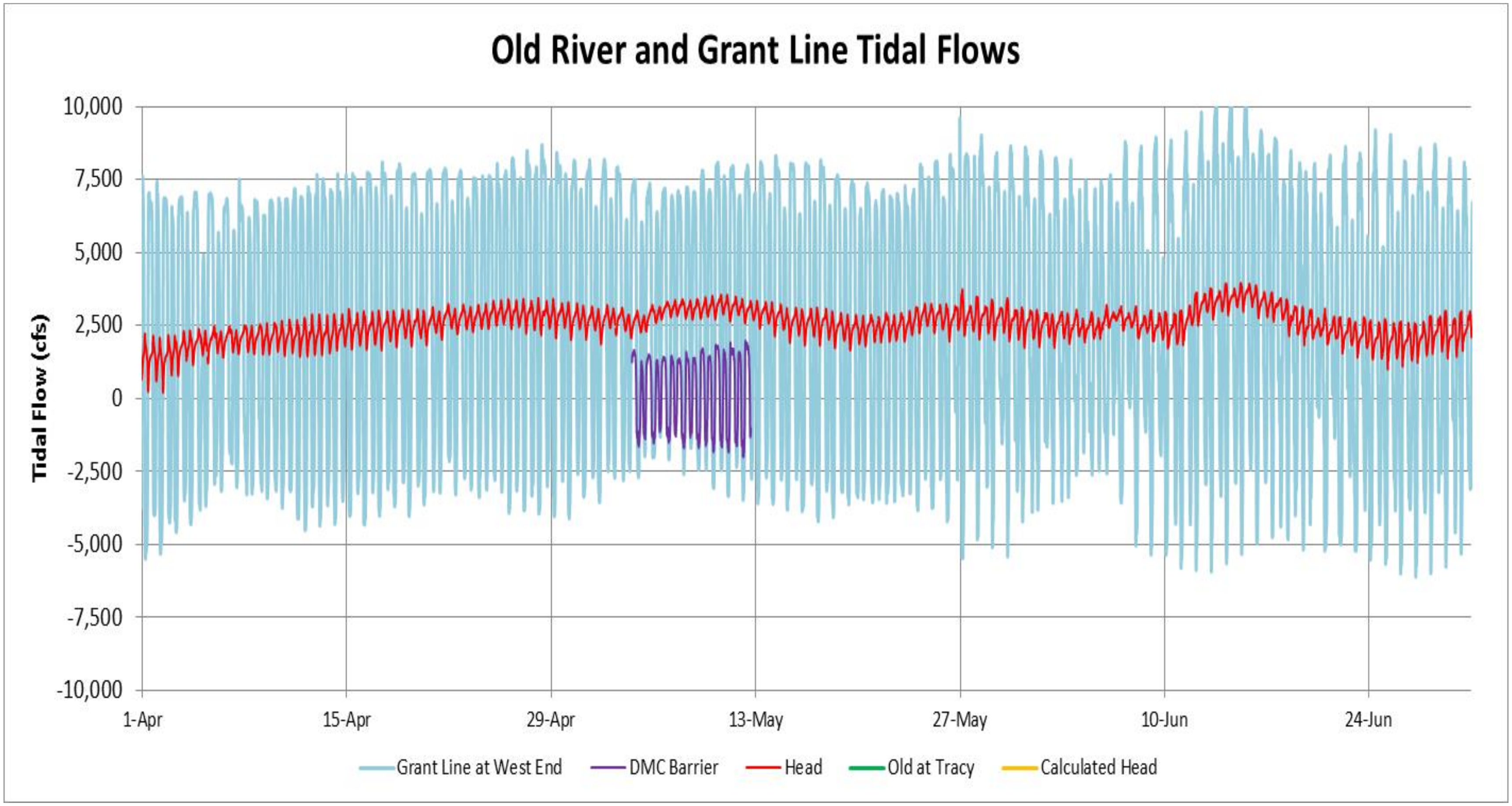
The minimum tide elevations were increased by about 1 foot when Grant Line Canal barrier was installed on July 5. The full effects of the temporary barriers were observed from July through October of 2010. The minimum tides were increased by 1.5-2 feet compared to the Old River downstream of the DMC barrier. The tidal elevation range was substantially reduced upstream of the barriers, with a tidal range of 2-3 feet. The net downstream flow in Old River at Tracy Boulevard (estimated as 10% of the head of Old River flow) of about 100 cfs at the head of Old River and about 100 cfs in Old River, but the tidal flushing of salt from Paradise Cut and Sugar Cut was reduced, allowing the EC in Paradise Cut and Sugar Cut to increase. The benefits of the higher minimum elevations for water diversions should perhaps be considered along with the water quality effects from reduced tidal flushing in the south Delta channels.



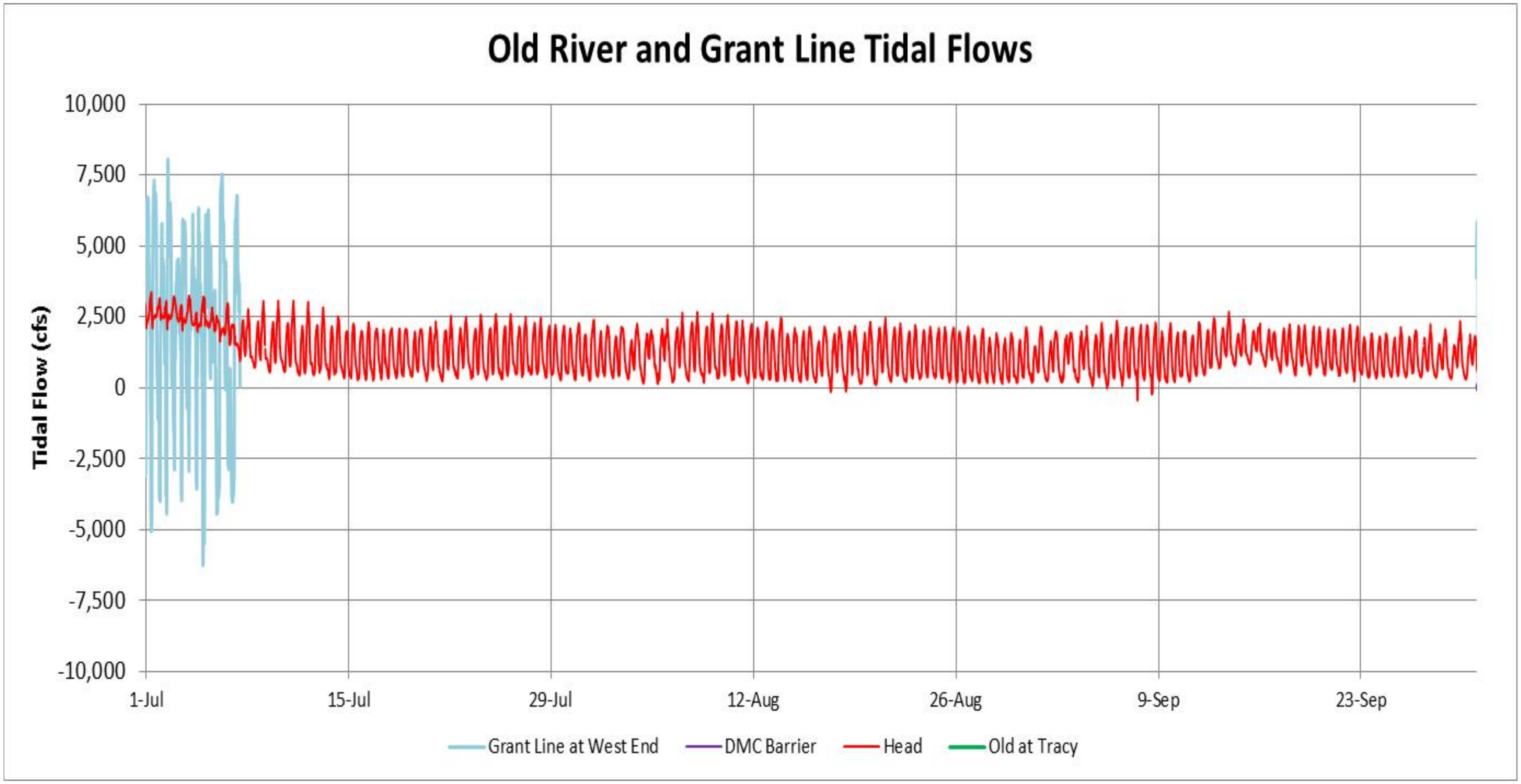
The Old River at DMC, Middle River, and Grant Line Canal temporary barriers were removed at the end of October. Tidal elevations were again uniform throughout the south Delta channels, with an average tidal range of 3-4 feet, with tidal elevations of 2 feet to 6 feet during spring tides. The tidal range at Mossdale and at the head of Old River was less than 2 feet without barriers. Tidal elevations were increased dramatically at Mossdale and at the head of Old River in December, with SJR flows of 5,000 cfs to 10,000 cfs.



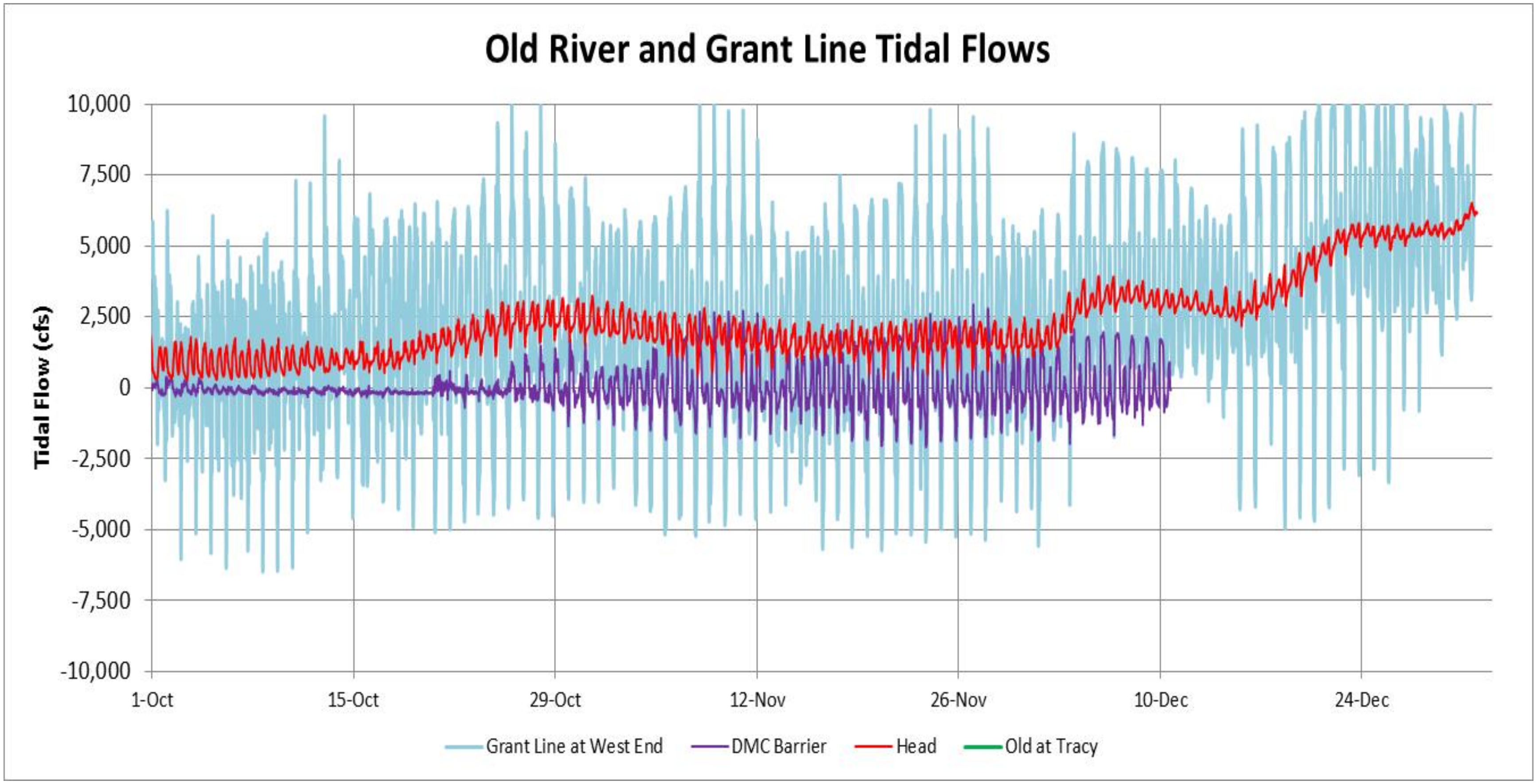
Tidal flows measured at the western end of Grant Line Canal and in Old River at the DMC barrier location indicate the maximum tidal flows in these south Delta channels during the January-March period with no temporary barriers. Tidal flows at the western end of Grant Line Canal (light blue line) varied from -5,000 cfs to 7,500 cfs (tidal range of about 10,000-12,000 cfs) with an average flow that followed the head of Old River flow (red line) because most of head of Old River flow is diverted to Grant Line Canal. Tidal flows in Old River at the DMC barrier (purple line) varied from about -1,500 cfs to 1,500 cfs (tidal range of about 3,000 cfs). Tidal flows in Old River at Tracy Boulevard were not measured in 2010, but are much smaller (about -250 cfs to about 250 cfs).



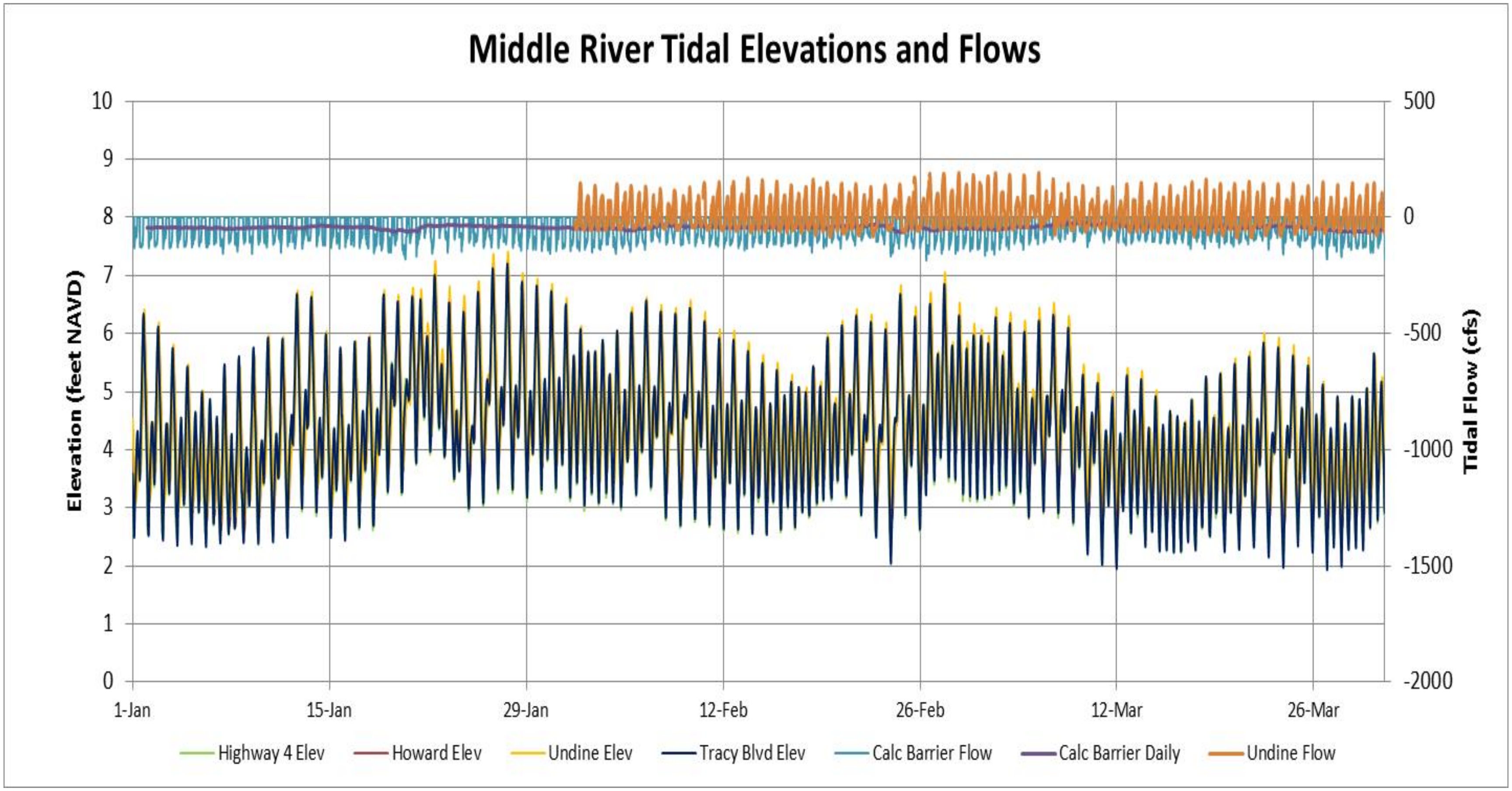
The Grant Line Canal tidal flows remained similar (full tidal flows) in the April-June period. The head of Old River flows were about 2,500 cfs with only a small tidal variation. The Old River at the DMC barrier flow was only measured at the beginning of May, and the Old River at Tracy Boulevard tidal flows were not measured in 2010.



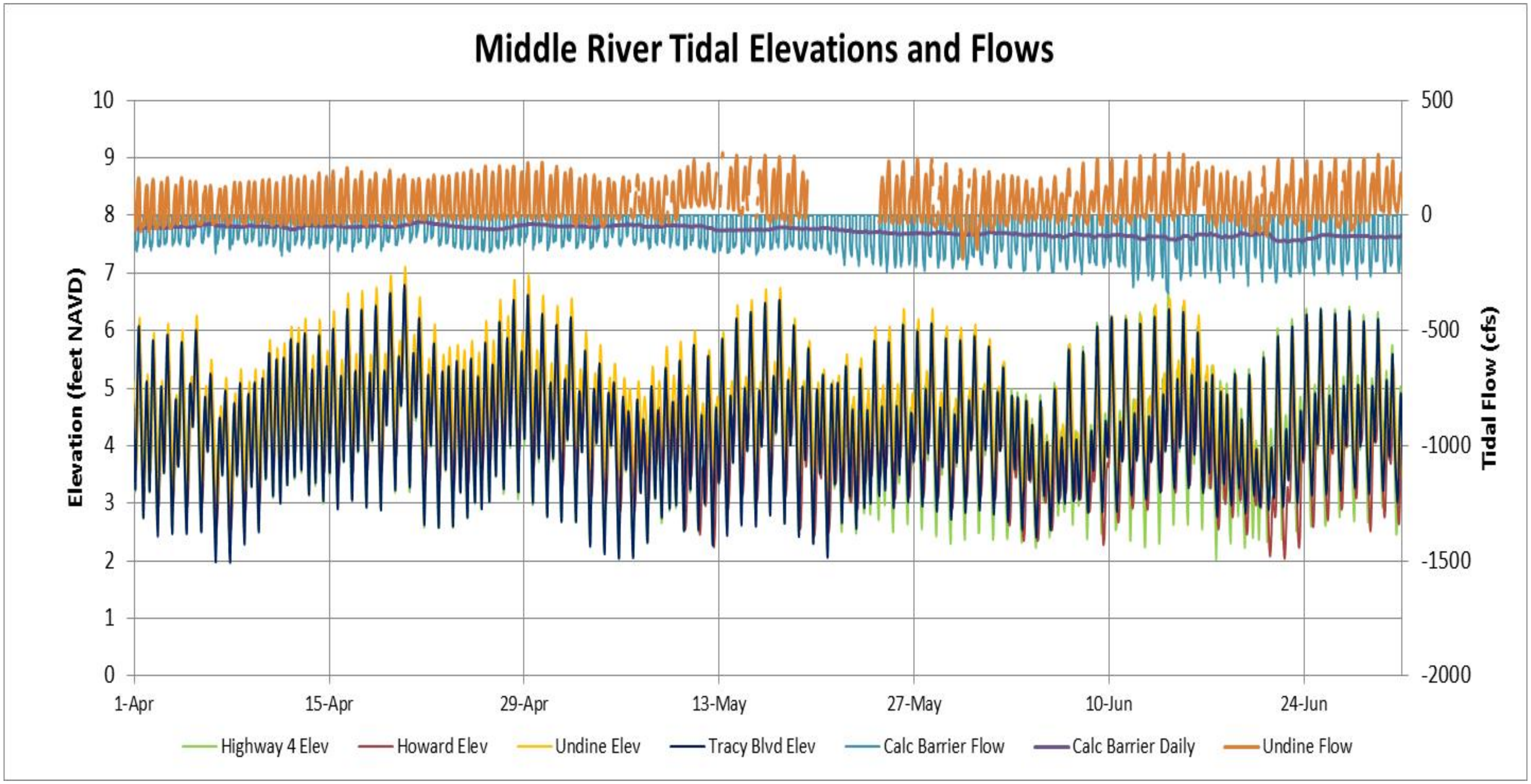
Only the head of Old River tidal flows were measured in the July-September period with the temporary barriers installed. Tidal flows at Tracy Boulevard (important for the Paradise Cut and Sugar Cut salt source evaluation) were estimated as 10% of the head of Old River flow. However, there might have been more periods of reverse (upstream) flow at Tracy Boulevard.



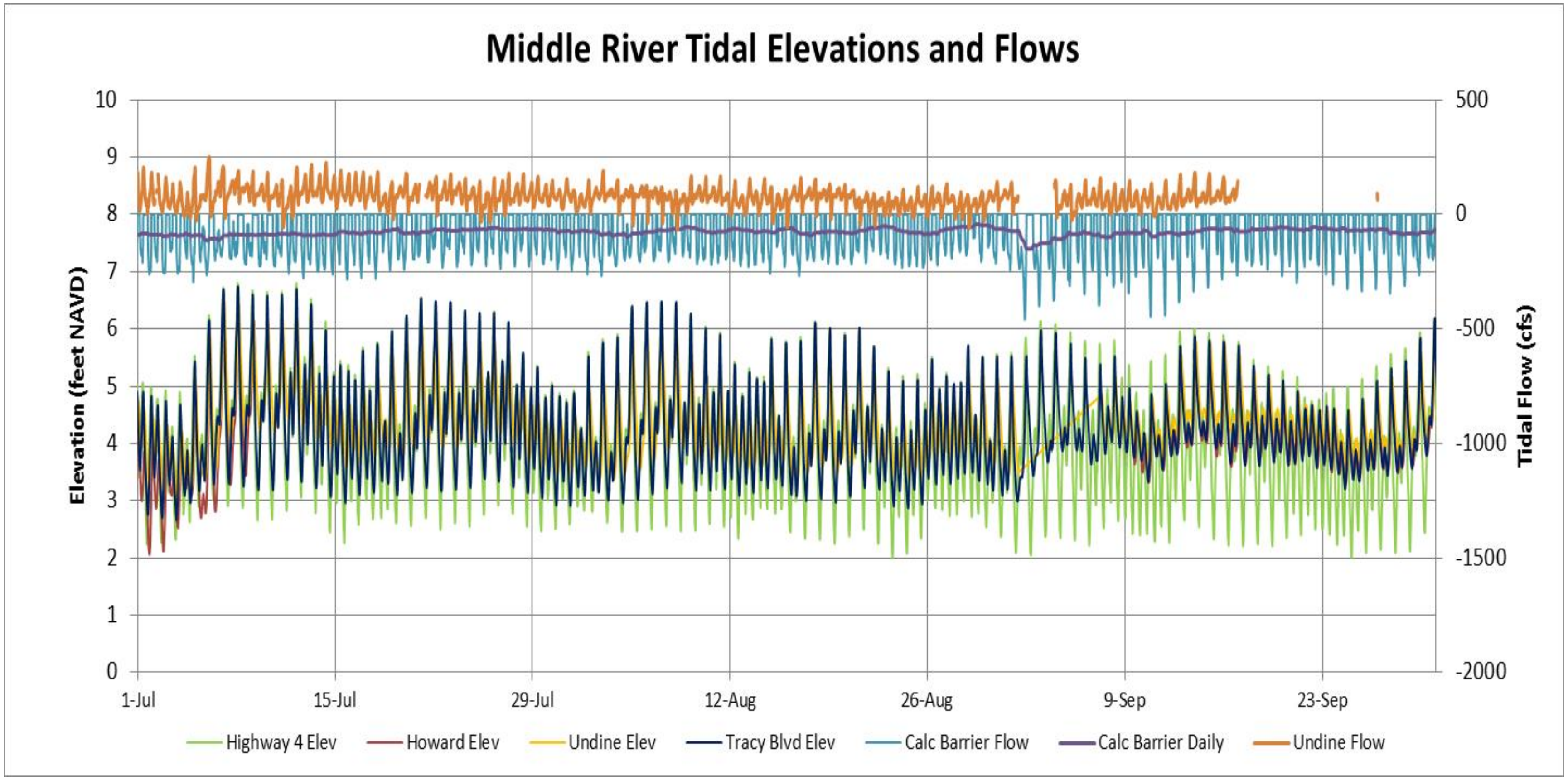
The temporary barriers in Middle River, Old River at the DMC and Grant Line Canal at Tracy Boulevard were removed in late October, and the tidal flow variations in Old River at the DMC barrier were increased. The tidal flows in Grant Line Canal ranged from -5,000 cfs to 5,000 cfs in October and November, but were increased in December when the head of Old River flows were increased to 2,500 and then 5,000 cfs. The Grant Line Canal tidal flows were the most consistent during 2010.



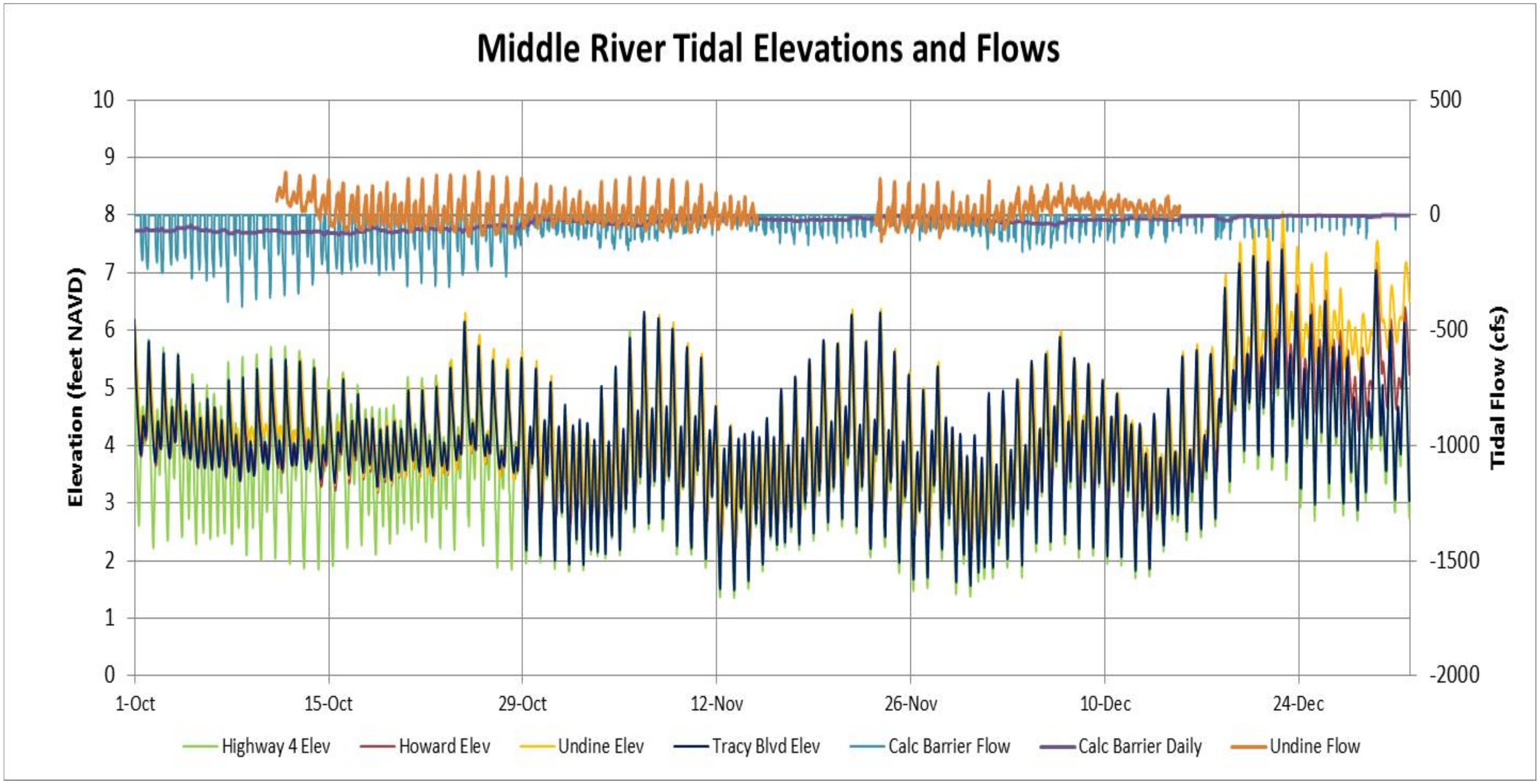
Middle River tidal elevations were similar to tidal elevations in all other south Delta channels from January through March. The tidal flow at Undine Road (brown line) was measured in February and March, with a maximum tidal flow of 100 cfs. The Middle River barrier was not installed during this period, but the calculated barrier flow (light blue line) indicates that the maximum upstream tidal flow would be less than 500 cfs.



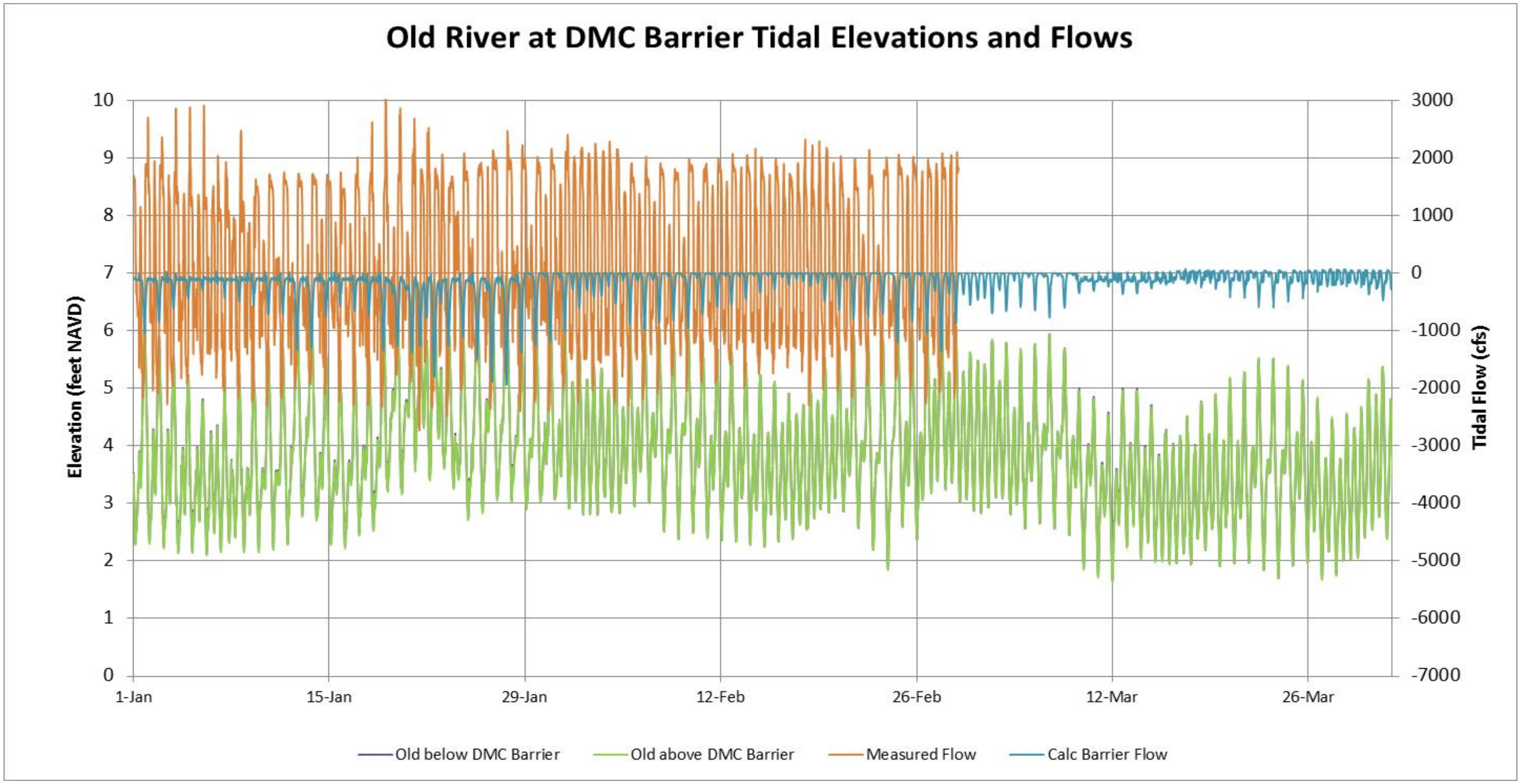
The Middle River barrier was installed in mid-May, but the flap gates were not closed (operated) until early June. The calculated upstream barrier flow in June was less than 500 cfs, with a daily average upstream flow of less than 100 cfs. Minimum tidal elevations upstream of the barrier were increased to about 1 foot higher than the minimum elevations at Borden (Highway 4). The maximum tidal flows measured at Undine Road, near the head of Middle River, were about 100-150 cfs, with an average flow of less about 50 cfs. With the barrier installed, water is entering Middle River from upstream and downstream to supply agricultural diversions of about 150 cfs.



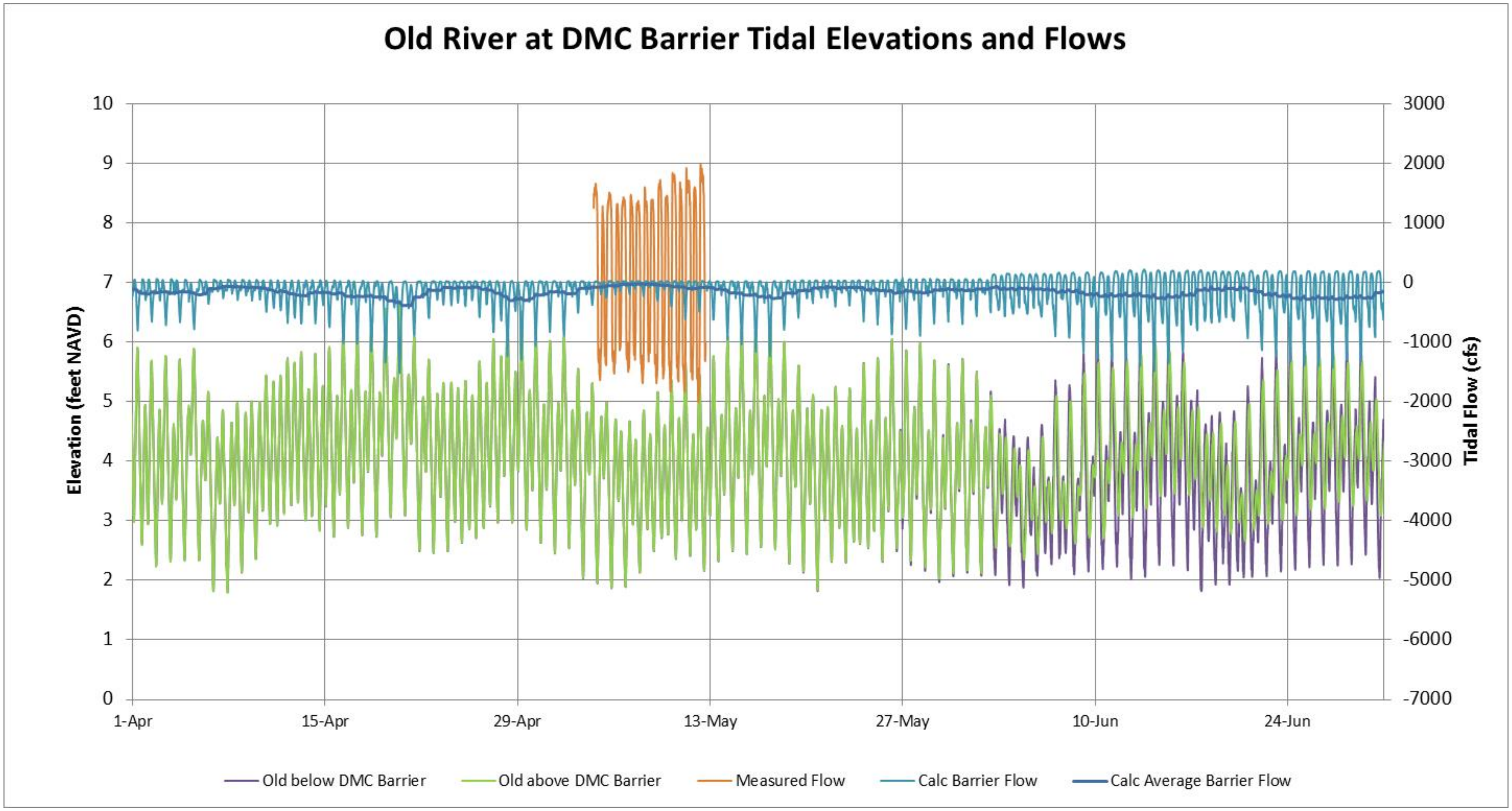
During this period when the three temporary barriers were installed, minimum tidal elevations in Middle River upstream of the barrier were less than 1 feet higher than the minimum elevations at Borden (Highway 4). The minimum elevations were increased after the Middle River barrier weir crest was raised to 4.5 feet on September 1. The measured tidal flows at Undine were positive, and the estimated tidal flows at the barrier were negative (upstream) so flow is entering this 10 mile (17 km) reach from both ends.



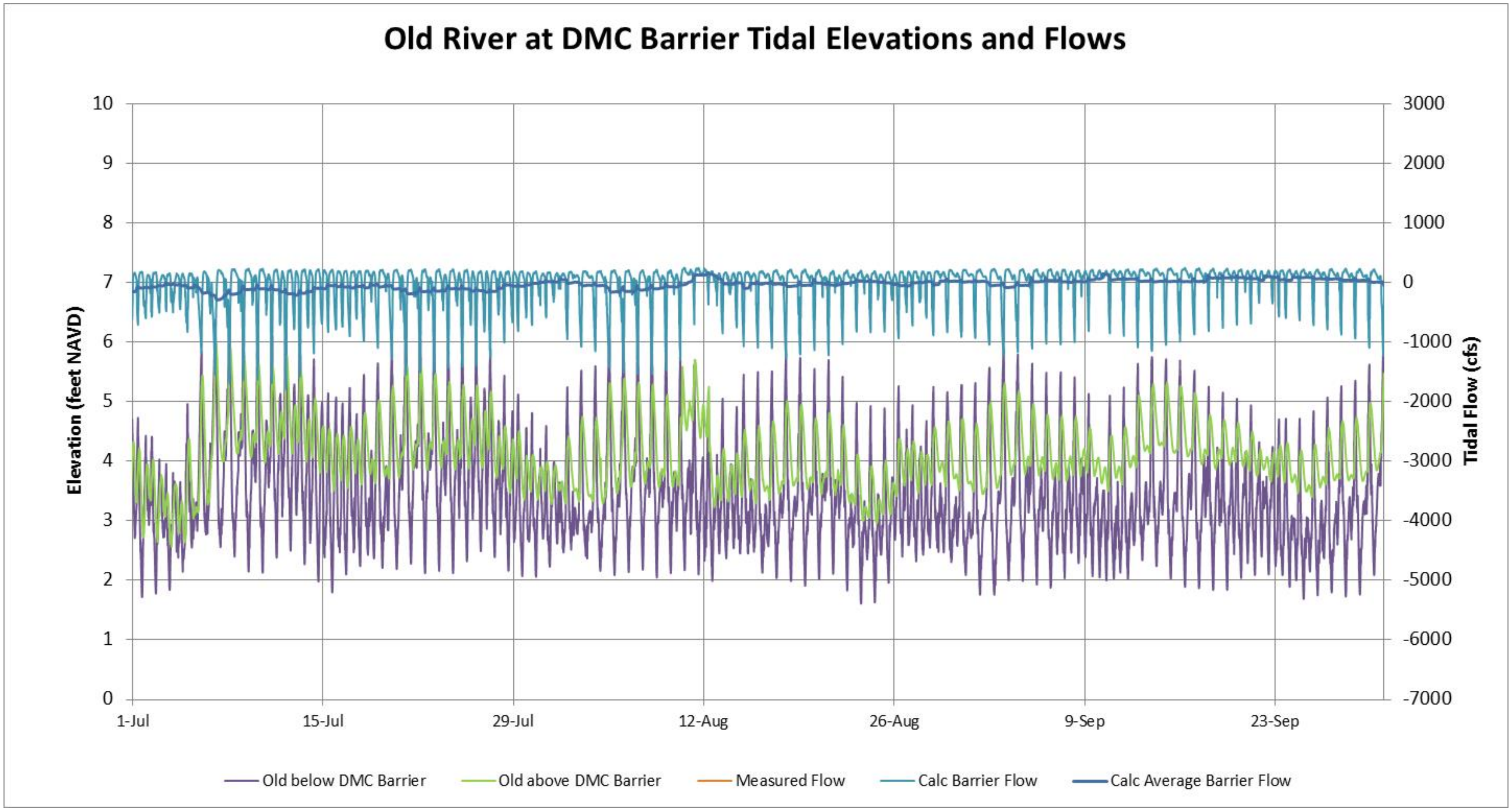
The temporary barriers were removed at the end of October, and the full range of tidal elevations was measured at the Middle River stations in November and December. The measured tidal flows at Undine Road were very low. Tidal elevations in Middle River increased during the higher SJR flows in December. The benefits from the Middle River barrier (increasing minimum elevations) should perhaps be considered along with the water quality effects (increased EC). Perhaps some localized dredging would allow all diversion pumps (and siphons) to be operated without the Middle River temporary barrier.



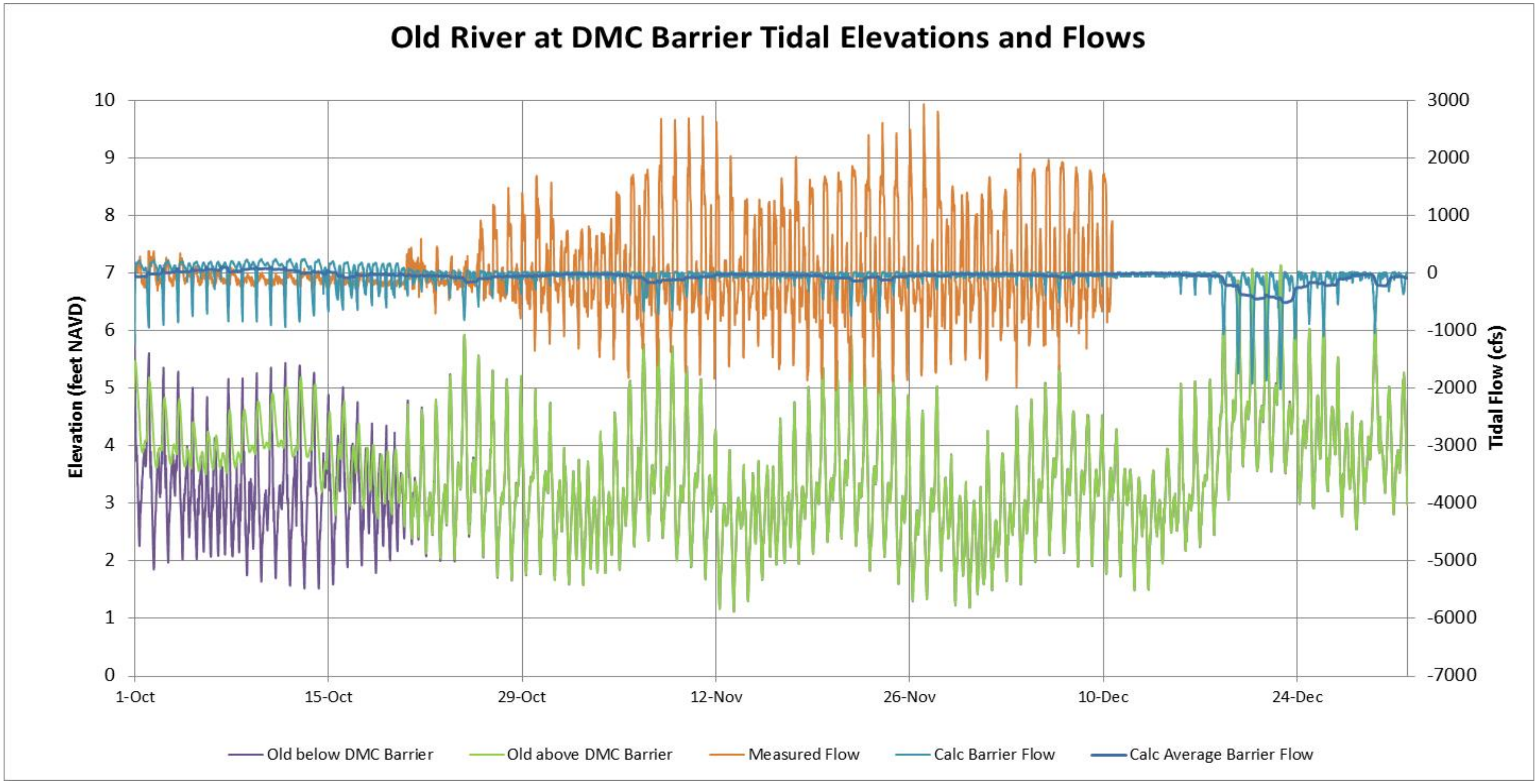
The Old River tidal elevations at the DMC barrier were similar to tidal elevations at other south Delta locations from January through March. The tidal flows were measured in January and February and March, with a maximum ebb-tide flow of 2,000 cfs and a maximum flood-tide flow of about 1,500 cfs. The Old at DMC barrier was not installed during this period, so the calculated upstream flows (light blue line) were small because there were very small elevation differences.



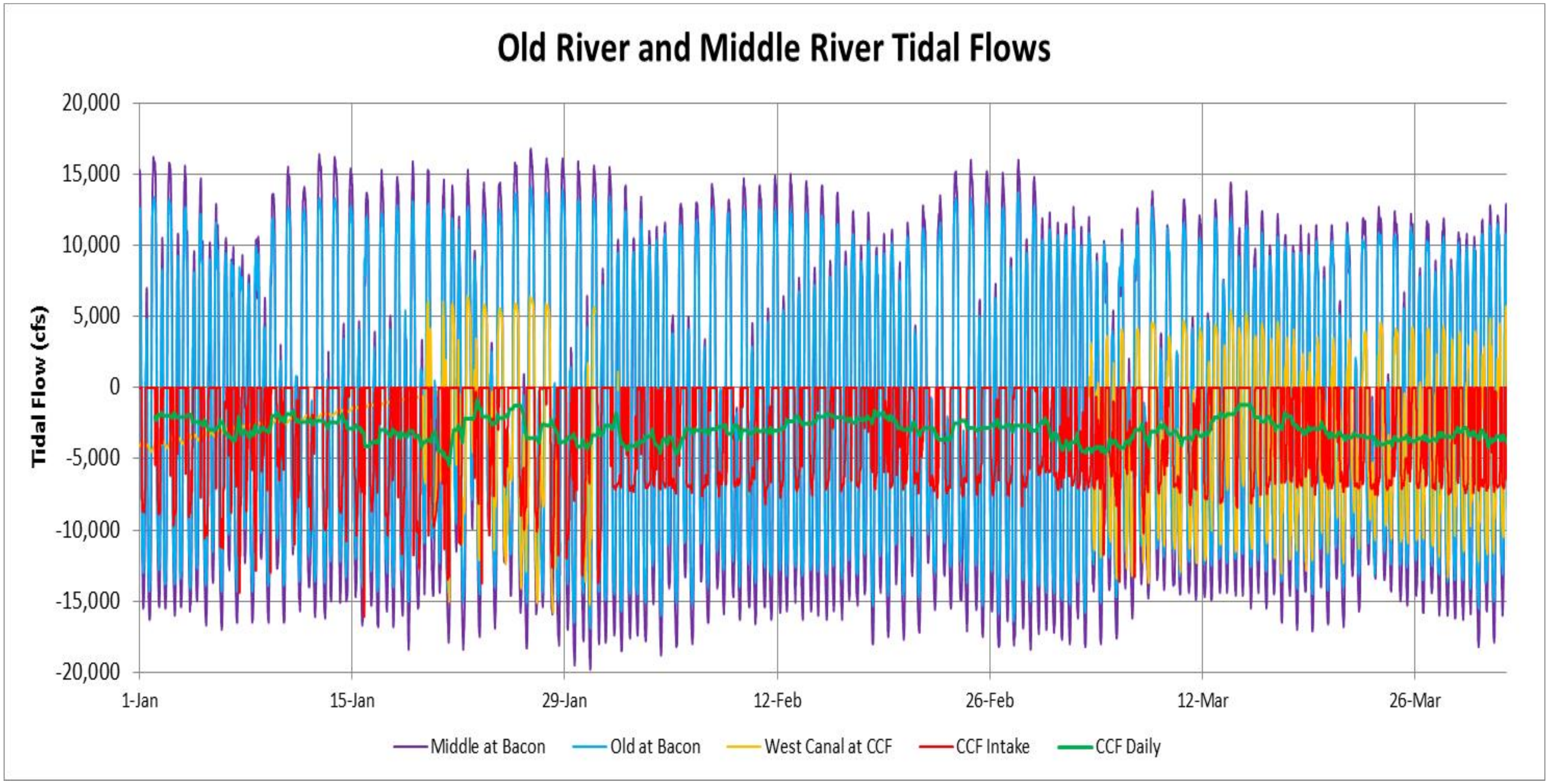
The tidal flows were measured only for a few days in May; the calculated upstream tidal flows were about 500 cfs at the lower-high tide and over 1,000 cfs at the higher-high tide in June, after the DMC barrier was installed. The elevation differences between downstream and upstream were greatest at the lower elevations, when the barrier was maintaining a higher minimum elevation upstream. Tidal flows were often flowing over the weir crest (3.4 feet NAVD), but the flow magnitude was greatly reduced in comparison to the full tidal flows (1,500 cfs). Some small downstream flows (100 cfs maximum) were calculated assuming leakage through the rock barrier.



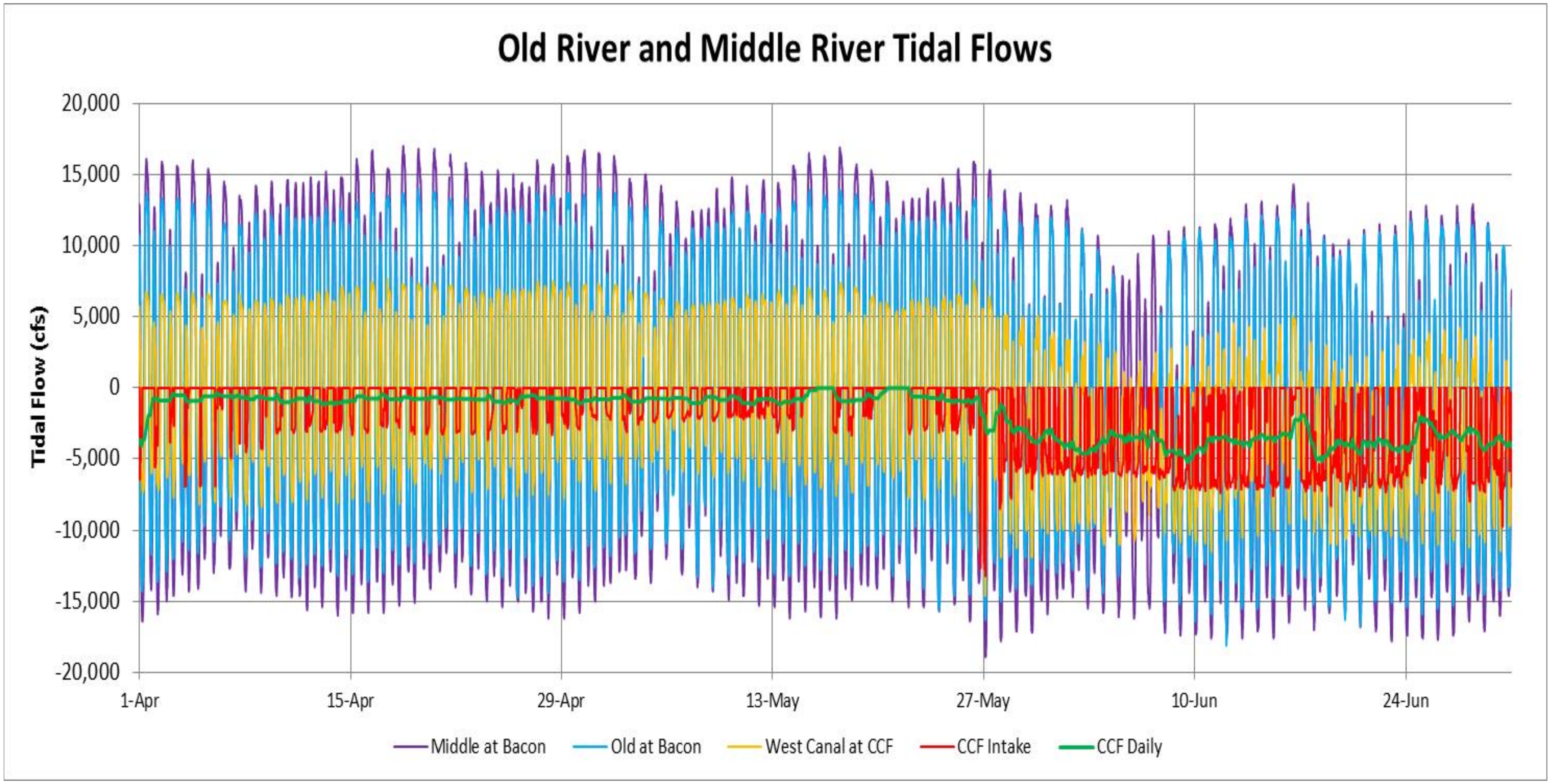
Tidal flows at the DMC barrier were not measured in July-September. The calculated upstream flows were limited to short periods of high tide, with a maximum upstream flow of about 1,000 cfs. The barrier weir was effective for maintaining the minimum tide elevation at about 3.5 feet NAVD, but the tidal flows were greatly reduced.



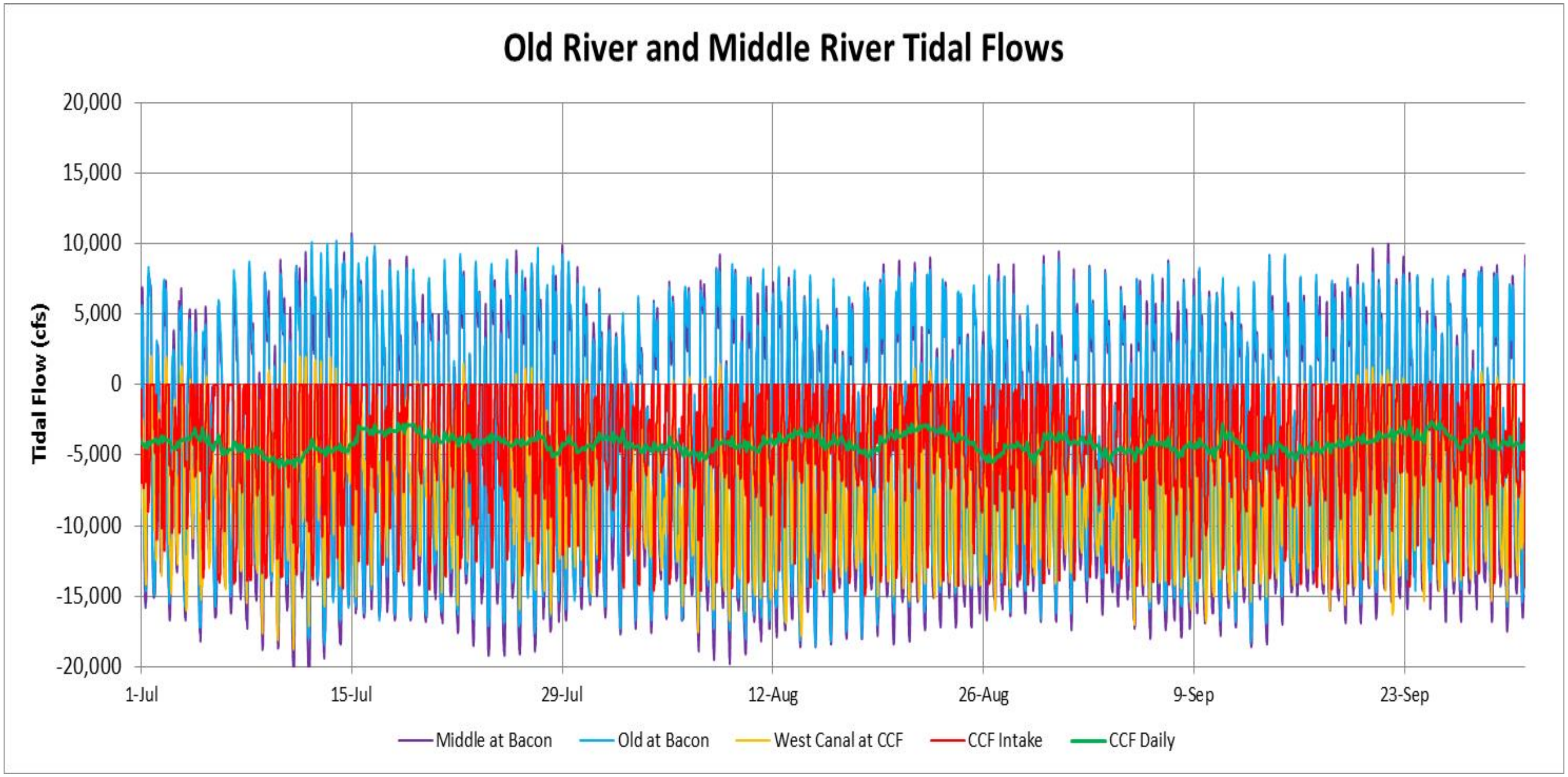
Tidal flows at the DMC barrier were measured in October and November. The measured tidal flows were very small until the barrier was removed at the end of October. The calculated tidal flow with the barrier in October appeared to overestimate the flow over the weir crest at high tide. Tidal flows in November were similar to those measured in January-March, with ebb-tide flows greater than flood-tide flows, because of the net downstream flow in Old River.



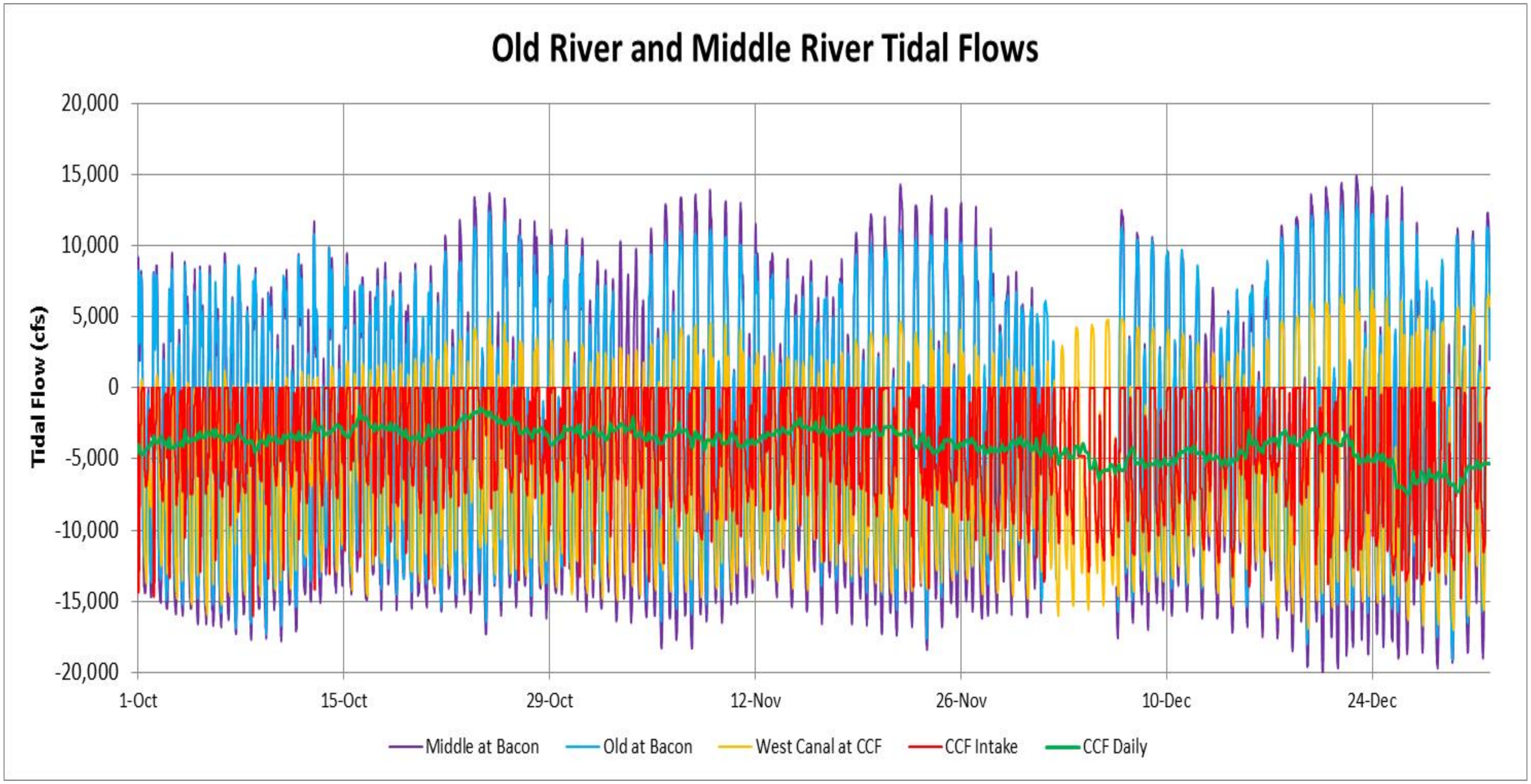
Tidal flows in Middle River at Bacon Island (purple line) and in Old River at Bacon Island (blue line) were similar, although the tidal flows in Middle River were about 10% higher. The tidal flows in West Canal just downstream of the CCF gates (gold line) were about 25% of the combined Old and Middle River tidal flows. The flood tide flow (negative) was greater than the ebb tide flow (positive) because of the CCF diversions (red line) and the DMC diversions (not shown). The CCF gates are generally opened after higher high tides (during the major ebb tide each day) to preserve the high tide elevations in the south Delta channels. The net daily CCF flows (green line) were 2,000 cfs to 4,000 cfs during this period.



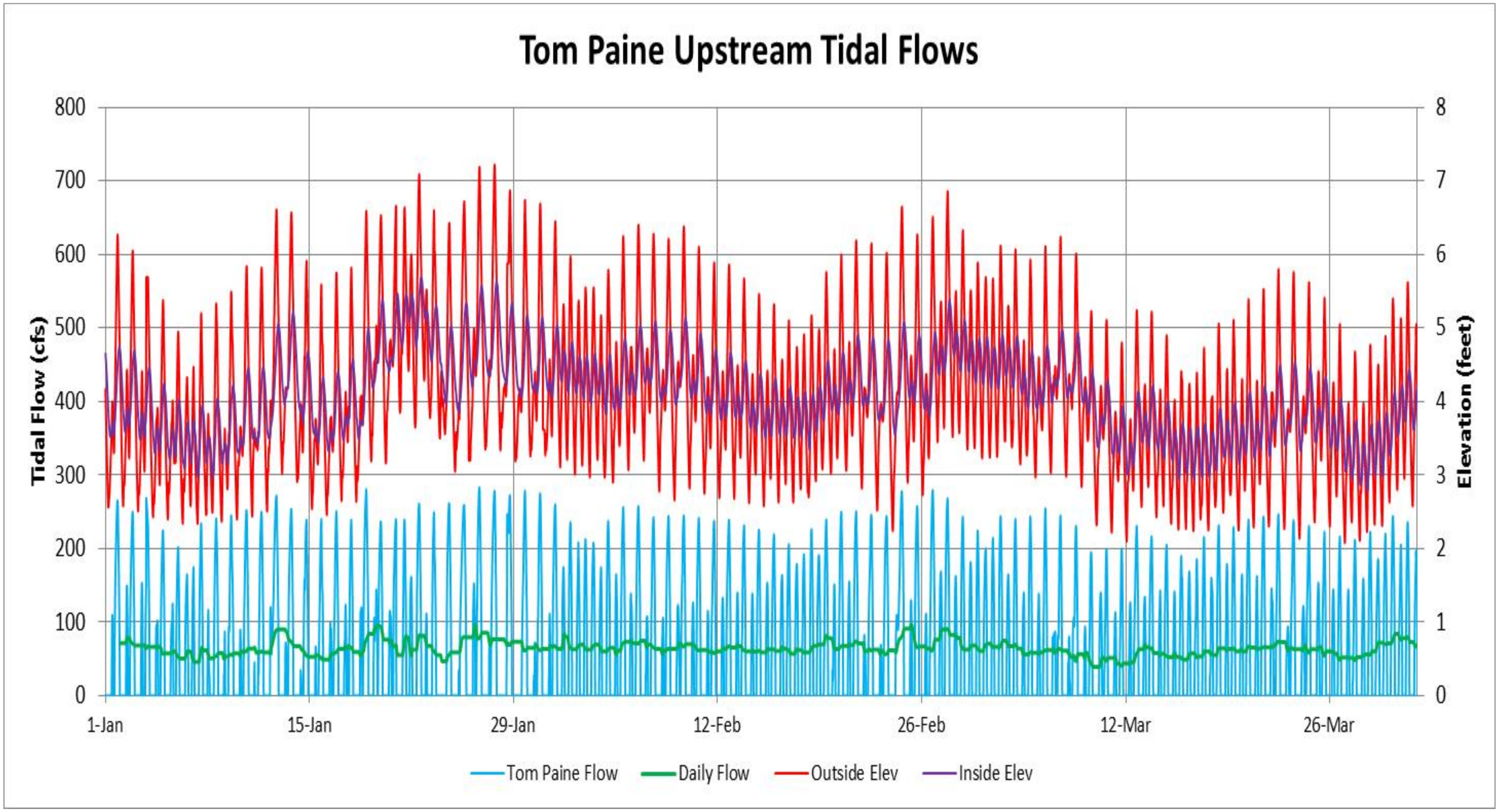
The CCF diversions were reduced considerably in the April-May period for SJR fish protection; the NMFS BiOp RPA restricted CVP and SWP pumping to 1,500 cfs and most of this was at the CVP Jones pumping plant. During this period of low pumping, the flood-tide and ebb-tide flows in Old River and in Middle River were nearly identical (-15,000 cfs to 15,000 cfs). The ebb-tide and flood-tide flows in West Canal downstream of the CCF intake were similar (-5,000 cfs to 5,000 cfs). The tidal flows in West canal shifted by -5,000 cfs (upstream) in June as the CCF flows increased to about 5,000 cfs.



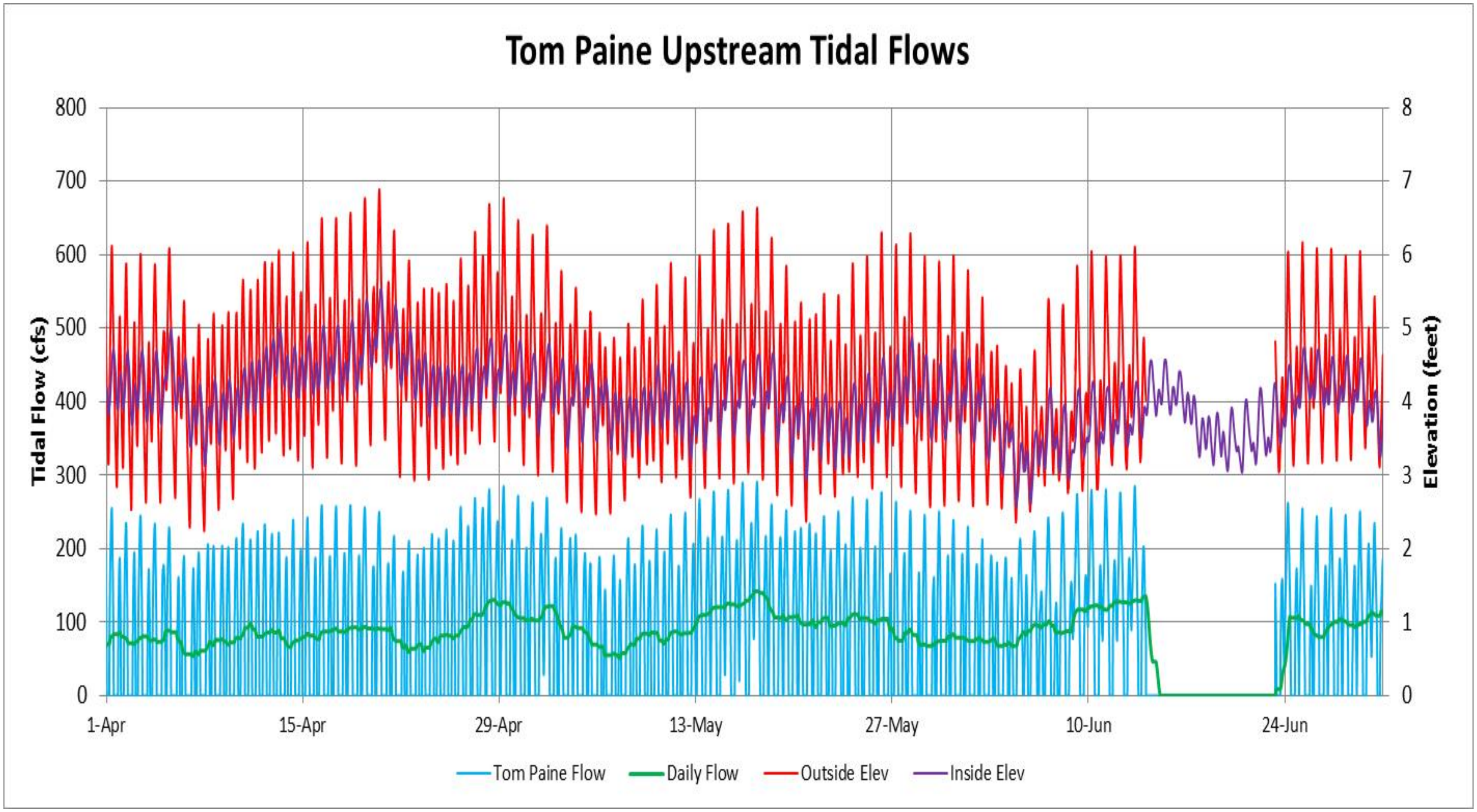
CCF diversions and DMC diversions were increased to maximum pumping of about 10,000 cfs in the July-September period. Nevertheless, there was a moderately strong ebb tide (downstream) flow of 5,000 cfs to 10,000 cfs during the major ebb tide period each day in Old River at Bacon and in Middle River at Bacon. Tidal flows in West Canal were completely reversed (negative) during most of this period. Some of the flood tide flow in West Canal enters CCF (during ebb tide after the higher high tide each day) and some flows into Grant Line Canal and to the DMC intake.



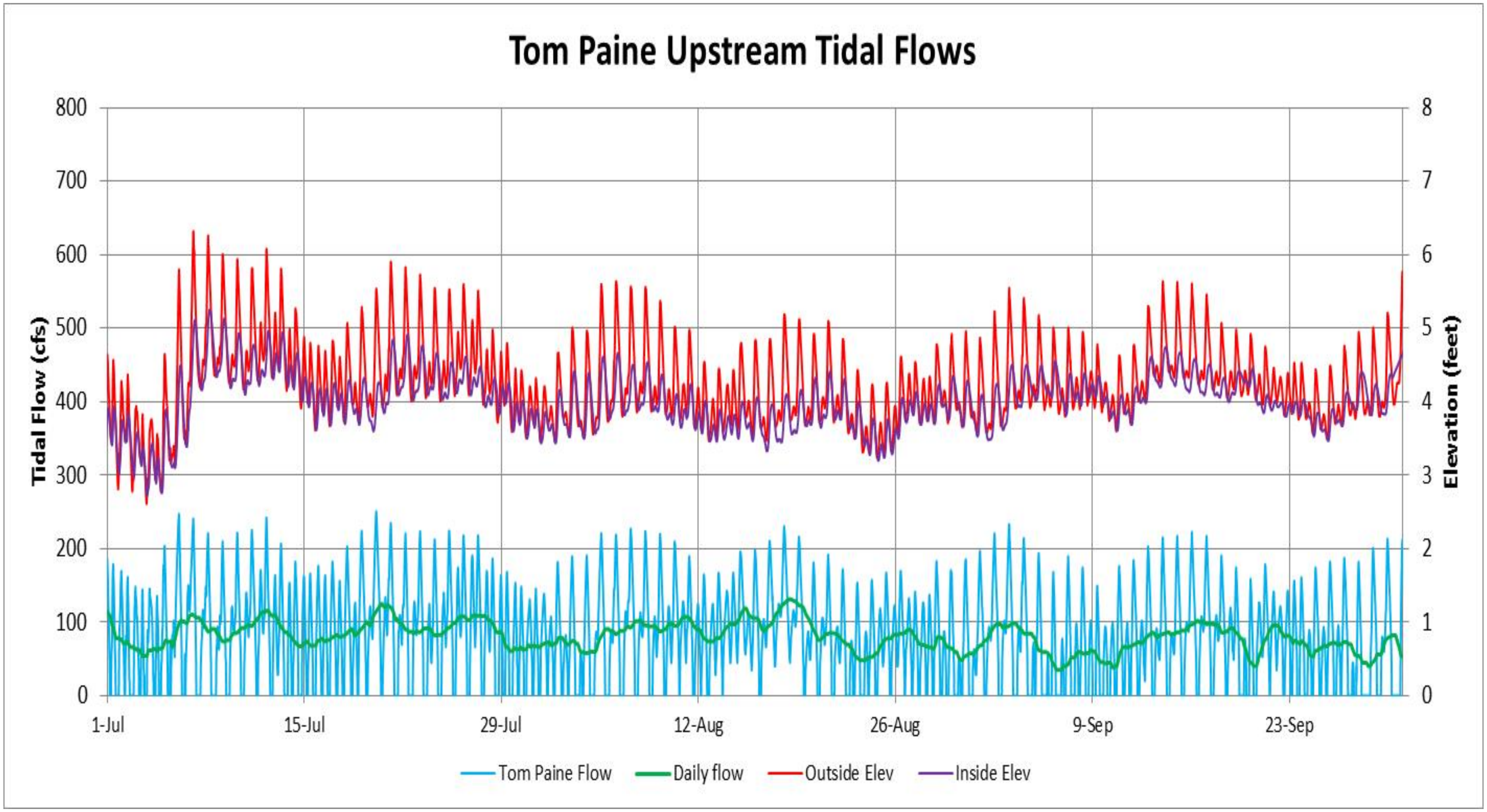
The flow into the CCF is controlled by five tidal gates (each 20 feet wide and 15 feet tall), with a maximum flow of about 15,000 cfs at a head difference of 1 foot. The inflow is controlled by partially closing the five gates to prevent scour from flows of greater than 15,000 cfs or to close the gates during the higher high flood tide period (to preserve the higher high tide elevation), or when the CCF elevation is higher than the West Canal (Old River) elevation. The CCF diversions were greater than 6,000 cfs in December and approached 8,000 cfs at the end of December, because of high SJR flows. This was one of the highest pumping rates for the SWP Banks pumping plant (CCF diversions can be increased from 6,680 cfs by 1/3 of the SJR flow from December 15 to March 15).



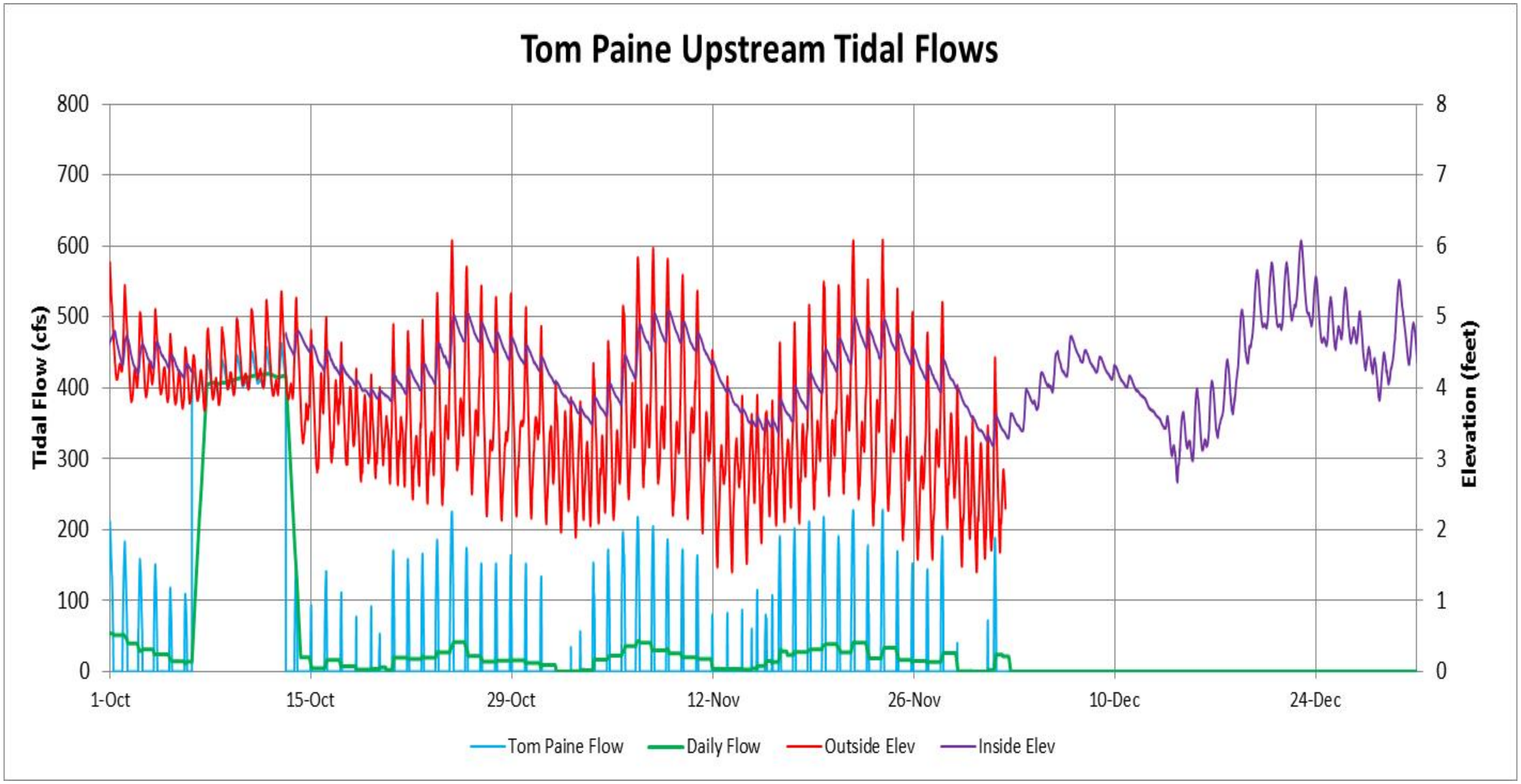
Tidal elevations in Tom Paine Slough are controlled by two box culverts and four siphons with flap gates. Diversions do not usually begin until April, so the upstream elevation (purple line) would remain higher if the flap gates were operating. The upstream flow (with flap gates) can be calculated as: Upstream Flow (cfs) = 300 x Elevation Difference (feet) ^ 0.5. This flow would move both directions if the flap gates were open. Because the upstream tidal elevations remained near the average of the downstream tidal elevations, the flap gates were likely open during this period.



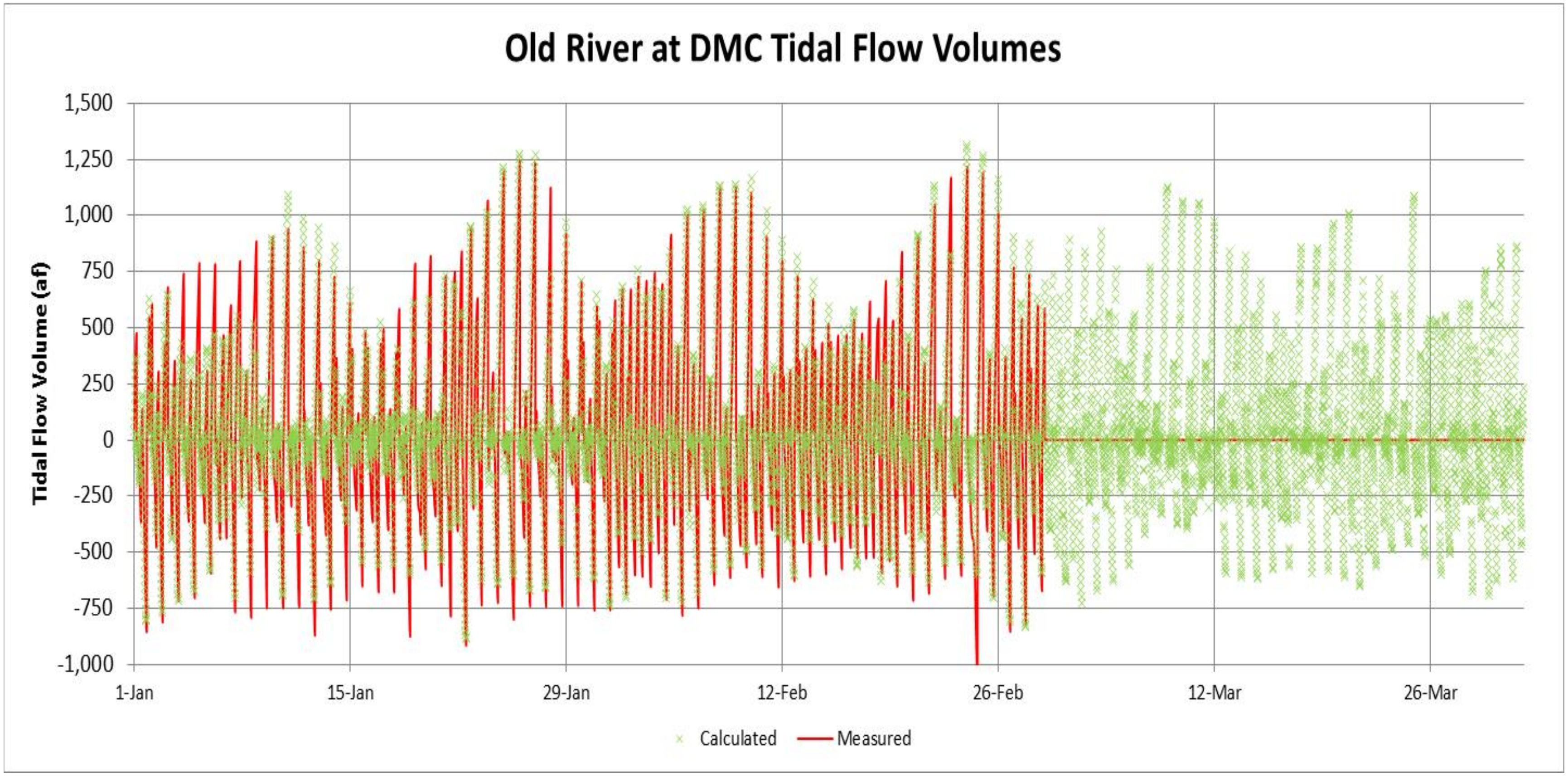
The tidal range was only slightly reduced in June when the Old River at DMC barrier was installed (the Grant Line Canal barrier was not installed until July). Diversions from Tom Paine Slough likely began in April, but the diversions were likely less than 100 cfs so the daily average upstream siphon flow (green line) was sufficient to maintain the water level above 3 feet. A diversion flow of 100 cfs would be much larger than the ebb tide flow from Sugar Cut; most of the Sugar Cut salt load was therefore likely diverted into Tom Paine Slough during the irrigation season. An EC measurement should be added to Tom Paine Slough to confirm this condition.



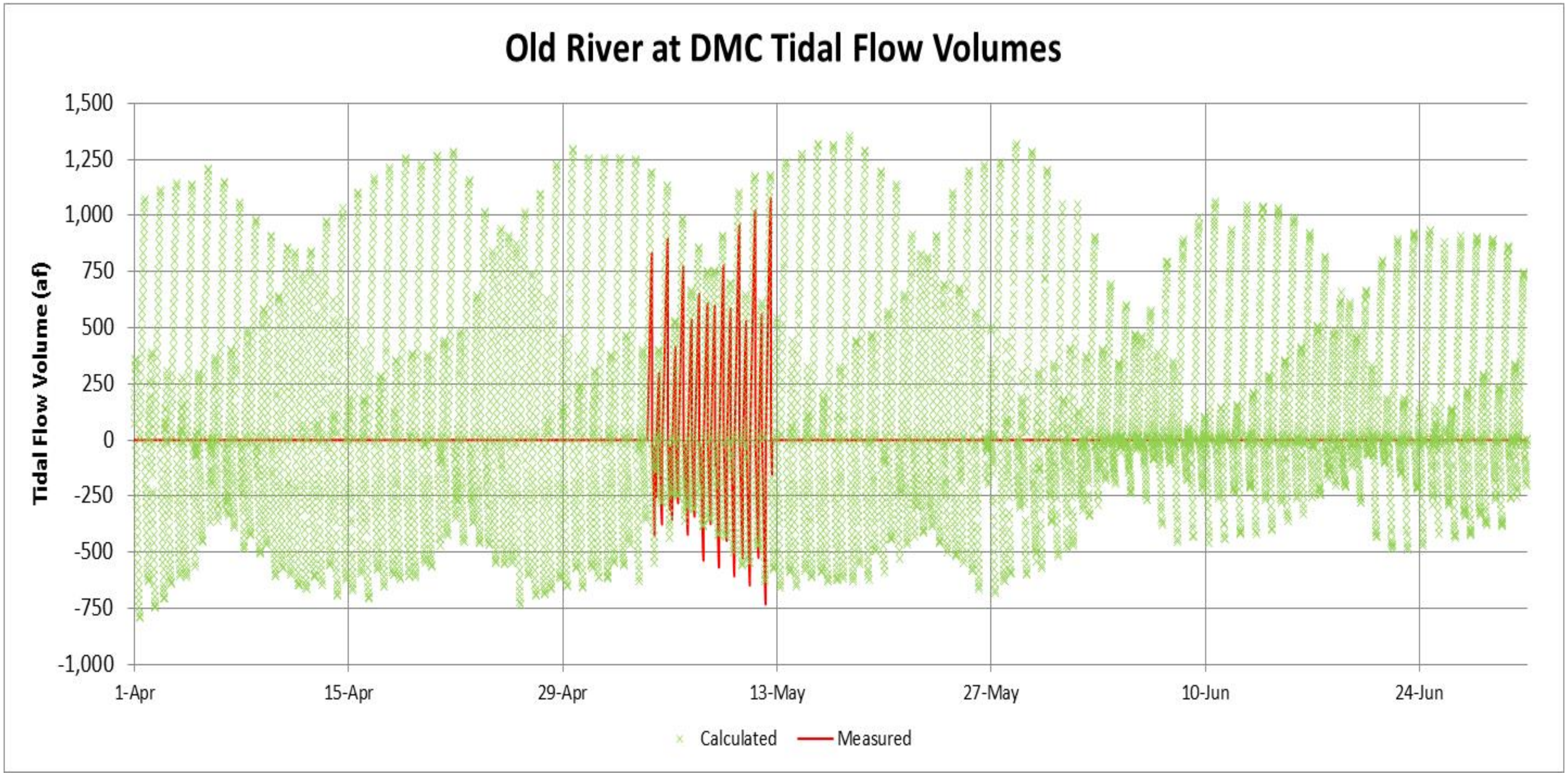
The tidal range in Old River and in Sugar Cut (at Tom Paine Slough) was substantially reduced by the temporary barriers in the summer months. The daily average diversions into Tom Paine Slough (siphons) were limited to less than 100 cfs; this was not enough to sustain full deliveries from Tom Paine Slough. This negative effect of the temporary barriers on water supply for the Tom Paine Slough diverters should be considered along with the effects on tidal flushing of salt in the south Delta channels.



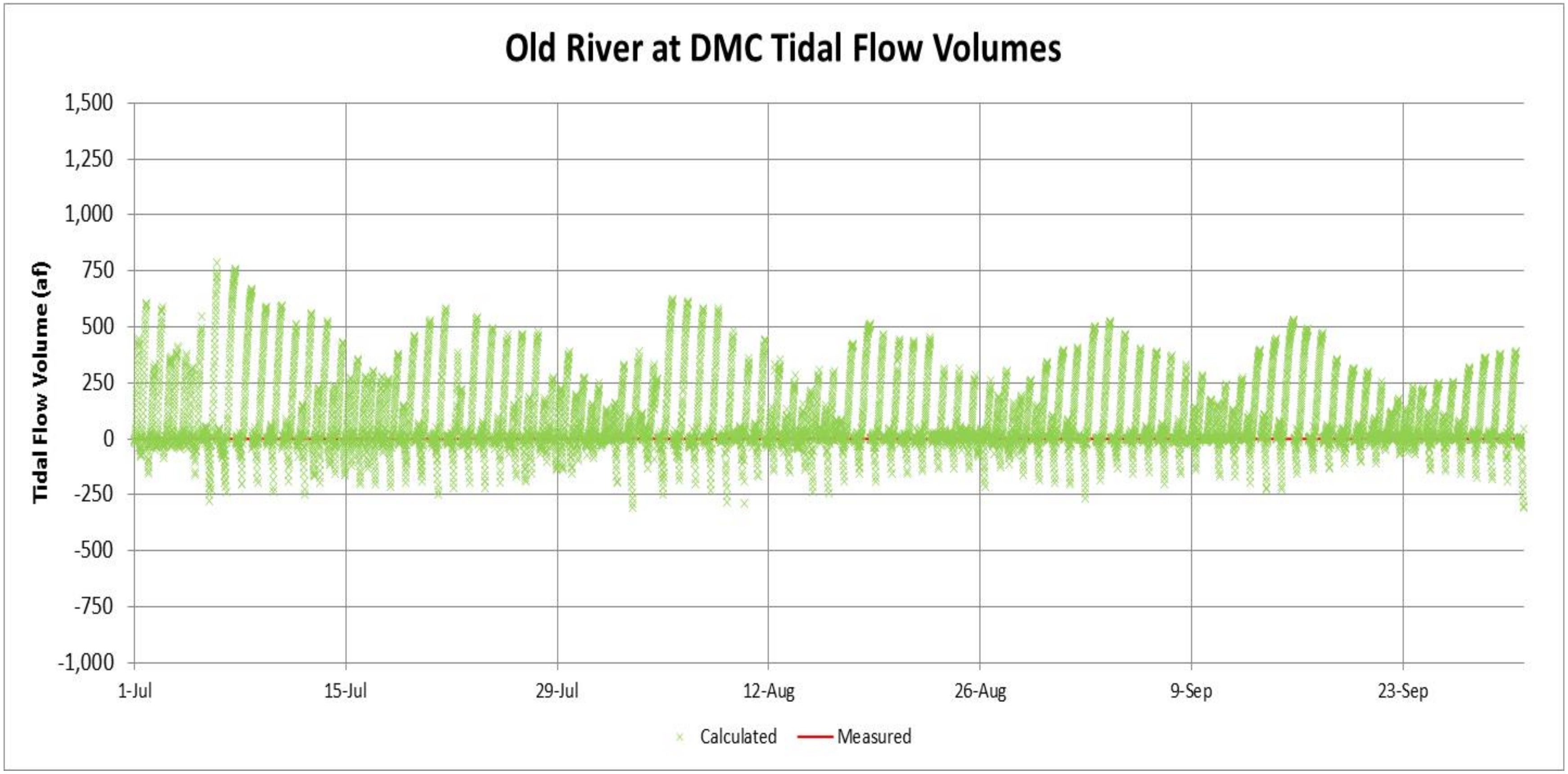
Diversion from Tom Paine Slough had likely ceased in the October-December period, because the upstream tidal elevations remained high. The decreasing upstream water elevations (2-3 inches per day) are difficult to explain unless one of the flap-gates might have been opened. The calculated daily average diversions were less than 25 cfs in November, and the downstream tidal elevations were not measured in December.



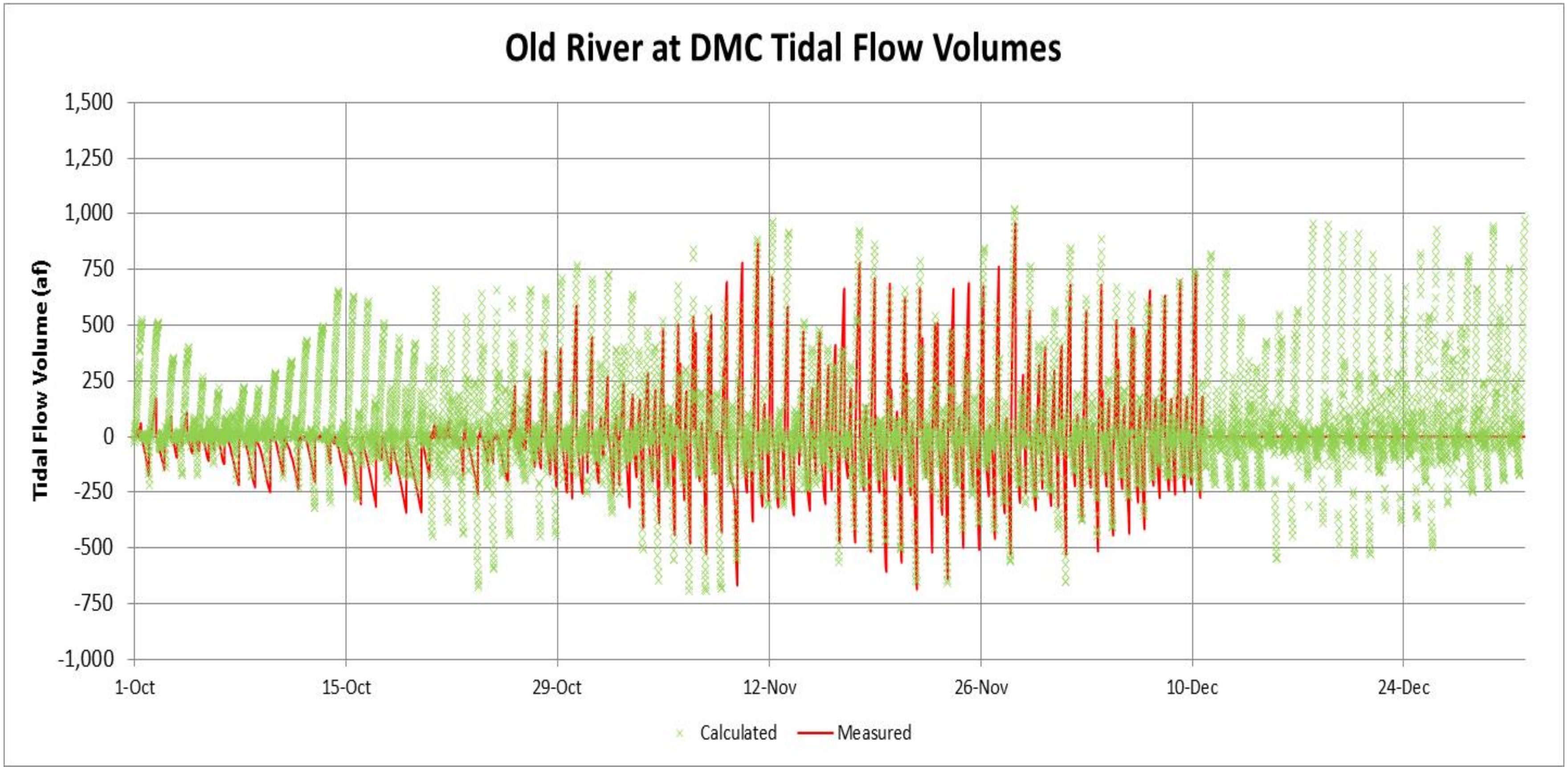
The tidal flow volume can be estimated as the change in tidal elevation times the upstream surface area that is filling or draining. For Old River at the DMC barrier, the upstream area is estimated as 300 acres. A net flow of 10% of the head of Old River was added to the tidal volumes, so that the ebb tide (positive) tidal volumes are greater than the flood tide volumes. But the ebb-tide flow volumes are always more variable over the spring-neap tidal cycle than the flood-tide (negative) flow volumes in the San Francisco estuary.



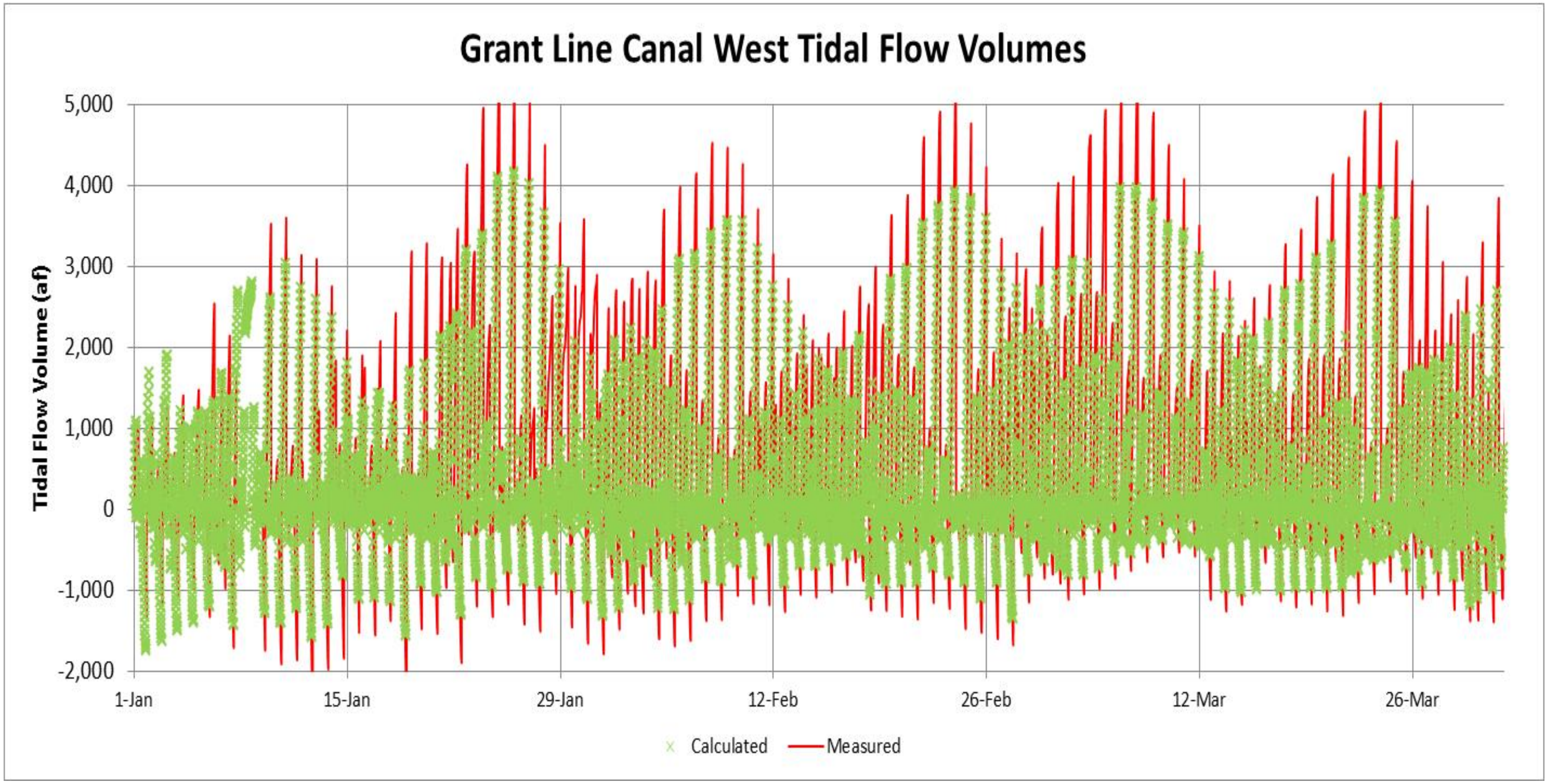
The calculated tidal flow volumes for Old River at the DMC barrier matched the short period with measured tidal flows in early May because the barriers were not yet installed. The ebb-tide (positive) flows were much higher than the flood-tide flows because of the relatively high Old River flow during this period of 2010. The calculated tidal flows were reduced in June because the barriers reduced the range of tidal elevations.



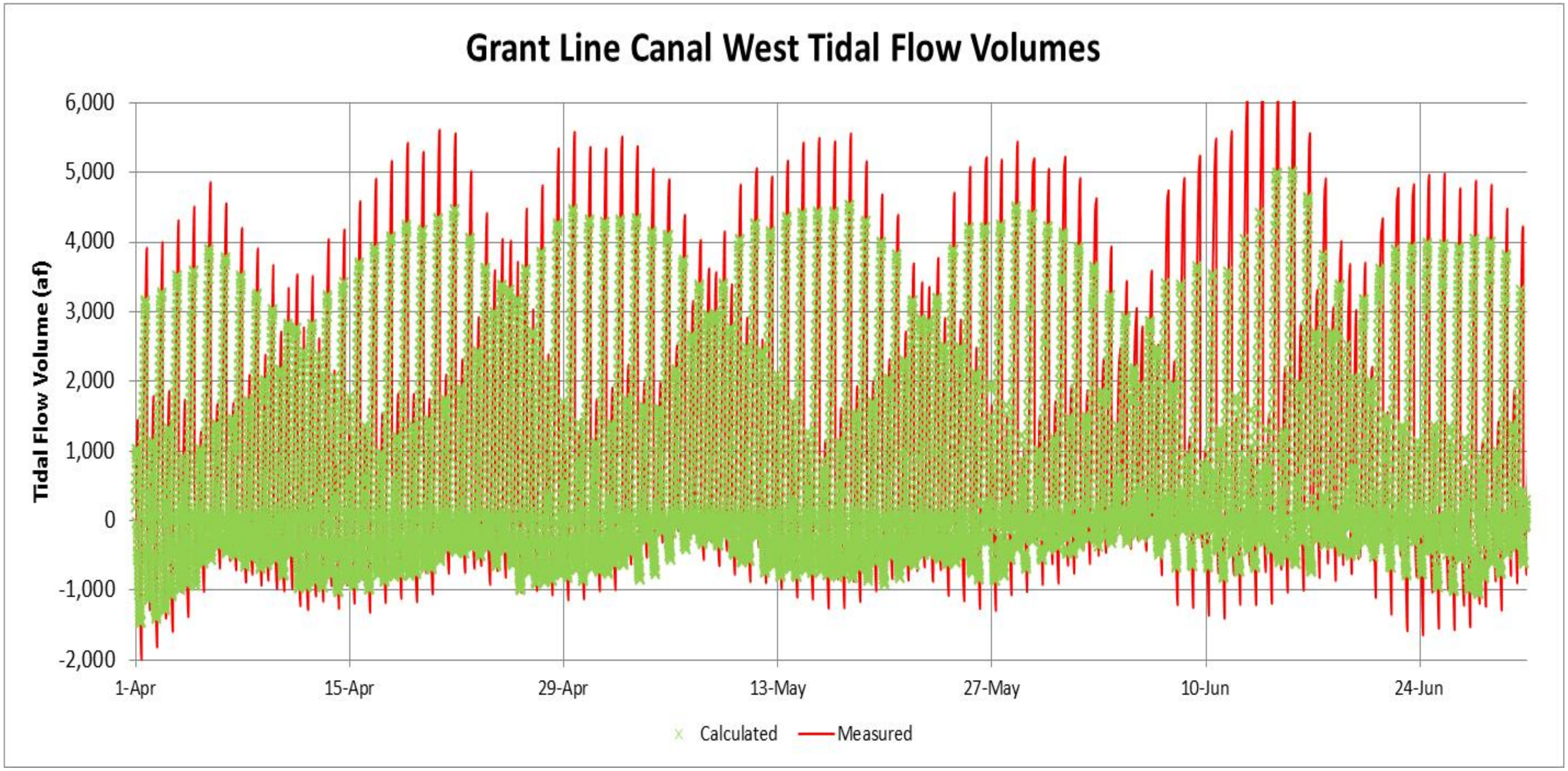
With the barriers installed and the flap-gates closed (operated), the minimum tidal elevations upstream were increased and the maximum tidal elevations were reduced, so the calculated tidal flows were generally cut in half. The tidal flows at the DMC were not measured in this period.



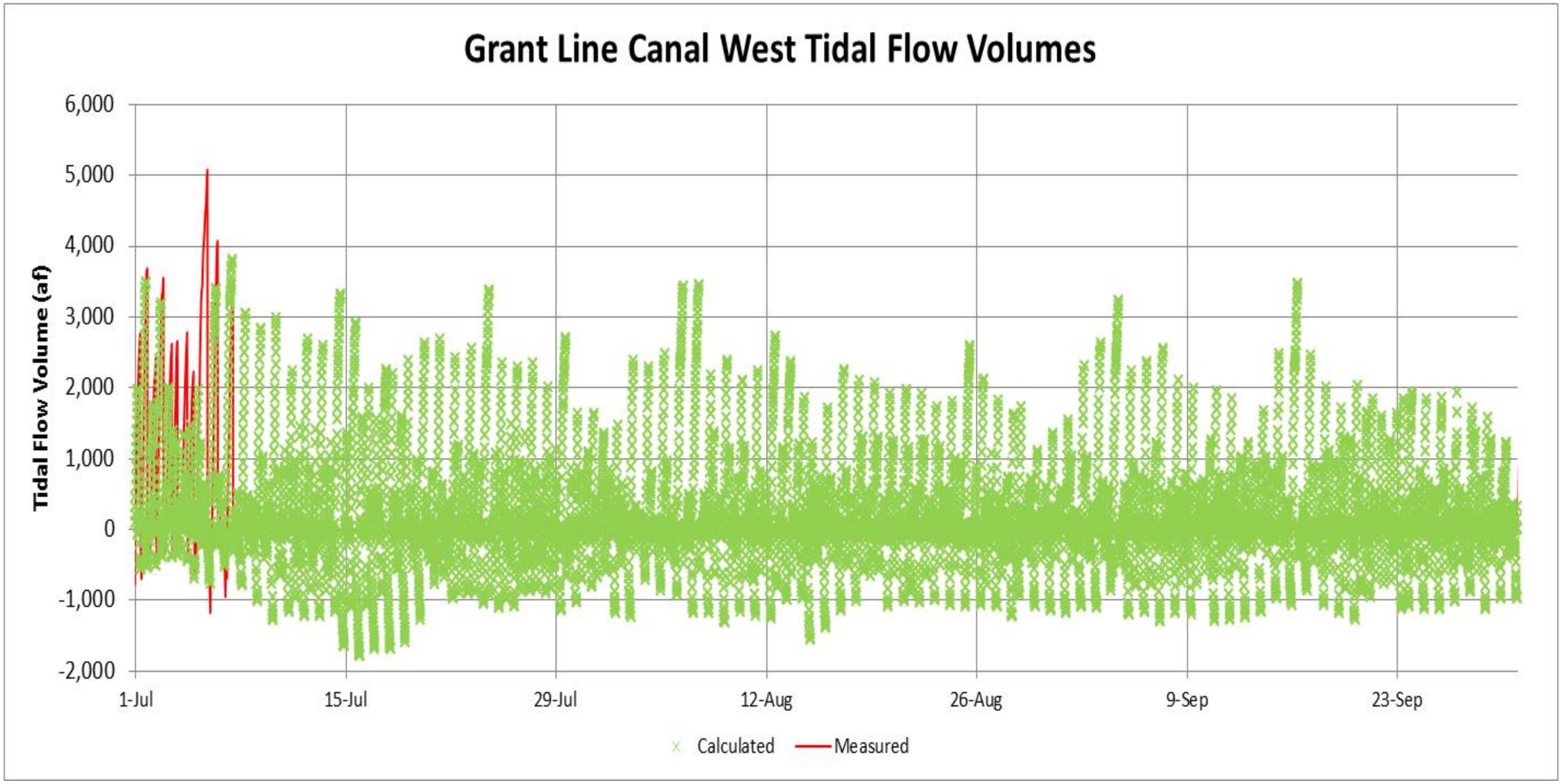
In October, the measured tidal flow volumes were negative (upstream). Once the Old River at DMC barrier was removed at the end of October, the measured ebb-tide and flood-tide flow volumes increased to about 500-750 af. The measured tidal flow volumes in November and early December matched the calculated tidal flow volumes reasonably well, and the assumed net flow of 10% of the head of Old River flow shifted the flood-tide flow volumes to be less than the measured flood-tide volumes.



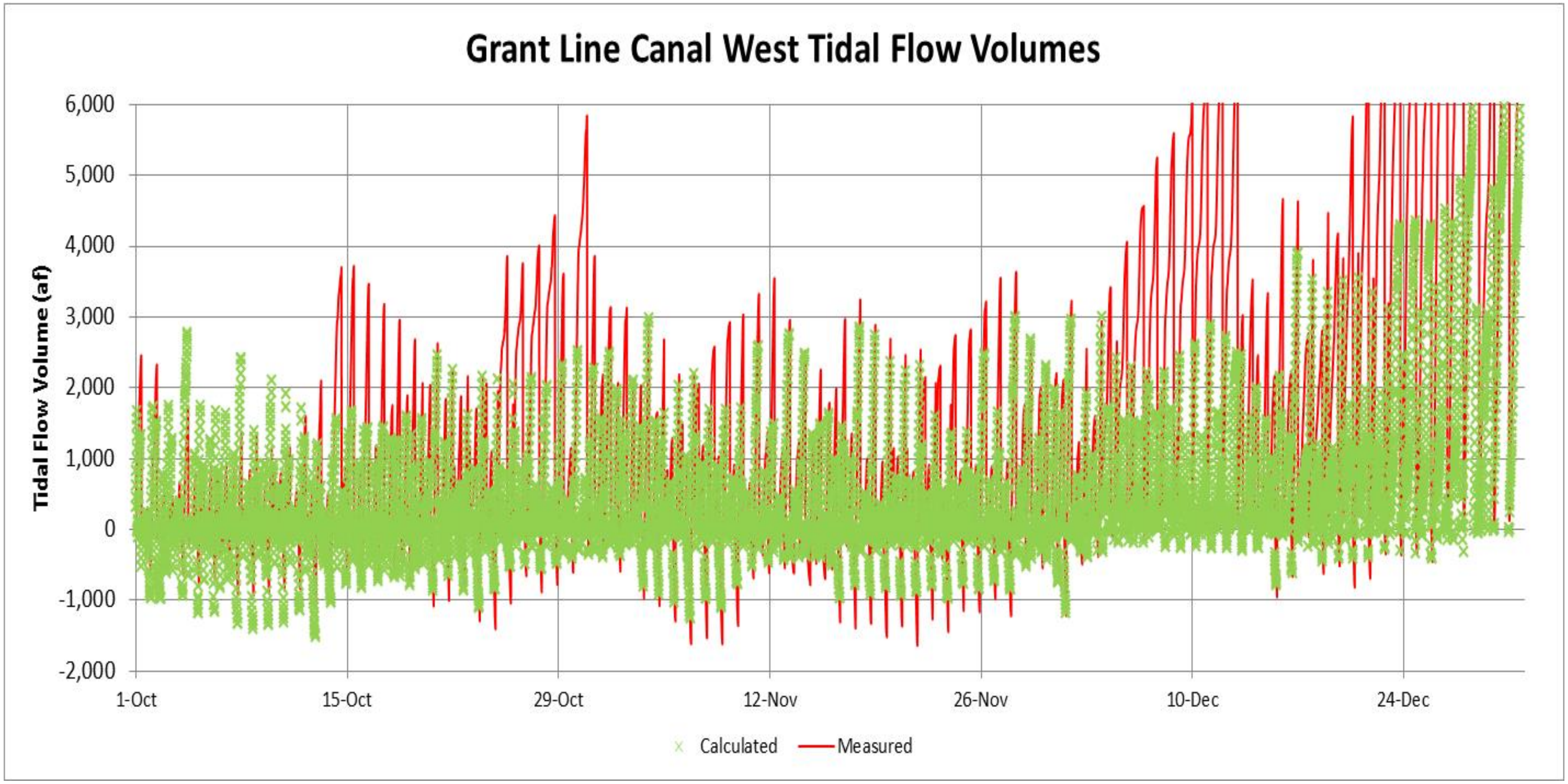
The Grant Line Canal tidal flow volumes were estimated with the measured tidal elevations and an upstream surface area of 750 acres, with a net flow of 85% of the Head of Old River flow. The calculated tidal flow volumes were less than the measured tidal flow volumes, suggesting that the upstream surface area might be greater than 750 acres.



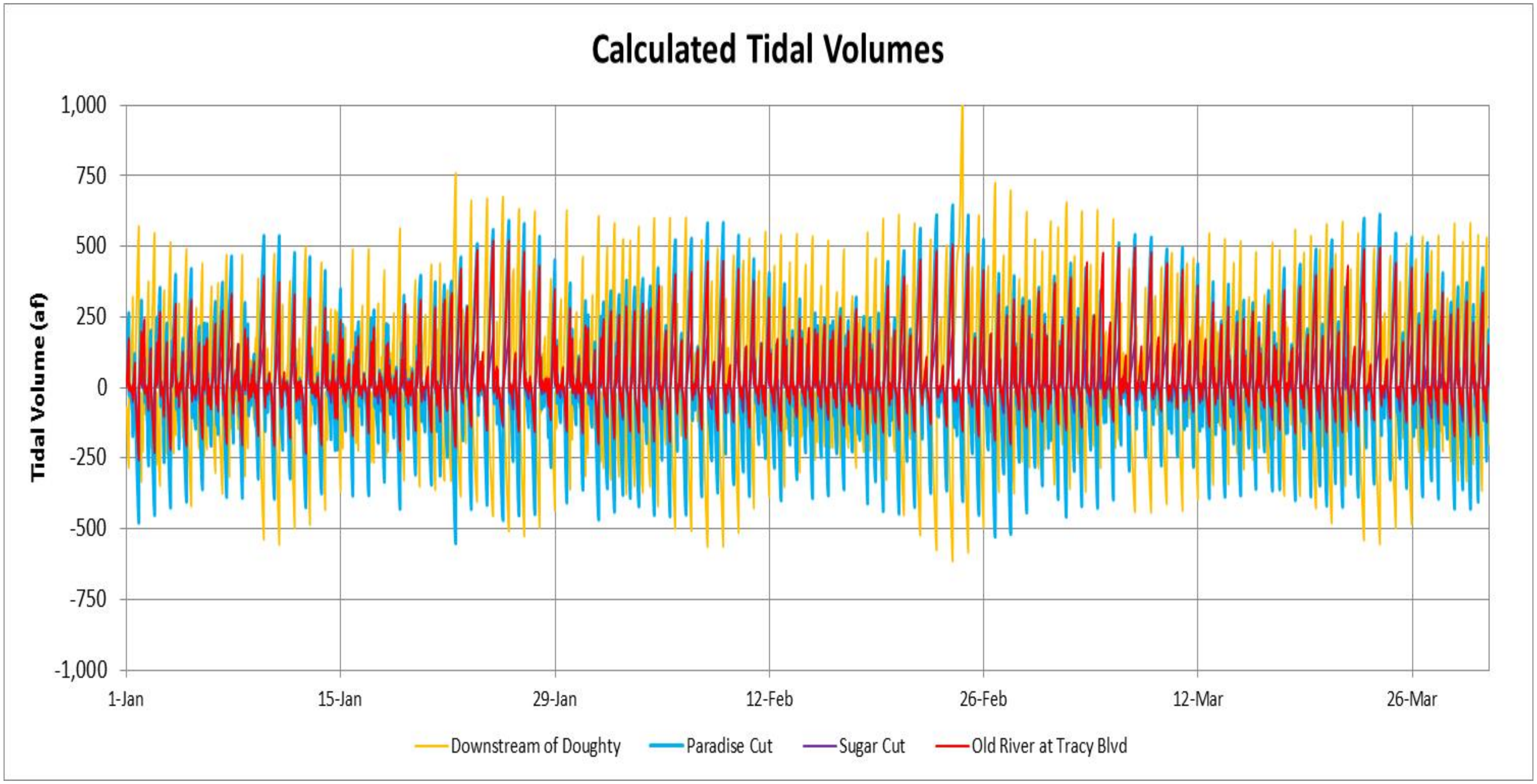
The measured flood-tide flows in Grant Line Canal were increased in June compared to the calculated tidal flows, because the Old River at DMC barrier blocked most of the flood-tide flows in Old River, shifting the tidal flows to Grant Line Canal.



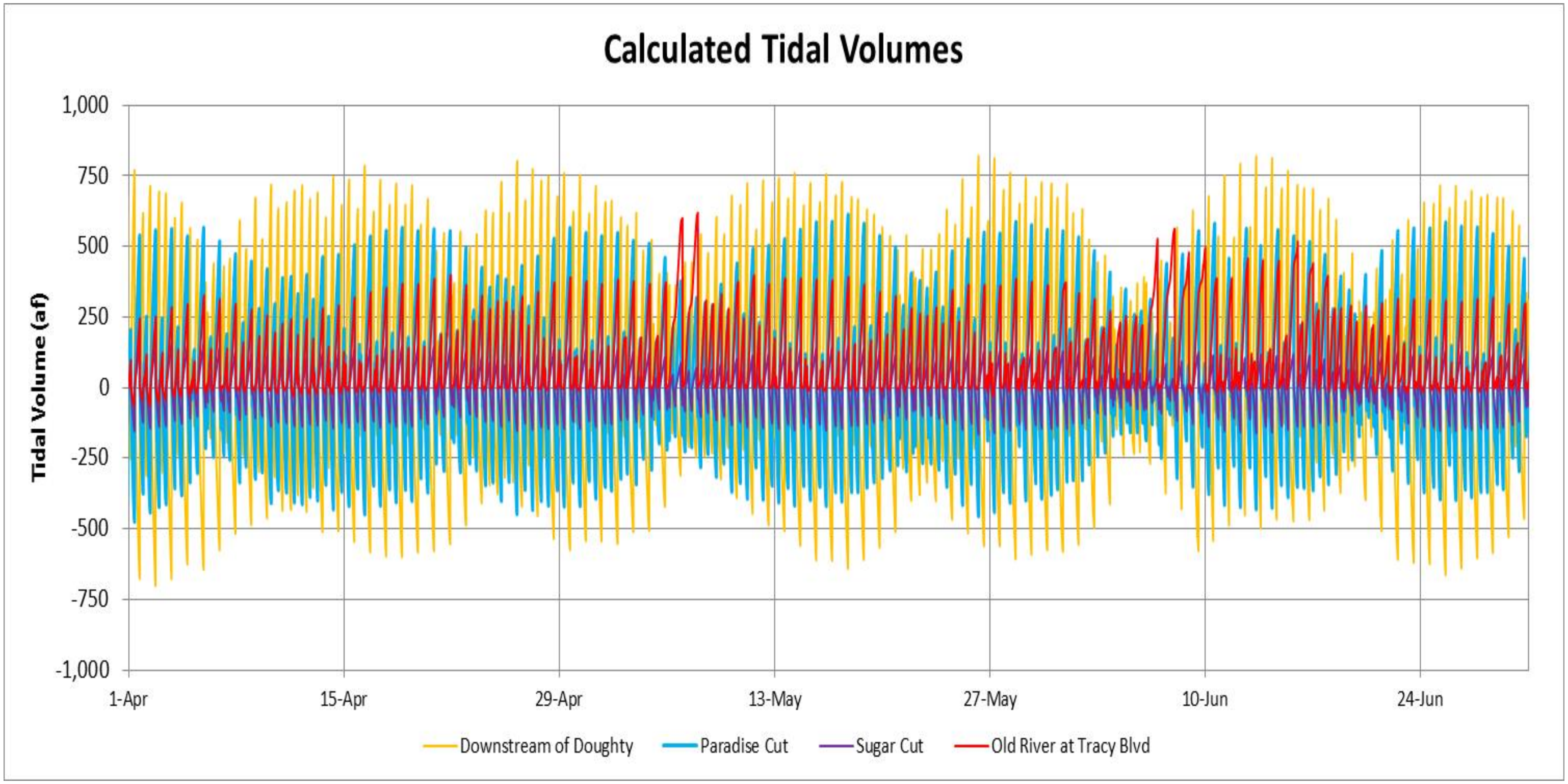
The calculated ebb-tide flow volumes in Grant Line Canal were reduced in the July-September period because the Old River flows were lower. The calculated flood-tide flow volumes remained about the same. Measured tidal flows were not available for most of this period.



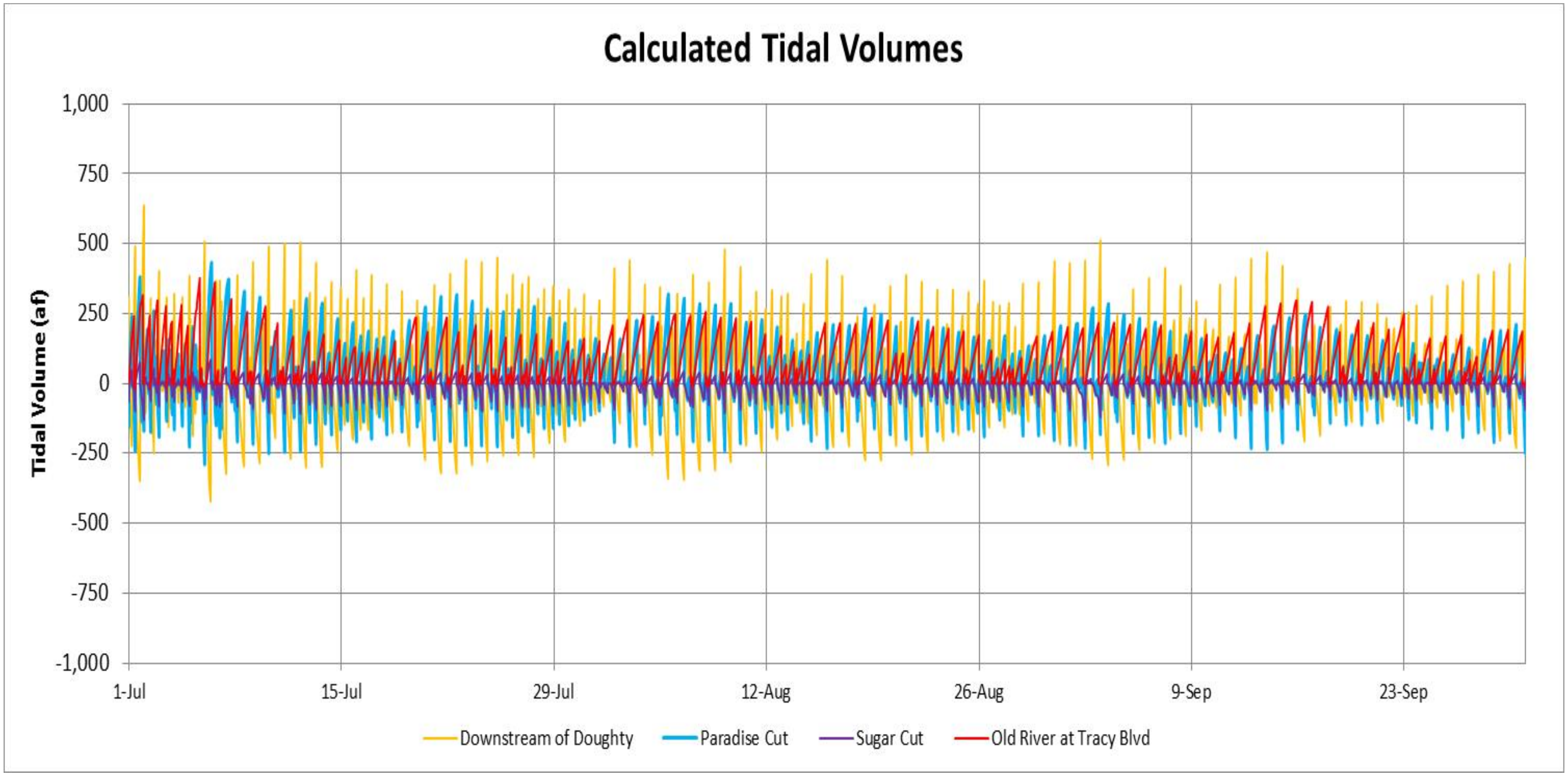
The calculated tidal flow volumes in Grant Line Canal were higher than the measured tidal flow volumes in October (with barriers) but were less than the measured flow volumes in November and December after the barrier was removed. The upstream surface area is greater than 750 acres without barriers and is less than 750 acres with the barriers.



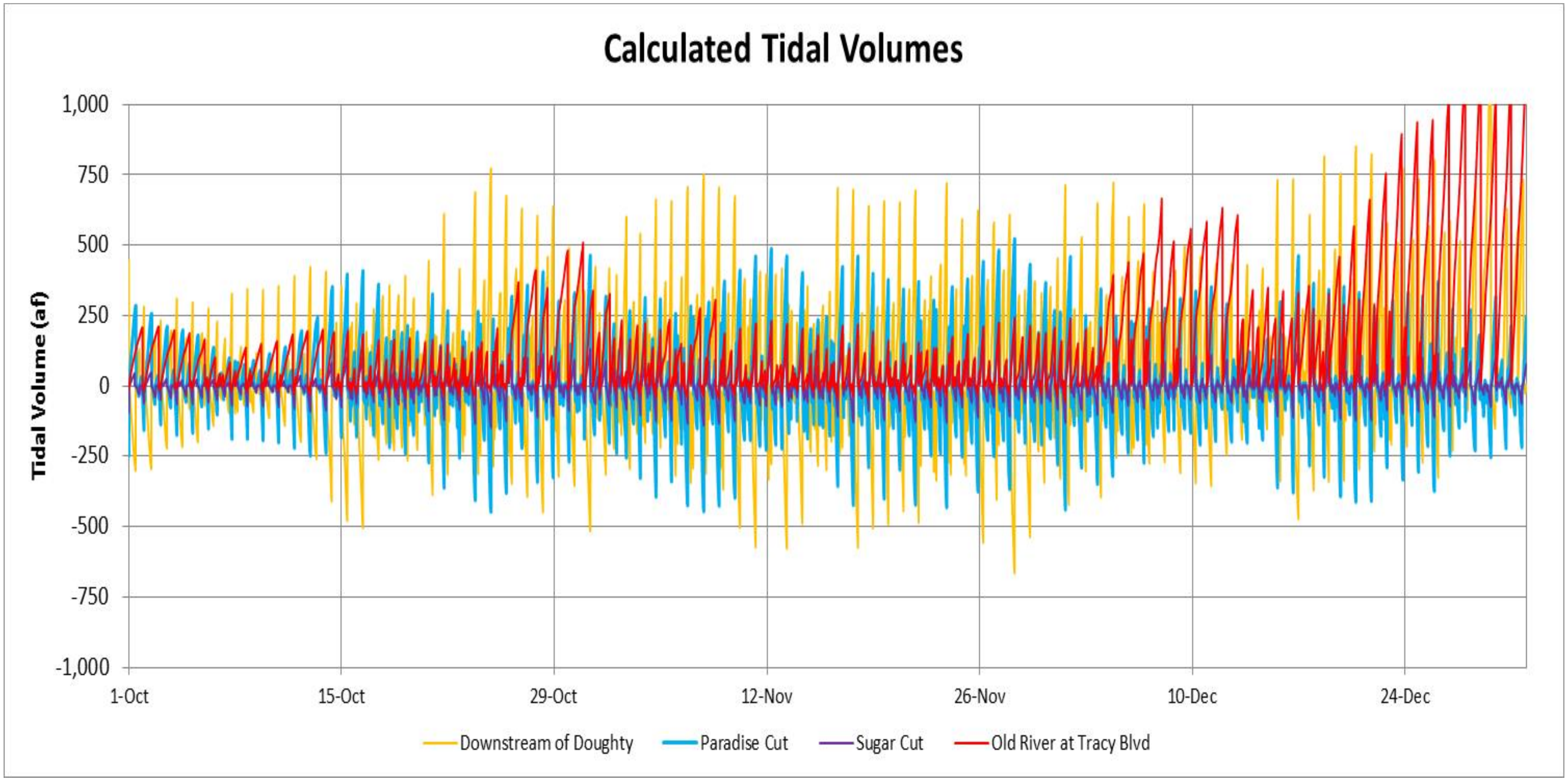
Tidal flow calculations for Old River at Doughty Cut, Paradise Cut, Sugar Cut, and Old River at Tracy Boulevard illustrate the movement of water from Paradise Cut and Sugar Cut during ebb tide (positive). The ebb-tide flow volumes from Paradise Cut and Sugar Cut are somewhat greater than the ebb-tide flow volumes at Tracy Boulevard, so some of the flow and salt moves into Old River and upstream to Doughty Cut. The details of the tidal flows in Old River downstream of Doughty Cut (gold line) and at Tracy Boulevard (red line) control the fraction of the salt load from Sugar Cut and from Paradise Cut that moves past Tracy Boulevard.



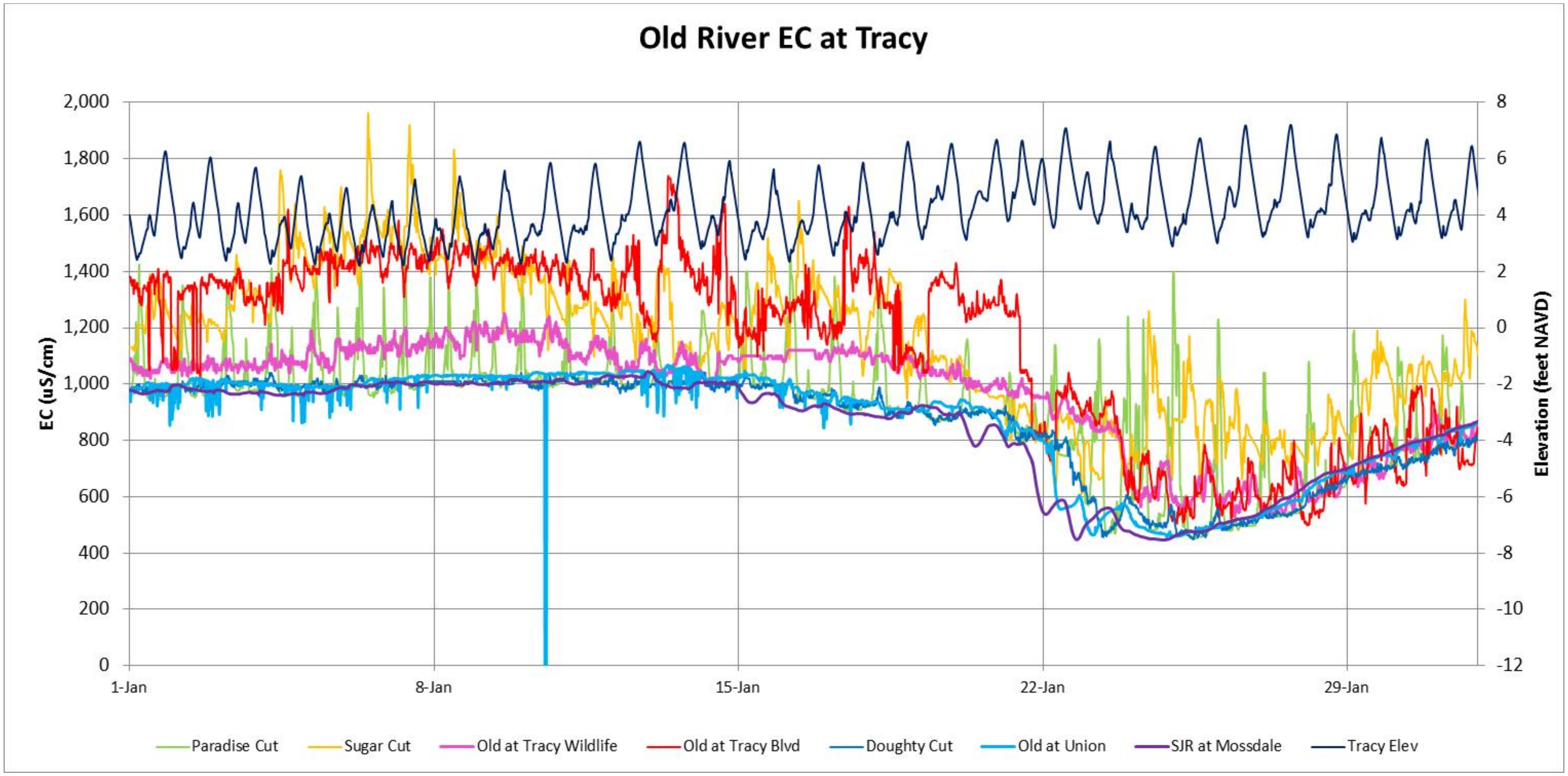
The calculated ebb-tide flow volumes (positive) for Paradise Cut and Sugar Cut are similar to the ebb-tide flow volume at Old River at Tracy Boulevard for April-June, so most of the ebb-tide flow moves downstream past Tracy Boulevard. The details of the tidal flows in Old River downstream of Doughty Cut (gold line) and at Tracy Boulevard (red line) control the fraction of the salt load from Sugar Cut and from Paradise Cut that moves past Tracy Boulevard.



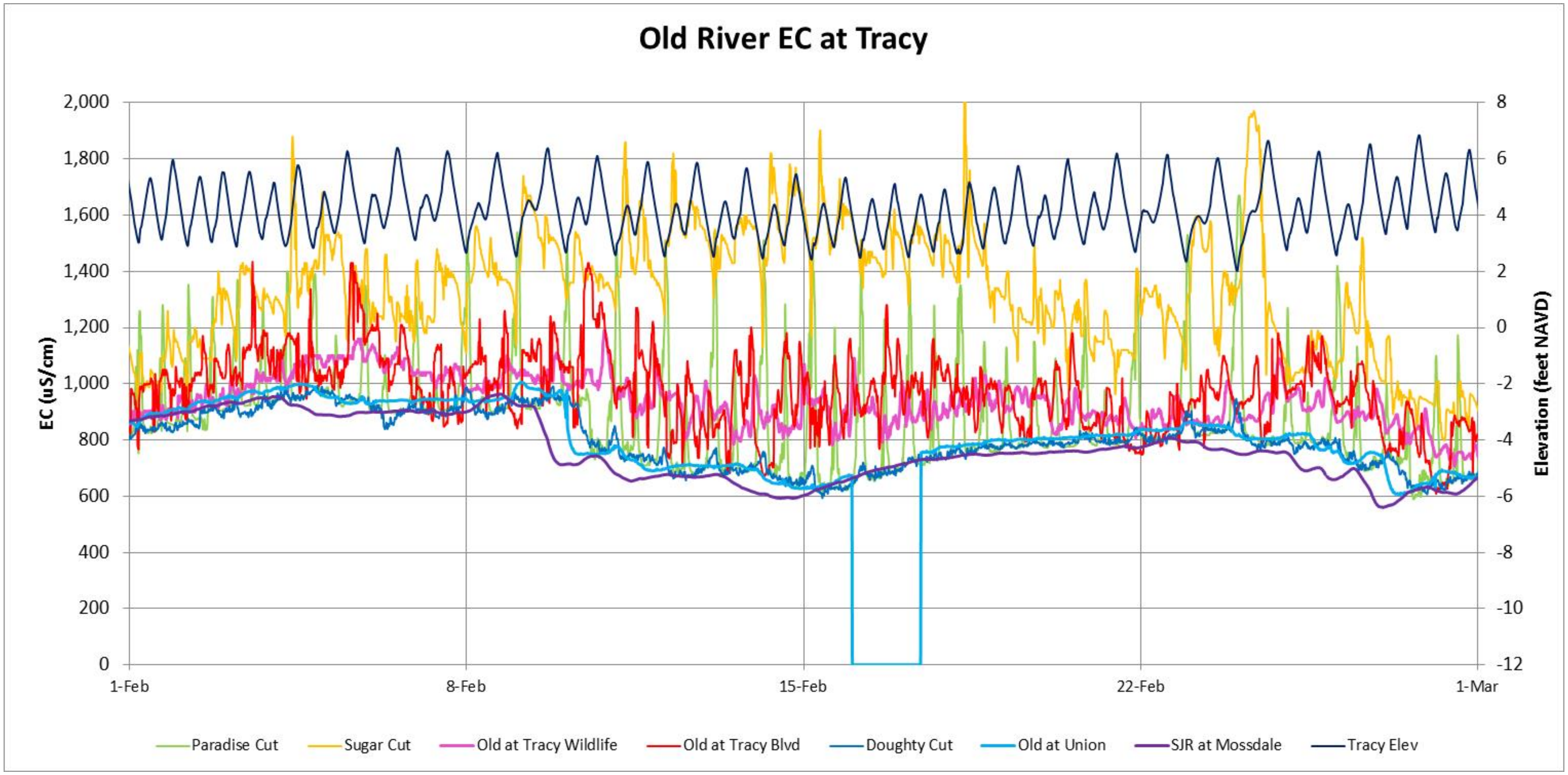
The calculated tidal flow volumes at Doughty Cut, Paradise Cut, Sugar Cut, and Old River at Tracy Boulevard for July-September were much less than the tidal flow volumes in January-June because the temporary barriers reduced the tidal flows upstream of the barriers. The details of the tidal flows in Old River downstream of Doughty Cut (gold line) and at Tracy Boulevard (red line) control the fraction of the salt load from Sugar Cut and from Paradise Cut that moves past Tracy Boulevard.



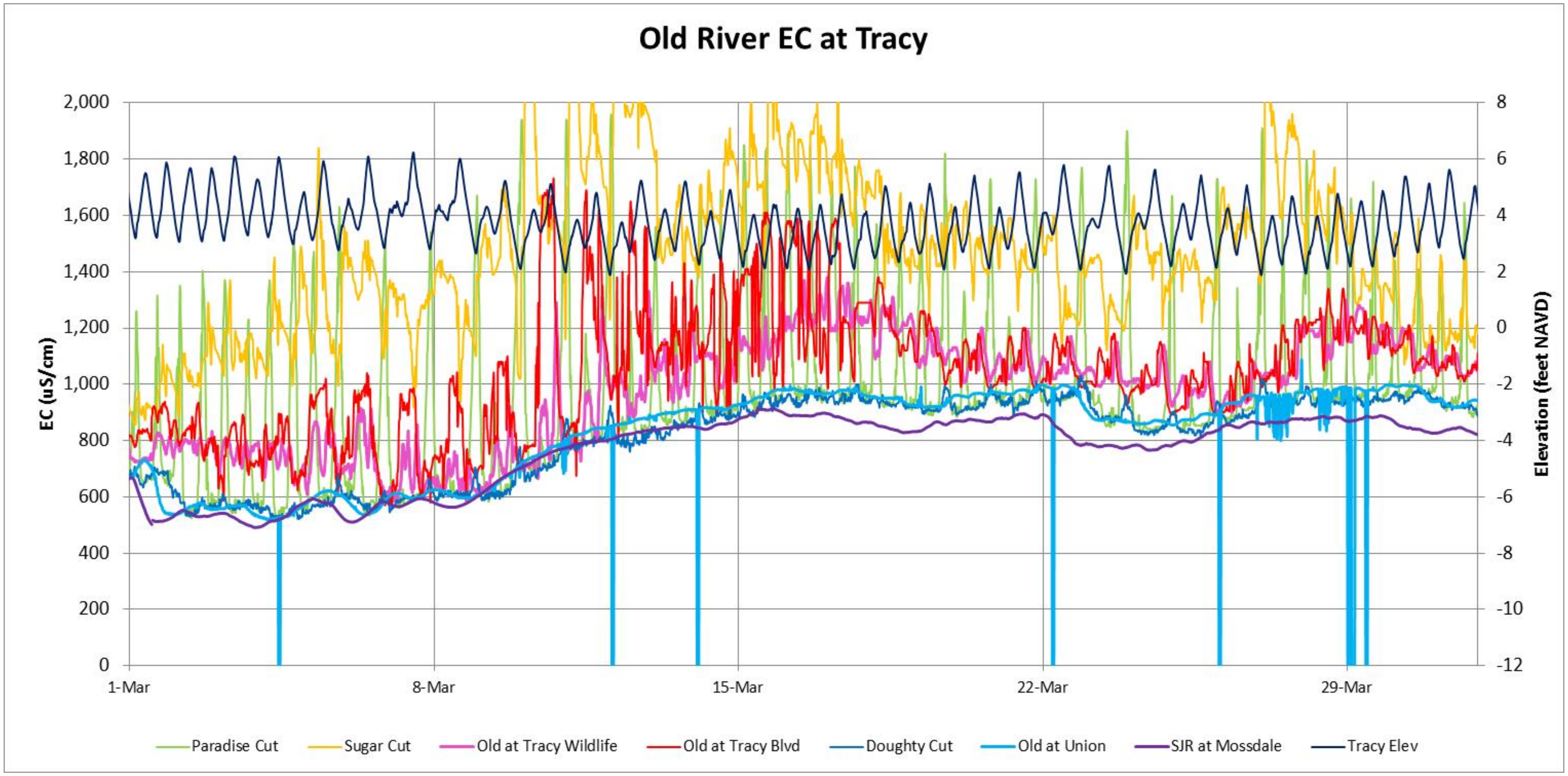
The calculated tidal flow volumes at Doughty Cut, Paradise Cut, Sugar Cut, and Old River at Tracy Boulevard for October were less than the tidal flow volumes in November and December because the temporary barriers reduced the tidal flows upstream of the barriers. The details of the tidal flows in Old River downstream of Doughty Cut (gold line) and at Tracy Boulevard (red line) control the fraction of the salt load from Sugar Cut and from Paradise Cut that moves past Tracy Boulevard.



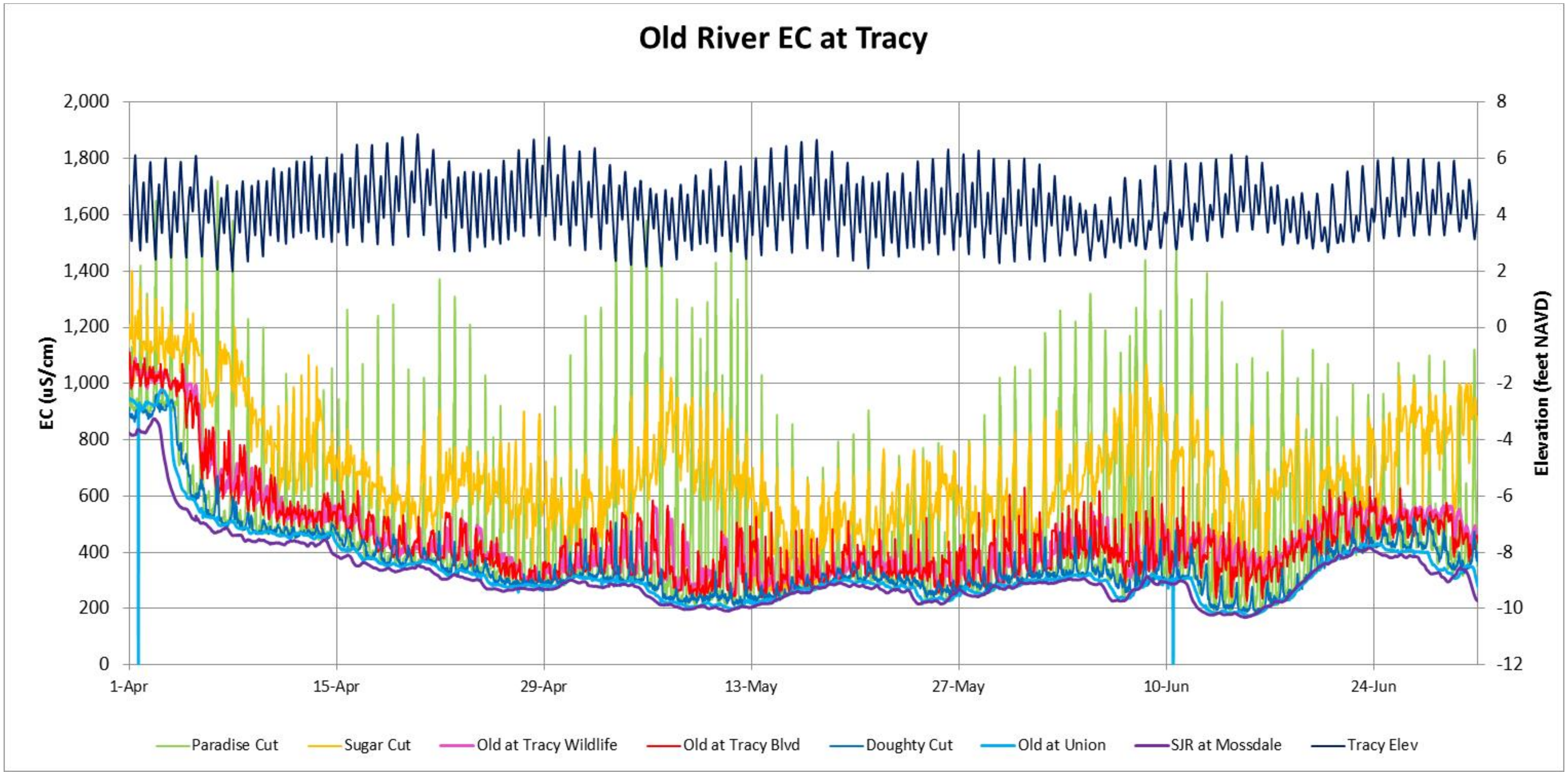
The salinity (EC) in Old River is generally controlled by the SJR EC. The SJR at Mossdale EC (purple line) and the Old River at Union EC (light blue line) and the Doughty Cut EC (dark blue line) were similar in January, beginning at 1,000 uS/cm (the Vernalis and south Delta EC objective for January) and decreasing with higher SJR flow to 500 uS/cm at the end of the month. The EC in Old River at Tracy Boulevard (red line) was much higher (200 to 400 uS/cm) than the EC at Tracy Wildlife at the beginning of the month. The EC increment at Tracy Boulevard and Tracy Wildlife was about 100-200 uS/cm. The Paradise Cut EC (green line) had a very large tidal variation of 200-600 uS/cm above the Old River EC, with the maximum EC at low tide each day, caused by the tidal movement of higher EC from the upstream end of Paradise Cut. The Sugar Cut EC (gold line) was also higher than the Old River EC, with a tidal variation of 200-400 uS/cm. The Sugar Cut EC measurement is midway upstream, and Old River water is not transported to the EC stations, so the Sugar Cut EC remains higher than Old River at Doughty Cut.



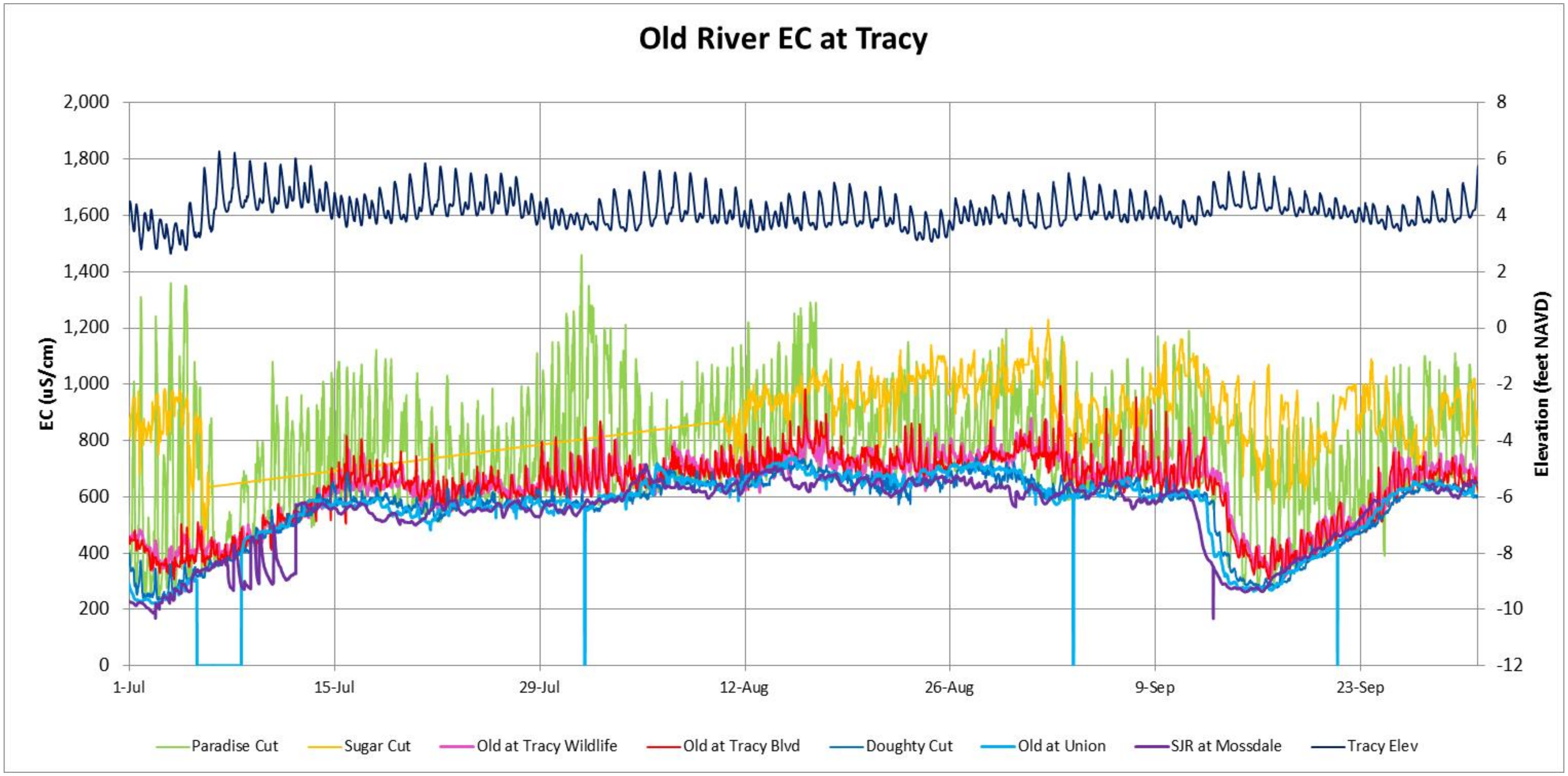
The Old River EC ranged from 600-1,000 uS/cm in February. The EC in Old River at Tracy Boulevard (red line) and at Tracy Wildlife (pink line) fluctuated during most days between the Doughty Cut EC and about 200-400 uS/cm higher. The Paradise Cut EC (green line) had a very large tidal variation of 400-800 uS/cm above the Old River EC, with the maximum EC at the lowest tides, caused by ebb-tide movement of higher EC from the upstream end of Paradise Cut. The Sugar Cut EC (gold line) remained higher than the Old River EC, with a tidal variation of 200 uS/cm on most days. The maximum Sugar Cut EC of about 1,500 uS/cm in the middle of the month indicates a buildup of salt during these days with reduced tidal fluctuation (neap-tides).



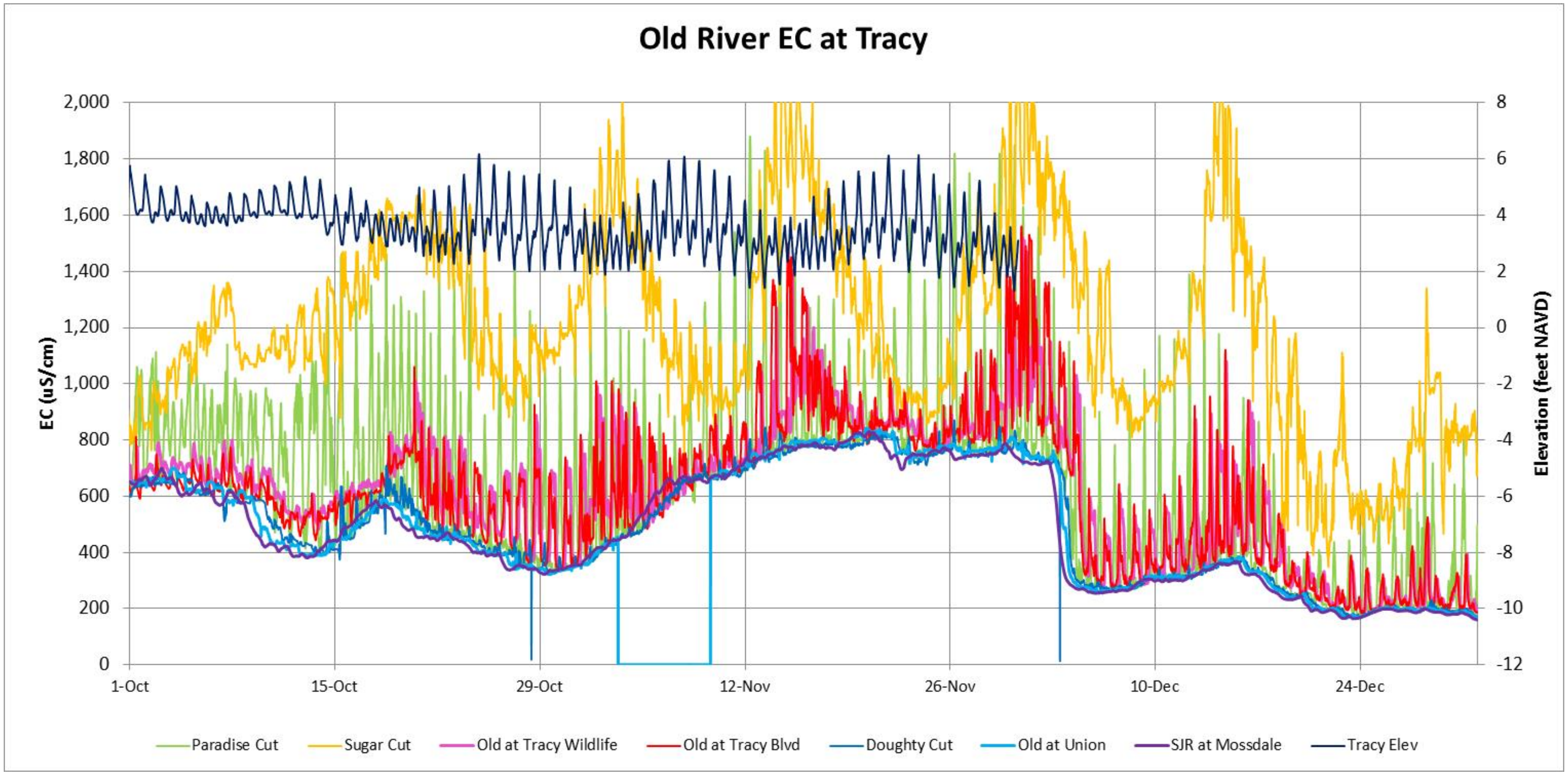
The Old River EC at Union and Doughty Cut ranged from 600-1,000 uS/cm in March. The EC in Old River at Tracy Boulevard (red line) and Tracy Wildlife fluctuated during most days between the Doughty Cut EC and about 200-400 uS/cm higher. The Tracy Boulevard EC measurements appear to be erratic in the middle of the month, but matched the Tracy Wildlife EC in the remainder of the month. The Paradise Cut EC (green line) had a very large tidal variation of 400-1,000 uS/cm above the Old River EC, with the maximum EC at the lowest tides. The Sugar Cut EC (gold line) remained higher than the Old River EC, with a tidal variation of 200-400 uS/cm on most days. The maximum Sugar Cut EC of about 2,000 uS/cm in the middle of the month indicates a buildup of salt during these days with reduced tidal fluctuation (neap-tides).



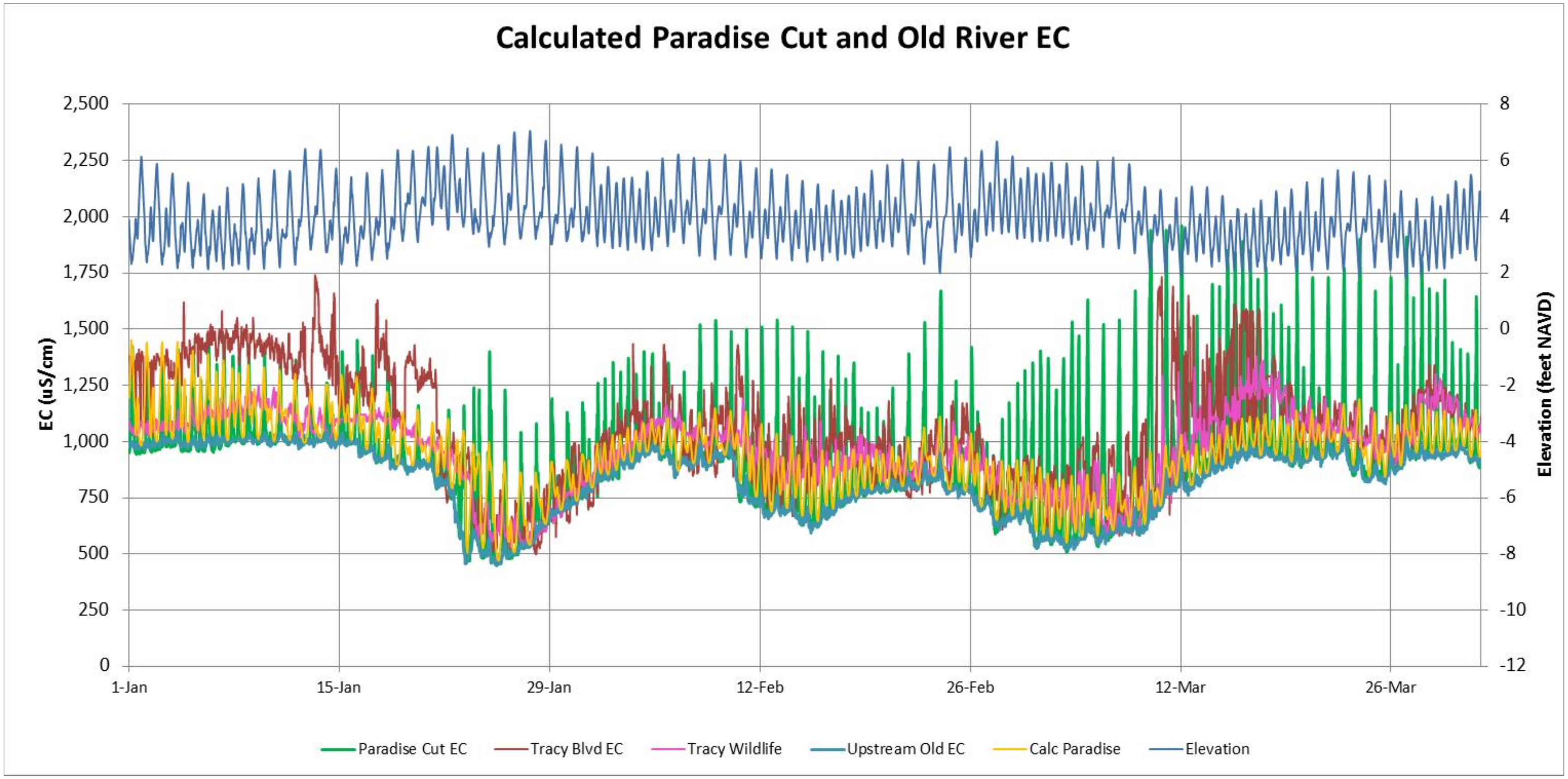
Because of increased SJR flows in April-June, the SJR EC was reduced to about 200-400 uS/cm. The Old River at Tracy Boulevard EC (red line) showed a more sustained daily maximum during the April-June period. The Old River at Tracy Wildlife EC (pink line) was nearly identical to the Tracy Boulevard EC. The Old River at DMC temporary barrier was installed at the beginning of June, but no changes in the Old River at Tracy Boulevard EC were observed. The tidal variations in Paradise Cut and Sugar Cut EC values remained similar to those measured in January-March. The tidal variation in Paradise Cut EC was greater than 1,000 uS/cm in early May and early June. During these same periods, the Sugar Cut EC was increased, suggesting less complete tidal flushing of the tidal sloughs during these neap tides (lower high tides).



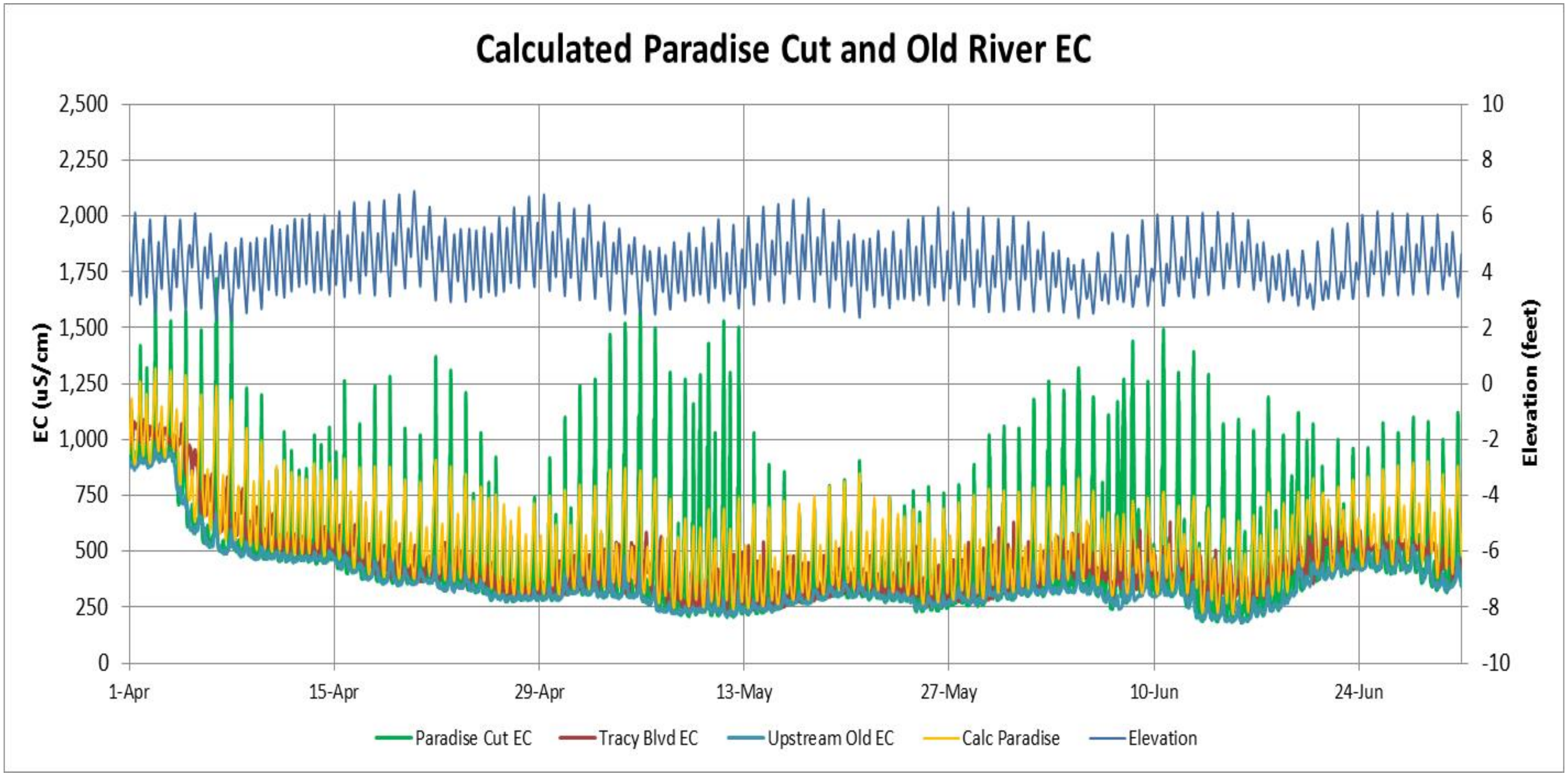
The SJR at Mossdale and Old River at Union EC were quite uniform at 600 uS/cm from mid-July to mid-September. The tidal variations in Paradise Cut EC were 200-600 uS/cm during these summer months. The Old River at Tracy Boulevard and Tracy Wildlife EC variations were 100-200 uS/cm and the average EC was about 50-100 uS/cm higher than the Doughty Cut EC. The maximum EC in Sugar Cut was similar to the maximum EC in Paradise Cut (suggesting similar source EC), but the Sugar Cut EC remained higher that the Old River EC throughout the tidal cycle.



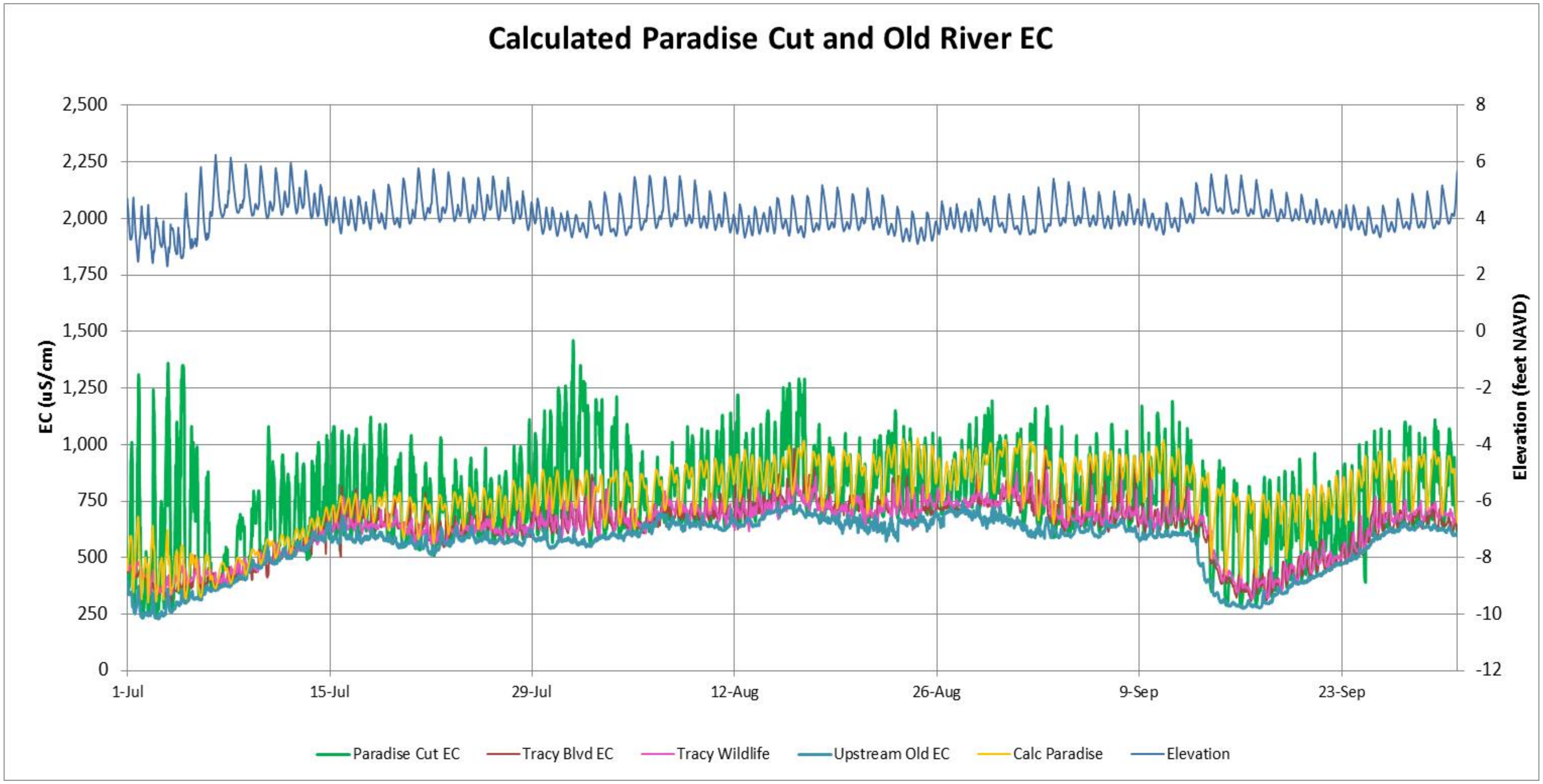
The effects of the spring-neap tidal cycle (daily range of tidal elevations) on the Sugar Cut EC were pronounced in the October-December period. The tidal variations of EC in Old River at Tracy Boulevard and Tracy Wildlife were also increased. The temporary barriers were removed at the end of October, which may have allowed the spring-neap tidal effects on the Paradise Cut, Sugar Cut, and Old River at Tracy Boulevard and Tracy Wildlife EC patterns to be greater. Additional EC stations located further upstream in Paradise Cut and nearer the mouth of Sugar Cut would provide additional information about the salt sources and tidal flushing of these tidal sloughs. An additional EC station in Old River between Tracy Boulevard and the DMC barrier would also provide additional useful information.



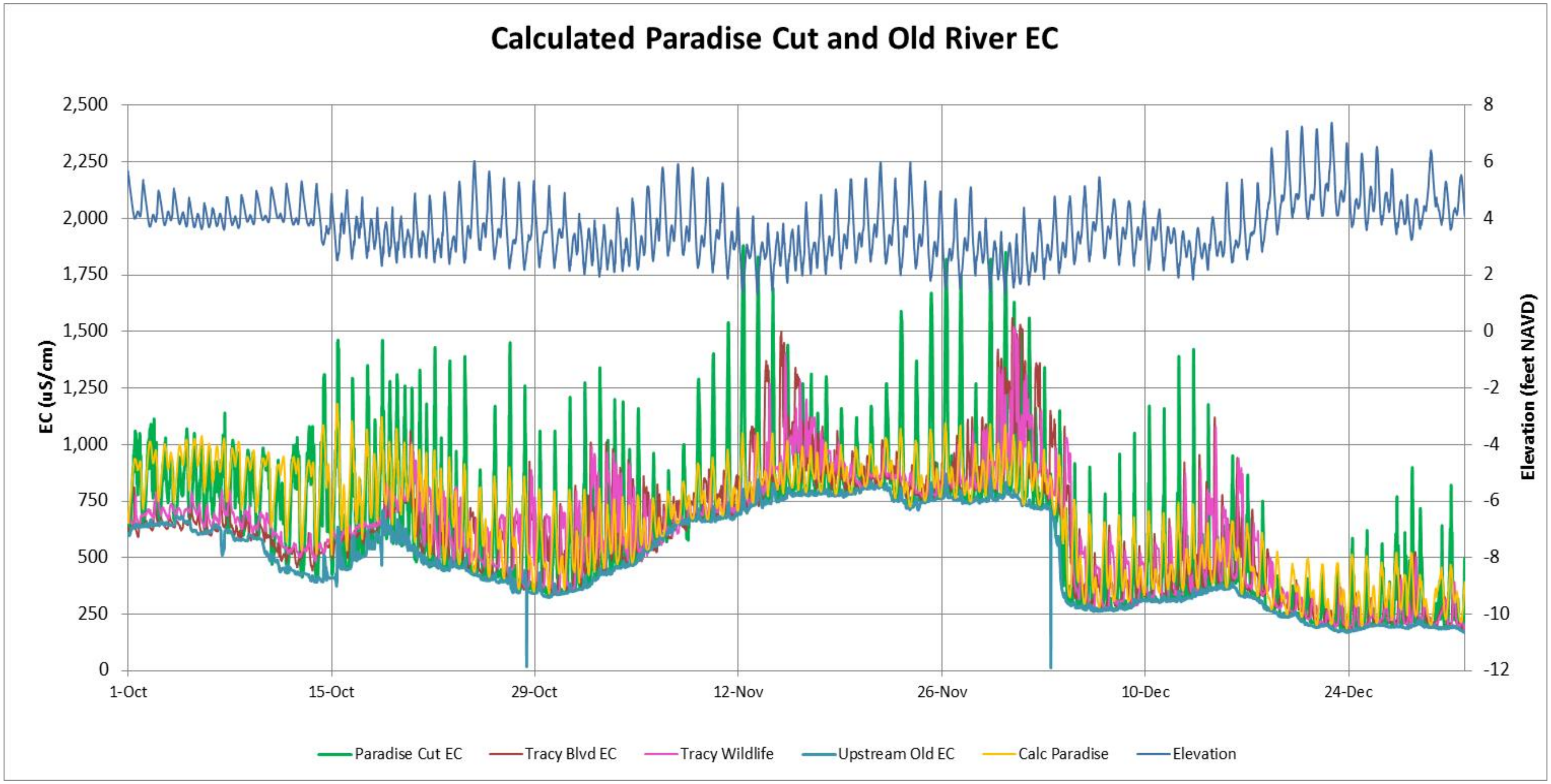
The Paradise Cut EC was calculated from the measured tidal elevations (blue line) and assumed geometry segments for Paradise Cut. The salt source was assumed to enter at the upstream end with an EC of 3,000 cfs and a constant flow of 10 cfs (52.5 tons/day). Paradise Cut discharged water and salt to Old River during ebb tides and filled with Old River water and salt during flood tides. The calculated fluctuations of Paradise Cut EC (gold line) through this period without temporary barriers were generally 125-250 uS/cm, which were considerably less than the measured EC variations. The calculated EC at the monitoring station (using 1-km segments to calculate the salinity gradient) did not change as rapidly as the measured data (tidal movement of the salinity gradient). The measured and calculated Paradise Cut EC fluctuations suggests that the Paradise Cut salt source was relatively constant.



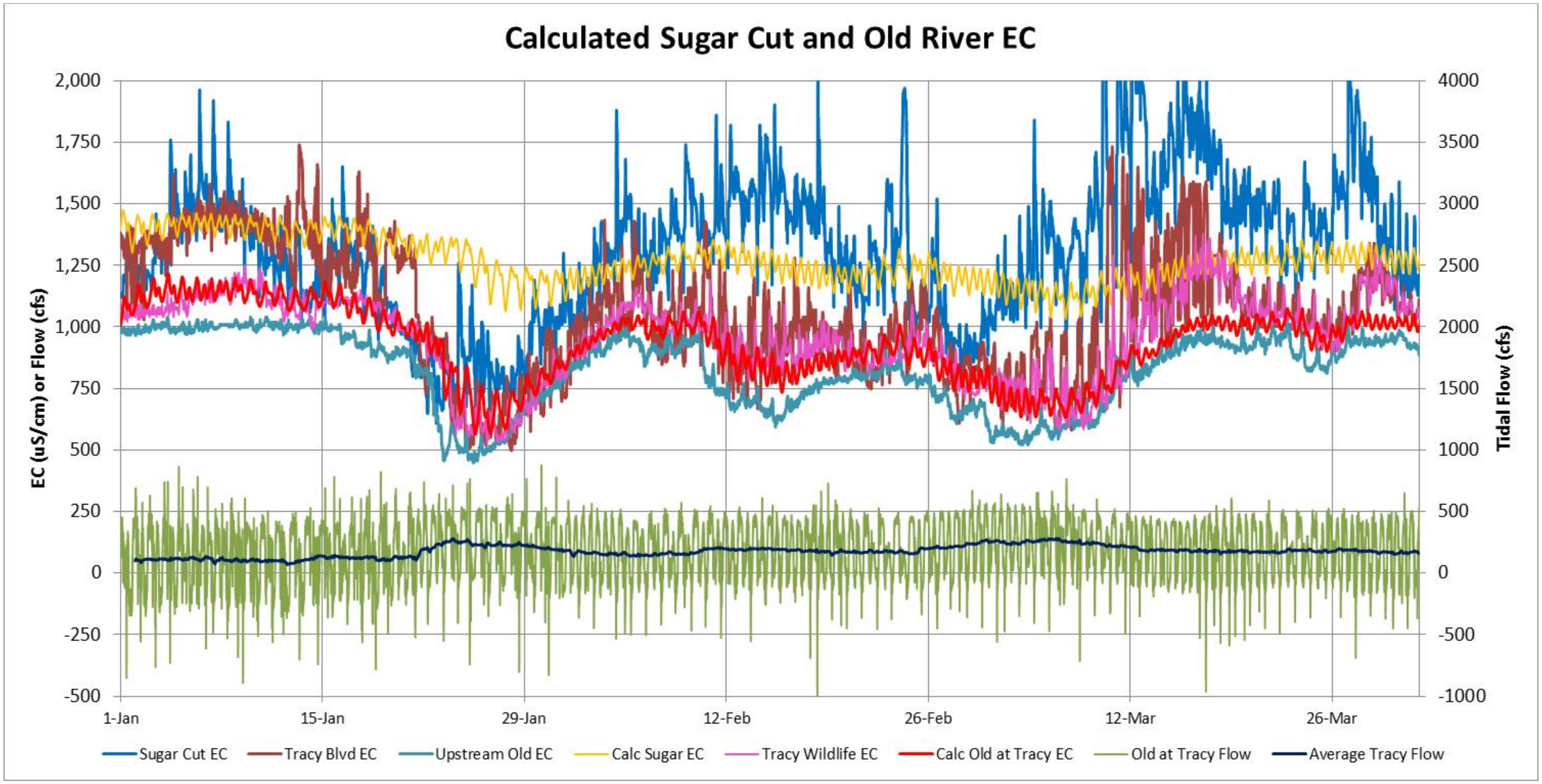
Paradise Cut was filled with Old River water during flood tide periods and the minimum Paradise Cut EC was therefore similar to the Old River EC. The maximum Paradise Cut EC was controlled by the calculated tidal flushing of the assumed salt source; the maximum EC was greatest during neap tide periods when the maximum tidal elevations were reduced (less flushing of salt). The calculated EC fluctuations were more uniform than the measured EC variations; the maximum calculated EC did not increase as much as the maximum measured EC during the neap tide periods.



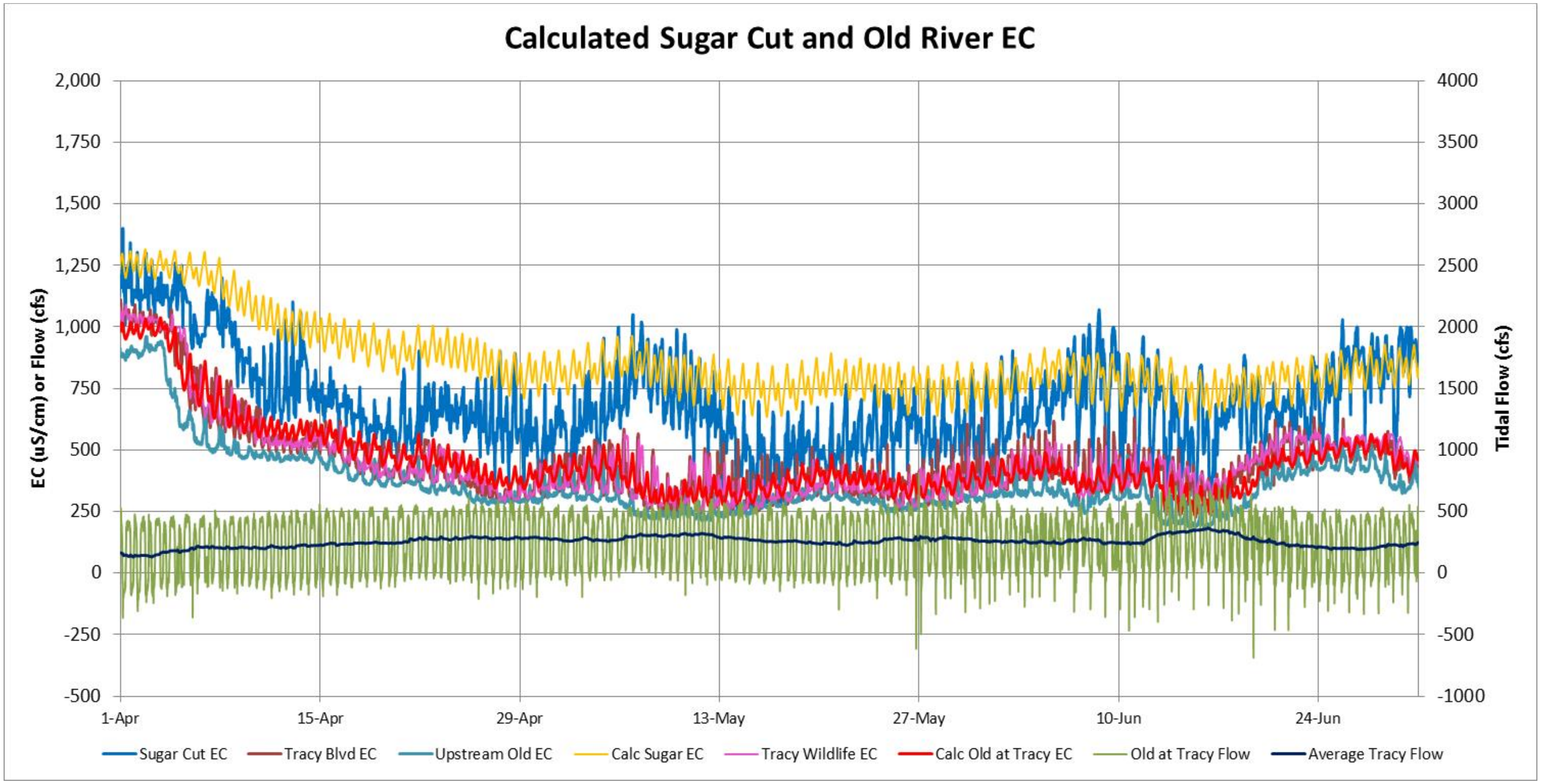
The tidal elevation variations were very small during the summer period when the Old River, Grant Line Canal and Middle River temporary barriers were installed. During this period the calculated EC variations in Paradise Cut of 250-500 uS/cm were less than the measured EC variations of 250-750 uS/cm.



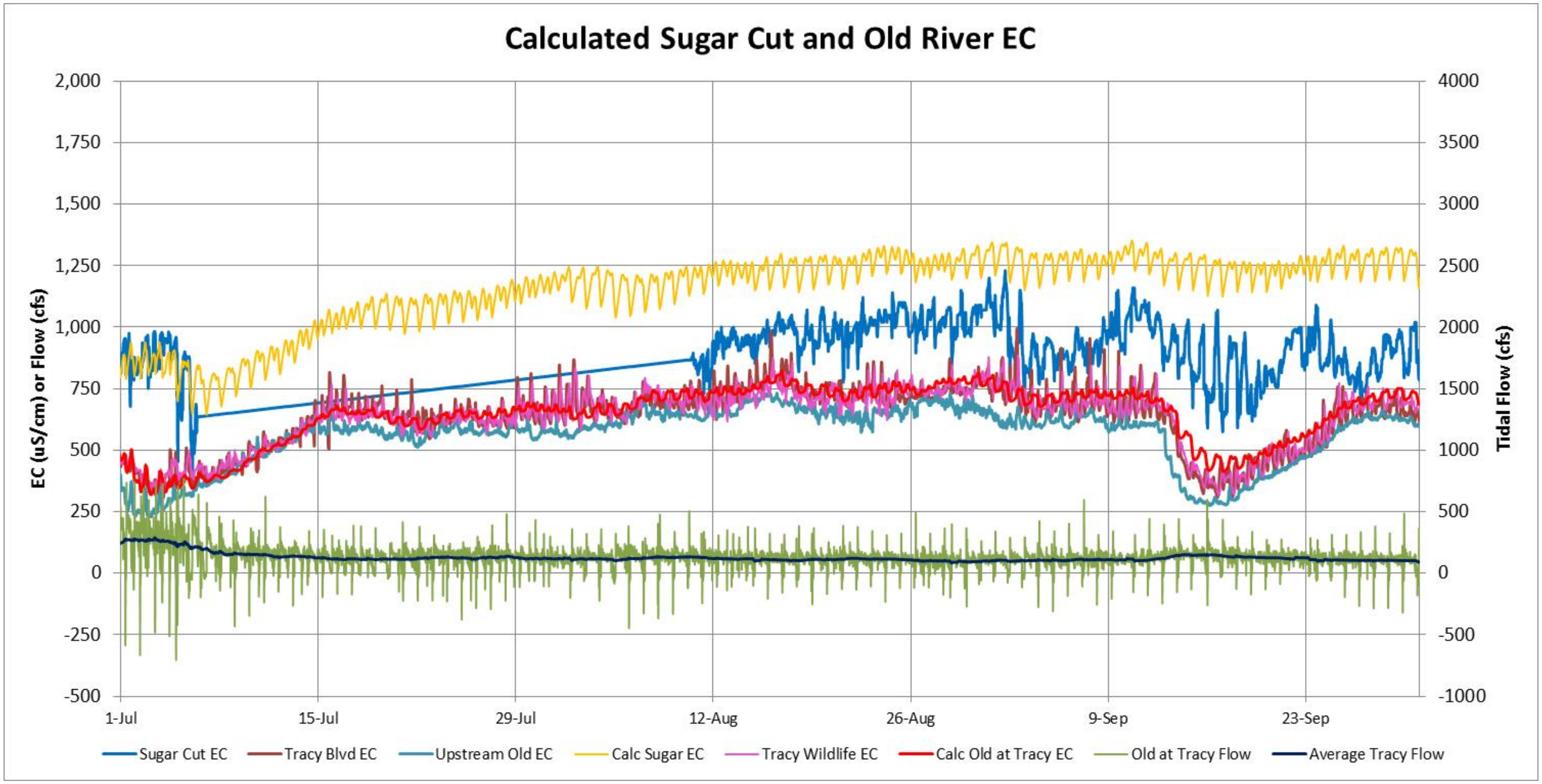
The measured Paradise Cut EC variations are controlled by several factors that are reasonably represented in the calculated Paradise Cut EC variations. The minimum EC is controlled by the Old River EC during flood tides, and the maximum EC is higher during neap-tide periods with reduced ebb tide flushing (lower tidal elevations). The assumed constant source of salt at the upper end of Paradise Cut appears to be confirmed by the general match with the measured EC throughout the year. The relatively simple tidal slough flushing calculations appear to provide a relatively good match with the Paradise Cut EC measurements for the entire year, during periods with full tidal movement (no temporary barriers) and during periods with reduced fluctuations in tidal elevations and flows (temporary barriers installed).



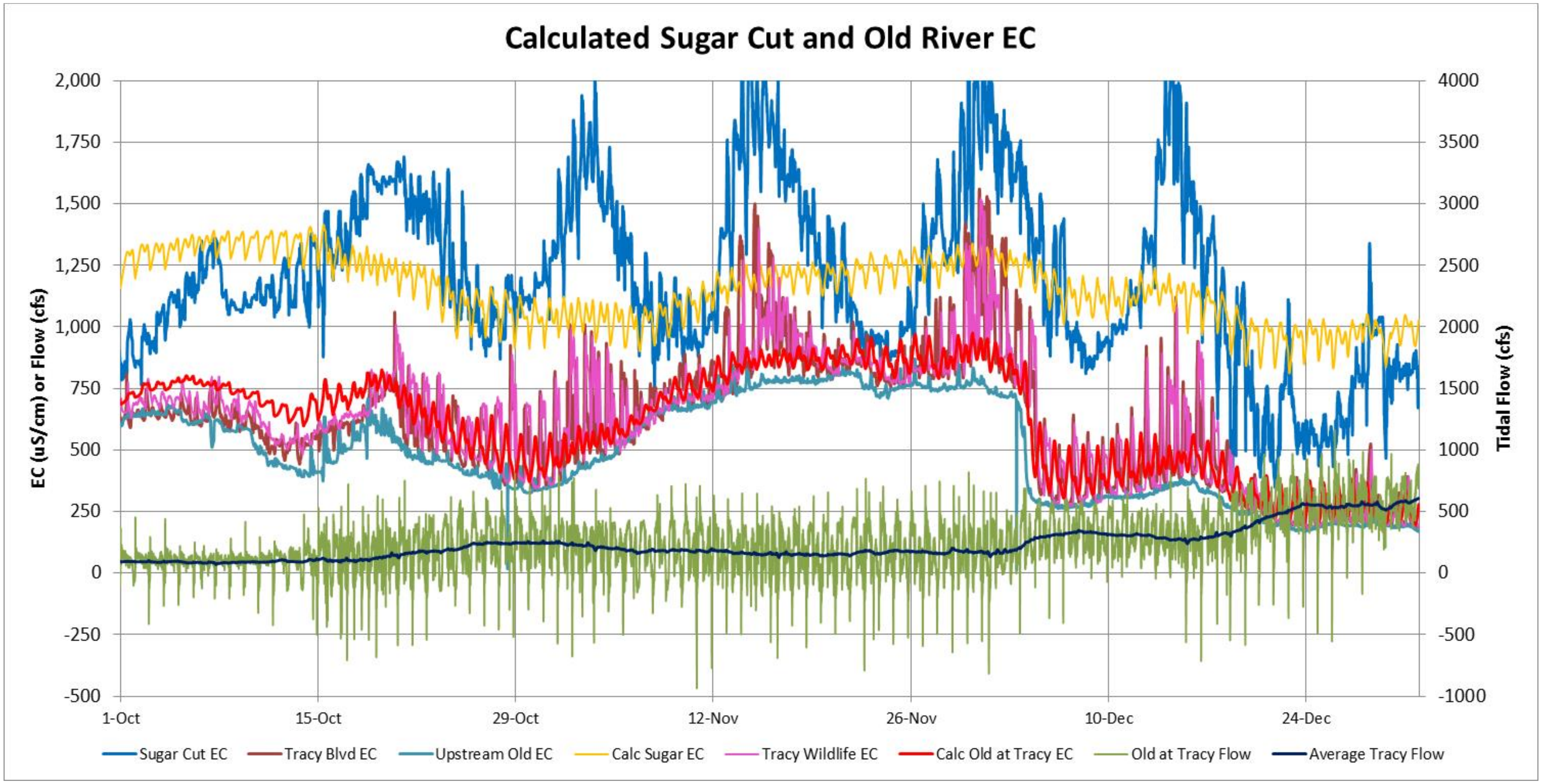
The measured Sugar Cut EC (dark blue) fluctuations were similar to the Paradise Cut EC fluctuations (previous graphs), but the minimum Sugar Cut EC was usually higher than the upstream Old River EC. This was likely caused by the EC measurements being further upstream (less flood tide flushing) and because during the summer months, the tidal gates on the Tom Paine Slough siphons divert the Old River water before it reaches the EC monitoring station. The assumed Sugar Cut salt source had an EC of 2,000 uS/cm with a flow of 10 cfs (35 tons/day). The Old River at Tracy Boulevard tidal flows were not measured in 2010; Old River at Tracy Boulevard tidal flows (green line) were estimated as 10% of the head of Old River flow. The calculated Sugar Cut EC (gold line) remained higher than the Old River EC, but the tidal variations in the calculated Sugar Cut EC were much smaller than the measured EC fluctuations. The calculated Old River at Tracy Boulevard EC matched the Tracy Wildlife EC, with an EC increment of about 50-150 uS/cm.



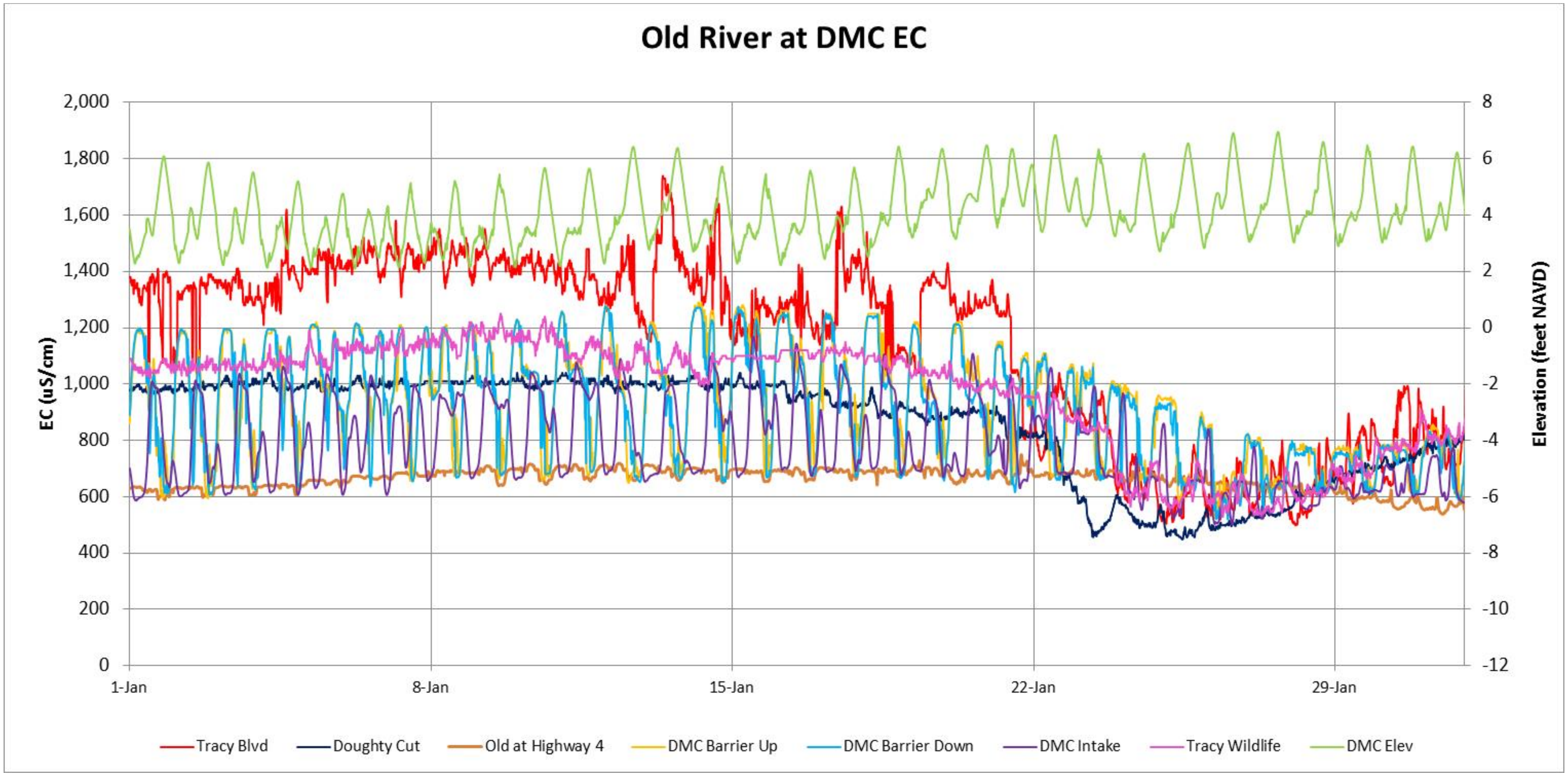
The calculated Sugar Cut EC was very uniform during the April-June period, with an average EC of about 750 uS/cm, about 500 uS/cm higher than the Old River EC of 250 uS/cm (relatively high SJR and Old River flow). The calculated Old River at Tracy Boulevard EC was similar to the measured EC at Tracy Boulevard (brown line) and Tracy Wildlife (pink line). Because there were no estimated upstream flows in Old River at Tracy Boulevard, most of the assumed salt loads from Paradise Cut and Sugar Cut were transported downstream to Tracy Boulevard (red line); only the water and salt diverted from Sugar Cut at the Tom Paine siphons would not have reached Tracy Boulevard. The calculated effects of the ebb tide flows and EC from Paradise Cut and Sugar Cut on the downstream Old River at Tracy Boulevard EC (red line) were generally similar to the measured EC at Tracy Boulevard (dark red line).



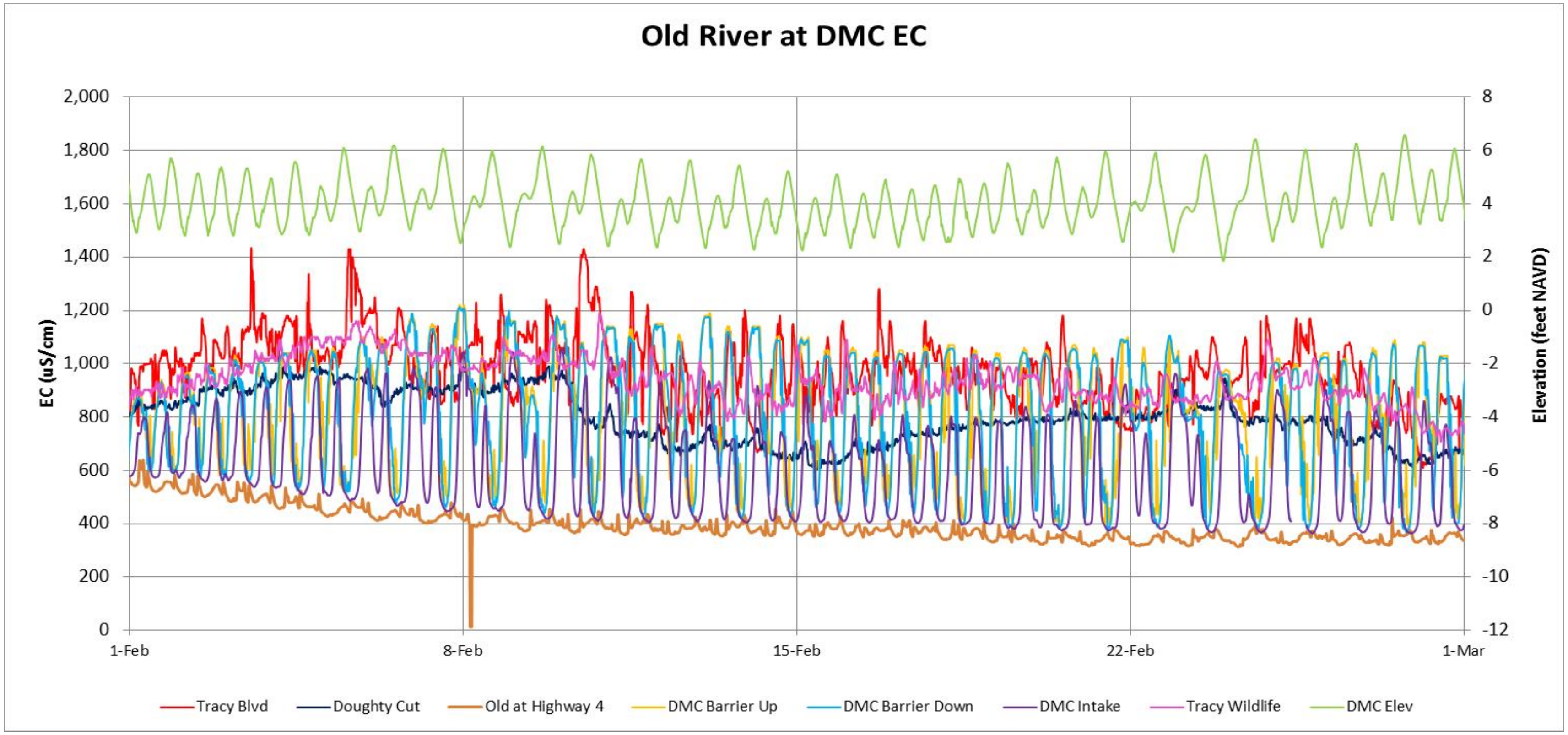
The calculated Sugar Cut EC was higher than the measured Sugar Cut EC during the July-September period when the temporary barriers were installed. However, the calculated Old River at Tracy Boulevard EC was very similar to the measured EC at Tracy Boulevard and at Tracy Wildlife. A considerable portion of the Sugar Cut EC source is diverted to Tom Paine Slough during the irrigation season, and there is less flood-tide movement of water upstream of the Tom Paine diversion dam. The Sugar Cut EC station is located upstream of the Tom Paine diversion dam and the lowest EC is measured at high tide each day, when some Old River water flows in to the upstream portion of Sugar Cut.



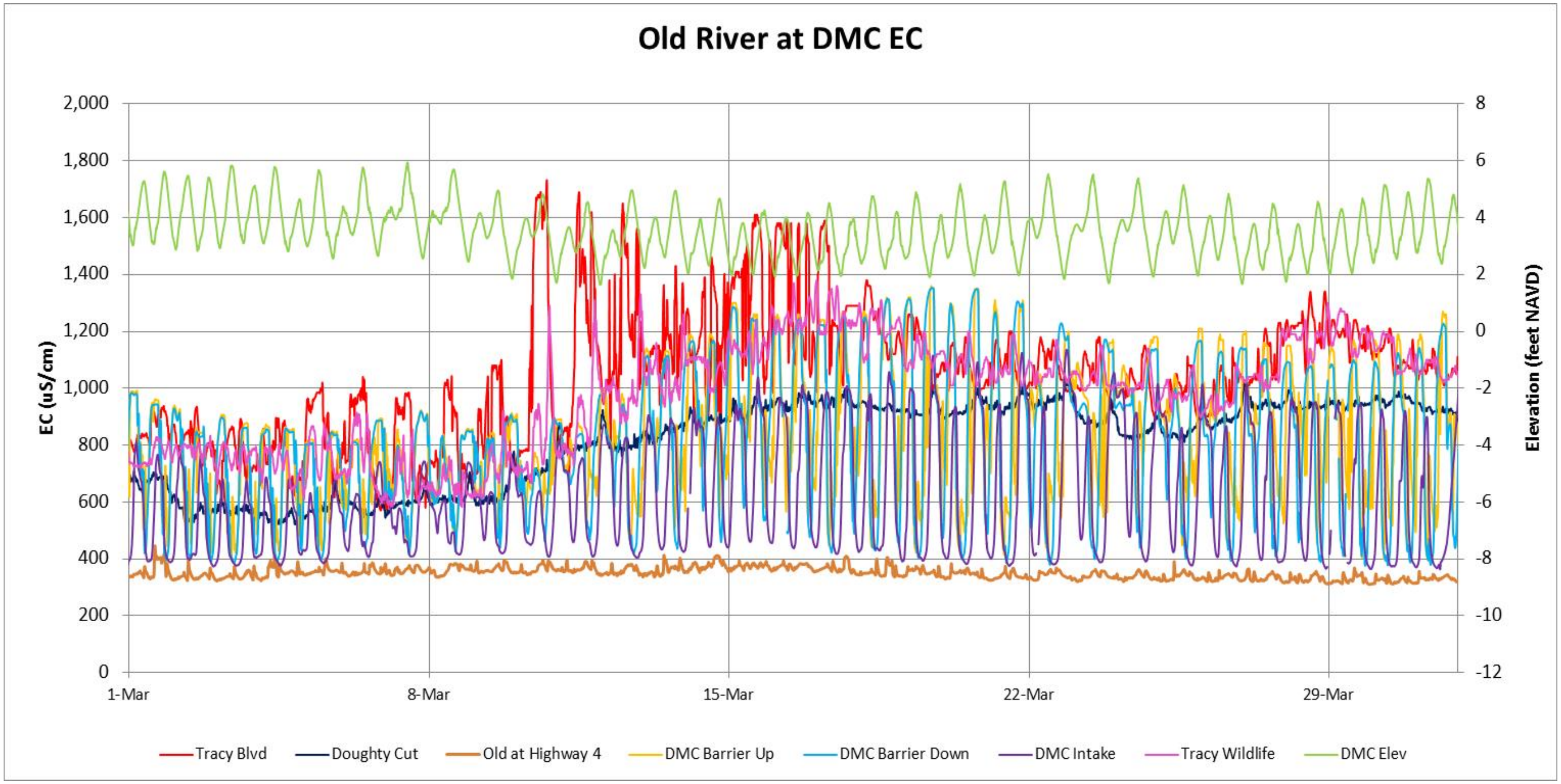
The calculated Sugar Cut EC in the October-December period was about 500-750 uS/cm higher than the Old River EC, but did not match the higher Sugar Cut EC measured during neap-tide periods (reduced tidal elevation range). The calculated effects on the Old River at Tracy Boulevard EC generally matched the measured EC at Tracy Boulevard and Tracy Wildlife. This suggests that the basic mechanisms of 1) tidal flushing of both Paradise Cut and Sugar Cut to Old River, with 2) downstream movement of higher salinity water to Tracy Boulevard, located about 2 miles downstream of Sugar Cut. The measured increase in Old River EC between Old River at Doughty Cut and Old River at Tracy Boulevard compliance station was generally matched with the assumed constant salt source from Paradise Cut and Sugar Cut. The EC increments were greatest during periods of low Old River flow. However, because the Old River at Tracy Boulevard flow was not measured in 2010, some of the calculated EC increments may not be accurate.



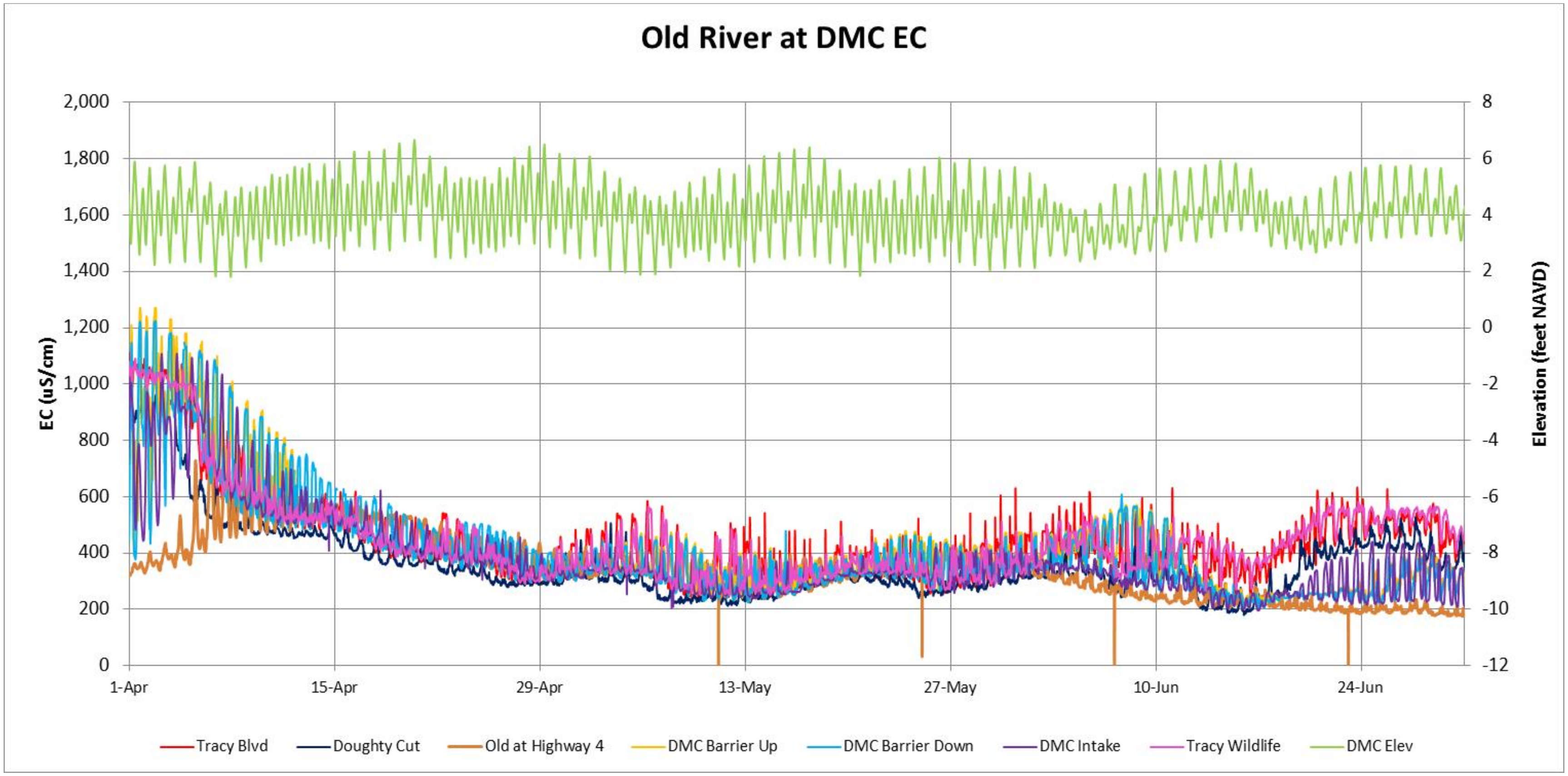
The Old River EC near the DMC barrier in January 2010 fluctuated with the tidal elevations (flows) because high EC water from upstream was measured at low tide and lower EC water from downstream (central Delta) was measured at high tide. The EC upstream of the DMC barrier (gold line) and the EC downstream of the DMC barrier (light blue line) were nearly identical during January 2010 (no barrier). At high tide, the minimum daily EC matched the Old River at Highway 4 EC (brown line) of about 600 uS/cm, and at low tide the maximum daily EC at the DMC stations was about 1,200 uS/cm. The maximum daily EC at the DMC barrier was about 200 uS/cm higher than the Doughty Cut EC (dark blue line) and matched the Tracy Wildlife EC, but was considerably less than the Tracy Boulevard EC (red line). The Tracy Wildlife EC is confirmed by the maximum EC at the DMC stations; the Tracy Boulevard EC was about 250 uS/cm high (until corrected on January 21 (field visit).



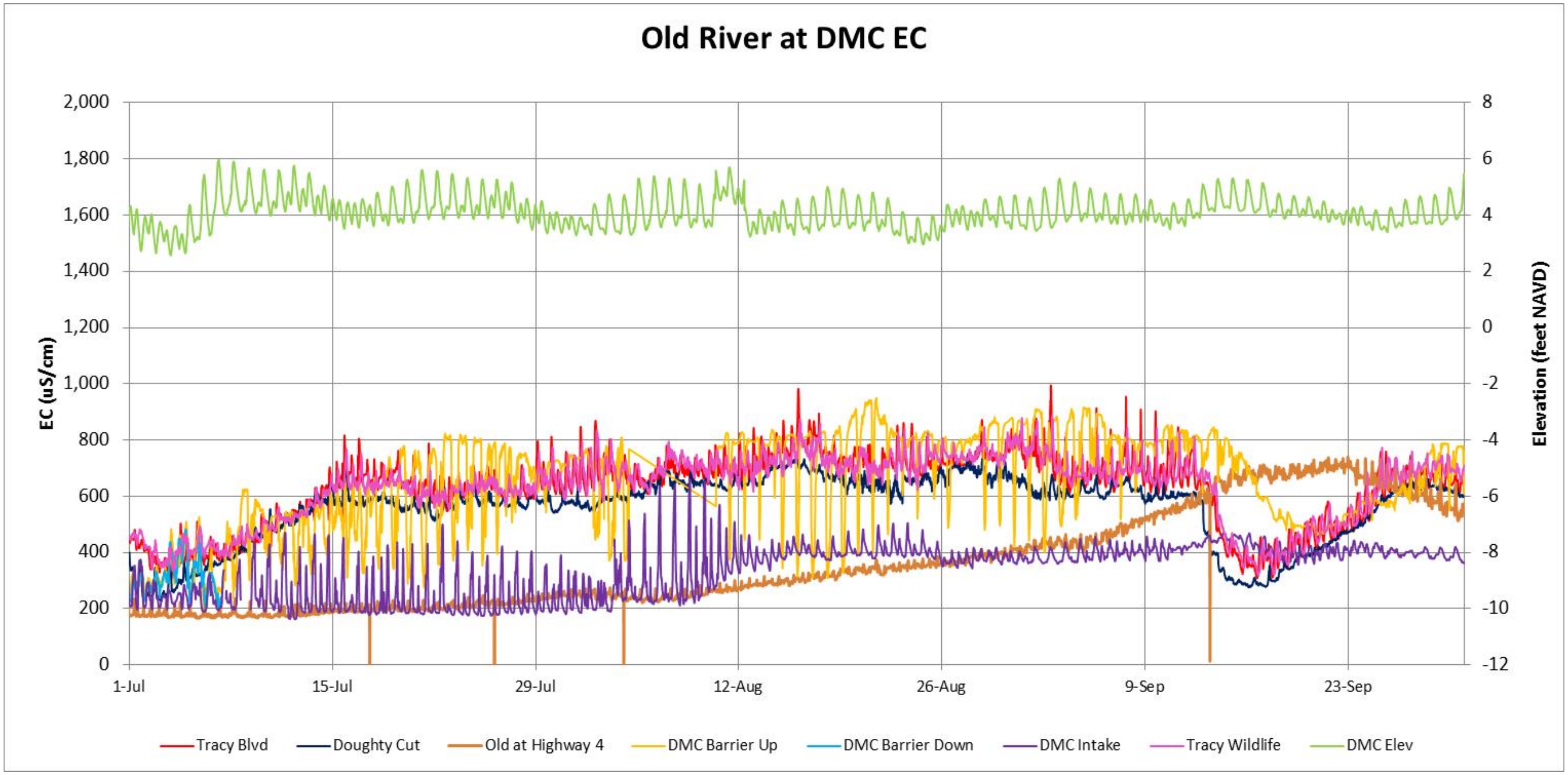
The Old River EC near the DMC barrier in February 2010 fluctuated with the tidal elevations because high EC water from upstream was measured at low tide and lower EC water from downstream was measured at high tide. The EC upstream of the DMC barrier (gold line) and the EC downstream of the DMC barrier (light blue line) were nearly identical. At high tide, the minimum daily EC matched the Old River at Highway 4 EC (brown line) of about 400 uS/cm, and at low tide the maximum daily EC at the DMC stations was between 800 and 1,200 uS/cm. The maximum daily EC at the DMC barrier was about 200 uS/cm higher than the Doughty Cut EC (dark blue line) and similar to the Tracy Boulevard EC (red line) and Tracy Wildlife EC (pink line). The EC fluctuations at the DMC intake (purple line), measured at the CVP pumping plant, were similar to the EC fluctuations at the DMC barrier stations, but the increase at low tide was generally less and was delayed by about 4 hours because of the tidal movement in Old River from the DMC barrier to the DMC intake (1.5 km) and travel time in the DMC channel. The reduction in the DMC intake EC occurred at about the same time as at the DMC barrier stations, because the low EC water was coming from downstream (flood-tide) with a similar travel time to the DMC barrier as to the DMC pumping plant.



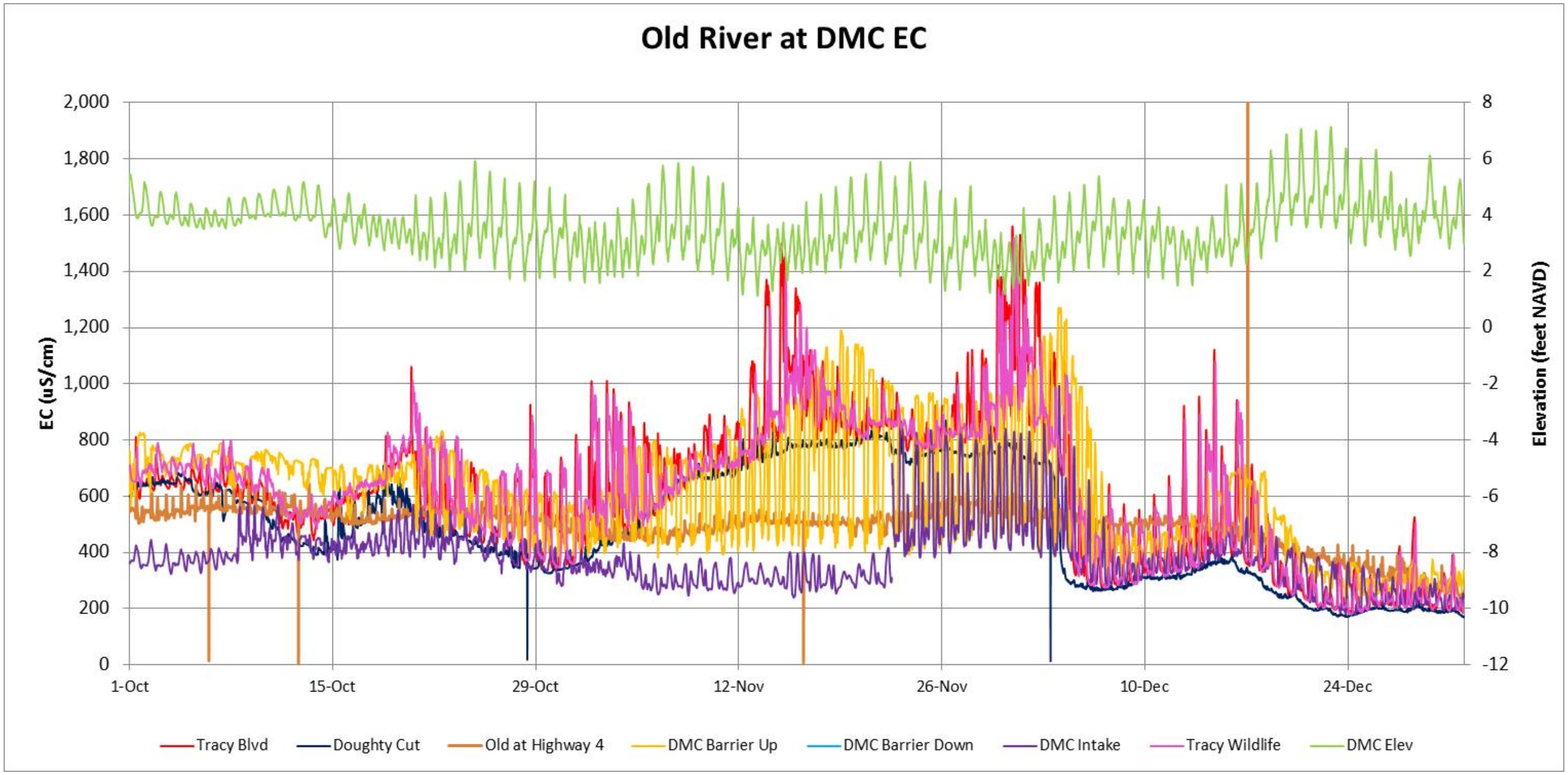
The Old River EC near the DMC barrier in March 2010 fluctuated with the tidal elevations (flows) with the greatest fluctuation (minimum of 400 uS/cm and maximum of 1,200 uS/cm) observed in the middle of the month. At high tide, the minimum daily EC matched the Old River at Highway 4 EC (brown line) of about 400 uS/cm, and at low tide the maximum daily EC at the DMC stations was between 800 and 1,200 uS/cm. The maximum daily EC at the DMC barrier was about 200-400 uS/cm higher than the Doughty Cut EC (dark blue line). The Tracy Boulevard EC (red line) and Tracy Wildlife EC (pink line) generally matched the maximum EC at the DMC stations. The EC fluctuations at the DMC intake (purple line) were similar to the EC fluctuations at the DMC barrier stations, but the maximum EC at low tide was generally less.



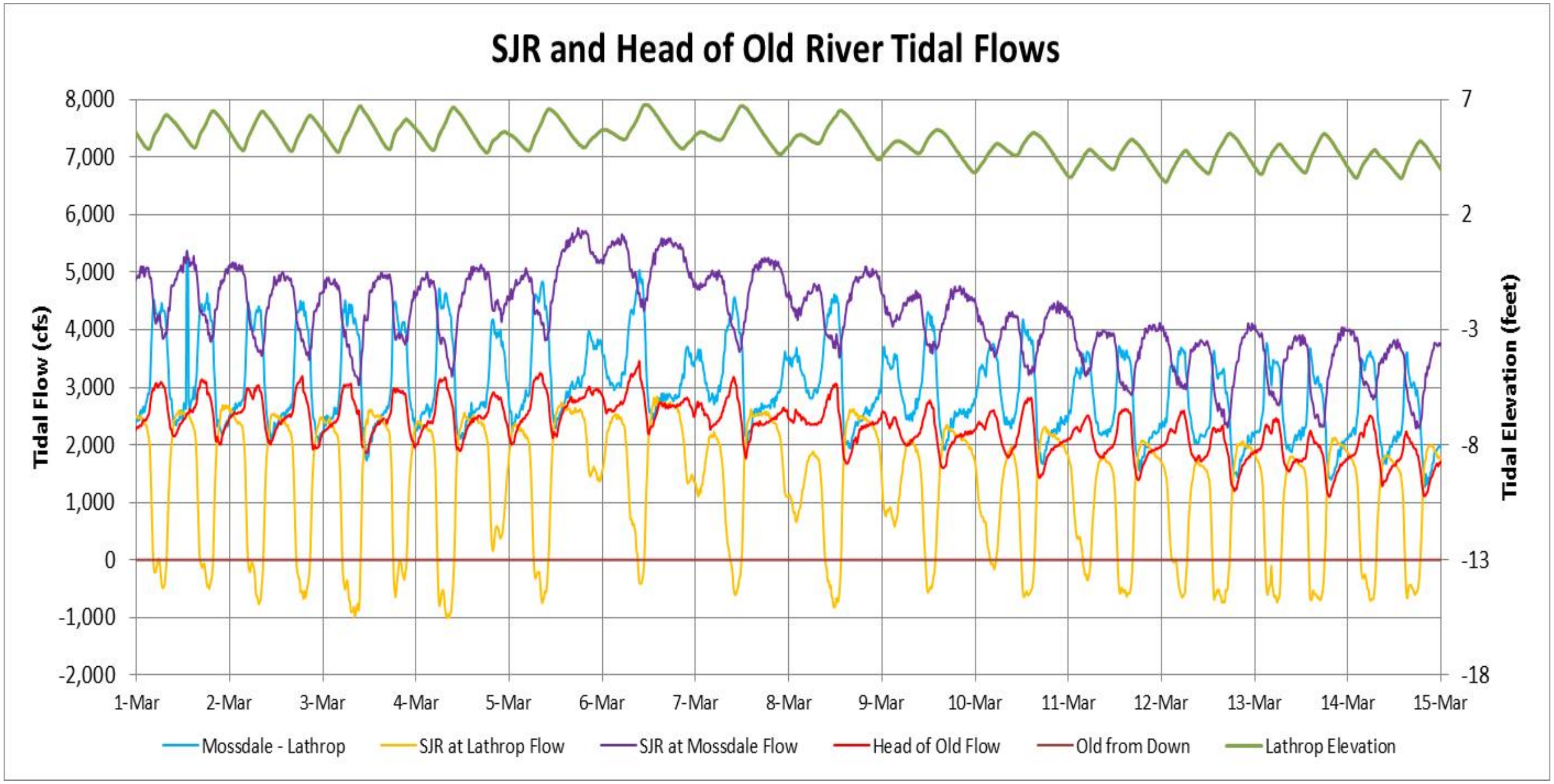
The Old River EC near the DMC barrier in April-June 2010 fluctuated with the tidal elevations (flows) with the greatest fluctuation (minimum of 400 uS/cm and maximum of 1,200 uS/cm) observed at the beginning of the month. The EC station below the barrier was out of service after April 12. The Old River at Doughty Cut and at Tracy Boulevard EC (red line) was reduced to 500 uS/cm by the higher SJR flow, so the EC fluctuations were much less for the remainder of April-June.



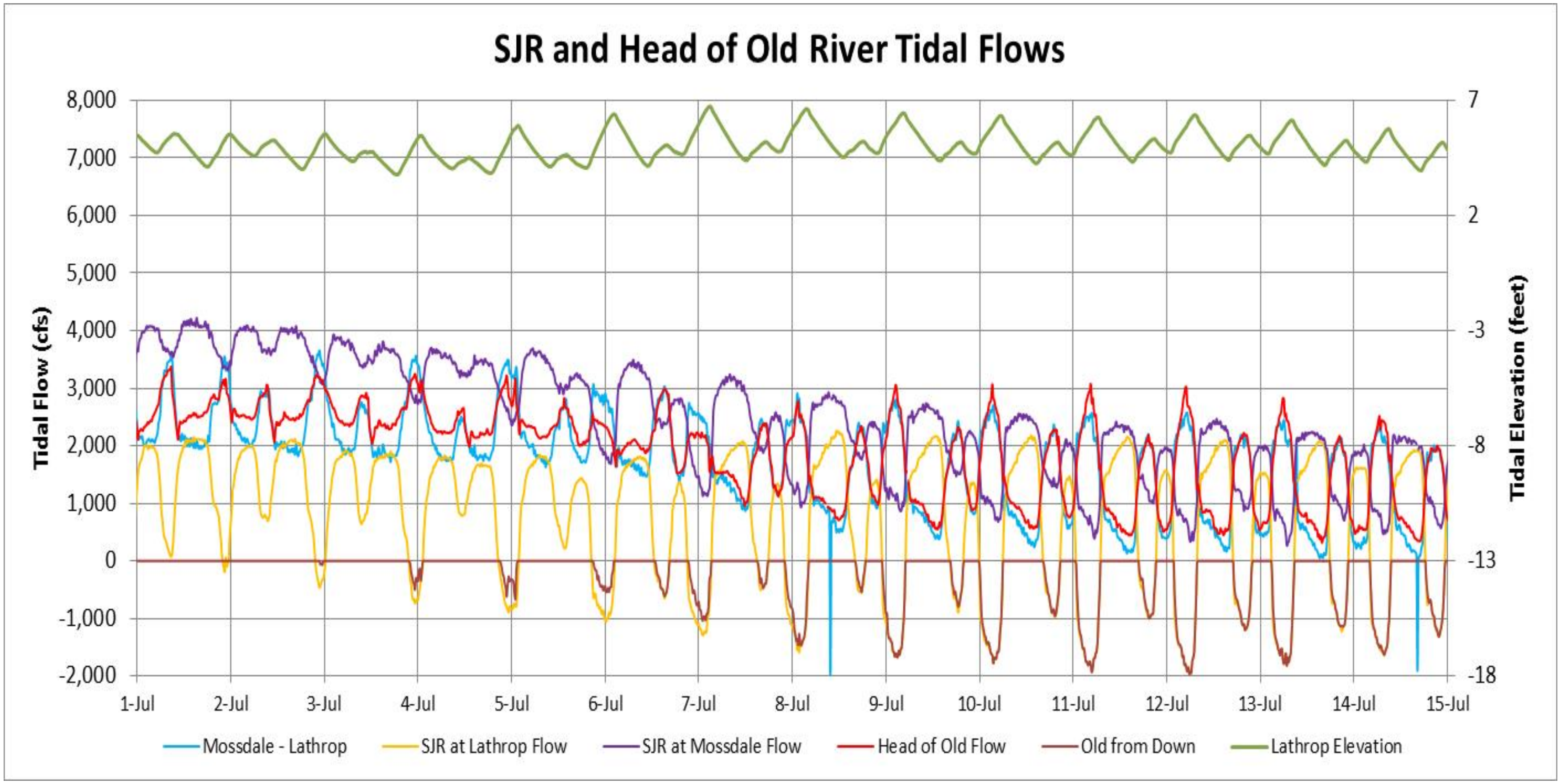
The EC fluctuations at the DMC barrier were small after the barriers were installed with flap-gates (minimum elevation of about 3.5 feet) in early July. The minimum EC upstream of the barrier remained higher, because the barrier reduced the tidal flow from downstream (lower EC). The lowest EC upstream of the barrier was measured only at the higher tides (>3.5 feet) when water flowed over the weir crest. The EC variations at the DMC barrier were nearly eliminated in September because seawater intrusion (low Delta outflow) caused the Old River at Highway 4 EC to increase to about 700 uS/cm (higher than the Old River at Tracy EC).



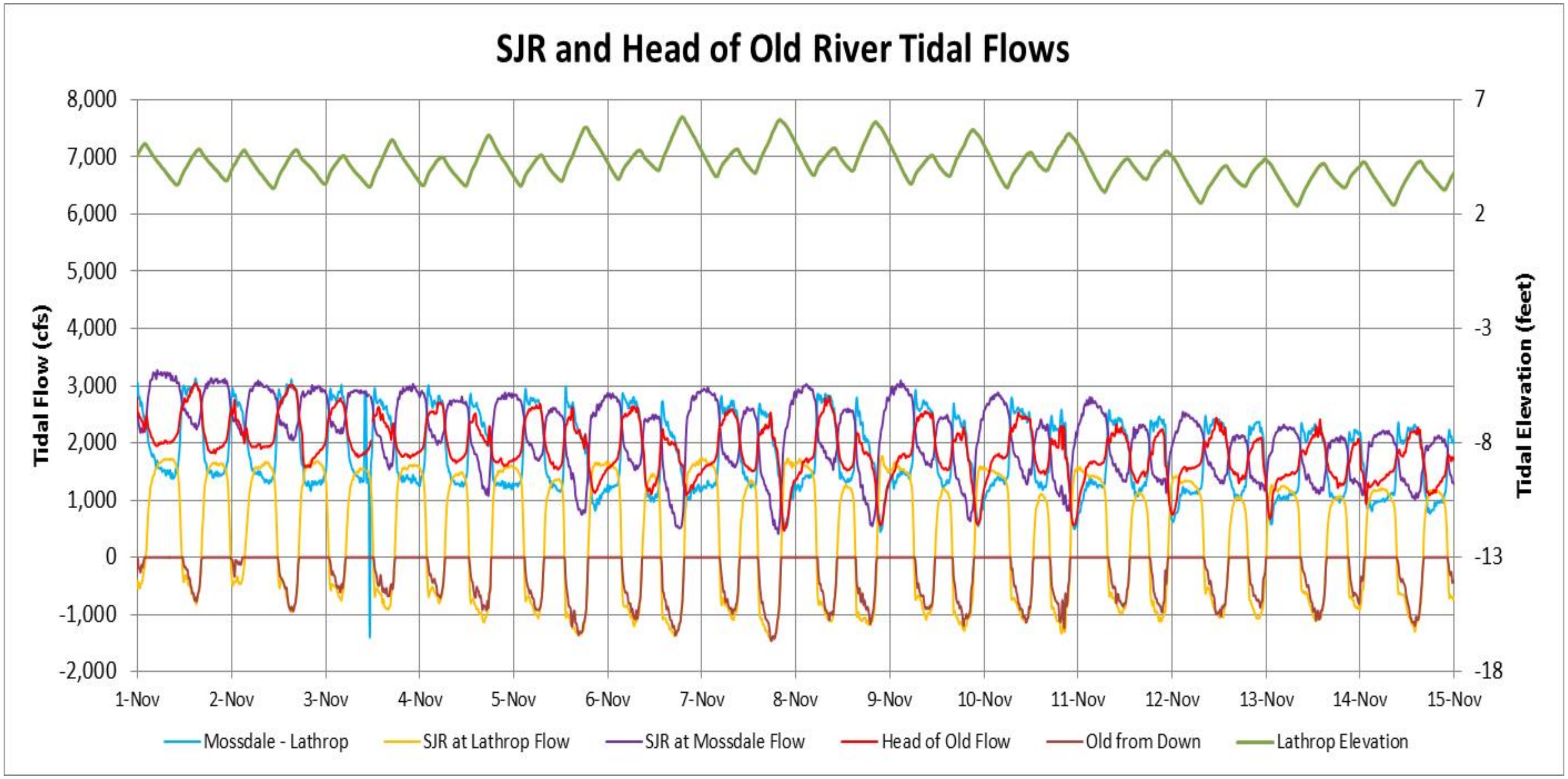
The EC variations at the DMC barrier increased after the barriers were removed in the last week of October. The DMC intake EC was reset at the end of November (it was reading lower than the Old at Highway 4 EC since late September). The Tracy Boulevard and Tracy Wildlife EC increased to the highest values (>1,000 uS/cm) following days with minimum tide elevations of less than 2 feet. The EC variations at the DMC barrier were reduced in December because the high SJR flow reduced the Old River EC at Doughty Cut to less than the EC at Highway 4.



The tidal flows in the SJR and at the head of Old River are controlled by the tidal elevations and the SJR flow at Mossdale. The daily average Mossdale flow increased from 4,000 cfs to 5,000 cfs and then decreased from about 3,000 cfs by mid-month. The tidal flows at Mossdale (purple line), located 5 kilometers upstream of Old River, were highest during ebb tide (decreasing elevations, downstream flow). The tidal flows at Lathrop (yellow line), located 0.5 kilometers downstream of Old River, were about 2,000-2,500 cfs during ebb tides and about -1,000 cfs (reverse flow) during flood tides. The tidal flows in Old River (red line) were about half of the Mossdale flow during ebb tides. During flood tides, as the Mossdale flow decreased the Old River flow increased to match the upstream flow (negative) from Lathrop (brown line). However, the Mossdale tidal flow was about 1,000 cfs higher than the Vernalis flow; this was confirmed by the Mossdale minus Lathrop estimate of Old River flow (bright blue line) being much higher than the measured Old River flow, especially during ebb tide.



During July 2010 the SJR flow at Mossdale (purple line) decreased from 4,000 cfs to about 1,500 cfs, and the tidal flow variation was more than 1,000 cfs by mid-month. The SJR flow diverted into Old River (red line) was lowest during ebb tides; most of the SJR flow continued downstream past Lathrop. The maximum flood tide flows at Lathrop were about -2,000 cfs and the peak flows into Old River were equal to the flood tide flow at Mossdale (downstream flow) plus the Lathrop upstream flow. The reverse flows at Lathrop enter Old River (brown line), unless the Mossdale flow is also reversed at the end of each flood tide. Old River flows were well estimated as the Mossdale flow minus the Lathrop flow (light blue line). Most of the water entering Old River was diverted during flood tides. Almost all of the upstream (negative) Lathrop flood tide flow is “squeezed” into Old River during relatively low SJR flow.



During the first half of November 2010, the SJR flow at Mossdale decreased from about 3,000 cfs to about 2,000 cfs. The maximum tidal flow at Mossdale was about 3,000 cfs, with a tidal flow variation of about 1,000 cfs. The Mossdale flows were not reversed (negative) during this period. Tidal flows at Lathrop ranged from about 1,500 cfs to -1,000 cfs. The Old River flow was an average of about 50% of the Mossdale flow during ebb tide, but the Old River flow increased during each ebb tide (likely caused by the Old River elevations decreasing faster than the SJR elevations). During flood tides, most of the reverse SJR flow at Lathrop entered Old River (brown line). The tidal flows at the head of Old River are relatively complex; it is remarkable that the daily average SJR diversion flow into Old River was generally well estimated as 50% of the Mossdale flow plus 5% of the CVP and SWP exports.