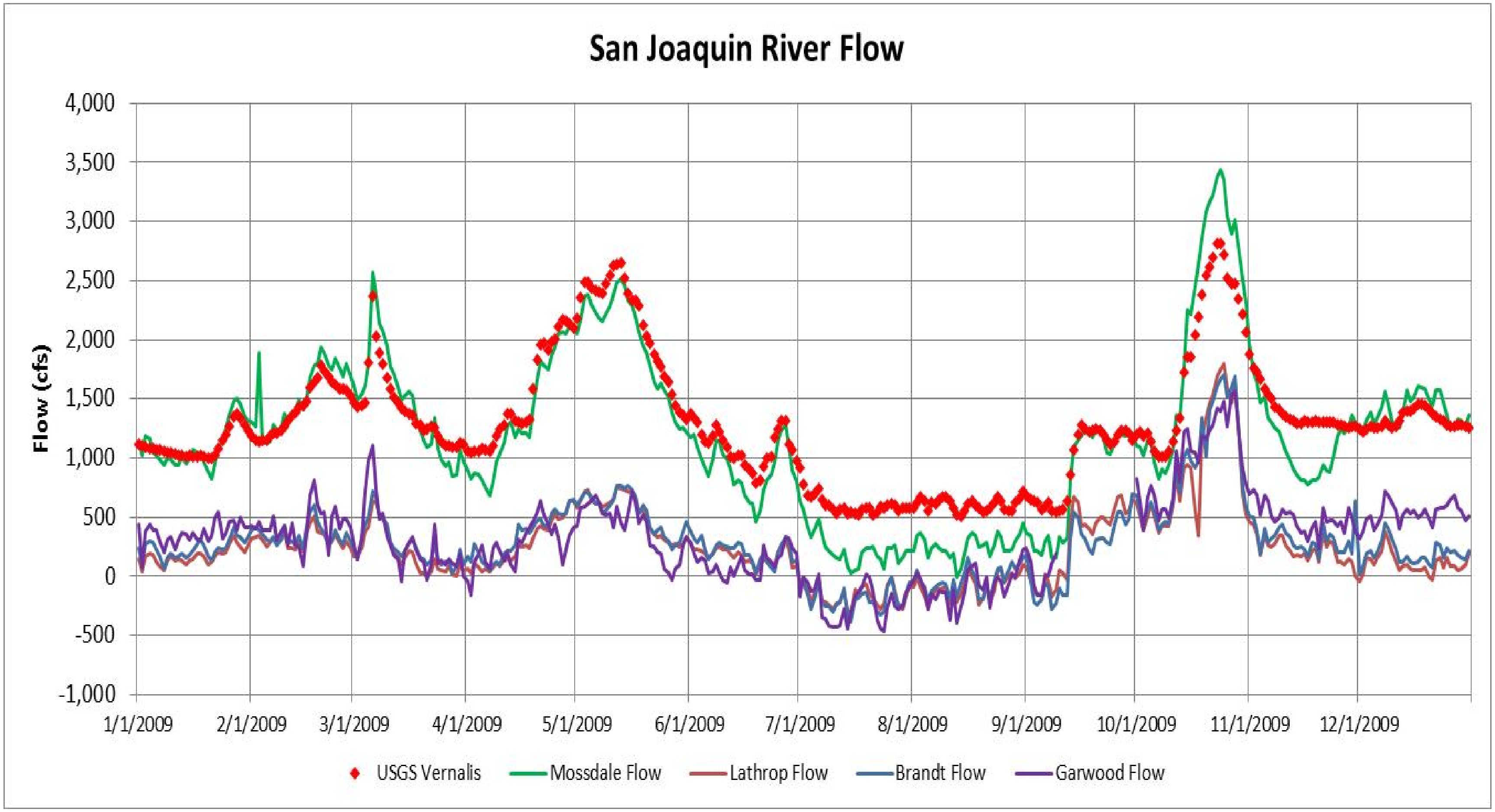
South Delta Tidal Data Atlas Graphs for Calendar Year 2009

This South Delta Data Atlas for 2009 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 2009. 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.

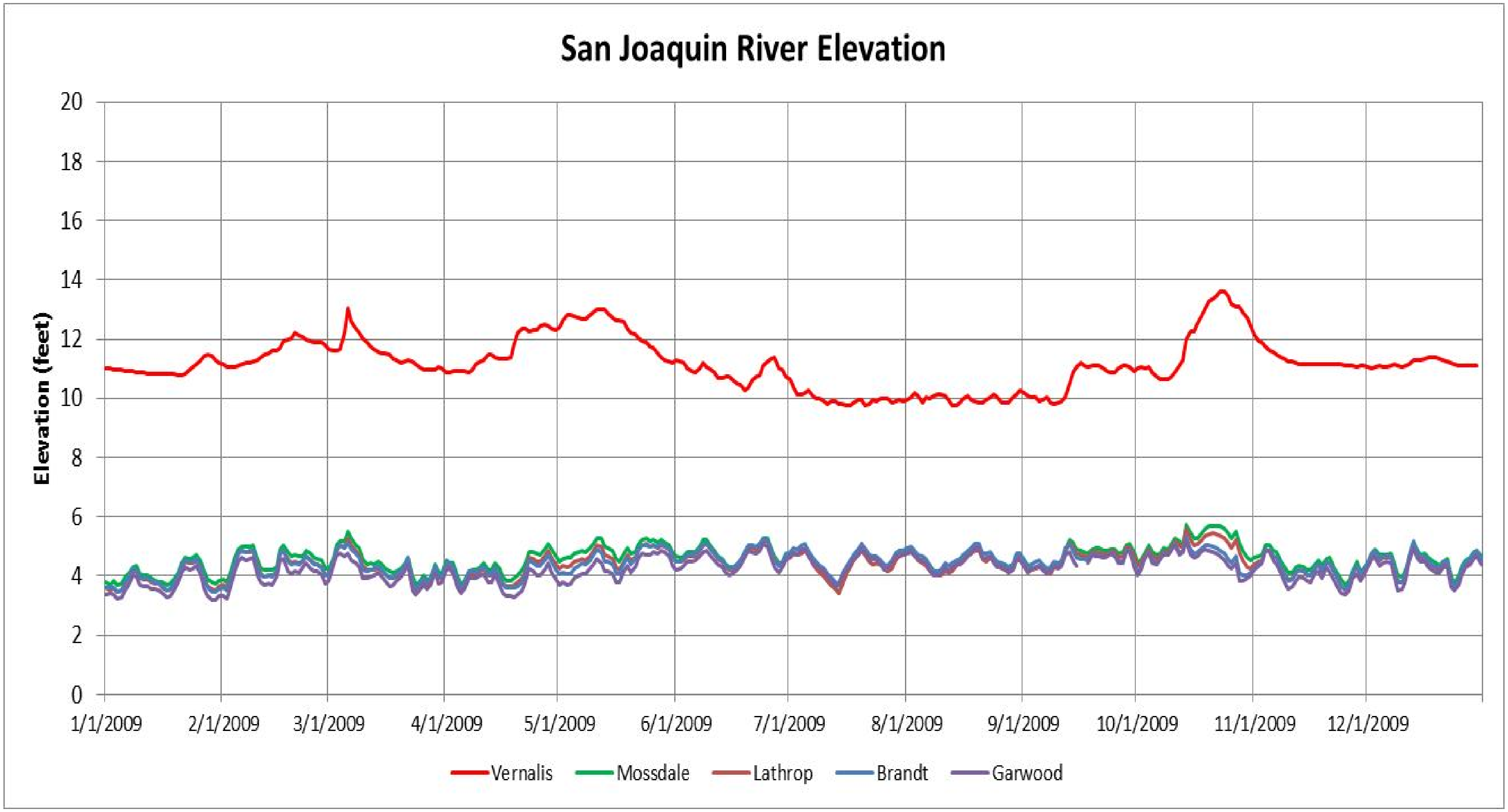
South Delta Data Atlas excel files have been compiled to support the review and summary of data patterns and relationship for 2009-2013. This year (2009) included relatively low SJR flows (1,000-2,000 cfs) with moderate exports (3,000-7,500 cfs) in the January-March period, a small SJR pulse flow in May (2,500 cfs) with low exports for SJR fish protection in April, May, and June, very low SJR flow (500 cfs) with very high exports (10,000 cfs declining to 5,000 cfs) in July-September, a moderate October pulse flow of 2,500 cfs with exports of 7,500 cfs (during the pulse), and SJR flows of about 1,250 cfs with exports of about 5,000 cfs in November and December.

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 2009. 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.

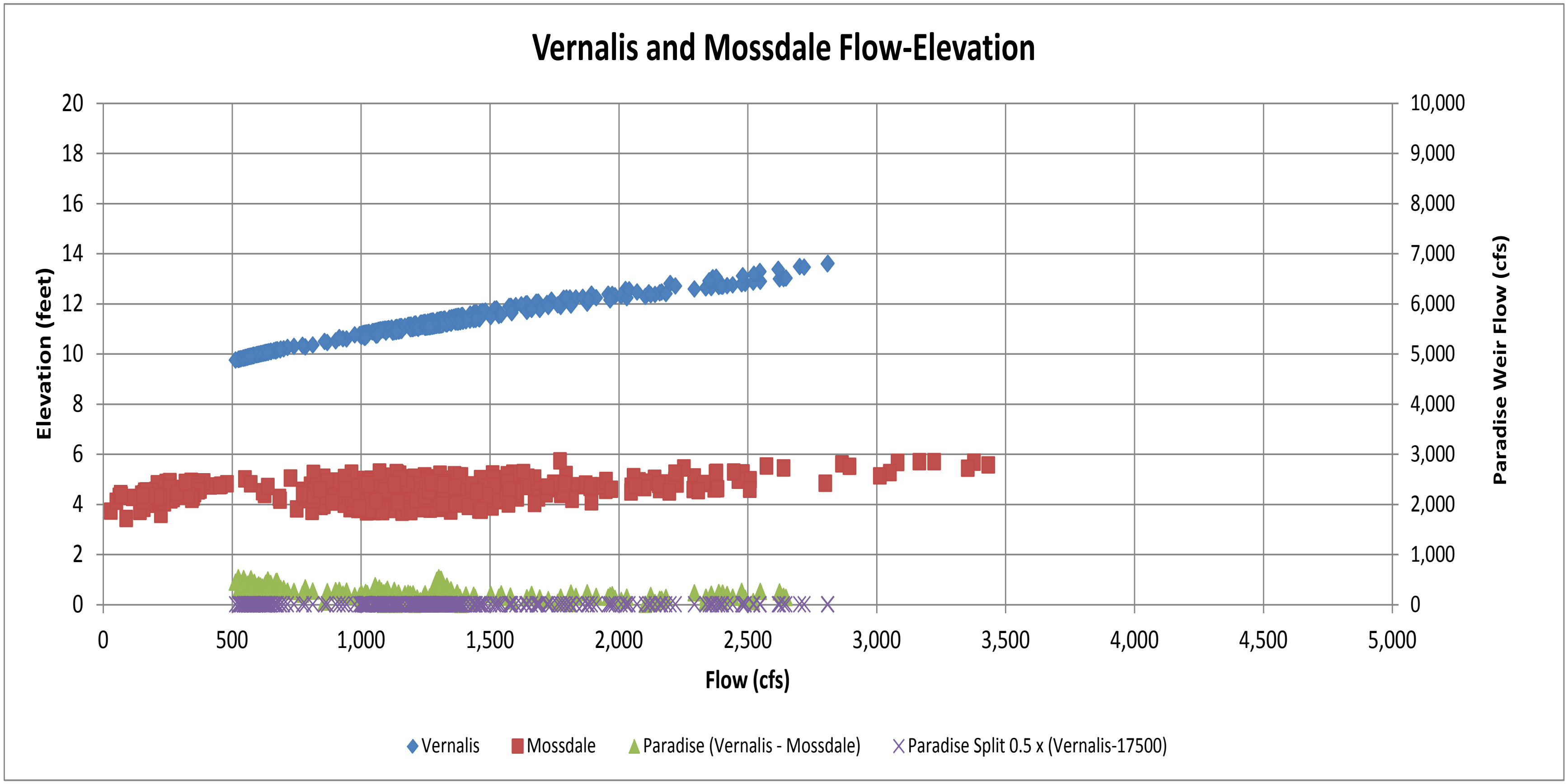
The basic flow splits in the south Delta are evaluated, and the effects of the temporary barriers on tidal elevations, tidal flows, and net downstream flows are described in the graphs. The tidal elevations and tidal flows in Old River at Tracy Boulevard provide the framework for evaluating the effects 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.



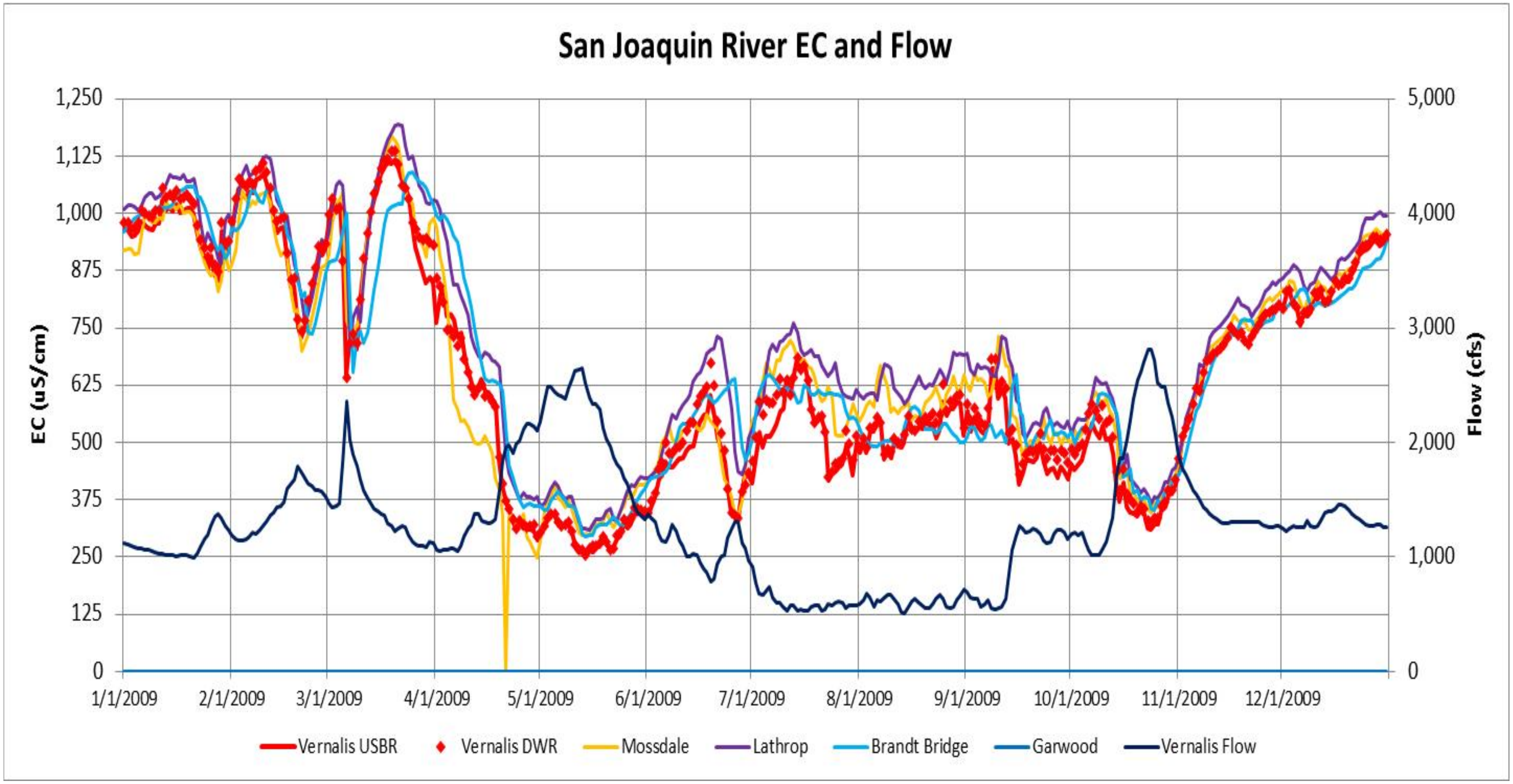
San Joaquin River flow at Vernalis (red diamonds) in 2009 was less than 1,500 cfs in January-March, slightly increased to about 2,500 cfs in May, and was about 1,000 cfs in June. The SJR flow was only about 500 cfs from July through mid-September, when the flow increased to about 1,000 cfs. A pulse flow of about 2,500 cfs for fish attraction was released from the tributary reservoirs (Stanislaus, Tuolumne, and Merced Rivers) in the second half of October. The Mossdale flow (green line) was similar to the Vernalis flow for most of the year, but was about 250 cfs less in the summer months, and was higher than the Vernalis flow during the October pulse flow. 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 at Lathrop, Brandt Bridge, and Garwood was negative (i.e., upstream) in July and August.



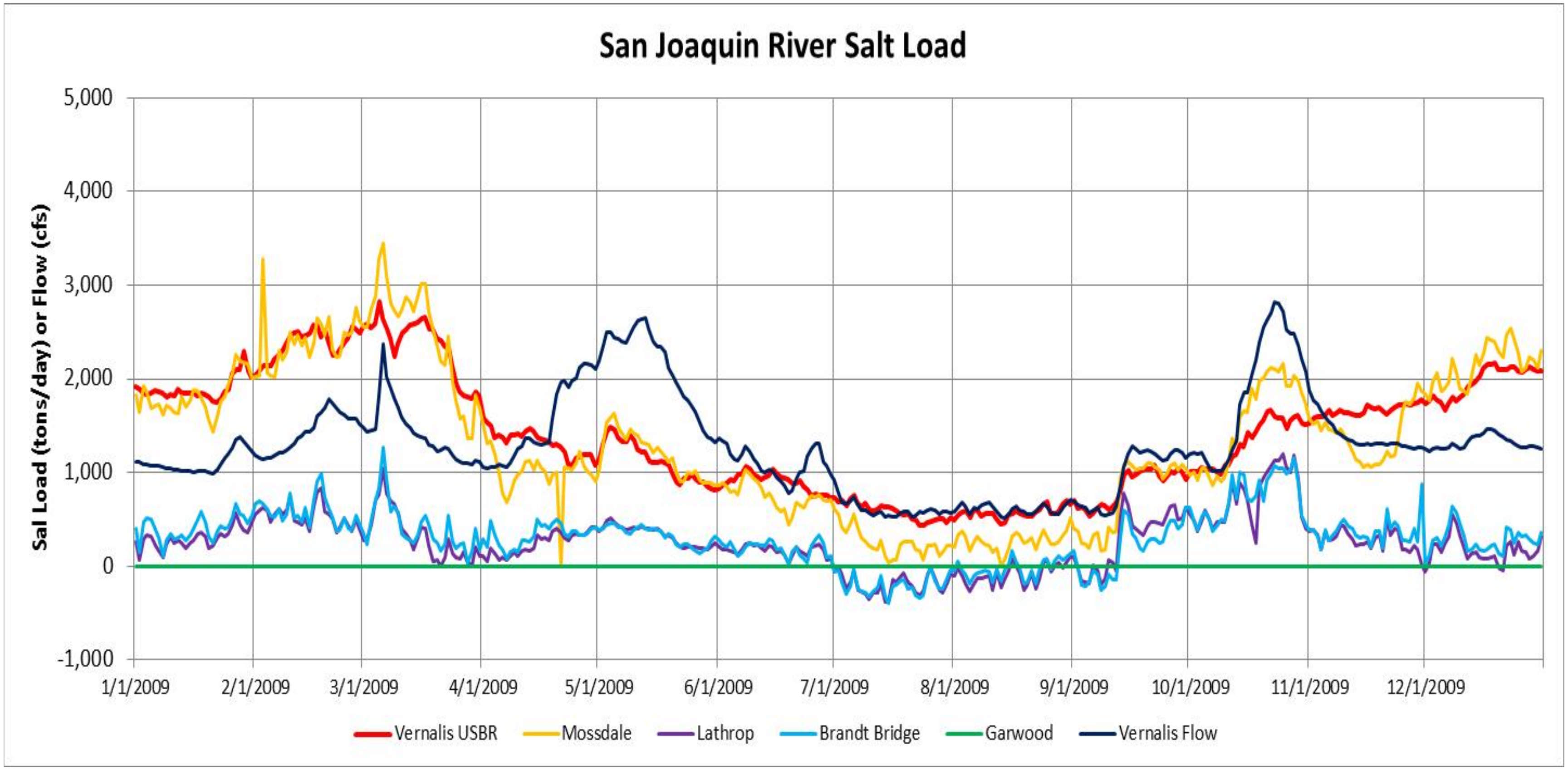
Because of low flows in 2009, the daily average elevations at Mossdale and downstream locations remained within the tidal range of 3-5 feet NAVD. Elevations at Mossdale, Lathrop, Brandt and Garwood indicated a slight elevation gradient (slope) when flows at Vernalis were greater than 2,500 cfs (Vernalis elevations greater than 12.5 feet). Average tidal elevations were about 4 feet NAVD throughout the year. Mossdale and downstream stations are tidal, without any backwater effects for SJR flows at Vernalis of less than about 1,500 cfs



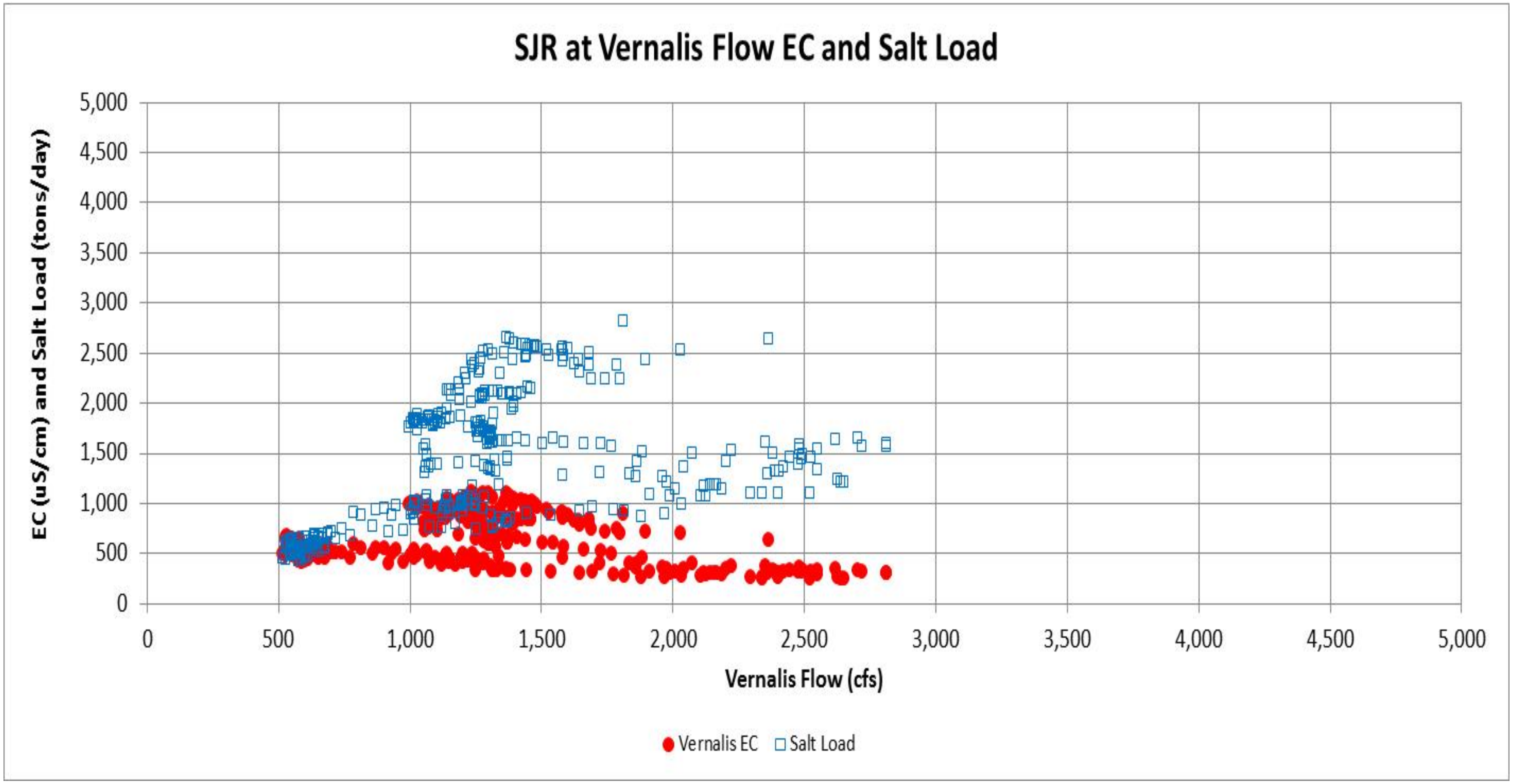
The elevation-flow relationships (rating curves) at Vernalis and Mossdale during 2009 are compared. River elevations at Mossdale were increased slightly above the average tidal elevation of 5 feet only when flows were greater than 2,000 cfs. Because the river is relatively wide, the river elevation only increases 2 feet as the flow increases from 500 cfs to 1,500 cfs. Therefore, the rating curve at Vernalis is checked periodically (generally every 6-8 weeks) and small shifts in the elevation-flow curve are applied throughout the year.



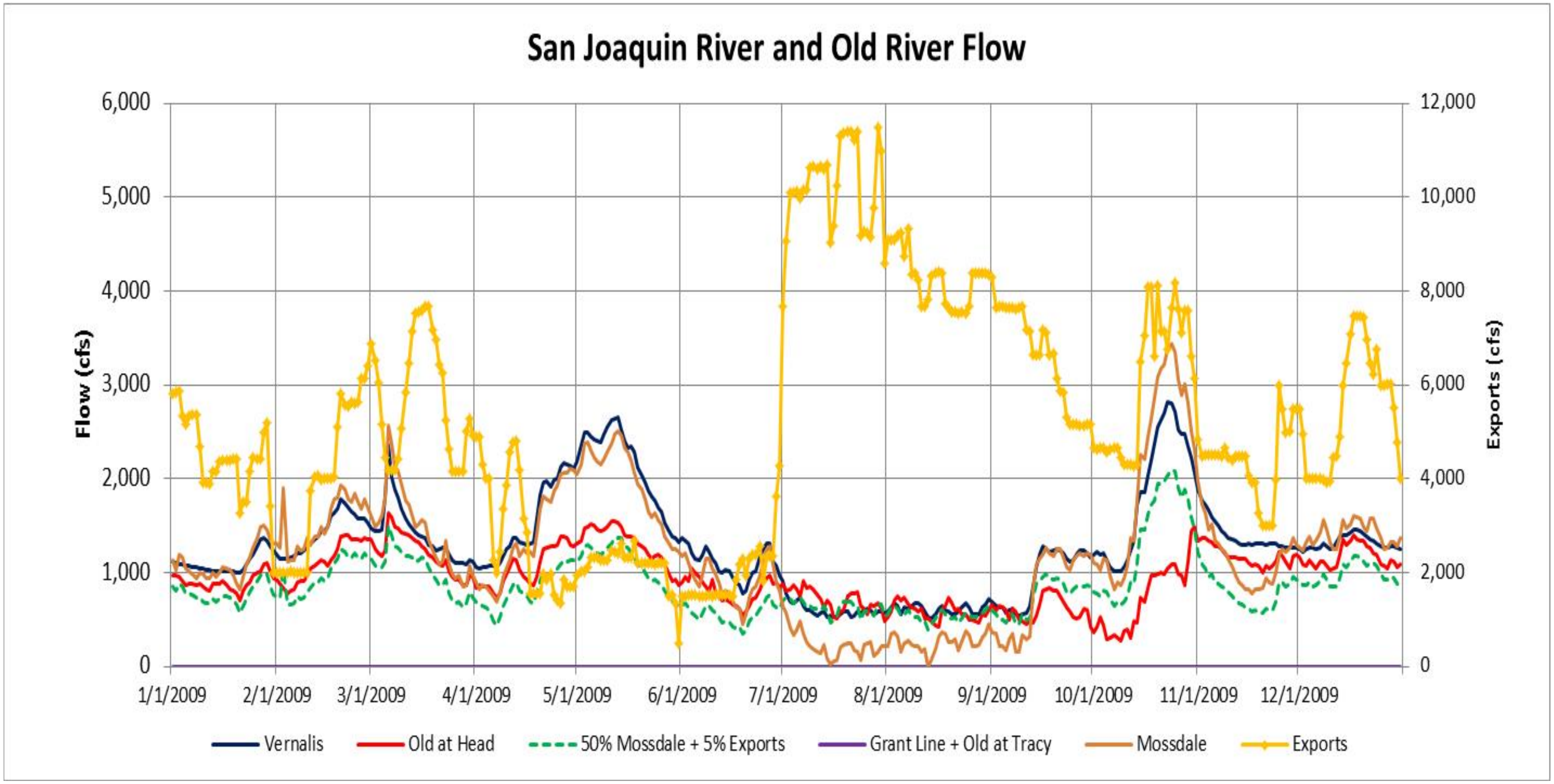
The SJR salinity (EC) at Vernalis is controlled by the combination of the salt load entering the SJR from high salinity groundwater seepage, agricultural drainage (e.g., Salt and Mud Sloughs), and surface runoff during storms. These major SJR salt loads are diluted by the tributary flows (Merced River, Tuolumne River, and Stanislaus River). The SJR minimum EC was about 250 uS/cm during the moderate flow in May and was about 375 during the pulse flow for fish attraction in late October (reservoir releases). The Vernalis EC objective (monthly average) is 700 uS/cm for April-August and 1,000 uS/cm for September-March. The highest SJR EC in 2009 was about 1,000 uS/cm in January-March, when the SJR flow at Vernalis was about 1,000-1,500 cfs. Because the SJR flows were low in the summer months of July through mid-September, the downstream changes in EC at Mossdale and Lathrop were moderately high (i.e., 125 uS/cm).



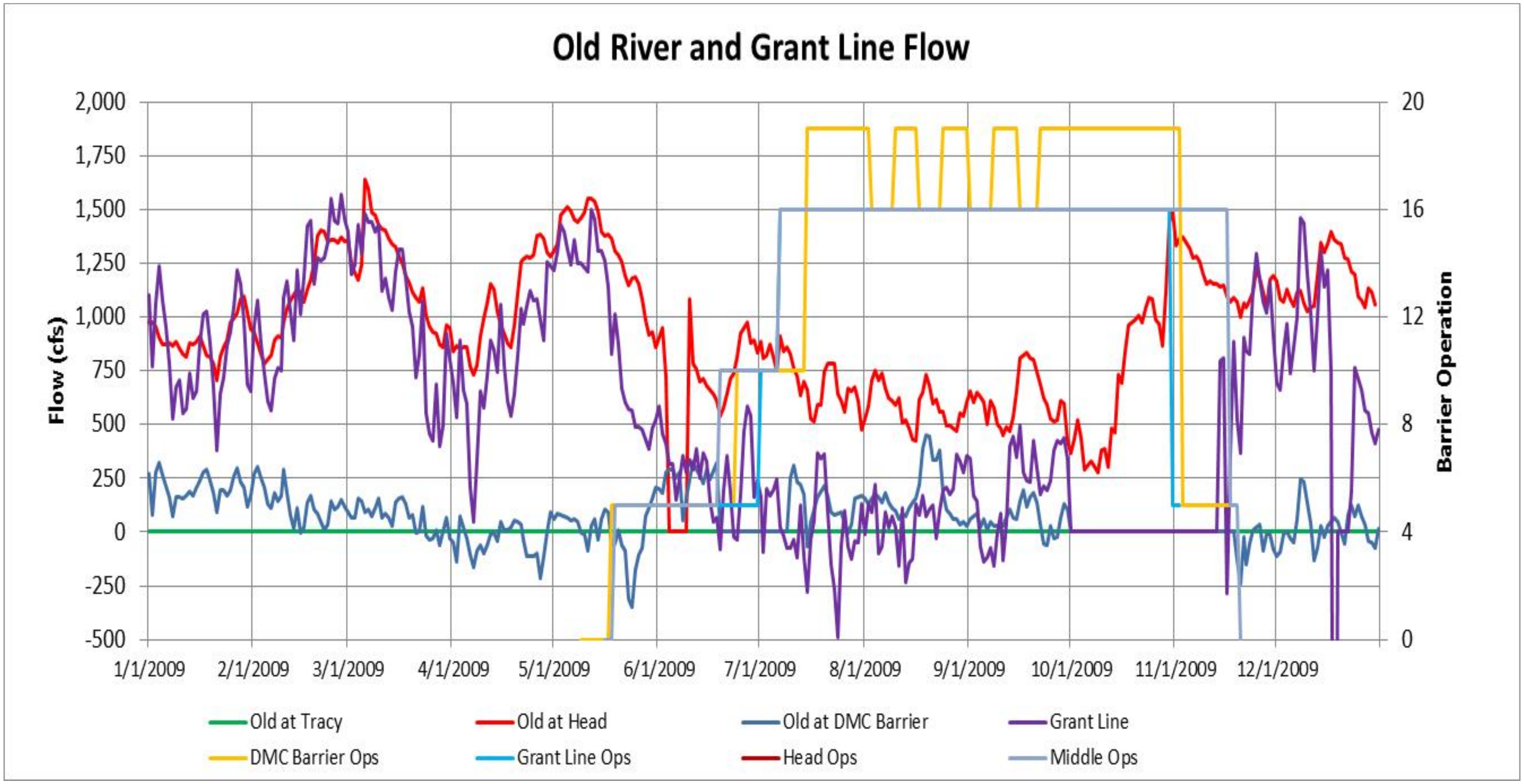
The SJR salt load was estimated as: Salt Load (tons/day) = flow (cfs) x EC (uS/cm) x 0.00175. The SJR salt load at Vernalis varied from about 2,500 tons/day in February and March to a minimum of 500 tons/day in July and August, and increased from September to December, with a salt load of about 2,000 tons/day at the end of the year. Because the SJR flow was reduced between Vernalis and Mossdale, the SJR salt load at Mossdale was reduced in July and August. The salt load was reduced considerably below the head of Old River, because most of the flow was diverted into Old River, and the SJR salt load downstream of Old River was negative (because flow moving upstream) in July and August.



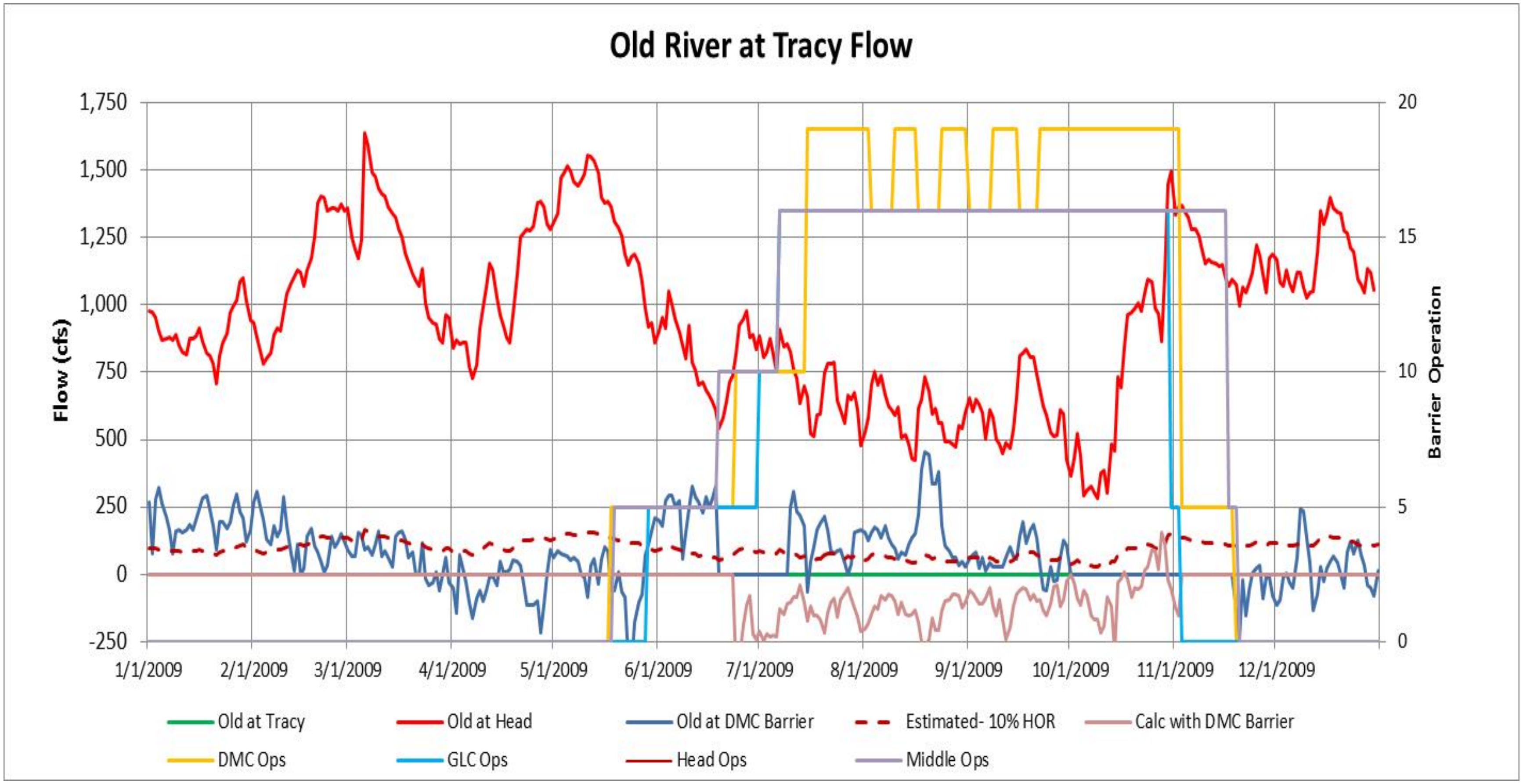
The relationship between the SJR at Vernalis flow and the Vernalis EC depends on the upstream salt loads. There is a general pattern of EC dilution with higher flows released from the tributary reservoirs, but there are seasonal changes in the salt loads, and higher flows from rainfall-runoff will also increase the SJR salt load and the EC of the runoff. These different seasonal patterns of flow and EC (and salt load) can be identified in the previous graph. The salt load was greatest in the January-March period and was quite low during the spring and summer months. The EC and the salt load increased in the October-December period in association with an increase in flow.



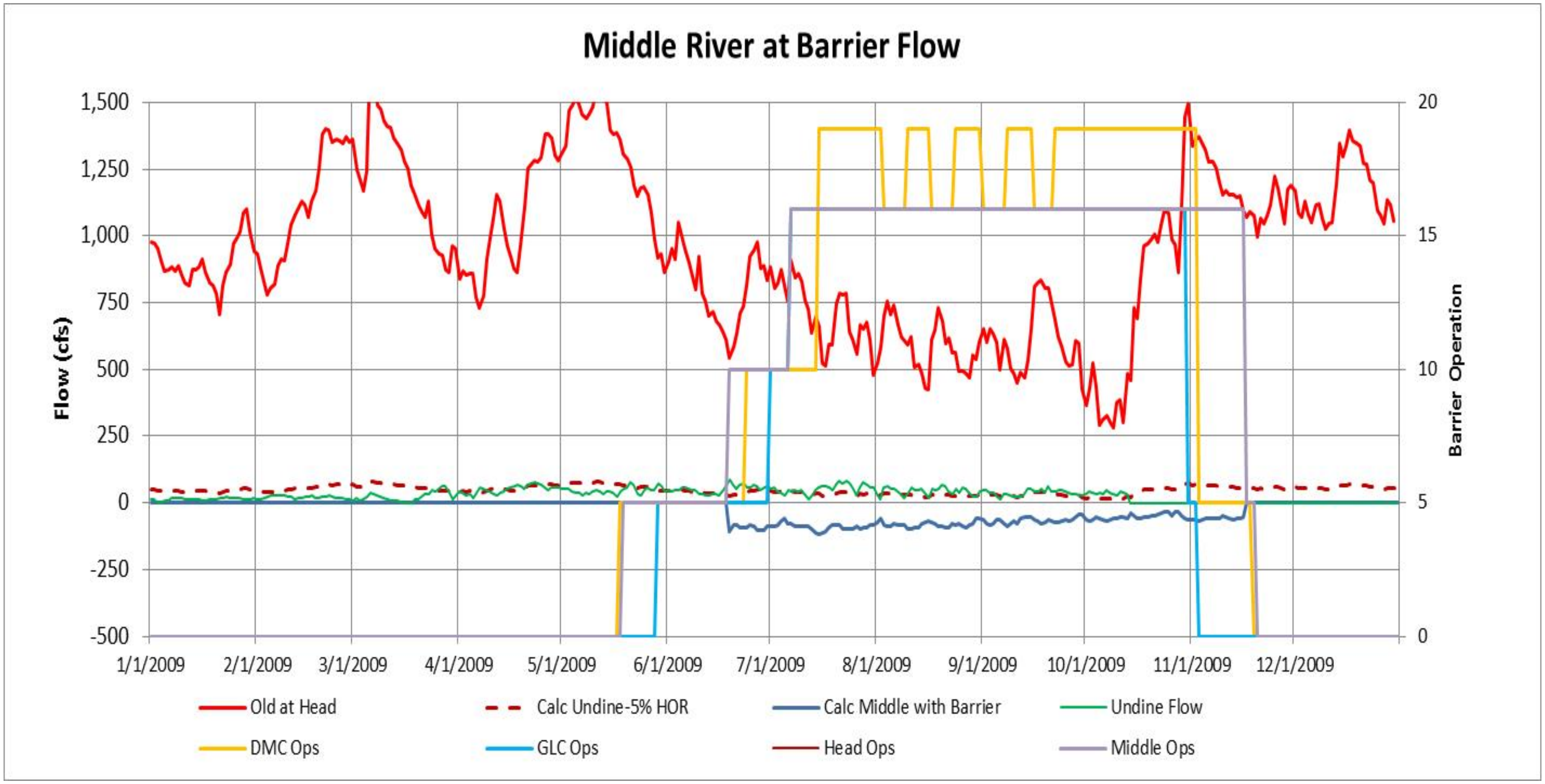
The SJR at Mossdale flow diverted into Old River was measured at the head of Old River (red line) and estimated (green dashed line) as: Old River Diversion = 50% Mossdale + 5% of the CVP and SWP exports (shown in gold). The measured Old River flow was slightly higher than estimated flow during most of the year, but was lower than the estimated flow in September and October. The Old River flow was about 500 cfs in July and August, when the Mossdale flow was only about 250 cfs and the export pumping was about 10,000 cfs. Reverse SJR flow from downstream (Lathrop) was being diverted into Old River during these months.



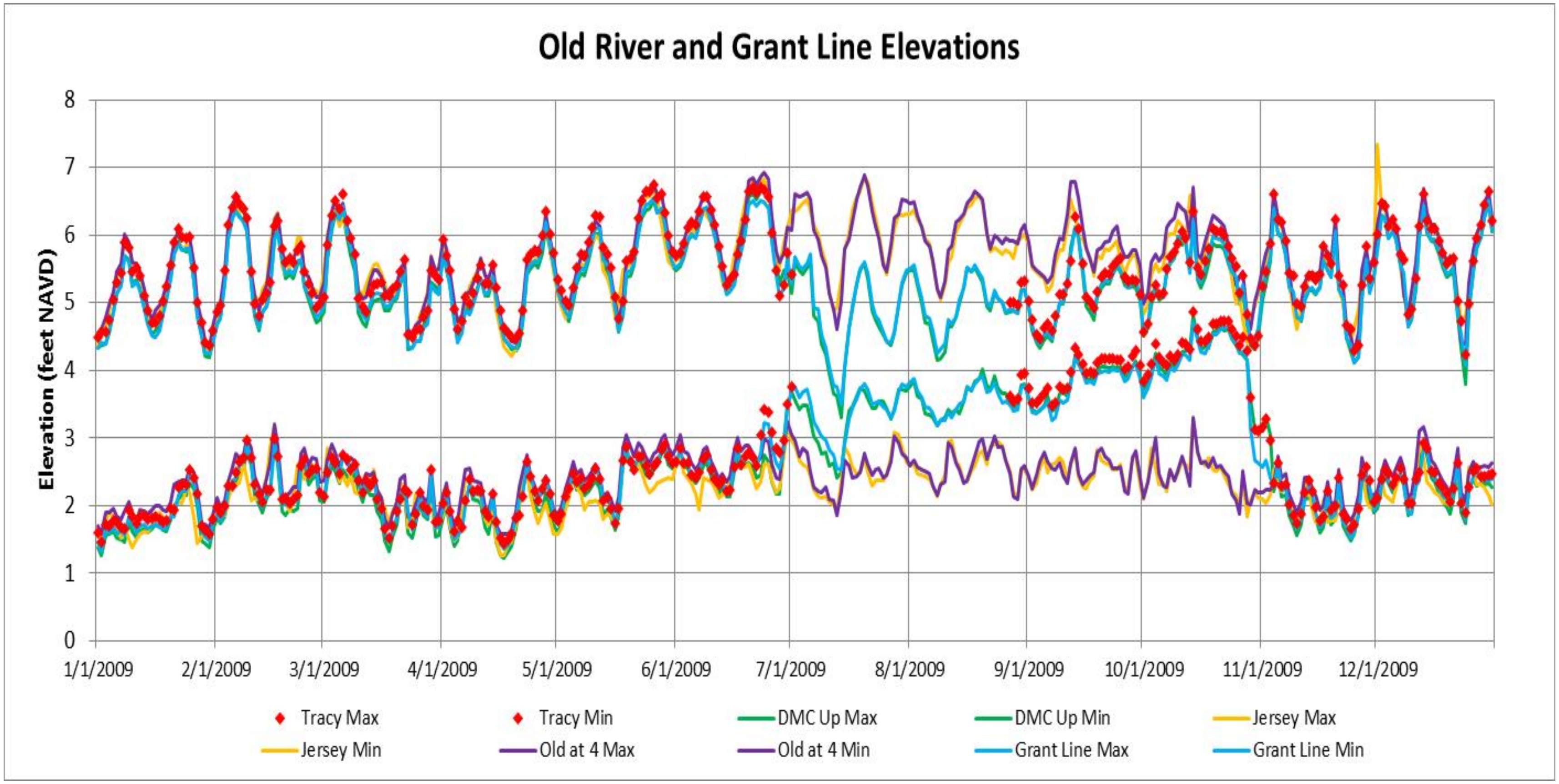
A barrier operation value of 5 (right scale) indicates barrier installation was initiated, a value of 10 indicates the weir was closed but the culverts were open, and higher values indicate the number of flap gates that were operational (10 + flap gates). The head of Old River flow (red line) was generally confirmed by the Grant Line Canal flow (purple line) in January-April and in December, when temporary barriers were not installed. The Grant Line Canal flow was reduced to near 0 cfs during the irrigation season of June-September. The Old River flow at Tracy Boulevard was not measured in 2009. The Old River flow at the DMC barrier (blue line) was less than 250 cfs in January, and was close to 0 cfs for most of the year. The barriers apparently did not provide a net upstream flow in Old River at the DMC barrier.



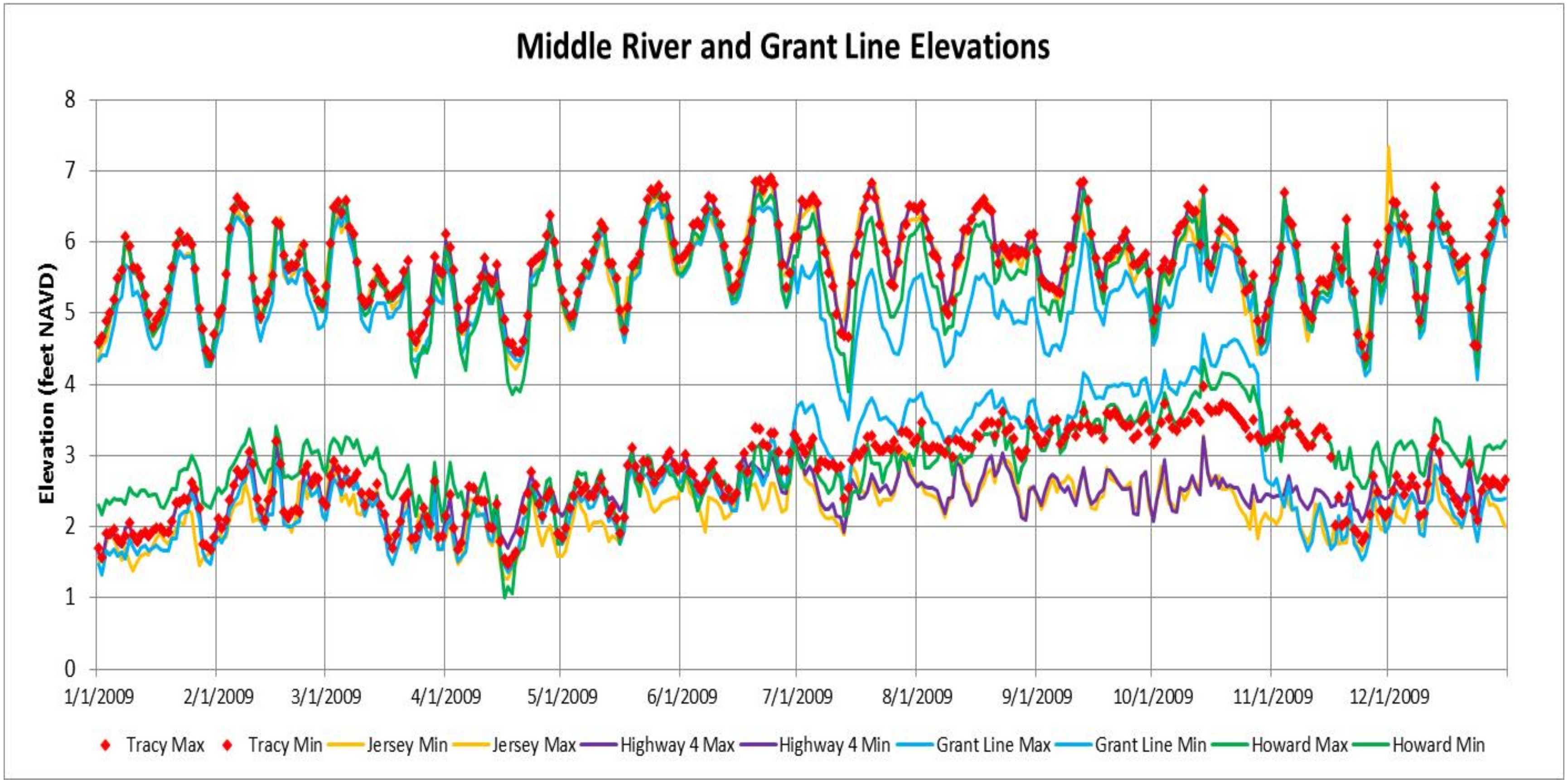
The Old River flow at Tracy Boulevard was not measured in 2009, but was estimated as 10% of the head of Old River flow (dashed brown line), based on flow measurements in other years. The Old River at the DMC barrier flow was consistent with the 10% of the head of Old River flow estimate. There was very little net flow in the south Delta channels during the summer months of 2009, because the SJR and head of Old River flows were very low. The calculated net upstream flows in Old River at the DMC barrier, based on barrier geometry and elevation differences (pink line), were not confirmed in 2009 with flow measurements.



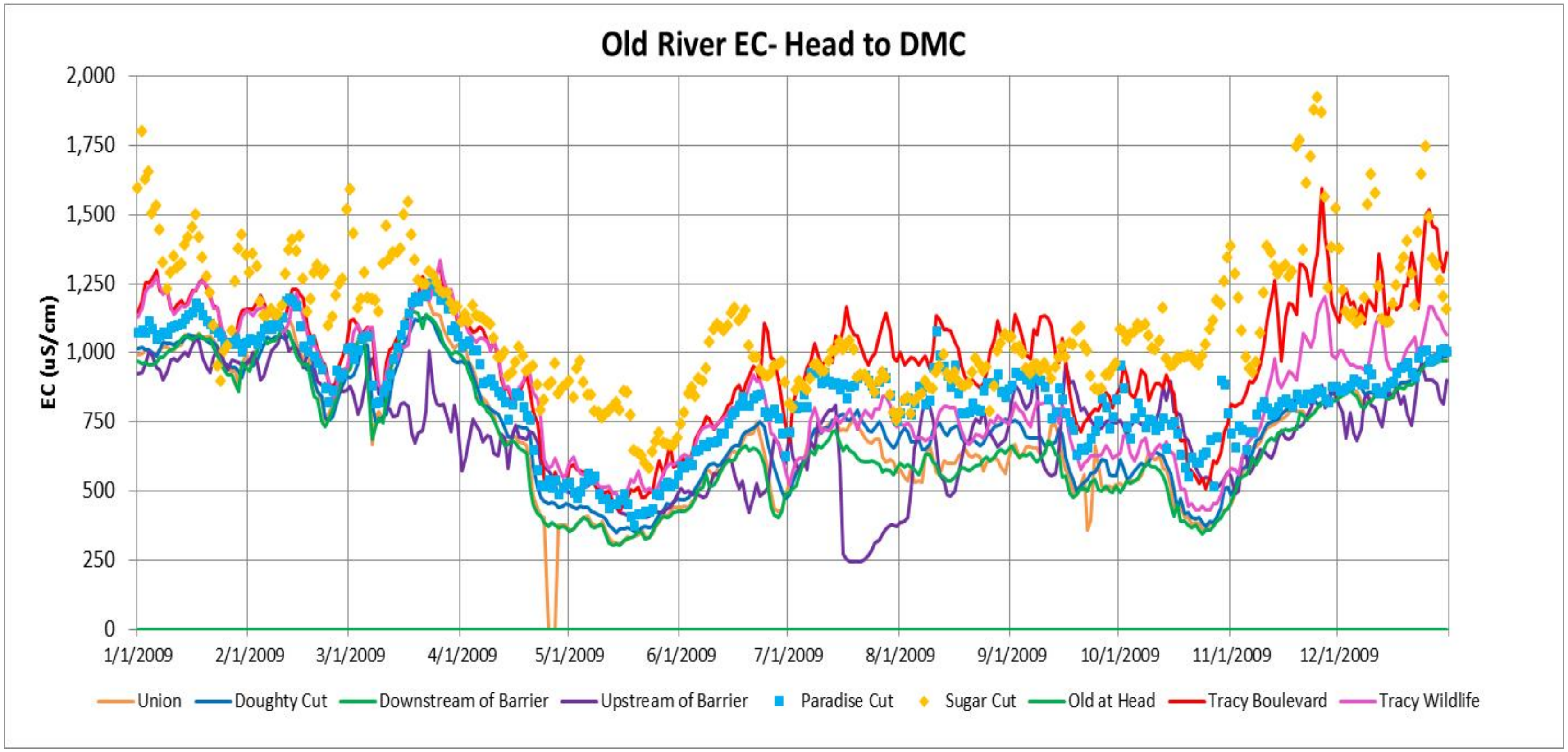
The Middle River flows were measured at Undine Road near the upstream end (head). Based on previous DSM2 modeling with the temporary barriers installed, about 5% of the Old River flow was diverted into Middle River. This estimated flow (brown dashed line) was similar to the measured daily average flow at Undine Road (green line) during the period with barriers. The estimated 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 50-100 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 in place.



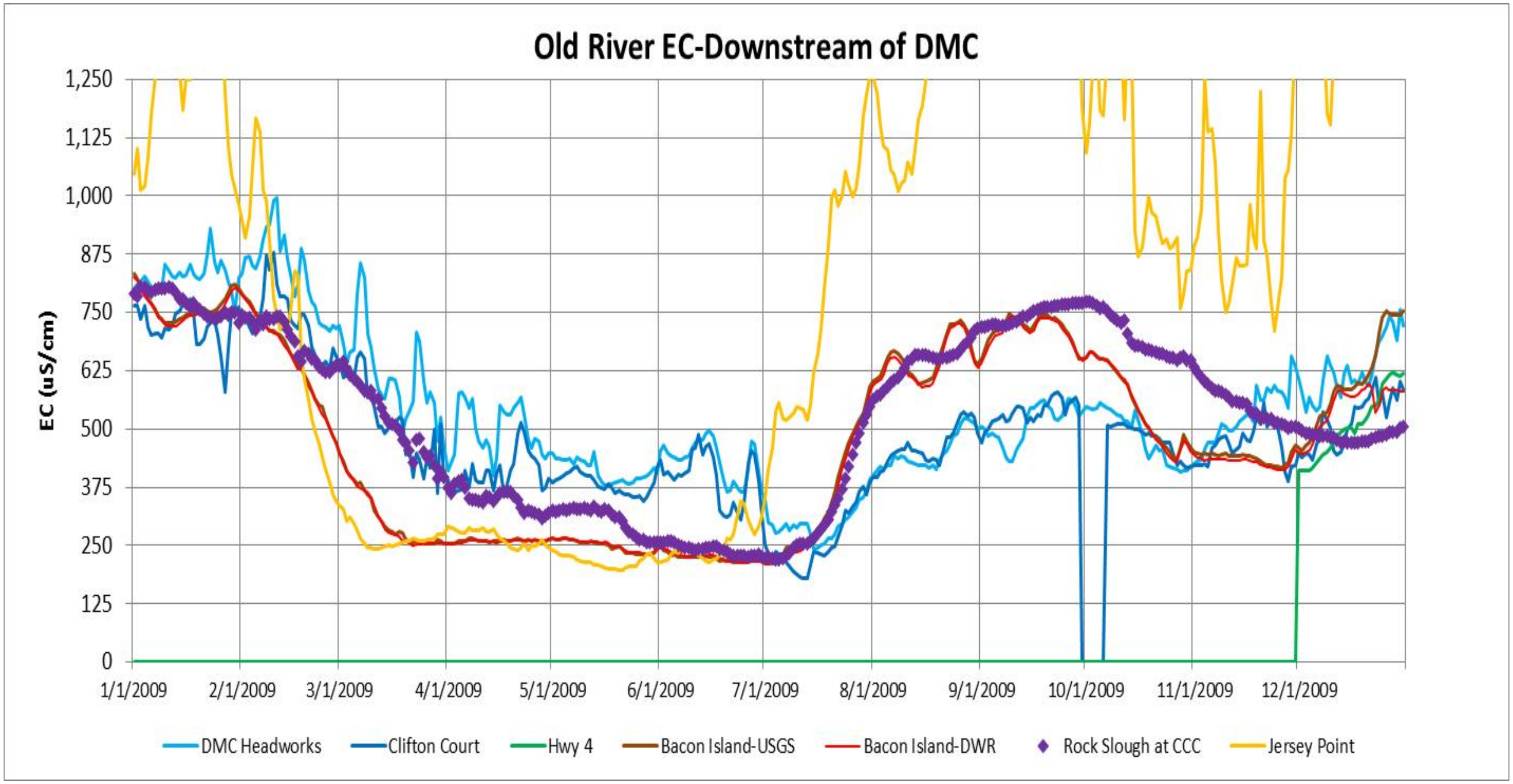
The Old River at Highway 4 minimum and maximum elevations (purple lines) indicate that the tidal elevations generally ranged from 2 feet to 6 feet (4-feet range). The SJR at Jersey Point elevations (gold line) were nearly identical to the Old River at Highway 4 elevations. The minimum elevations in Old River at Tracy Boulevard were increased slightly to 3 feet in April when the DMC barrier was installed, with a weir crest of 4.5 feet. The minimum elevations in Old River and in Grant Line Canal were increased to between 3.5 feet and 4.5 feet from July through October when the Old at DMC and Grant Line Canal temporary barriers were installed. The tidal elevation range in Old River and in Grant Line Canal was reduced to less than 1.5 feet (reduced tidal flows) from July through October. The minimum elevations at Tracy Boulevard were highest in October, when the flap gates were closed; some of the flap gates were opened periodically from July-September, but irrigation diversions were also reduced in October.



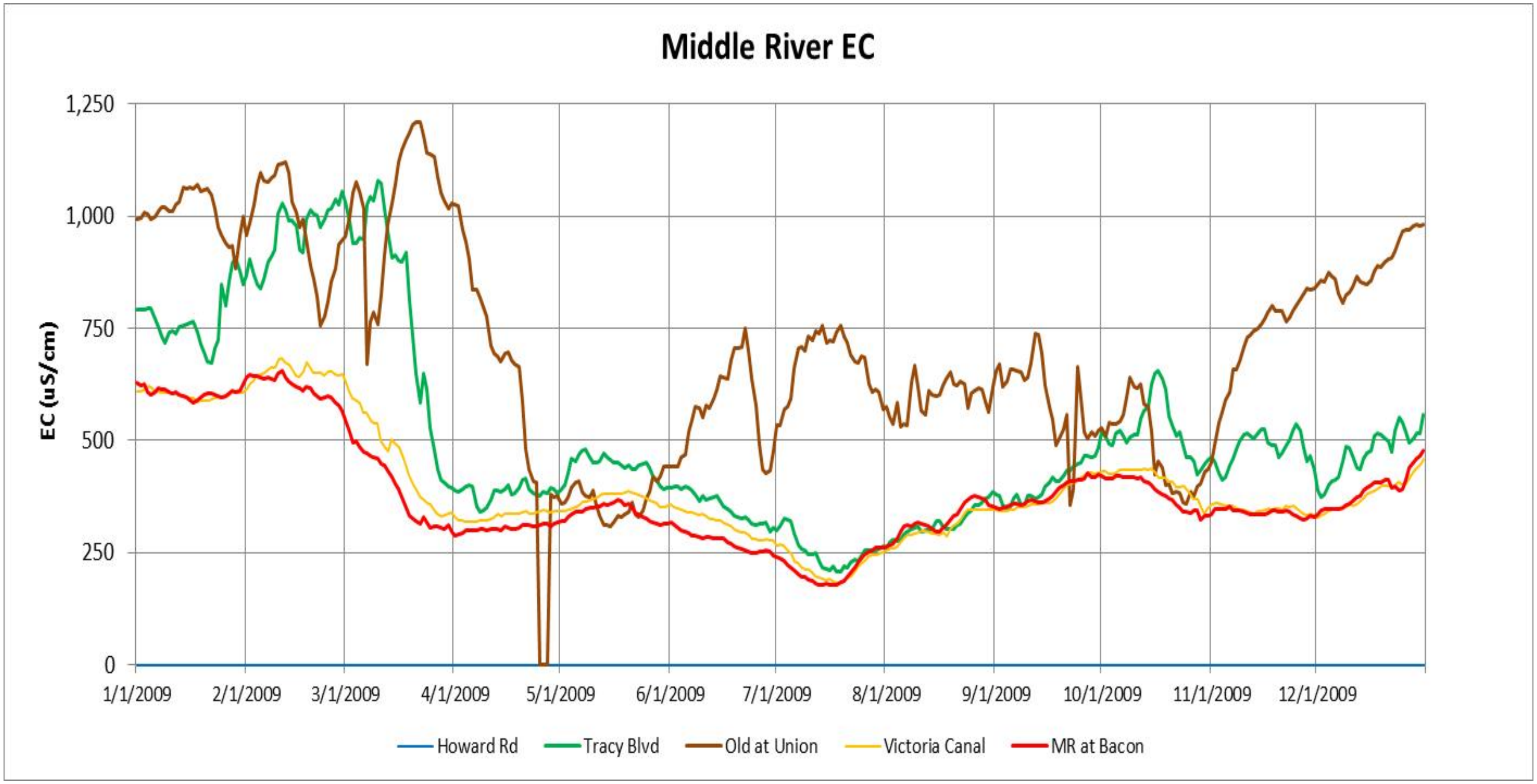
The Middle River Barrier, with a weir crest of about 4.5 feet, was installed in mid-May and flap gates were operated beginning on June 20. The Grant Line Canal barrier was installed with a weir crest of 3.5 feet on June 25. The minimum elevations in Middle River at Tracy Boulevard (red diamonds) were slightly increased compared to the Highway 4 elevations in July and August, and were increased slightly more in September and October (lower diversions). The high tides at Tracy Boulevard were not reduced with the barrier. The high tide elevations in Middle River at Howard Road were reduced slightly with the barrier installed. The minimum elevations in Middle River at Howard Road (green line) were similar to the Middle River at Tracy Boulevard elevations. The tidal elevation range in Middle River at Howard Road was greater than the tidal elevation range in Grant Line Canal with the barriers installed.



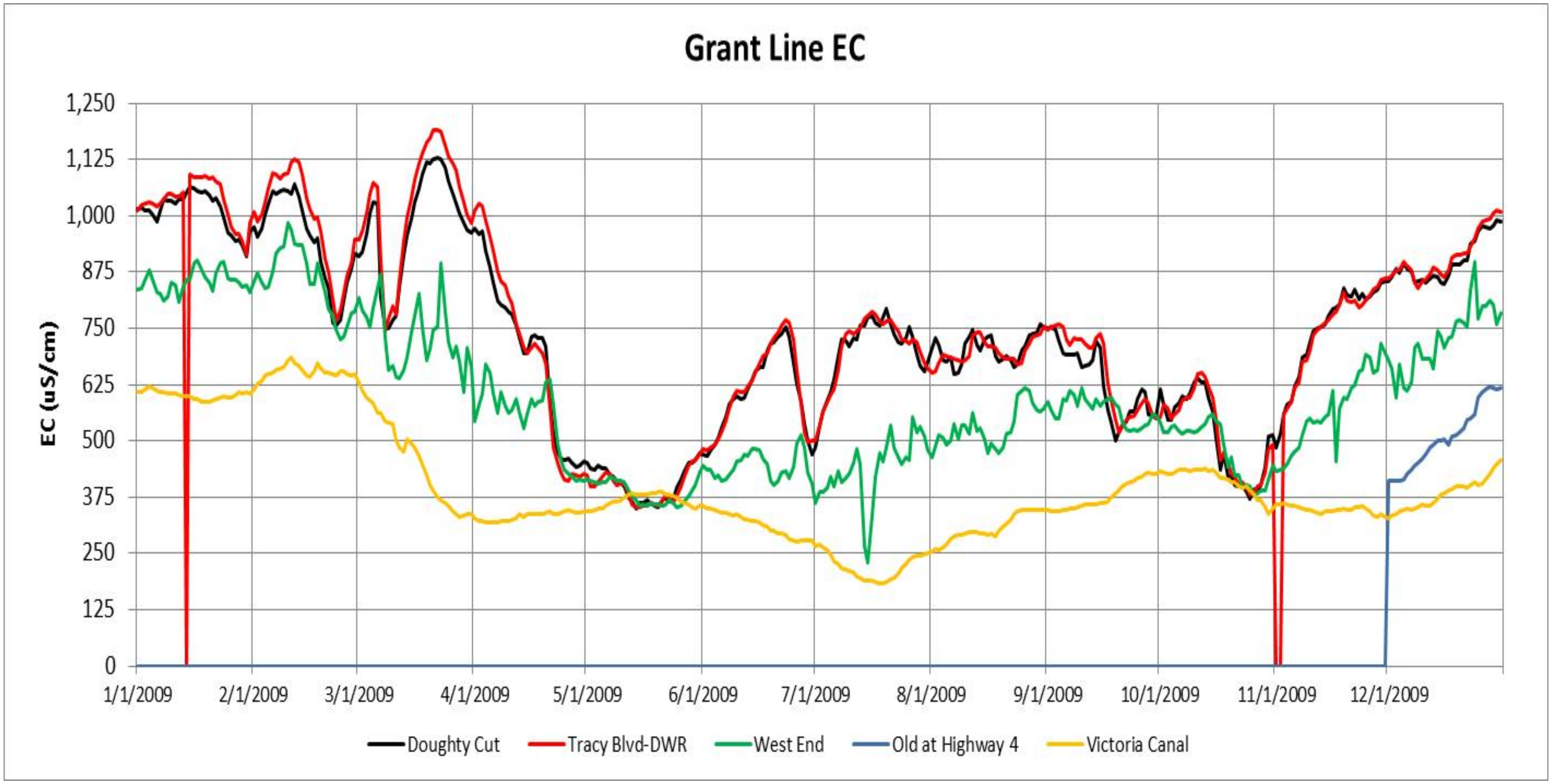
The Old River EC measured at the head of Old River (green line), Union (light brown line) and at Doughty Cut (dark blue line) was similar for most of the year. The most dramatic EC increases were measured between Doughty Cut and Tracy Boulevard (a distance of about 2 miles). The EC in Old River at Tracy Boulevard (red line) was above 1,000 uS/cm in January-March, was reduced to 500 uS/cm in May, was about 1,000 uS/cm from July to mid-September, and was highest (1,250 uS/cm) in November and December. The EC at Tracy Boulevard was generally 100-250 uS/cm higher than the EC at Doughty Cut, but was 500 uS/cm higher in November and December. The EC at Tracy Wildlife (0.25 km downstream of Tracy Boulevard) was nearly identical to Tracy Boulevard EC until June 25, when the Tracy Boulevard EC increased and remained about 250 uS/cm higher than Tracy Wildlife EC for the remainder of the year. The higher EC measured in Sugar Cut (750 to 1,500 uS/cm) throughout the year, and in Paradise Cut (500 to 1,000 uS/cm) from July-December indicate sources of higher salinity water that could influence the Old River at Tracy Boulevard EC.



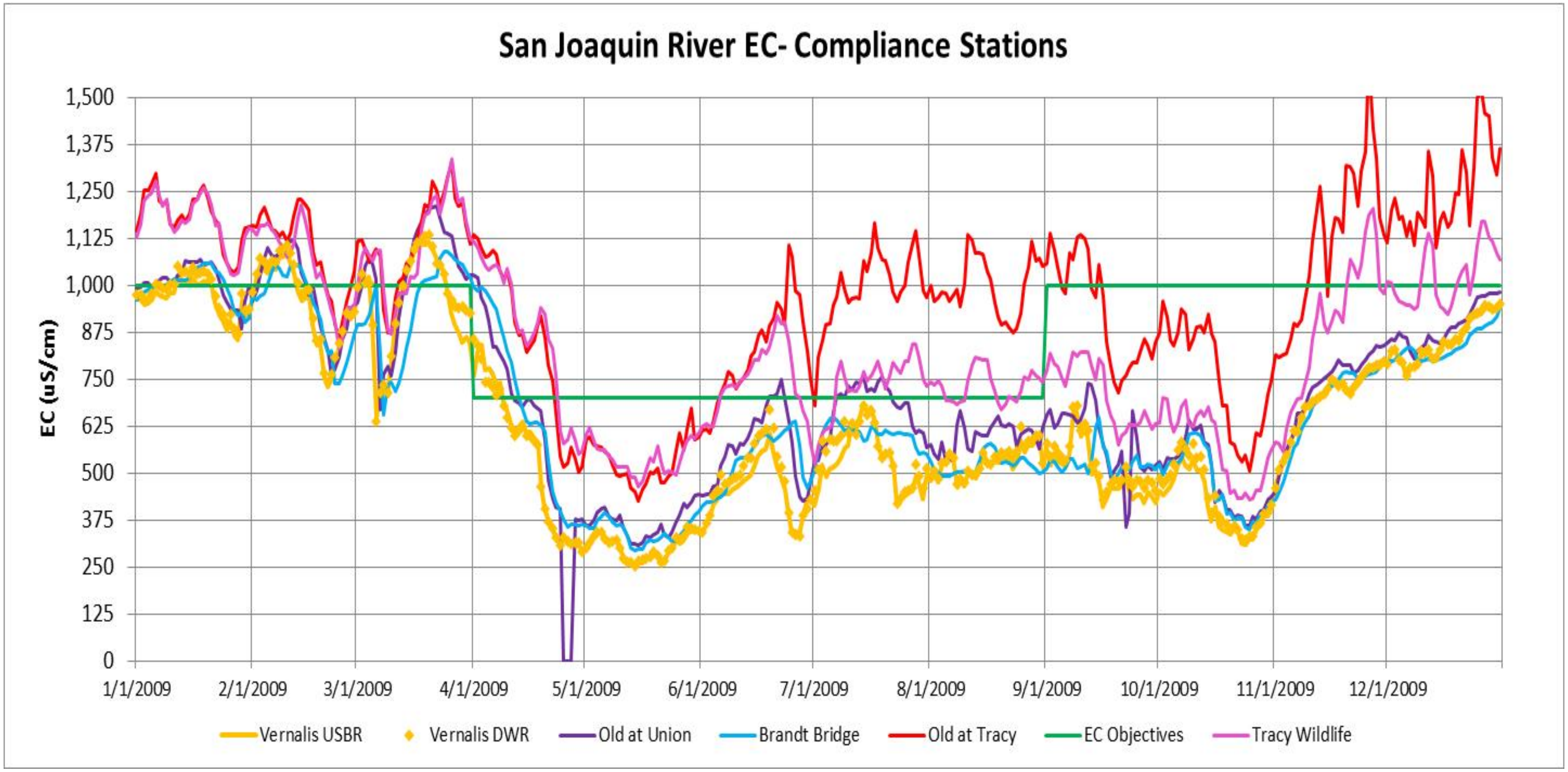
The Old River EC downstream of the DMC intake may have an increasing salt gradient when seawater intrusion is high during periods of low Delta outflow. The SJR at Jersey Point EC (gold line) is highest when seawater intrusion is greatest. False River, located just upstream of Jersey Point, connects the 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 will be about 250 uS/cm 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.



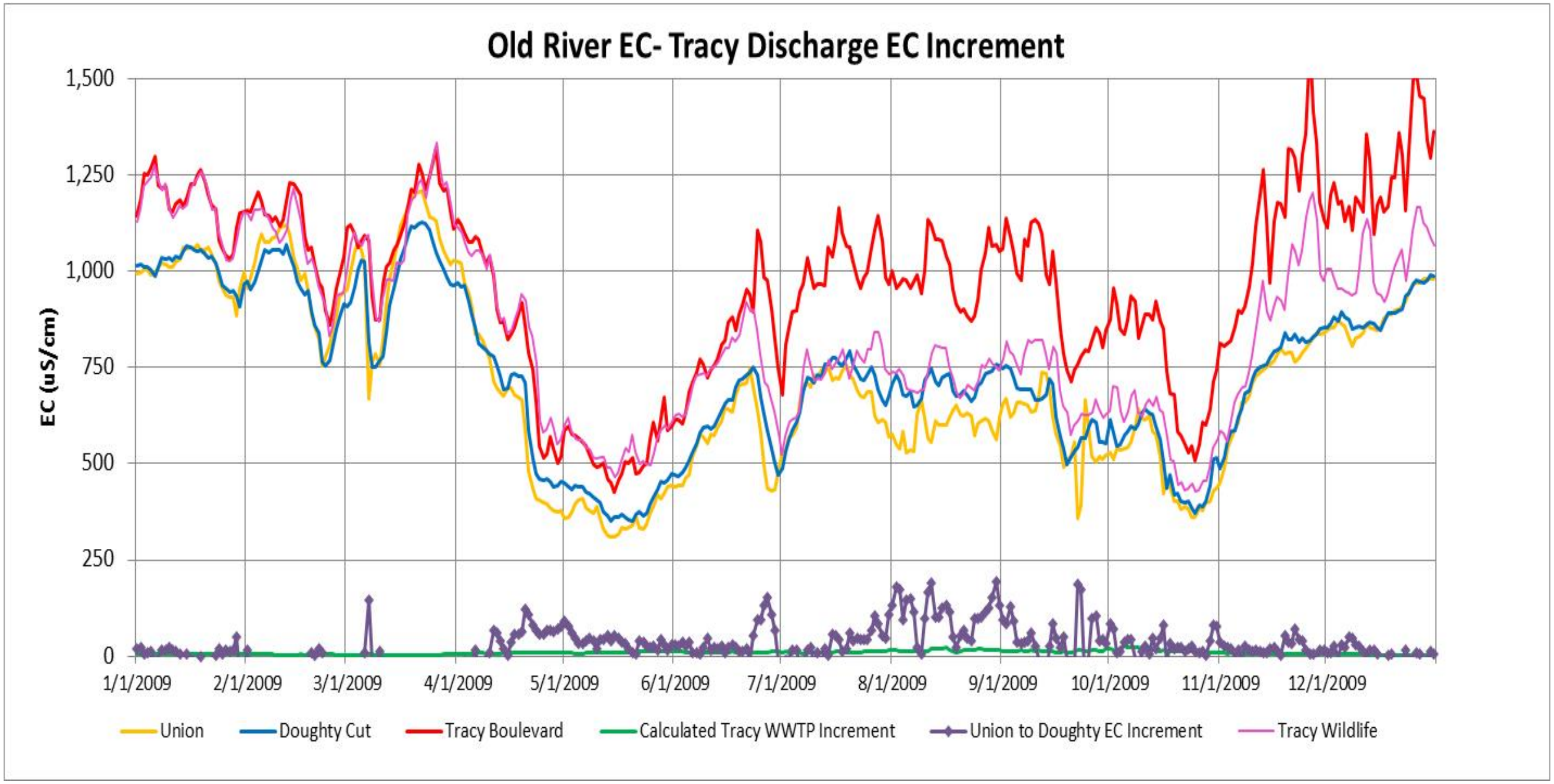
The Middle River EC downstream of the barrier at Bacon Island (red line) and at Victoria Canal (gold line) was nearly identical and varied from 250 to 650 uS/cm in 2009. The EC in Old River at Union (brown line), which is at the upstream end (head) of Middle River, was about 1,000 uS/cm from January through March, and was reduced to about 350 uS/cm in May. The Middle River EC at Tracy Boulevard (green line) was similar to the downstream EC at Victoria Canal for most of the year, suggesting an upstream flow or tidal mixing with the downstream portion of Middle River from May-September. The Tracy Boulevard EC was similar to the Old River at Union EC in February and March, suggesting downstream flow in Middle River during this portion of the year.



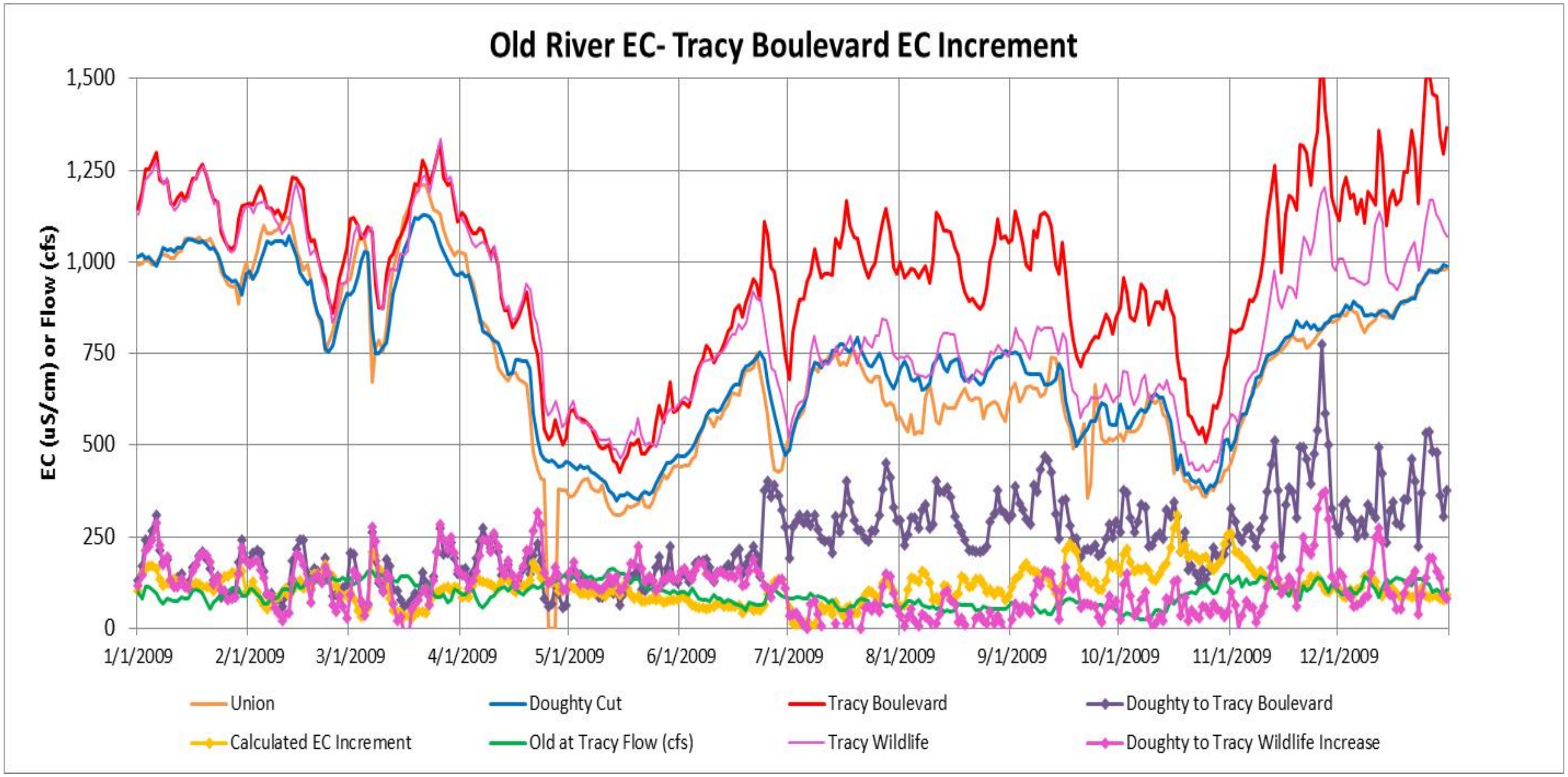
The Grant Line Canal EC at Doughty Cut and at Tracy Boulevard followed the SJR EC pattern that was controlled by SJR flow (EC dilution effect). The Grant Line Canal EC at the western end (green line) was usually less than the EC at Tracy Boulevard because of the high tidal flows at the downstream end 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 also controlled the EC at the Clifton Court Forebay (CCF) and EC at the DMC intake.



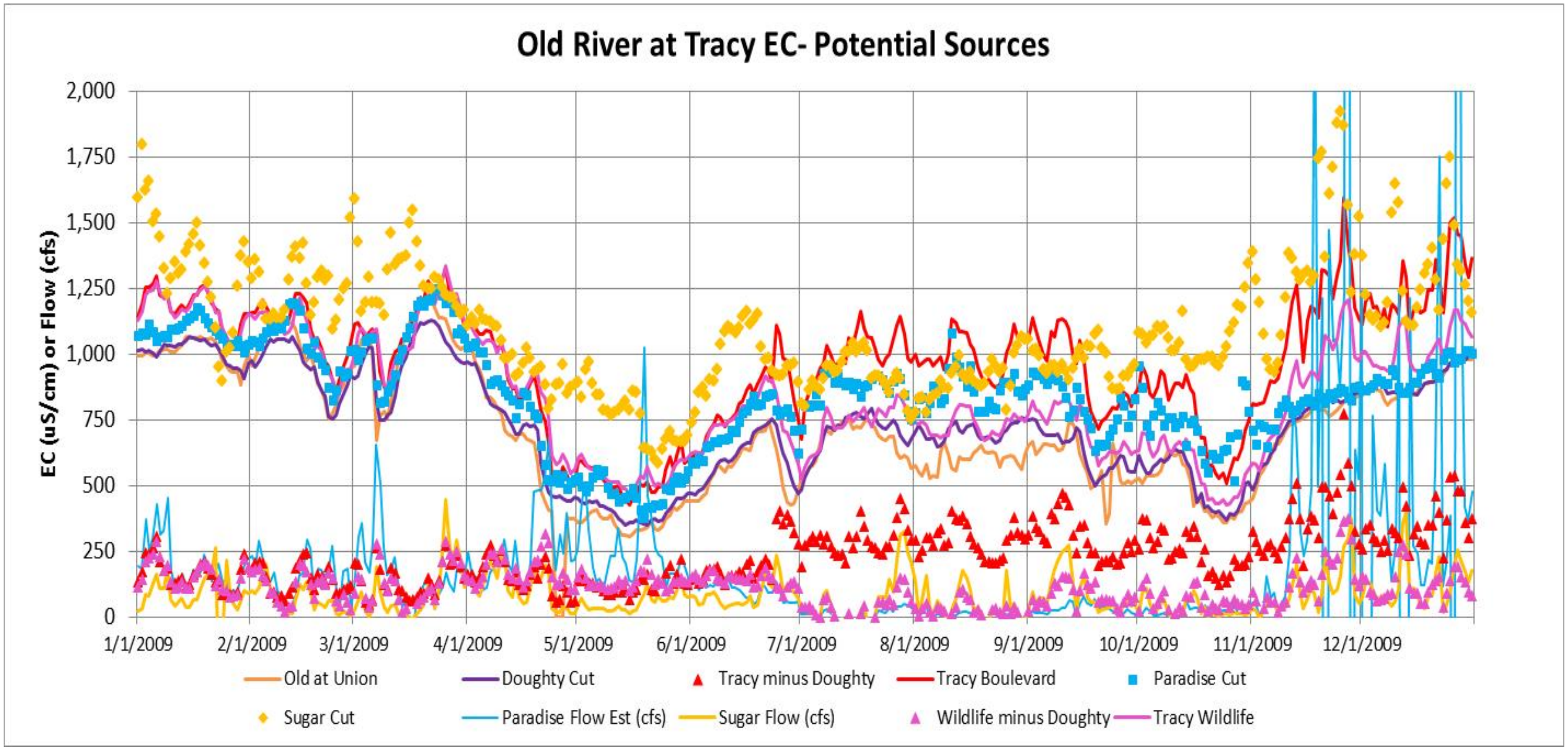
The SJR at Vernalis and the south Delta EC Objectives are 700 uS/cm from April through August and 1,000 uS/cm from September through March (30-day running average). The EC at Vernalis and at Brandt Bridge and at Union stations were generally similar; however, the Old River at Tracy Boulevard EC was often 125-250 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 Tracy Wildlife EC confirmed the Tracy Boulevard EC until the end of June. But the Tracy Boulevard EC remained 250 uS/cm higher than the Tracy Wildlife EC through the end of the year. Additional effort to field-check (verify) the Tracy Boulevard EC readings should be made. Comparative graphs of nearby stations or adjustments based on field visits could be incorporated into the monitoring program. The higher EC at Tracy Boulevard and Tracy Wildlife was measured both during periods with the temporary barriers installed (July-October of 2009) and during periods without barriers (January-June and November-December of 2009).



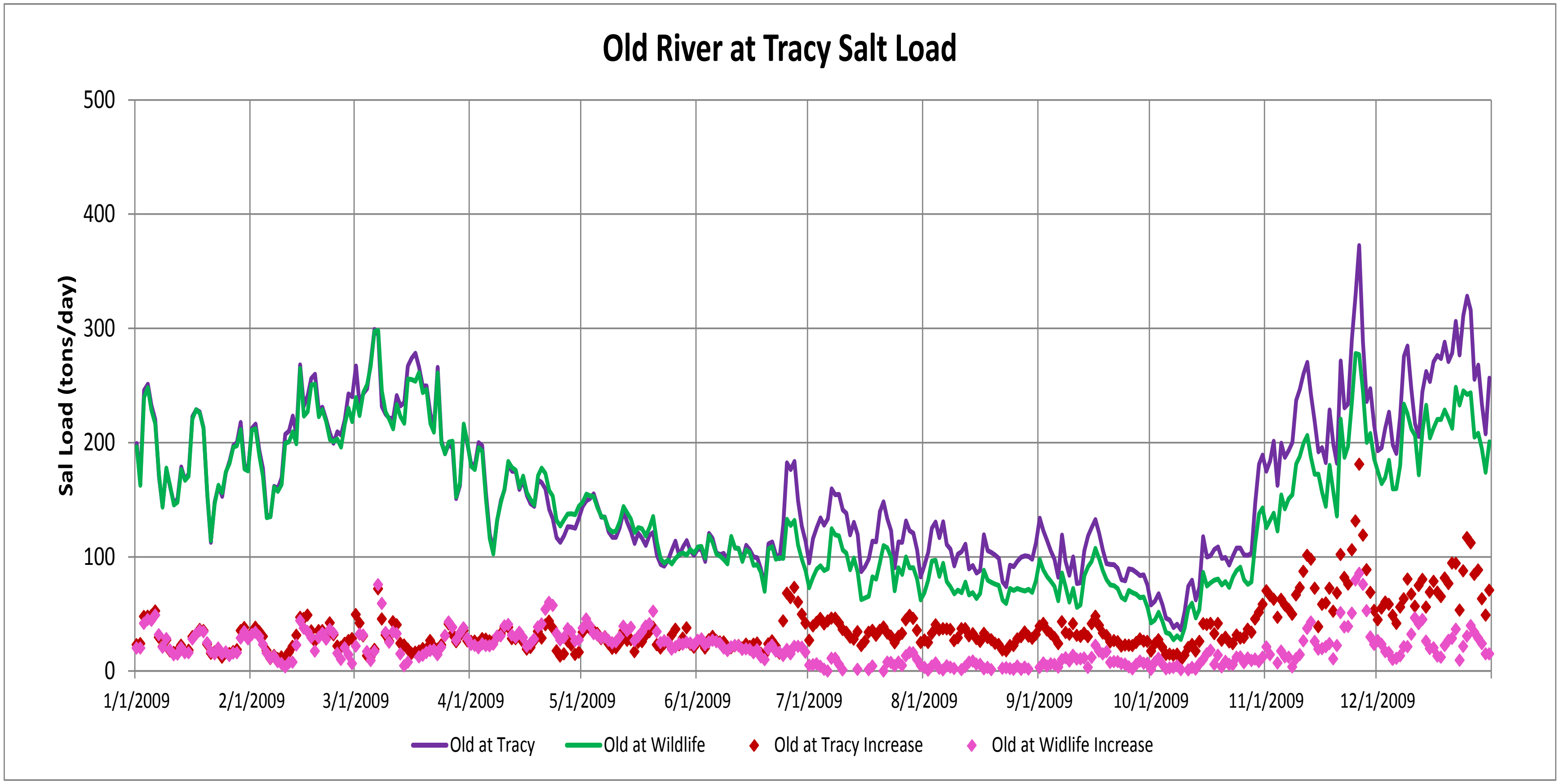
The measured daily EC increment between any two locations along Old River can be approximated with a source discharge (cfs) and a source EC (uS/cm). The expected EC increment between Union and Doughty Cut caused by the Tracy Wastewater Discharge (green line) was calculated as: EC increment (uS/cm) = (Tracy Discharge EC – River EC) x Tracy Discharge / (River Flow + Tracy Discharge). The measured daily Old River EC increments between Union and Doughty (purple diamonds) were compared to the daily calculated Tracy Discharge EC increments for the measured Tracy discharge and EC. The calculated EC increments were highest in July-September when the head of Old River flow was about 500 cfs. The EC increase between Union and Doughty Cut was generally higher during these months, suggesting that some other salt sources were reaching Doughty Cut. For example, some of the salt from Paradise Cut can be moved upstream by flood tide flows to Doughty Cut, when net flows in Old River at Tracy Boulevard are low.



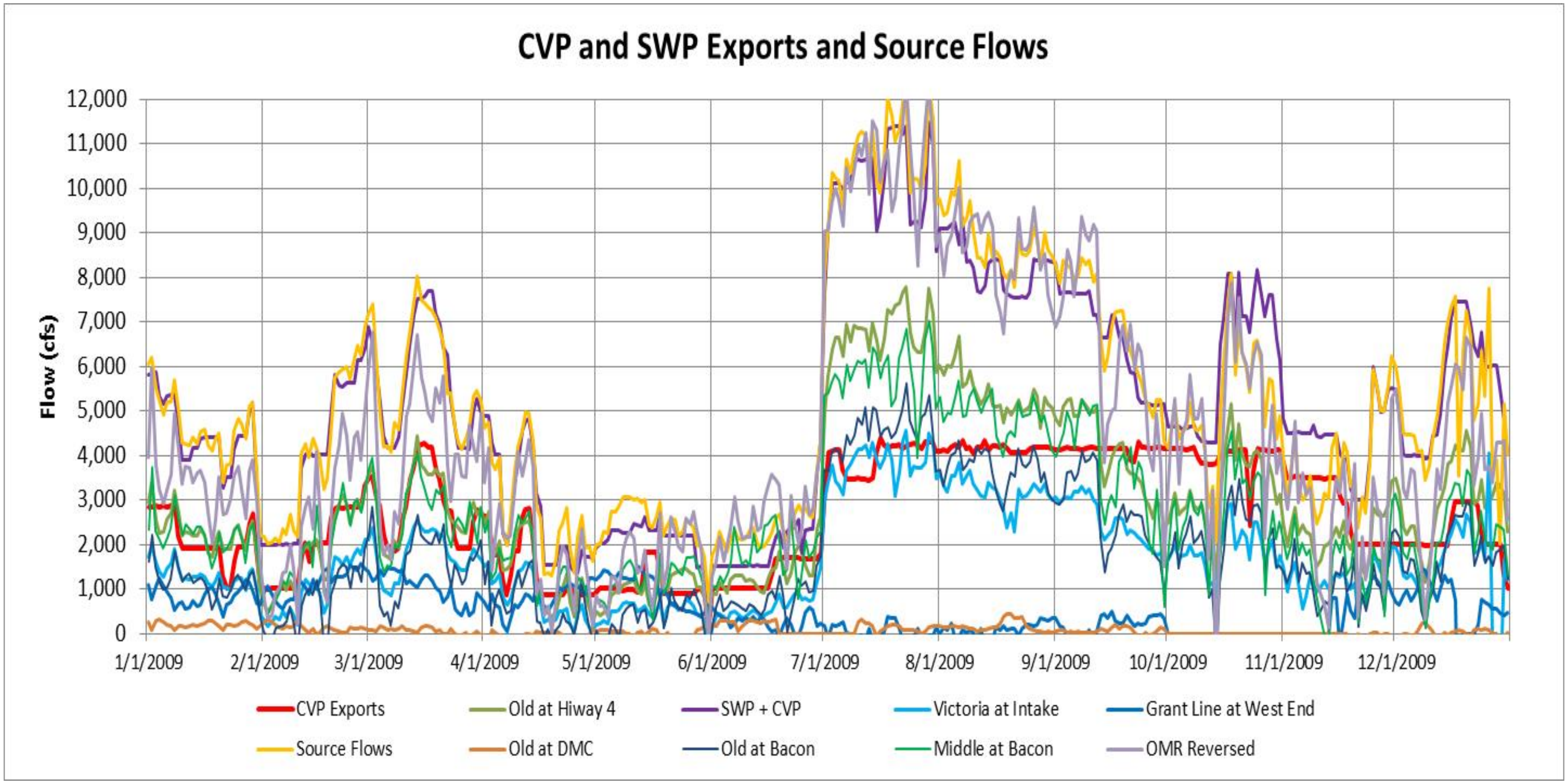
The Old River EC increments between Doughty Cut and Tracy Boulevard (purple diamonds) or Tracy Wildlife (pink diamonds) were compared with the calculated EC increments from Paradise Cut and Sugar Cut, assuming the Old River at Tracy Boulevard flow was 10% of the head of Old River flow plus a tidal flow for 100 acres. The calculated EC increments (gold diamonds) depend on the assumed tidal flow at Tracy Boulevard, and on the tidal movement of salt from Paradise Cut and Sugar Cut. The calculated EC increments were greatest during the late summer and early fall when the Old River flow (green line) was lowest, and generally matched the measured EC increments of about 125 uS/cm in the January-June and November-December periods (without barriers), with less than 100 uS/cm increments in the July-October period (with barriers). The measured EC at Tracy Boulevard was about 250 uS/cm higher than at Tracy Wildlife from July to the end of the year; the Tracy Wildlife EC is likely more accurate.



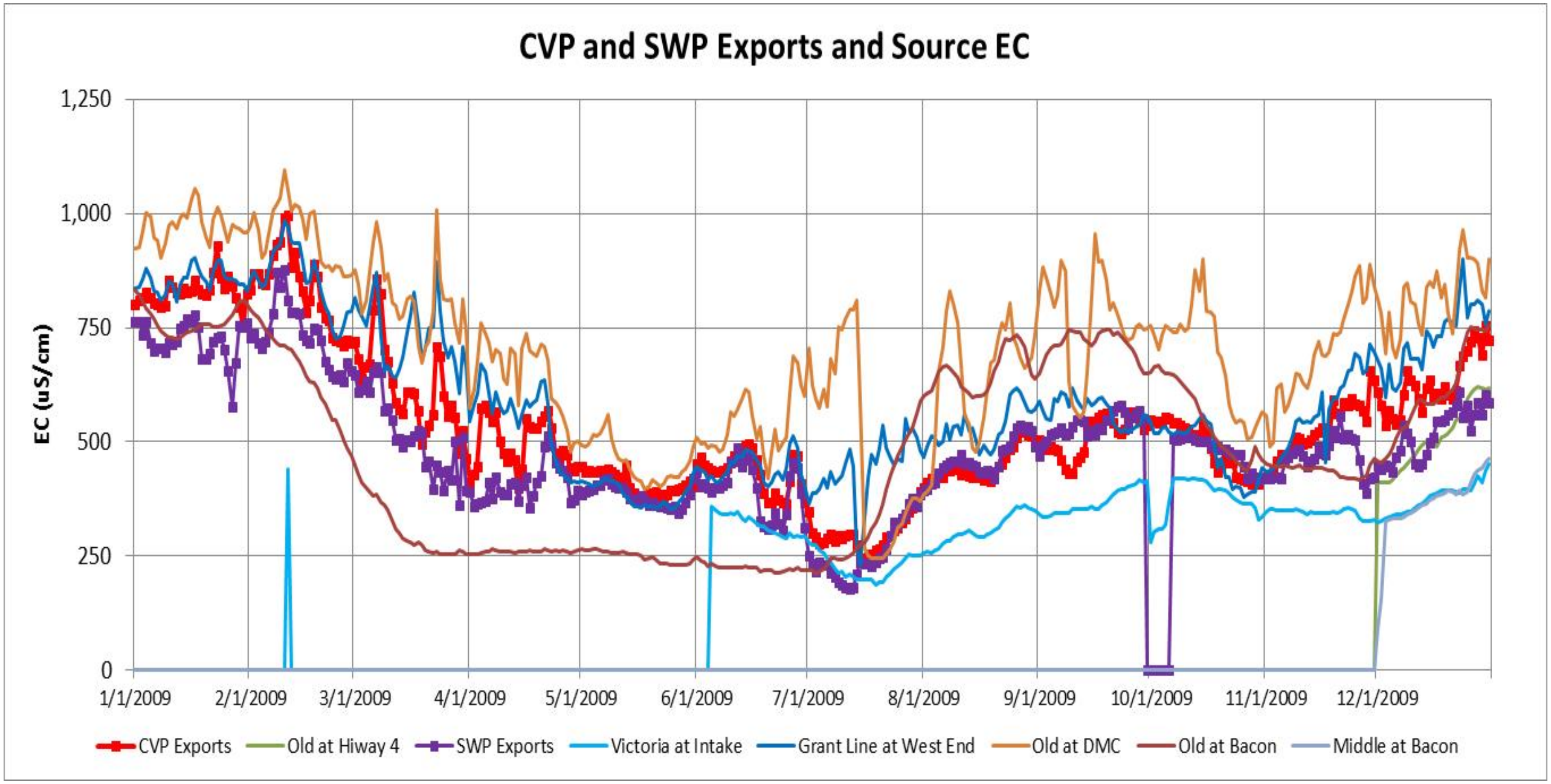
The EC increment between Doughty Cut and Tracy Boulevard or Tracy Wildlife can approximated as: EC increment (uS/cm) = (Source EC – River EC) x Source Discharge / (River flow + Source Discharge). The daily Old River EC increments at Tracy Boulevard (red triangles) or Tracy Wildlife (pink triangles) were matched with the daily average Paradise Cut EC (blue squares) and Sugar Cut EC (gold diamonds) to estimate the "salt source discharge" for Paradise Cut (blue line) or Sugar Cut (gold line) that would be required to cause the measured EC increment. A larger salt source discharge is needed when the Tracy Boulevard EC increment is large and when the flow in Old River at Tracy Boulevard is greater. For most of the year, the Paradise Cut EC was only 50-100 uS/cm higher than the Old River at Doughty Cut EC, so the estimated Paradise Cut discharge (bright blue line) was 100-250 cfs (unrealistically high). During the July-October period (with barriers) the estimated Paradise Cut discharge was much lower, because the Tracy Wildlife EC increment was relatively small. The calculated Sugar Cut discharge (gold line) would have been 50-150 cfs, because the Sugar Cut EC was much higher than the average Paradise Cut EC.



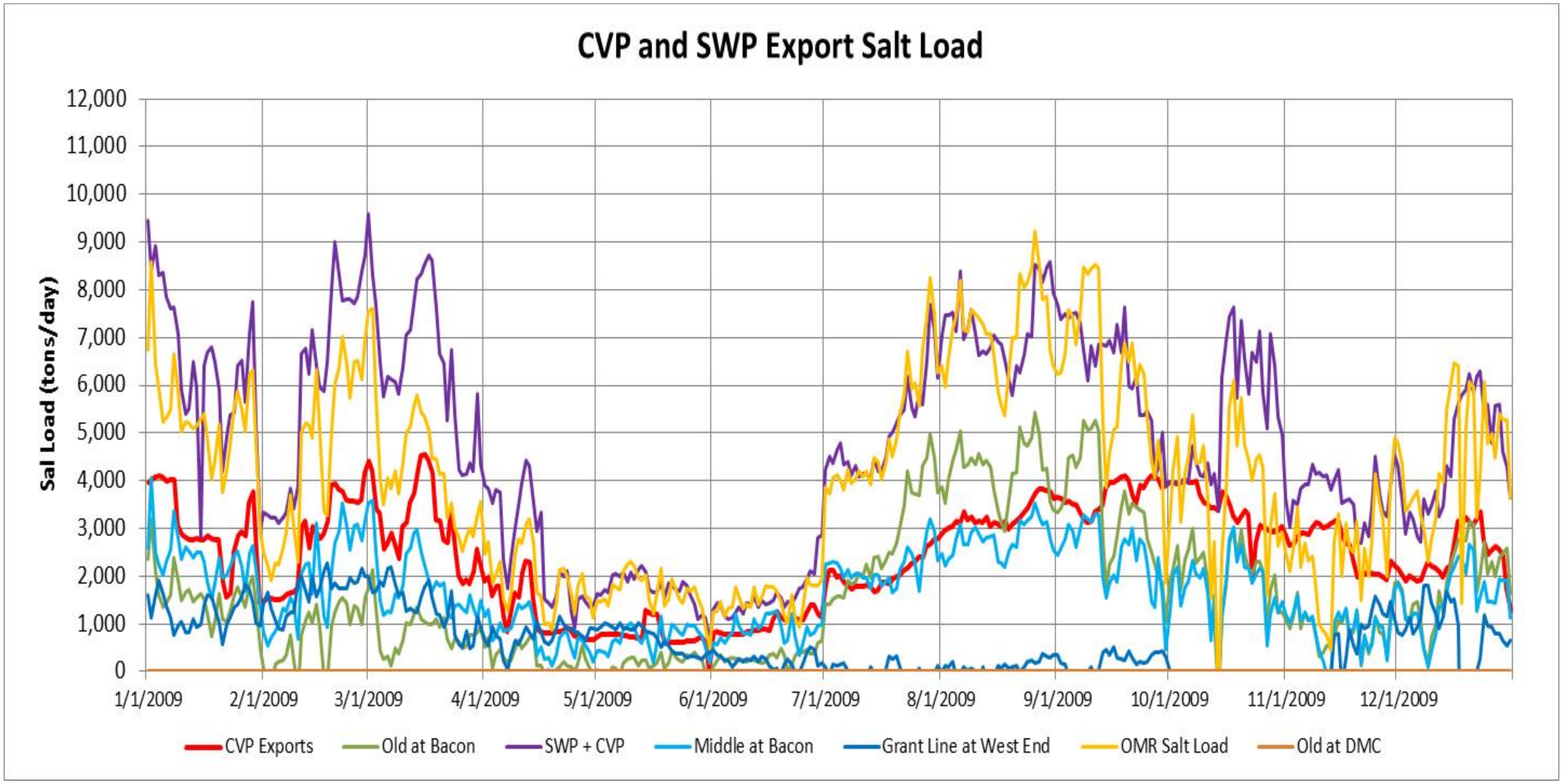
The measured salt loads in Old River at Tracy Boulevard and at Tracy Wildlife (purple and green lines, respectively) were calculated from the Old River EC at these locations and estimated flow at Tracy Boulevard. The salt load increments between Doughty Cut and Tracy Boulevard and Doughty Cut and Tracy Wildlife (red and pink diamonds, respectively) were calculated from the EC increment and the Old River flow at Tracy Boulevard. The salt load increment varied from about 0 tons/day to about 100 tons/day, with an average salt load increment of about 20 tons/day in 2009 at Tracy Wildlife. The EC at Tracy Boulevard and the EC at Tracy Wildlife were very similar in 2009 through June. However, the loads differed from July-December because during this time the Tracy Boulevard EC was 250 uS/cm higher than the Tracy Wildlife EC.



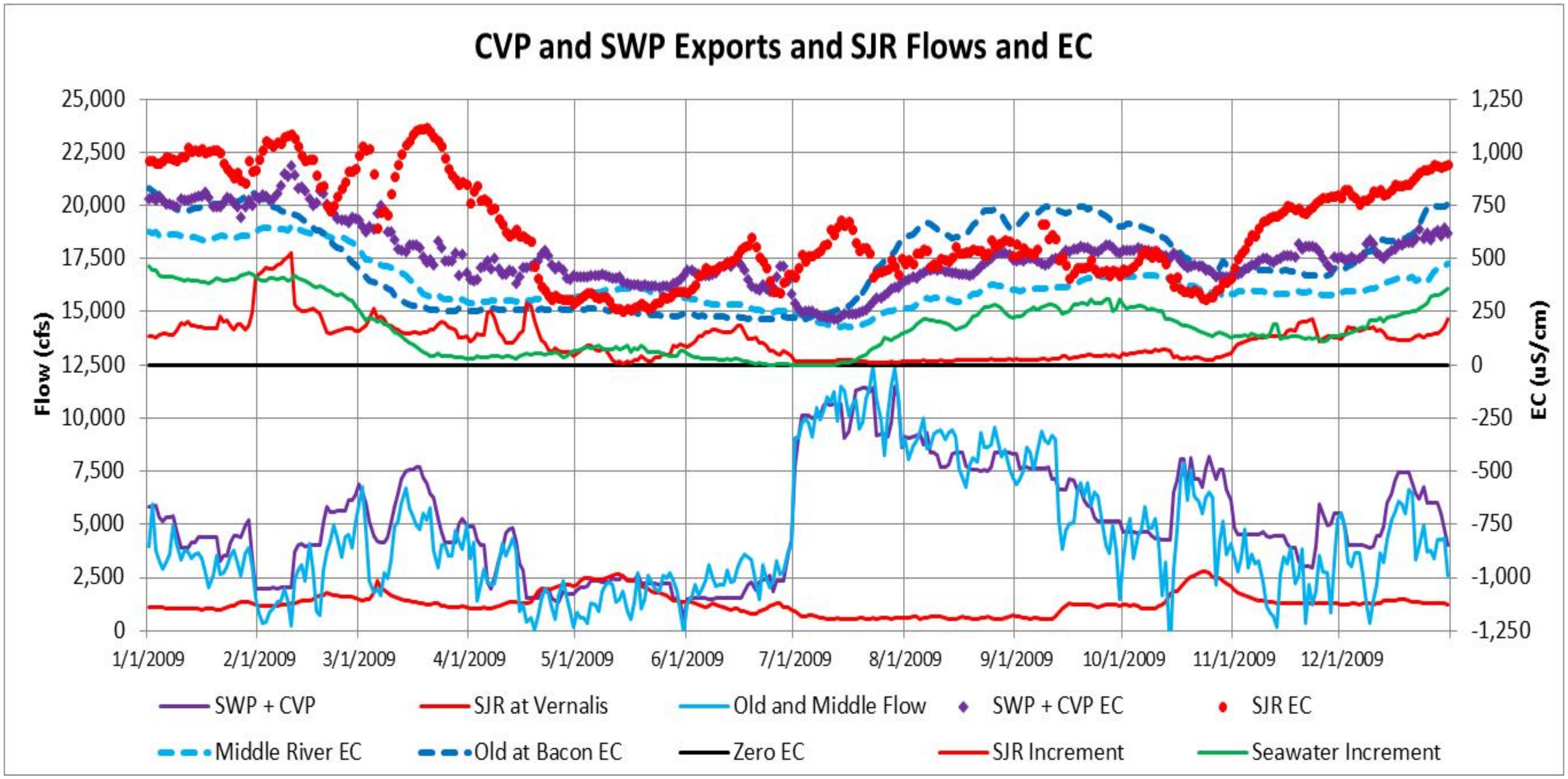
During 2009, the average flows in the south Delta channels (gold line) provided an accurate match with the CVP and SWP export flows. The Old River at Highway 4 flow was the largest source of water for CVP and SWP exports; when pumping was near the maximum (permitted) of about 11,000 cfs, the Old River 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). The Grant Line Canal flow and the Old River at DMC flow was generally less than 250 cfs during the summer months, when irrigation diversions in the south Delta are greatest. During periods when all four flow stations were operating, the match with CVP and SWP exports (purple line) was very accurate (within 10%).



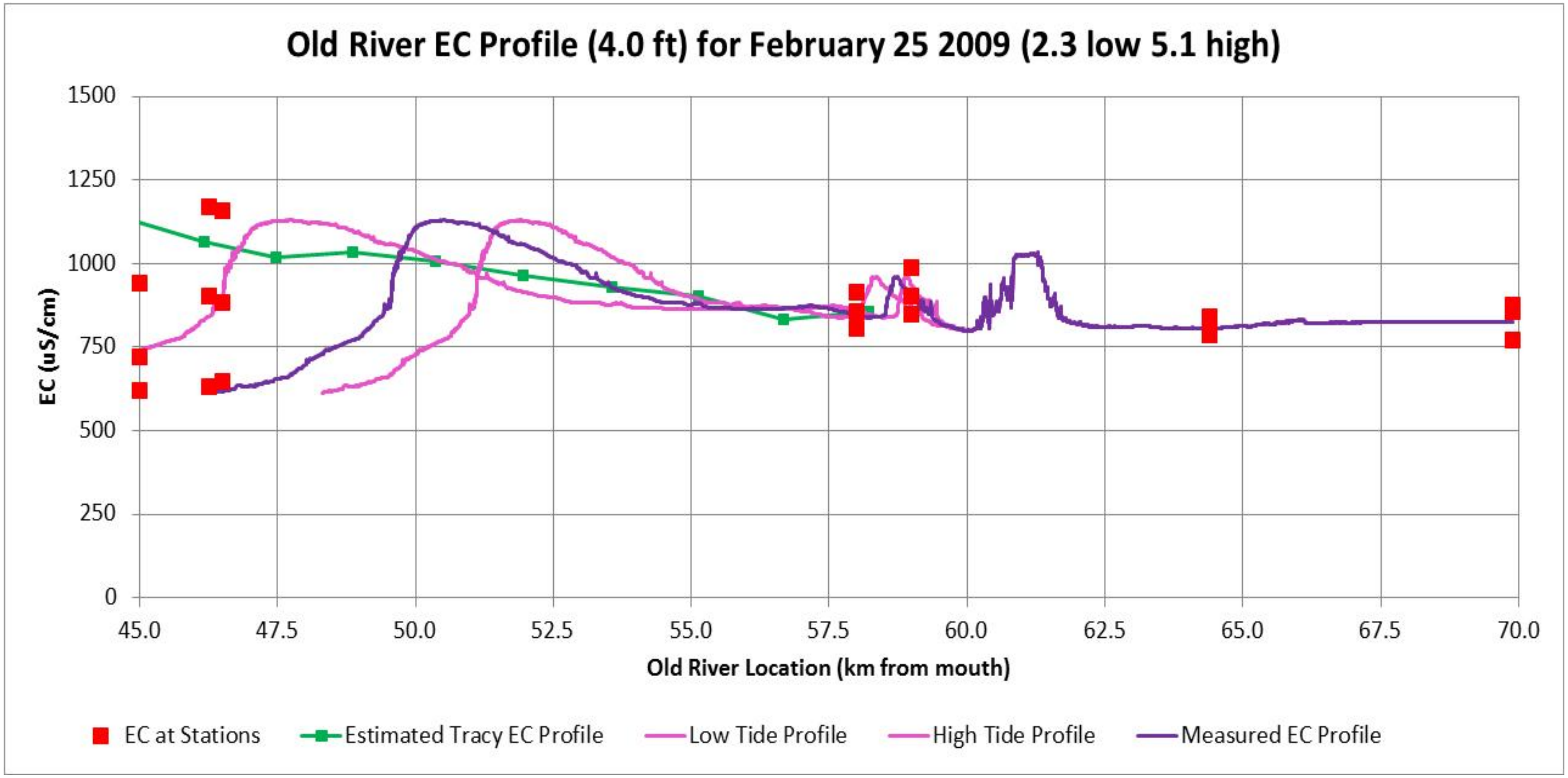
The salinity (EC) of the CVP and SWP exports and the water sources for the CVP and SWP exports are slightly different during most of the year. The CVP intake is located just 1 mile south of the SWP intake, but Grant Line Canal enters Old River between the two intakes. The EC in Old River at the DMC barrier (light brown line) was the highest and the EC in Grant Line Canal (dark blue line) was often higher than the exports. Although the water in both of these channels originates from the SJR through the head of Old River, the Grant Line Canal EC is tidally mixed with the lower EC water from Victoria Canal and from Old River at Bacon Island. The EC in Old River at Bacon Island (dark brown line) was higher than the EC in Victoria Canal in August-October because of seawater intrusion into Old River during periods of low Delta outflow.



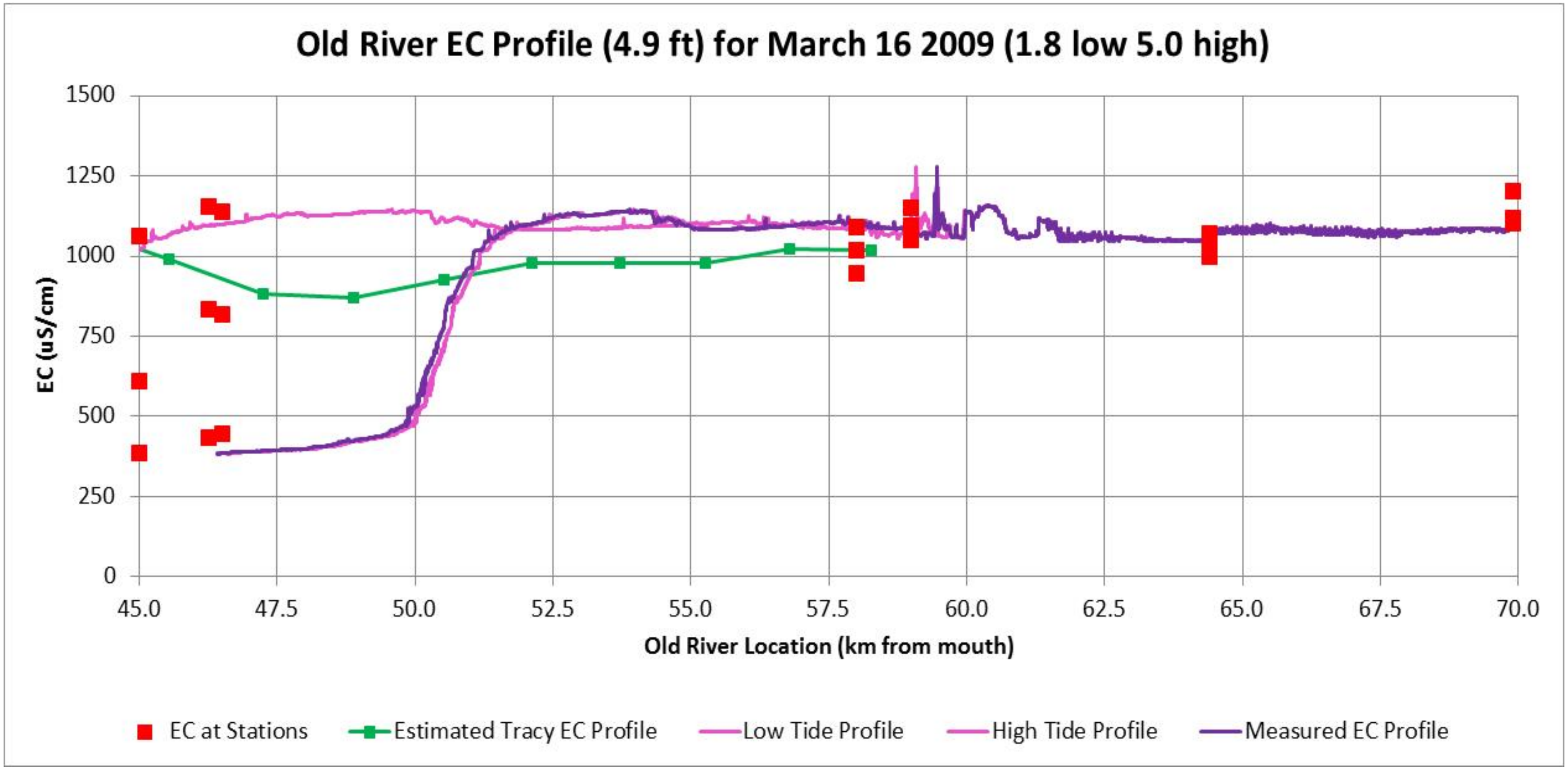
The salt load exported at the CVP and SWP pumping plants increases with pumping flow and with salinity (EC). The net tidal flows and the daily average EC values were used to calculate the CVP and combined CVP and SWP salt loads (tons/day) as well as the salt loads from Old River at Bacon and Middle River at Bacon (combined as OMR salt load), Grant Line Canal at west end, and Old River at the DMC barrier. The Middle River and Old River salt loads (OMR salt loads) provide most of the salt load at the CVP and SWP exports, because the majority of the flows are from these channels.



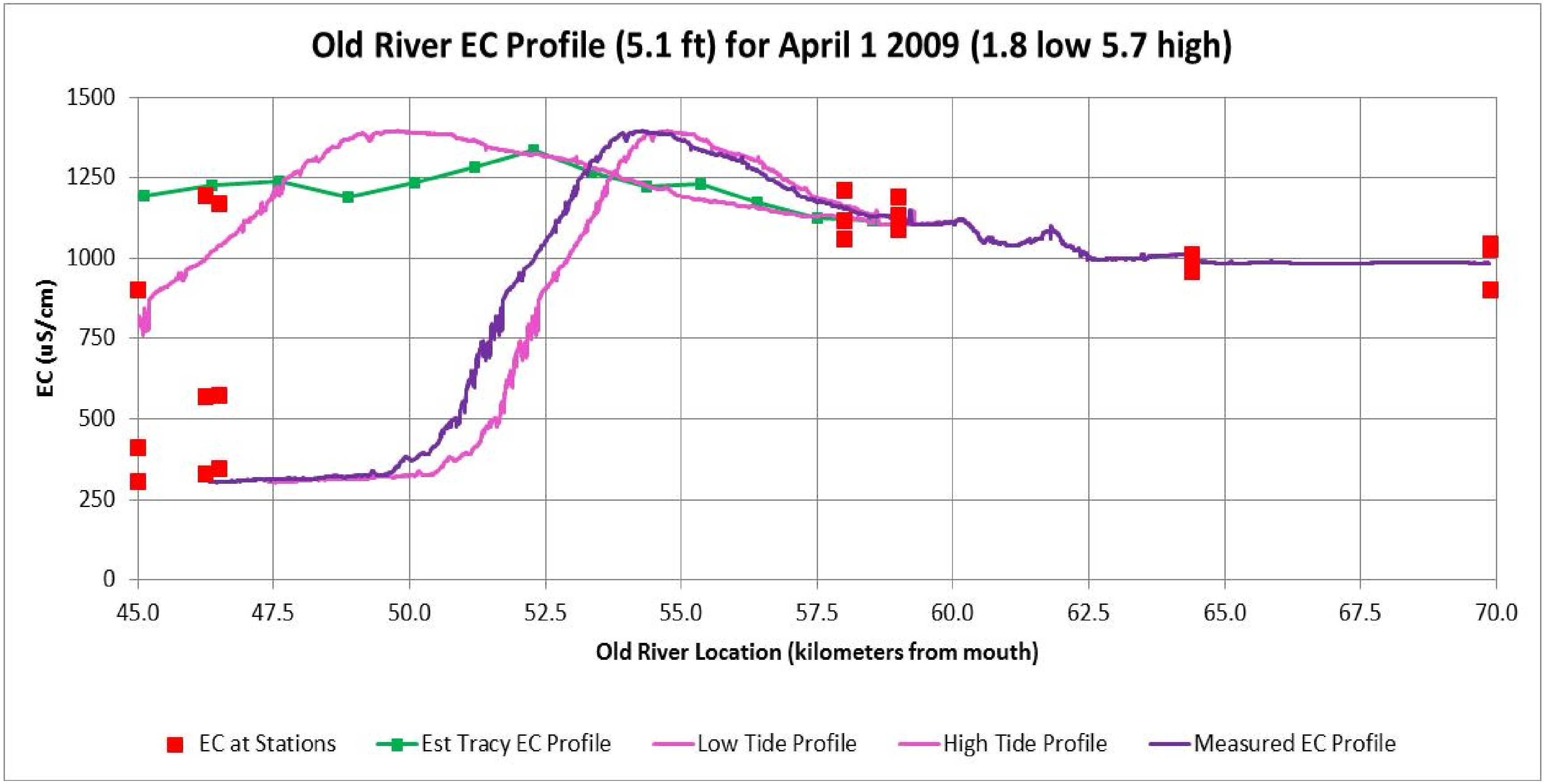
The water sources for the SWP and CVP exports can be estimated from the SJR flow at Vernalis and the Old and Middle River (OMR) flows. The salt sources in the exports can be estimated from the EC increments, with a minimum of 250 µS/cm assumed from Sacramento River water. All of the SJR flow was exported in 2009 because the exports were greater than the SJR flows. The SJR EC increment was calculated as the SJR flow fraction (SJR flow/exports) times the (SJR EC - 250). The SJR EC increment was 125-250 µS/cm in January-March, May, and November-December. The seawater intrusion EC increment was calculated as the OMR flow fraction times the (OMR EC – 250). Seawater intrusion was about 375 µS/cm in January-February, and was about 250 µS/cm in August-December. For 2009, the average exports were 5,185 cfs and the average (flow-weighted) export EC was 490 µS/cm; the Sacramento River EC increment was 250 µS/cm (51%), the SJR EC increment was 90 µS/cm (18%), and the seawater EC increment was 180 µS/cm (36%).



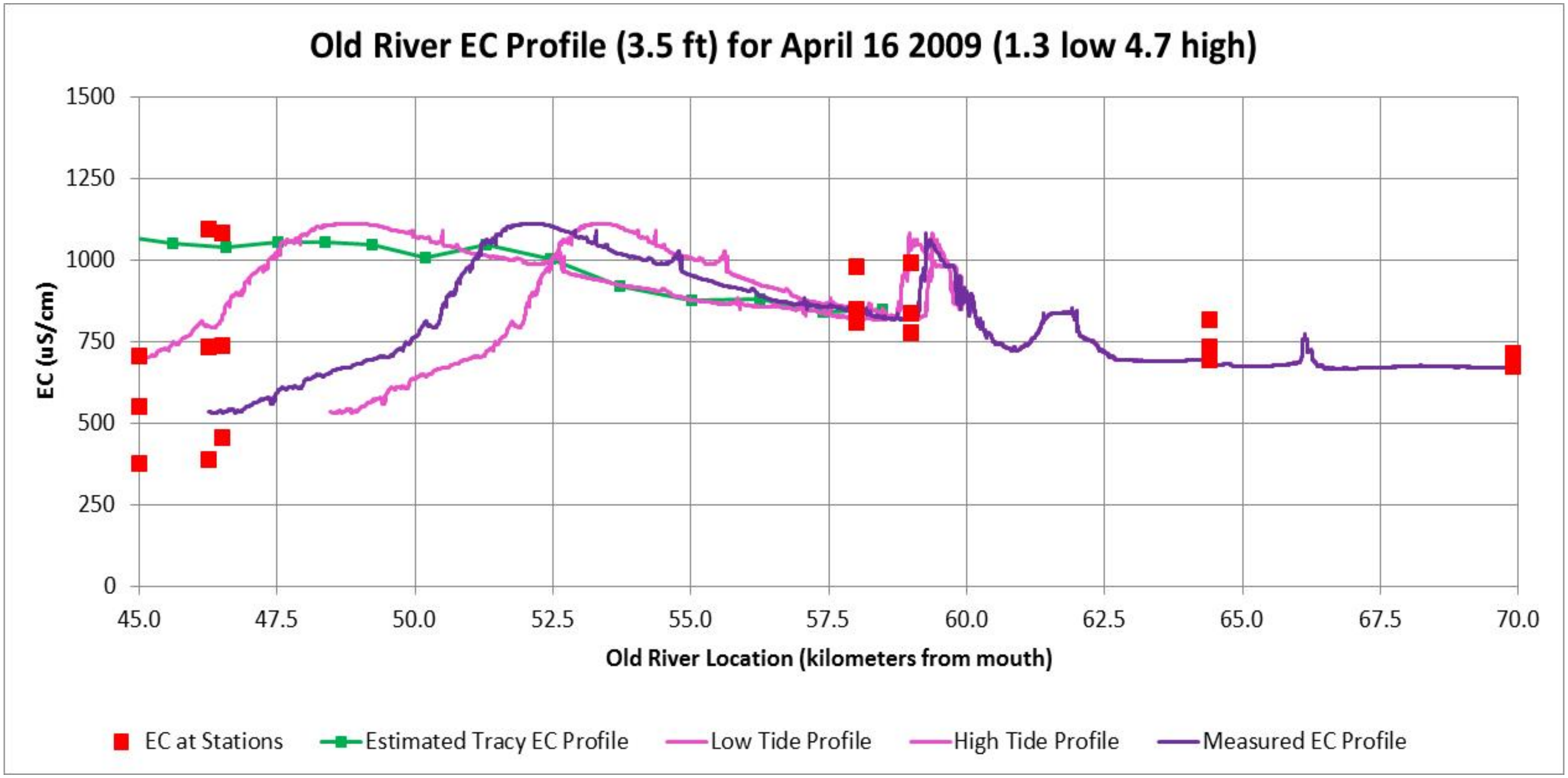
During 2009, DWR collected several EC Profiles along Old River by boat surveys with GPS from the head of Middle River (Union Island EC station) at Old River kilometer 70 to the DMC intake at Old River kilometer 45. These longitudinal EC profiles were compared to the daily minimum, average, and maximum EC at the Old River EC station at Union (70 km), Doughty Cut (64 km), Tracy Boulevard (59 km), above DMC barrier (km 46.5), and below DMC barrier (km 46). The EC Profile matched the daily EC values from each of the Old River stations. There is a large daily EC variation at the downstream stations, because during ebb-tide high EC water from upstream flows past these stations, but during flood-tide water from Old River downstream with lower EC flows past these stations and moves upstream about 5 km in Old River (from 45 km to 50 km). The upstream tidal movement from 45 km at low tide is about 2 km for each 1 feet of tidal elevation change. The measured EC profile was shifted upstream to the high tide and downstream to the low tide (pink lines).



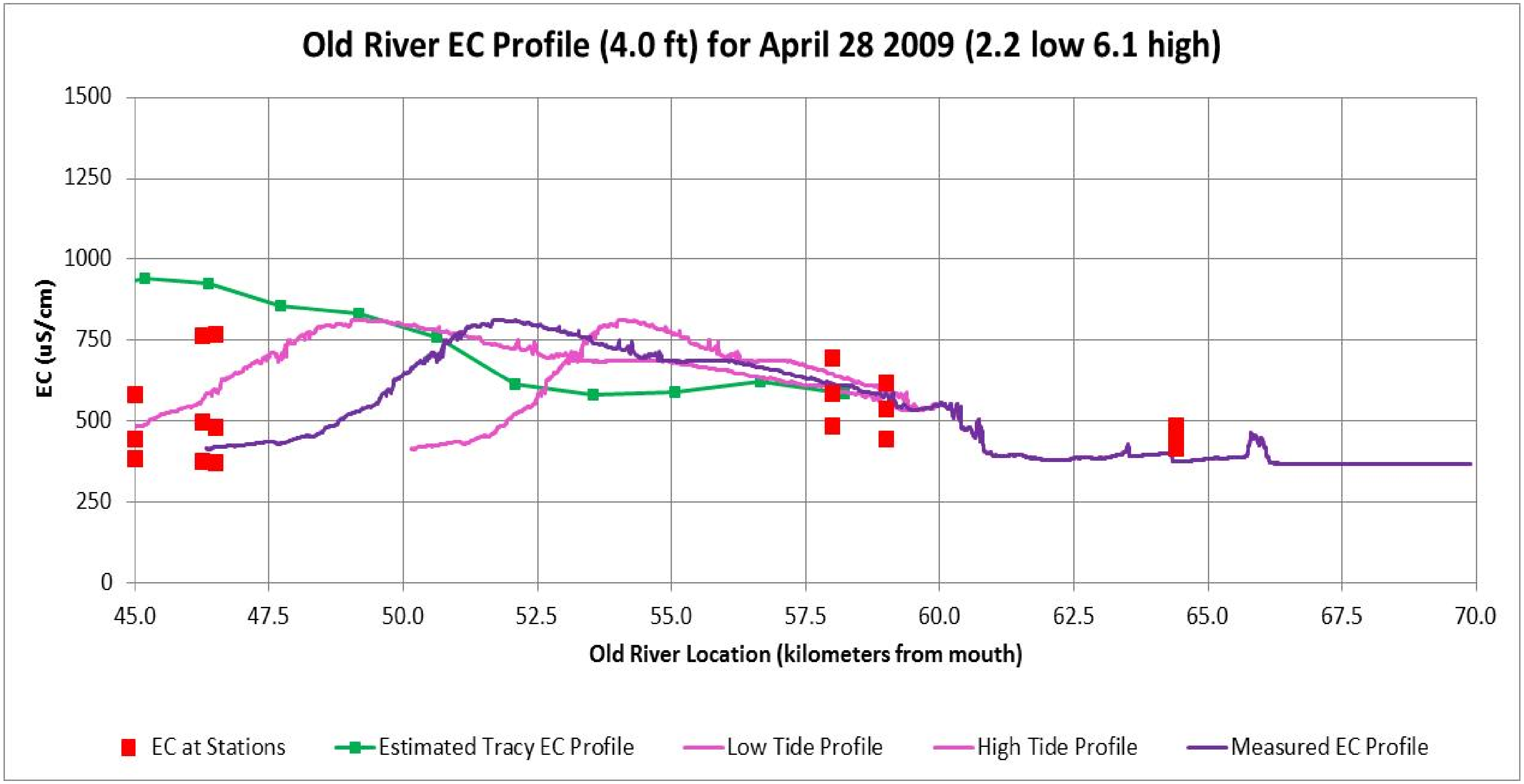
The Old River EC profile on March 16 provided a very good example of the downstream EC gradient (from < 500 uS/cm to > 1,000 uS/cm) measured at high tide about 5 km upstream of the DMC intake at 50 km. The low tide profile was shifted downstream about 6 km. The low tide EC profile matches the maximum EC measured at the downstream stations, and the high tide EC profile matches the minimum EC measured at the downstream stations.



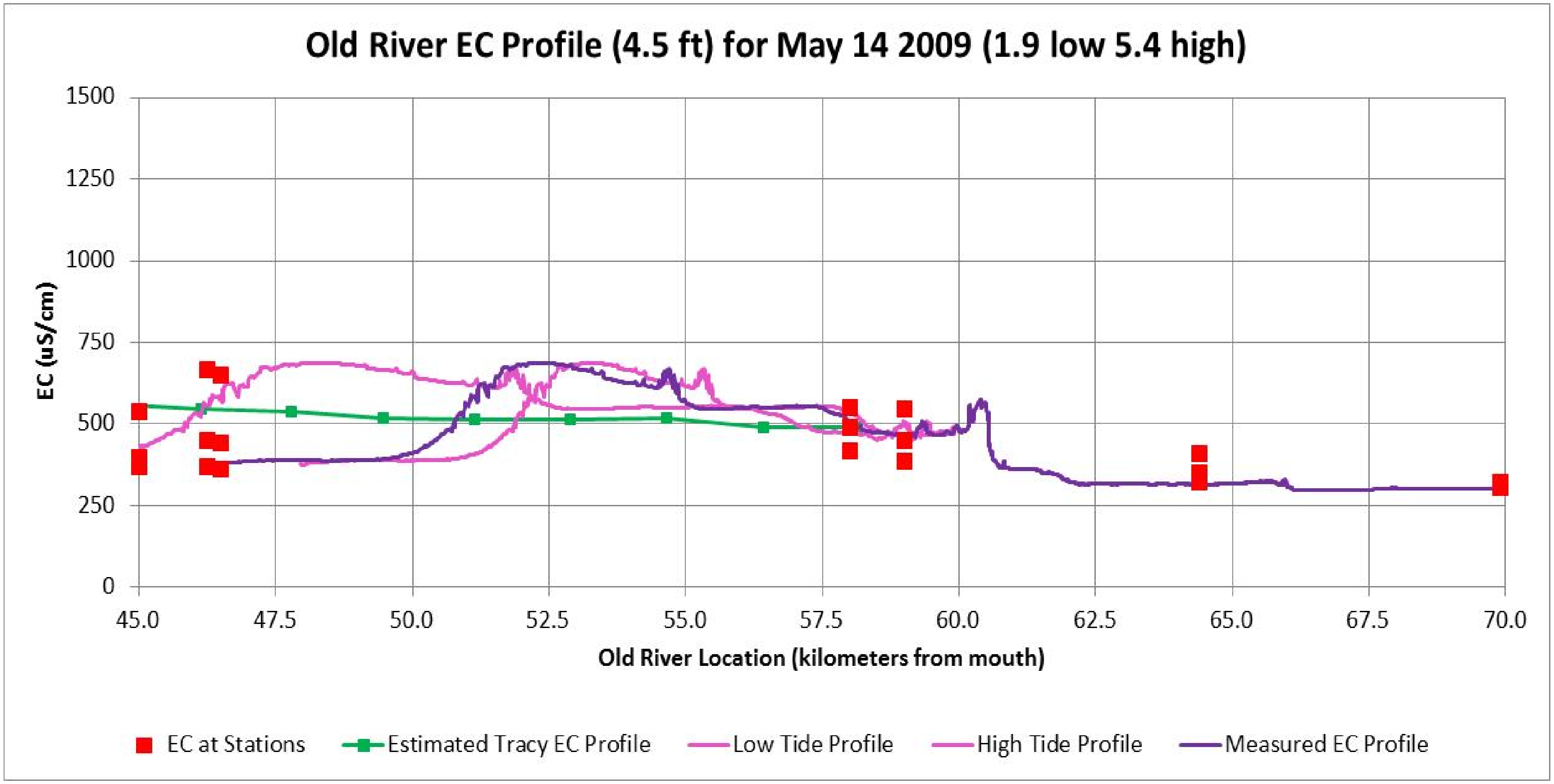
The measured Old River EC profile for April 1 was another example of the strong salinity gradient upstream of the DMC intake. Because of high Sacramento River flows and Delta outflow, the minimum EC at the DMC stations was reduce to 250 uS/cm, while the Old River EC downstream of Tracy Boulevard had increased to 1,250 uS/cm. The measured EC gradient was therefore 1,000 uS/cm over 4 km. The shifted low tide EC profile (pink line) was shifted downstream about 5 km, from 54 km to 49 km. The estimated Tracy EC profile (green line and boxes) was estimated using the daily average Tracy Boulevard flow volume to move the daily average Tracy EC for the previous days down the Old River channel, assuming about 175 af per km (based on DSM2 geometry) at high tide. The estimated EC profile (green boxes) indicates that the Tracy Boulevard EC had been 1,250 uS/cm about a week prior to the measurements on April 1.



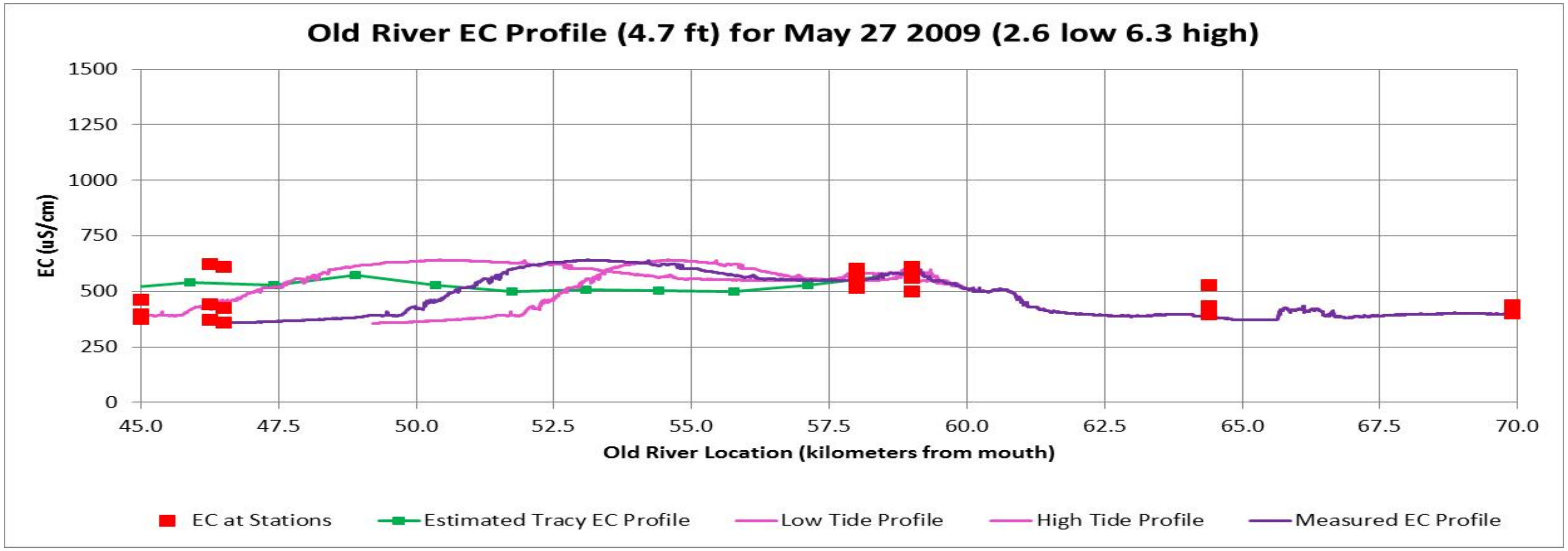
The measured Old River EC profile for April 16 (red line) is shown along with the daily minimum, average and maximum EC at each of the Old River stations (red boxes). The downstream EC gradient was reduced from the April 1 EC profile, because the minimum EC in Old River downstream of the DMC was about 400 uS/cm and the maximum EC in Old River upstream of the DMC was about 1100 uS/c,. The shifted low tide EC profile almost matched the maximum EC at the DMC stations (perhaps it actually moved downstream another 1 km). The EC pulse measured just upstream of Tracy Boulevard is consistent with the minimum, average and maximum measured EC at the Tracy Boulevard station.

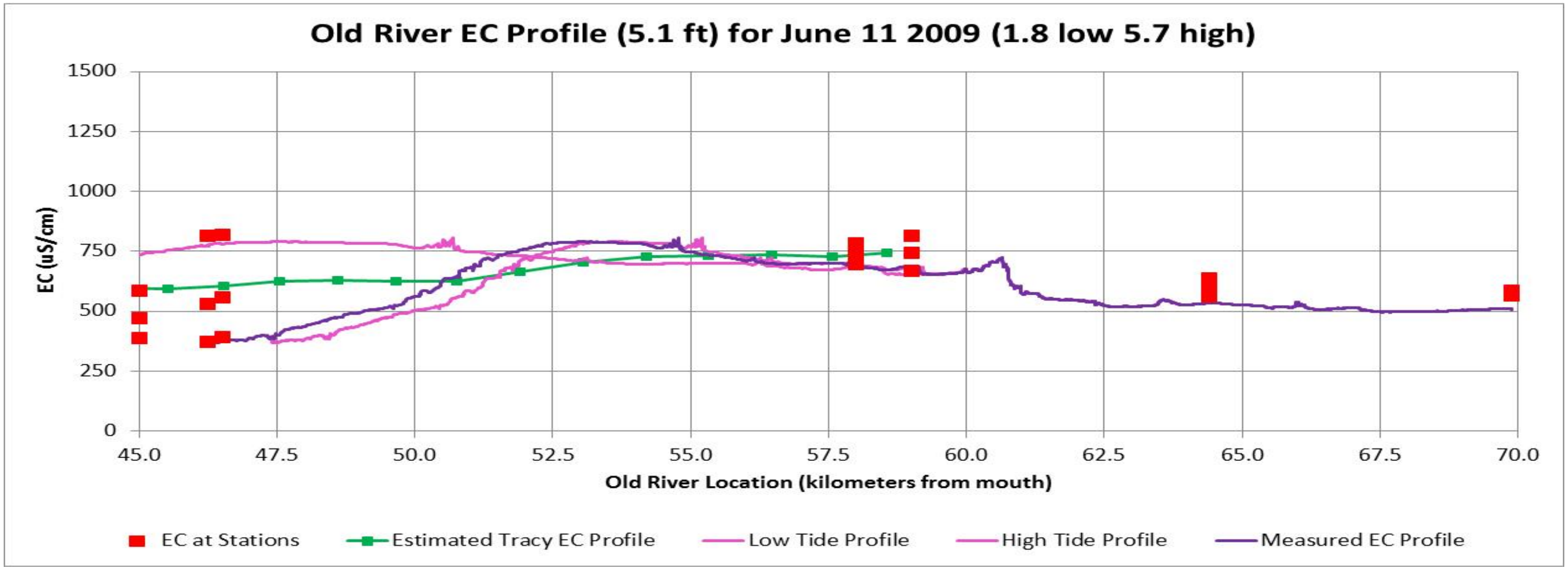


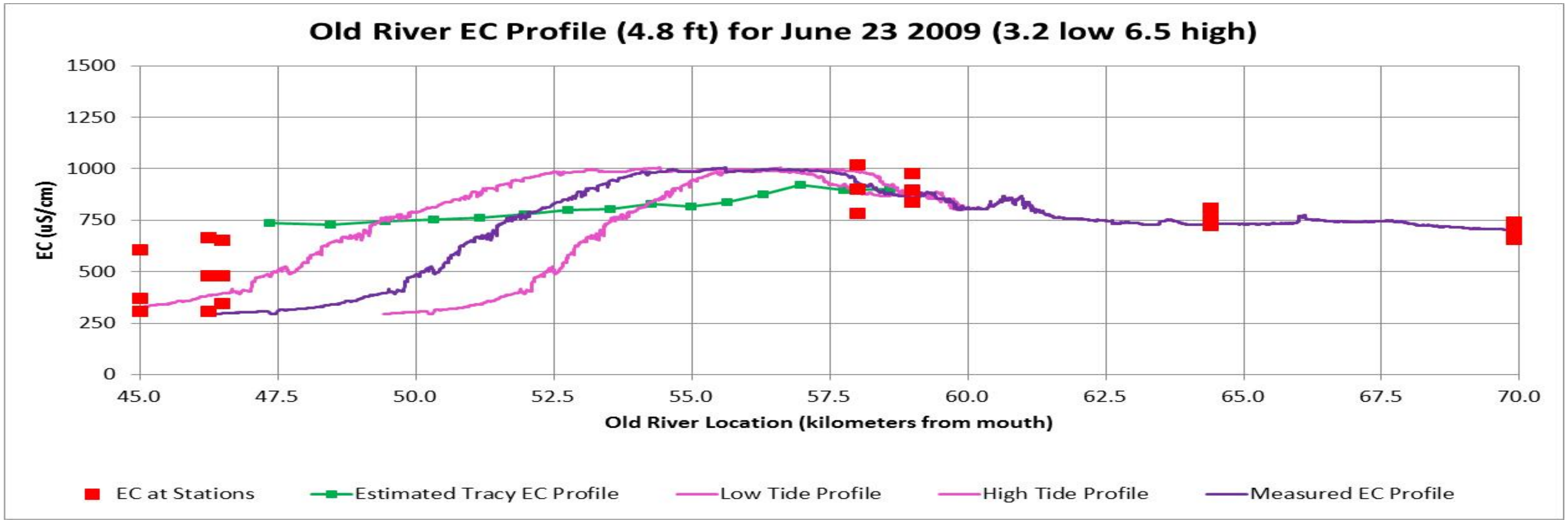
The measured Old River EC profile for April 28 (red line) is shown along with the daily minimum, average and maximum EC at each of the Old River stations (red boxes). There was a definite EC increase downstream of Doughty Cut (64 km), and the maximum EC at 52 km is consistent with Tracy Boulevard EC from a week ago. The downstream movement was estimated assuming the Old River at Tracy Boulevard flow was 10% of the head of Old River flow, and might have been too high. There could also be additional salt sources downstream of Tracy Boulevard.

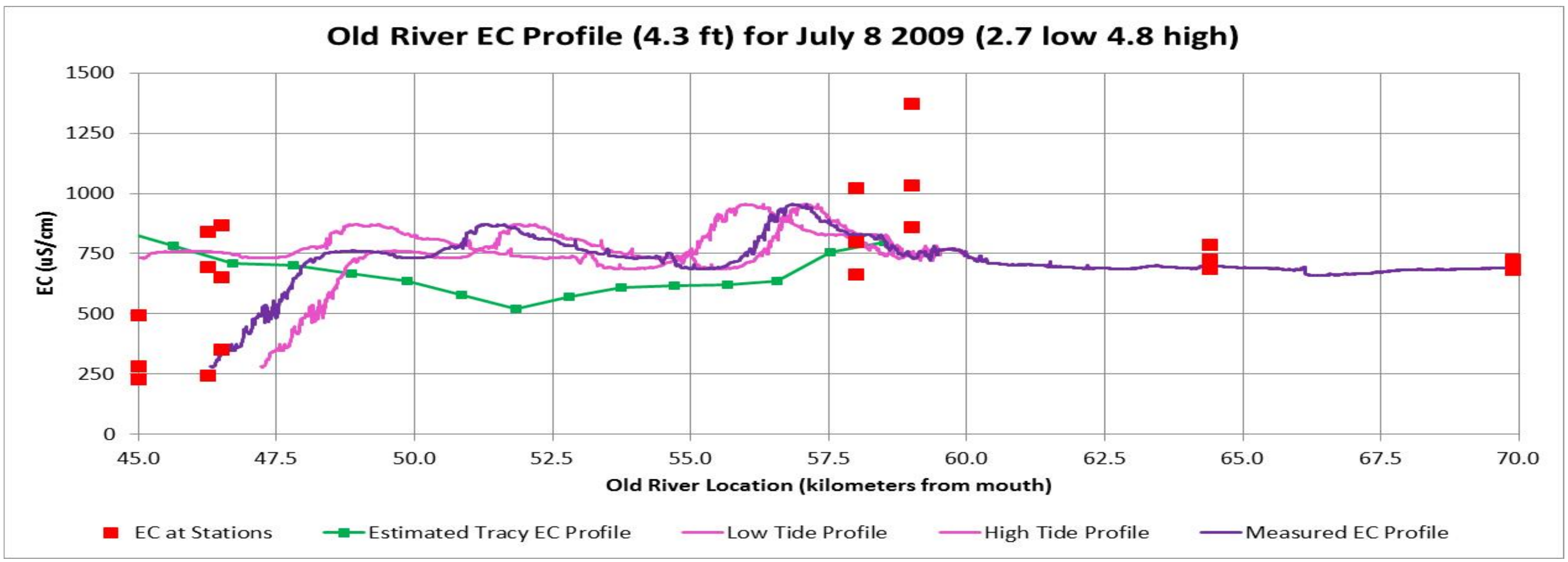


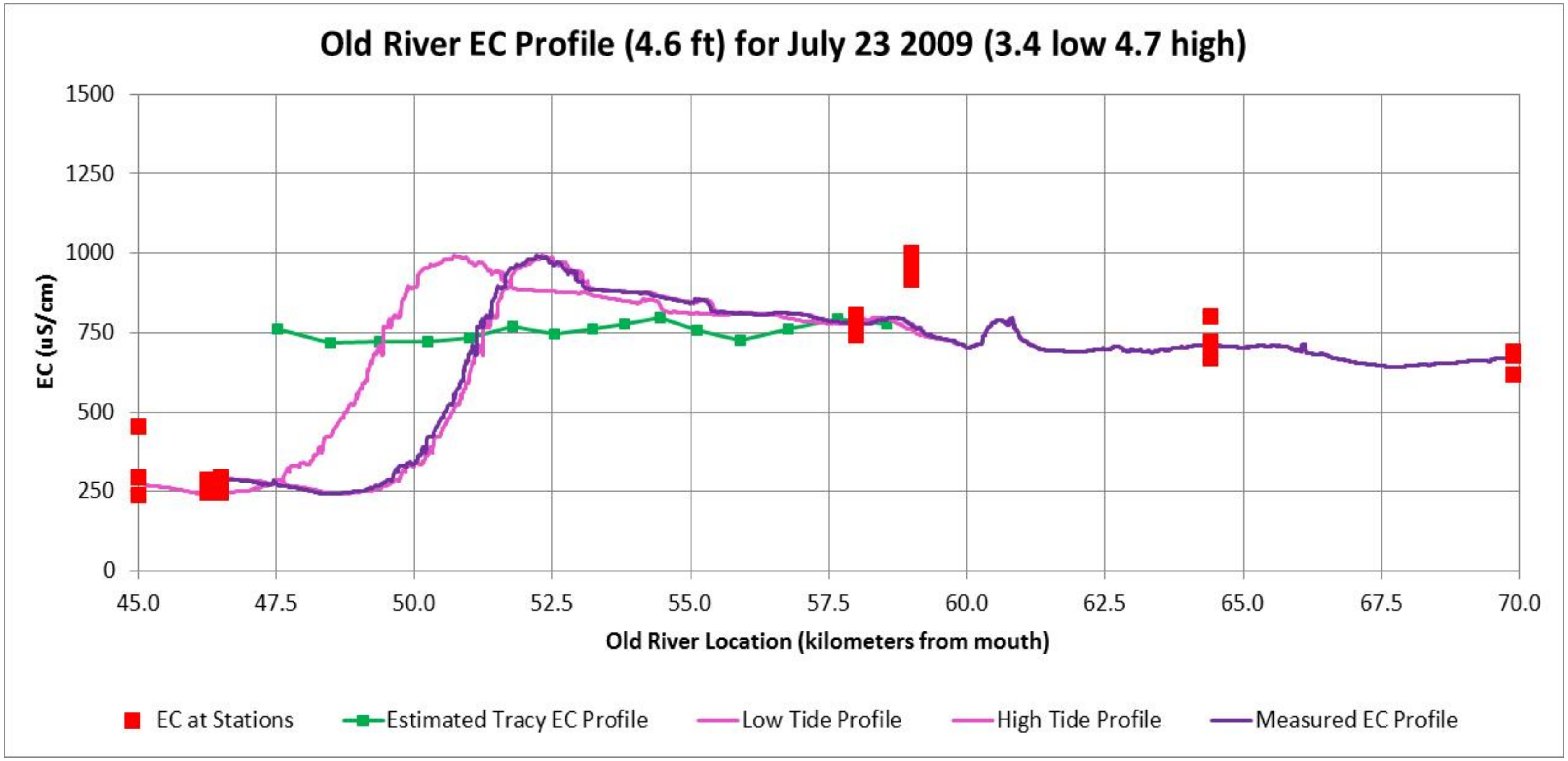
The measured Old River EC profile for May 14 (red line) is shown along with the daily minimum, average and maximum EC at each of the Old River stations (red boxes). Because of higher SJR flows in May, the Old River EC profile is more uniform, increasing from about 300 uS/cm at Union (70 km) to about 500 uS/cm at Tracy Boulevard, with similar EC measured at the DMC stations. The measured EC profile was higher that the estimated Tracy EC profile (green boxes), suggesting additional salt sources downstream of Tracy Boulevard. The shifted low tide EC profile (pink line) matched the maximum EC measured at the DMC stations, suggesting that the estimated movement of 4.5 km (based on tidal elevations) was accurate.


Old River EC Profile (4.7 ft) for May 27 2009 (2.6 low 6.3 high)
EC (uS/cm)
1500
1250
1000
750
500
250
0
45.0
47.5
50.0
52.5
55.0
57.5
60.0
62.5
65.0
67.5
70.0
Old River Location (kilometers from mouth)
EC at Stations
Estimated Tracy EC Profile
Low Tide Profile
High Tide Profile
Measured EC Profile

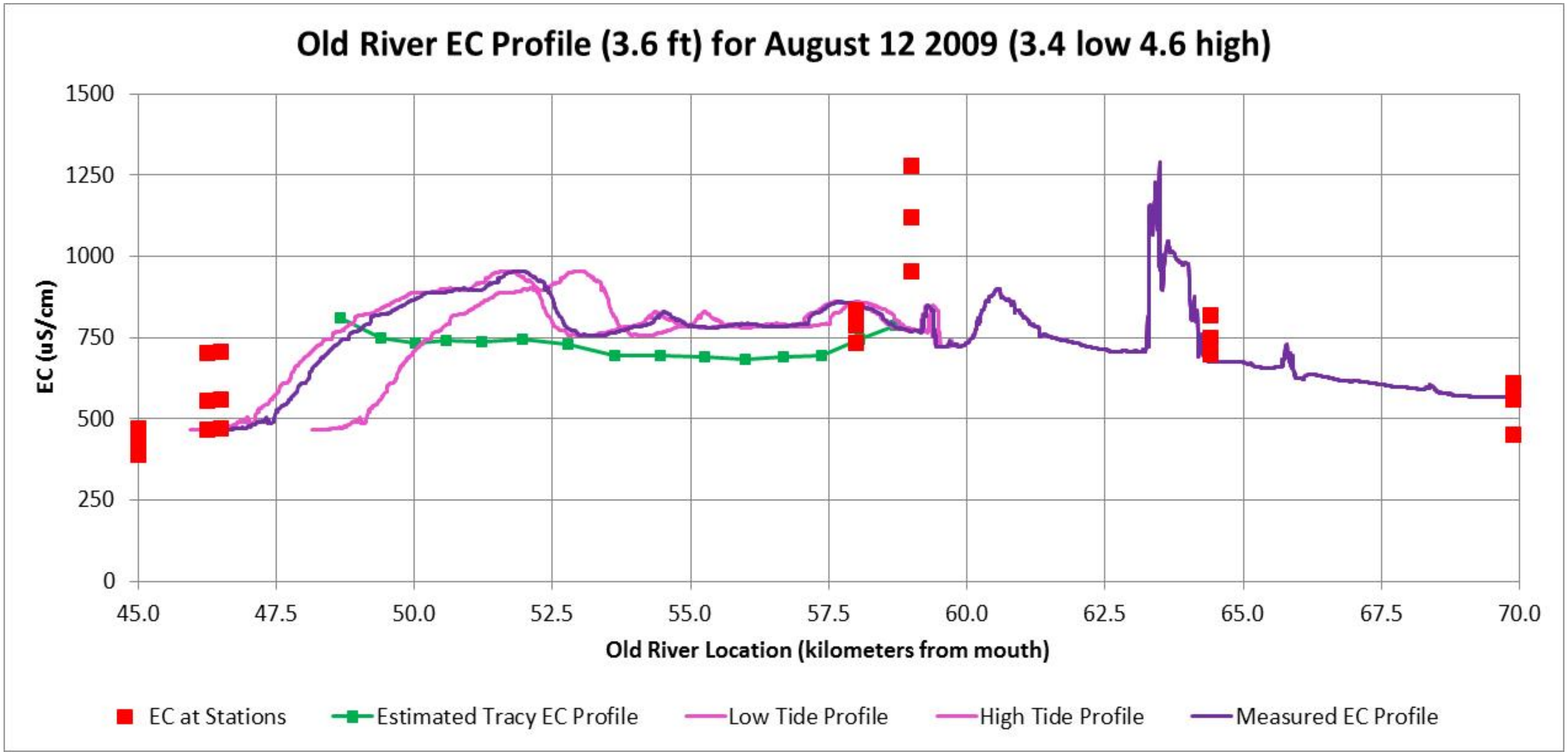

Old River EC Profile (5.1 ft) for June 11 2009 (1.8 low 5.7 high)
EC (uS/cm)
1500
1250
1000
750
500
250
0
45.0
47.5
50.0
52.5
55.0
57.5
60.0
62.5
65.0
67.5
70.0
Old River Location (kilometers from mouth)
EC at Stations
Estimated Tracy EC Profile
Low Tide Profile
High Tide Profile
Measured EC Profile


Old River EC Profile (4.8 ft) for June 23 2009 (3.2 low 6.5 high)
EC (uS/cm)
0
250
500
750
1000
1250
1500
45.0
47.5
50.0
52.5
55.0
57.5
60.0
62.5
65.0
67.5
70.0
Old River Location (kilometers from mouth)
EC at Stations
Estimated Tracy EC Profile
Low Tide Profile
High Tide Profile
Measured EC Profile

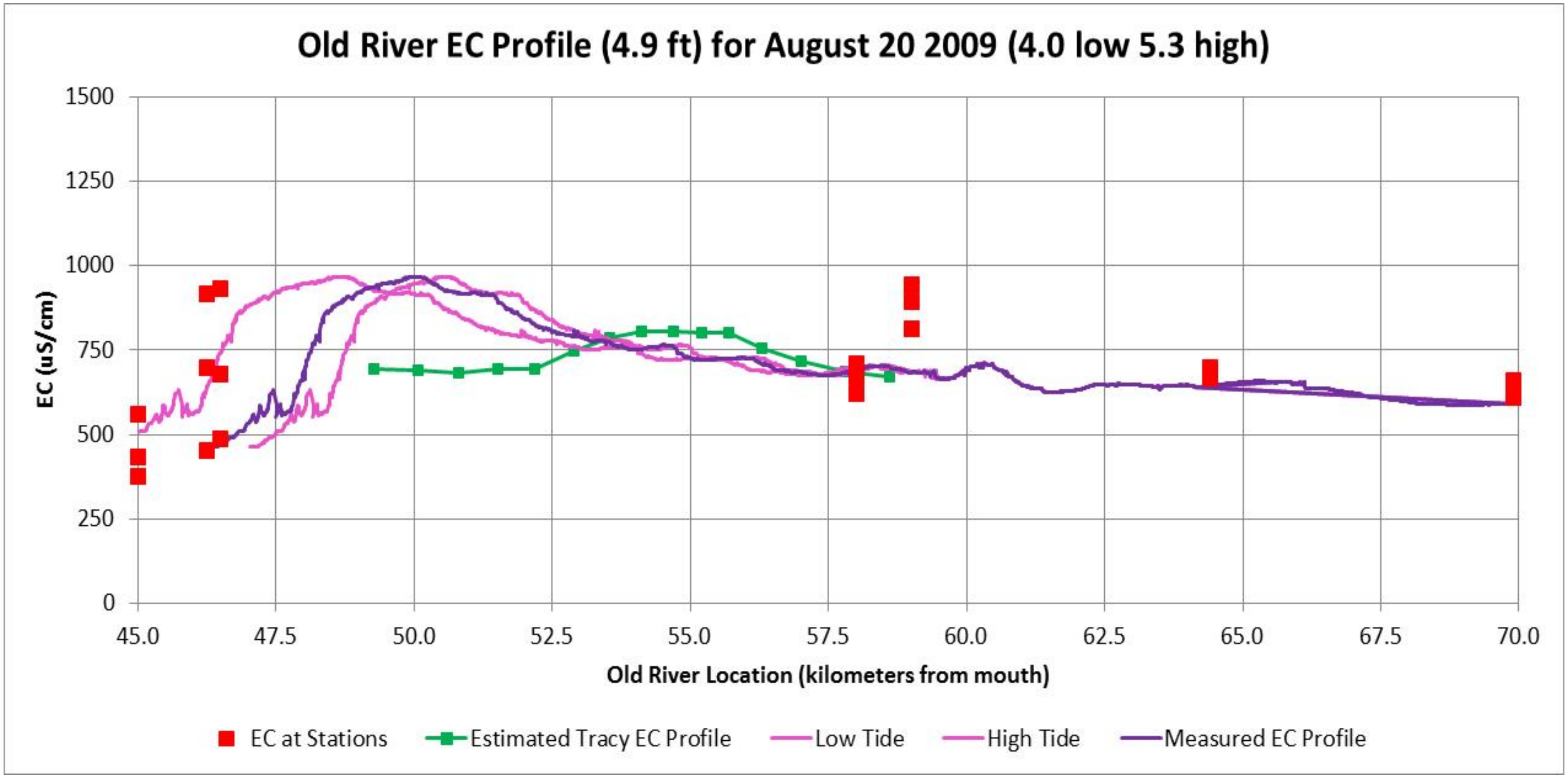

Old River EC Profile (4.3 ft) for July 8 2009 (2.7 low 4.8 high)
EC (uS/cm)
0
250
500
750
1000
1250
1500
45.0
47.5
50.0
52.5
55.0
57.5
60.0
62.5
65.0
67.5
70.0
Old River Location (kilometers from mouth)
EC at Stations
Estimated Tracy EC Profile
Low Tide Profile
High Tide Profile
Measured EC Profile



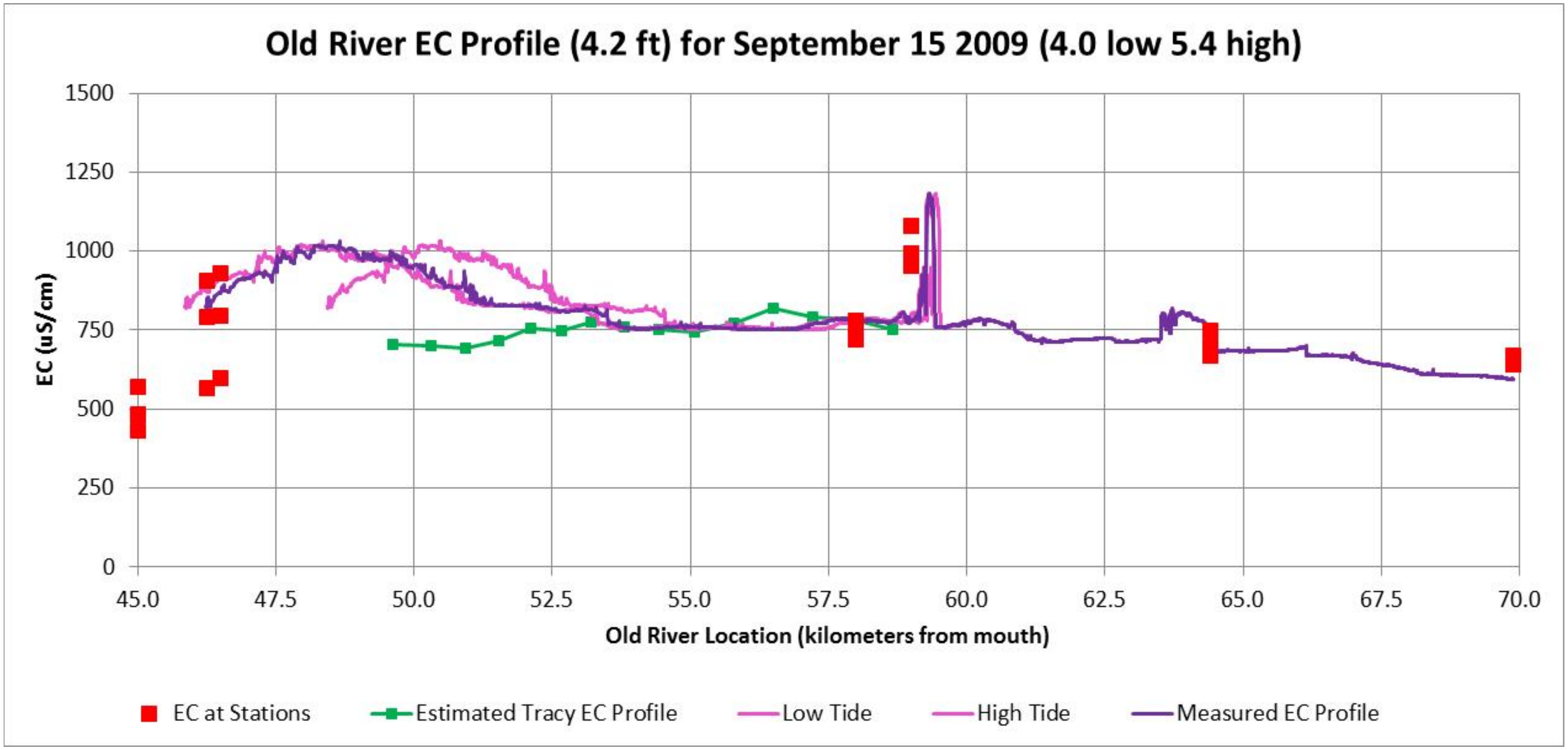
The Old River EC profile on July 23 showed the effects of the temporary barriers with flap gates operating. The EC gradient measured between 50 km and 52.5 km indicates that water from downstream of the DMC moved 5 km upstream of the DMC barrier. This was similar to the upstream movement of the EC gradient with full tidal flows (without the DMC barrier). The low tide shifted EC profile was only 2 km downstream of the measured (and high tide) EC profile, because the tidal elevation change was much less (only 1.3 feet on July 23). The upstream locations of the EC gradient suggests that the upstream flow through the flap gates was providing a net upstream flow that was maintaining low EC water (250 uS/cm) at Wicklund Cut (50 km), but was not moving low salinity water further upstream. The Westside ID was diverting about 75 cfs (150 af/day) and other pumps along this portion of Old River may exceed the net upstream flow created by the DMC barrier flap gates.



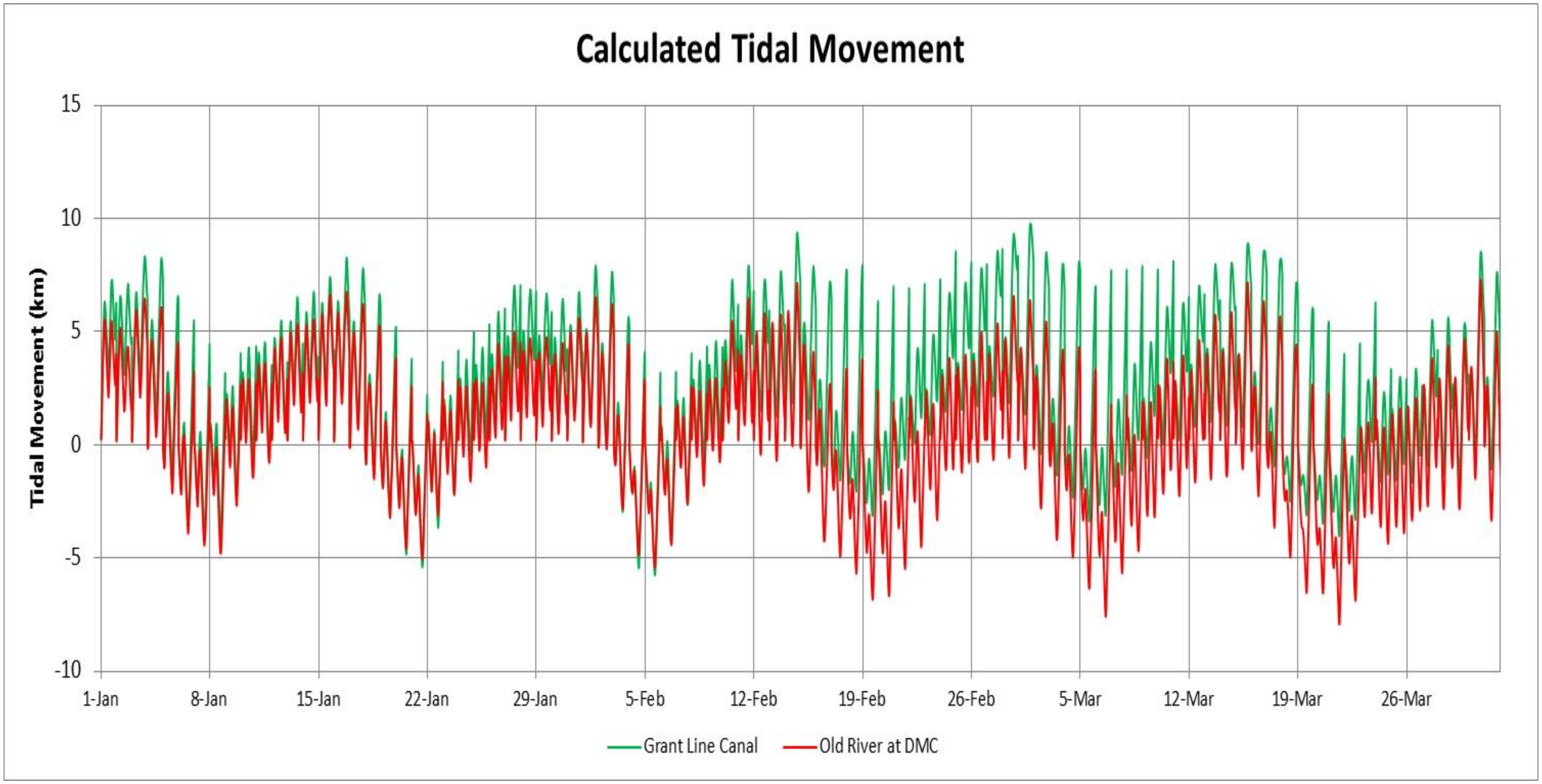
The Old River EC profile on August 12 showed the effects of the temporary barriers with flap gates operating. The EC gradient measured between 47.5 km and 50 km indicates that water from downstream of the DMC moved about 2.5 km upstream of the DMC barrier. This was much less movement than with full tidal flows (without the DMC barrier). The high tide shifted EC profile was only 1 km upstream of the measured (and low tide) EC profile, because the tidal elevation change was much less (only 1.2 feet) that the full tidal elevation range (without barriers). The Old River at Tracy daily minimum, average, and maximum EC values were higher than the EC profile (also on July 23). The average EC at Tracy Boulevard was about 200-250 uS/cm higher than the EC profile (also on July 23), so the Tracy Boulevard EC data may have been measuring about 200-250 uS/cm higher than the actual EC during this period.



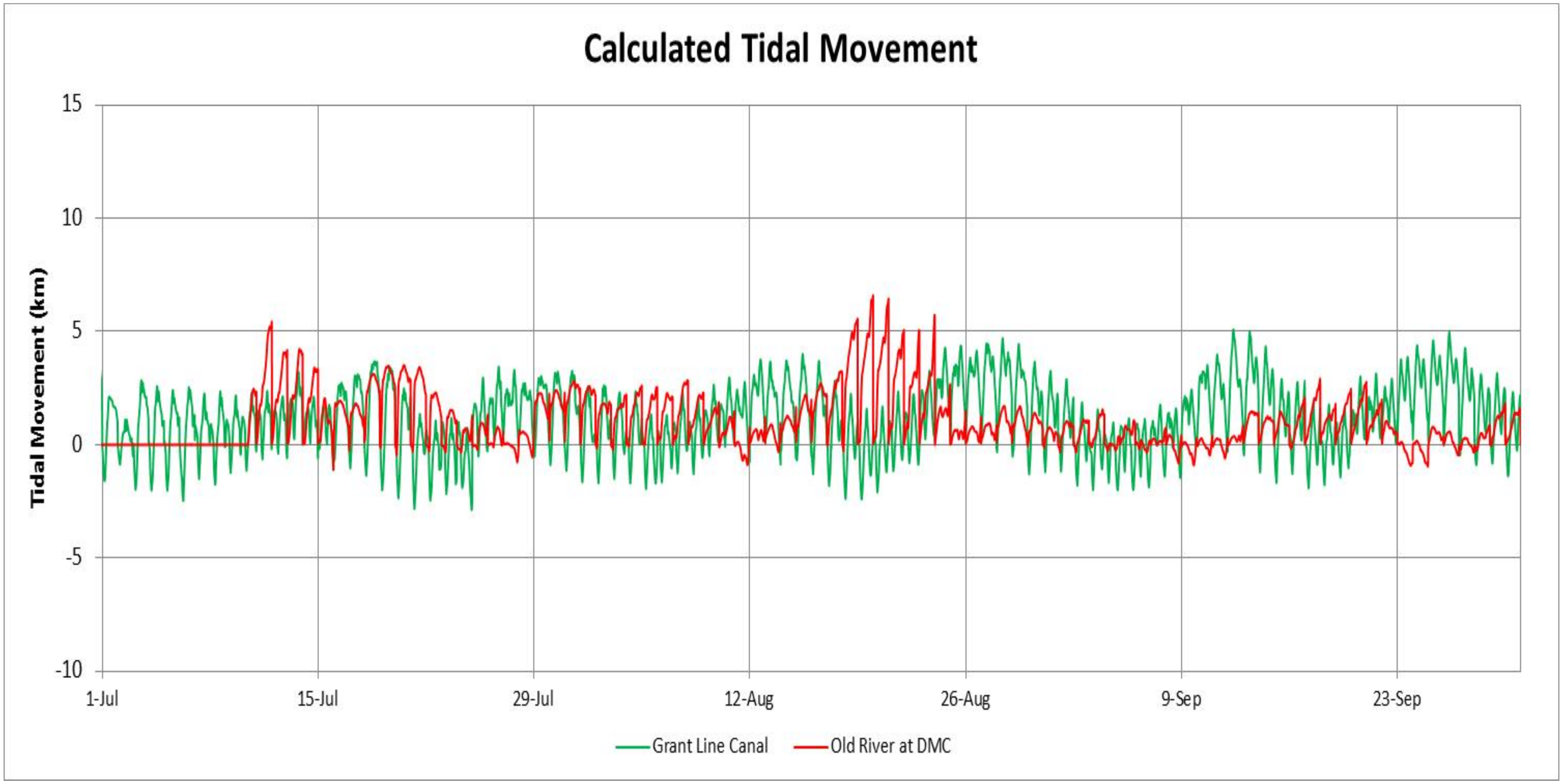
The Old River EC profile on August 20 showed the effects of the temporary barriers with flap gates operating. The EC gradient was measured between 47 km and 49 km indicates that water from downstream of the DMC moved only about 2 km upstream of the DMC barrier. The low tide shifted EC profile was about 2 km downstream of the measured (and high tide) EC profile, because the tidal elevation range was much less (only 1.3 feet) that the full tidal elevation range (without barriers). The Old River at Tracy daily minimum, average, and maximum EC values were higher than the EC profile. The average EC at Tracy Boulevard was about 200-250 uS/cm higher than the EC profile. The measured EC profile shows an increase in the salinity downstream of Tracy Boulevard; suggesting additional sources of high salinity water between Tracy Boulevard and the DMC barrier.



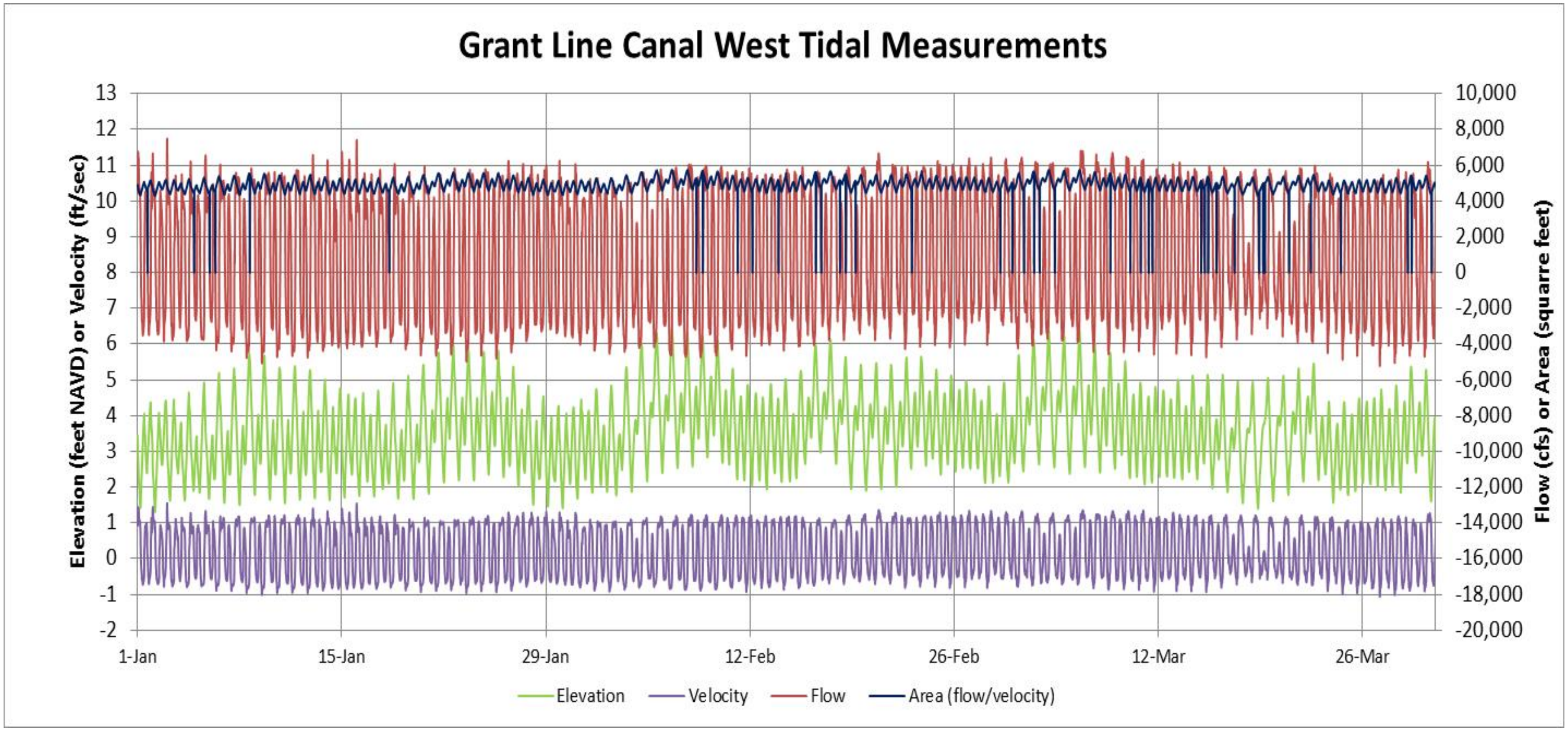
The Old River EC profile on September 15 (at low tide) showed an EC spike just upstream of the DMC barrier. This profile was measured during a week when 3 of the 9 flap gates were opened. This likely eliminated the slight upstream net flow that was observed with all flap gates operating. Because the EC profile was measured at low tide, the upstream movement of lower EC water (from downstream of the DMC intake) cannot be confirmed. The average EC at Tracy Boulevard was again 200-250 uS/cm higher than the EC at Tracy Wildlife and the EC profile. The EC profiles in July-September 2009 suggest the Tracy Boulevard EC was reading 250 uS/cm high. Additional Old River EC profiles, together with EC profiles in Paradise Cut, Tom Paine Slough-Sugar Cut, and Grant Line Canal should be collected to confirm the location and magnitude of the salt sources in Paradise Cut and Sugar Cut and to verify the tidal movement of water and salt in Old River and in Grant Line Canal (similar salinity gradient are expected about 5 km upstream of the mouth).



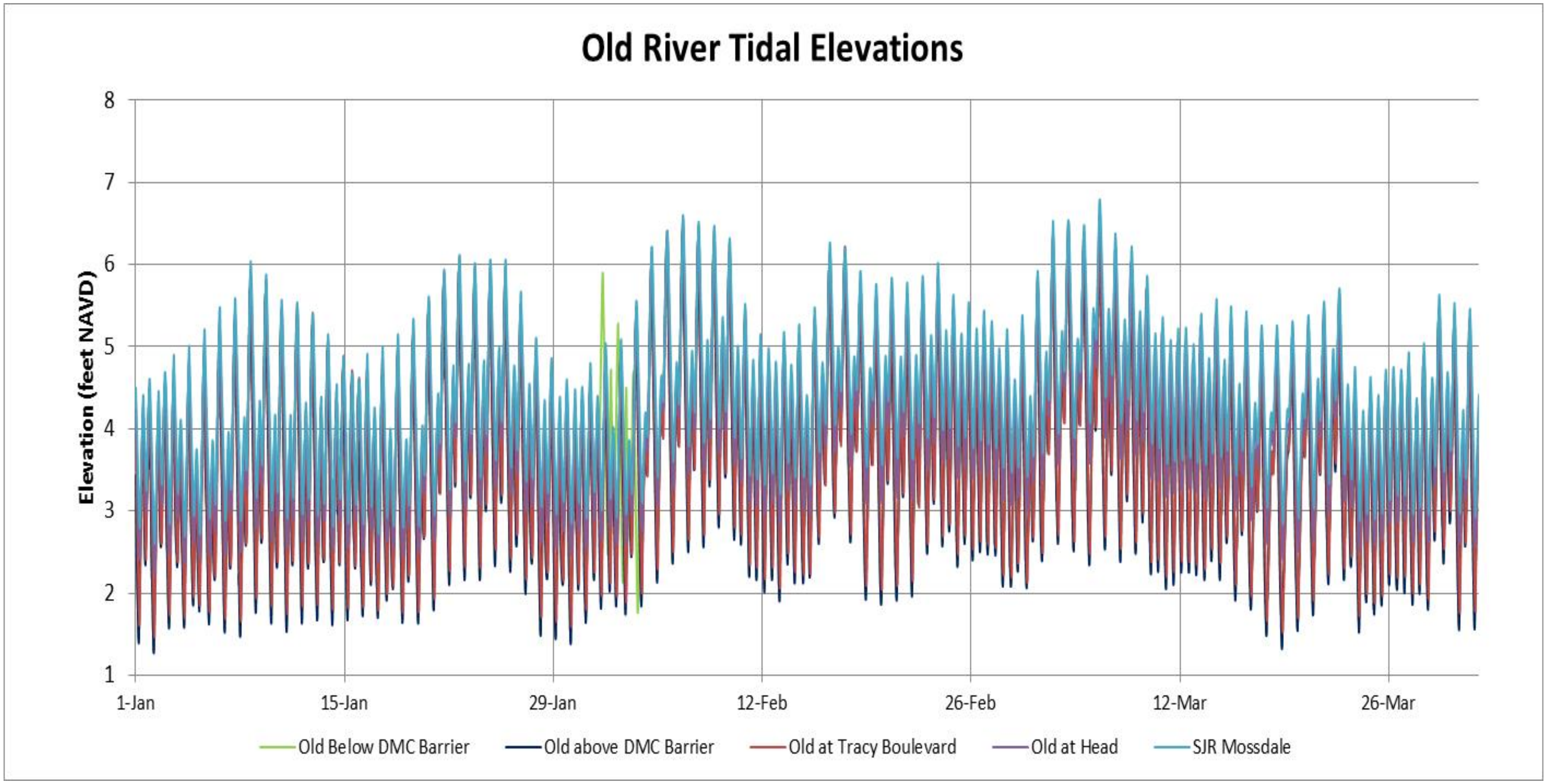
The tidal movement was calculated from the measured velocity at the monitoring stations. The tidal movement at the DMC barrier location January-March (without temporary Barriers) was generally balanced; the flood-tide movement (upstream) was about the same as the ebb-tide movement (downstream. The tidal movement at the Grant Line Canal was dominated by the net downstream flow. During January (low net flow) the flood-tide movement was similar to the Old River flood-tide movement of 5-6 km.



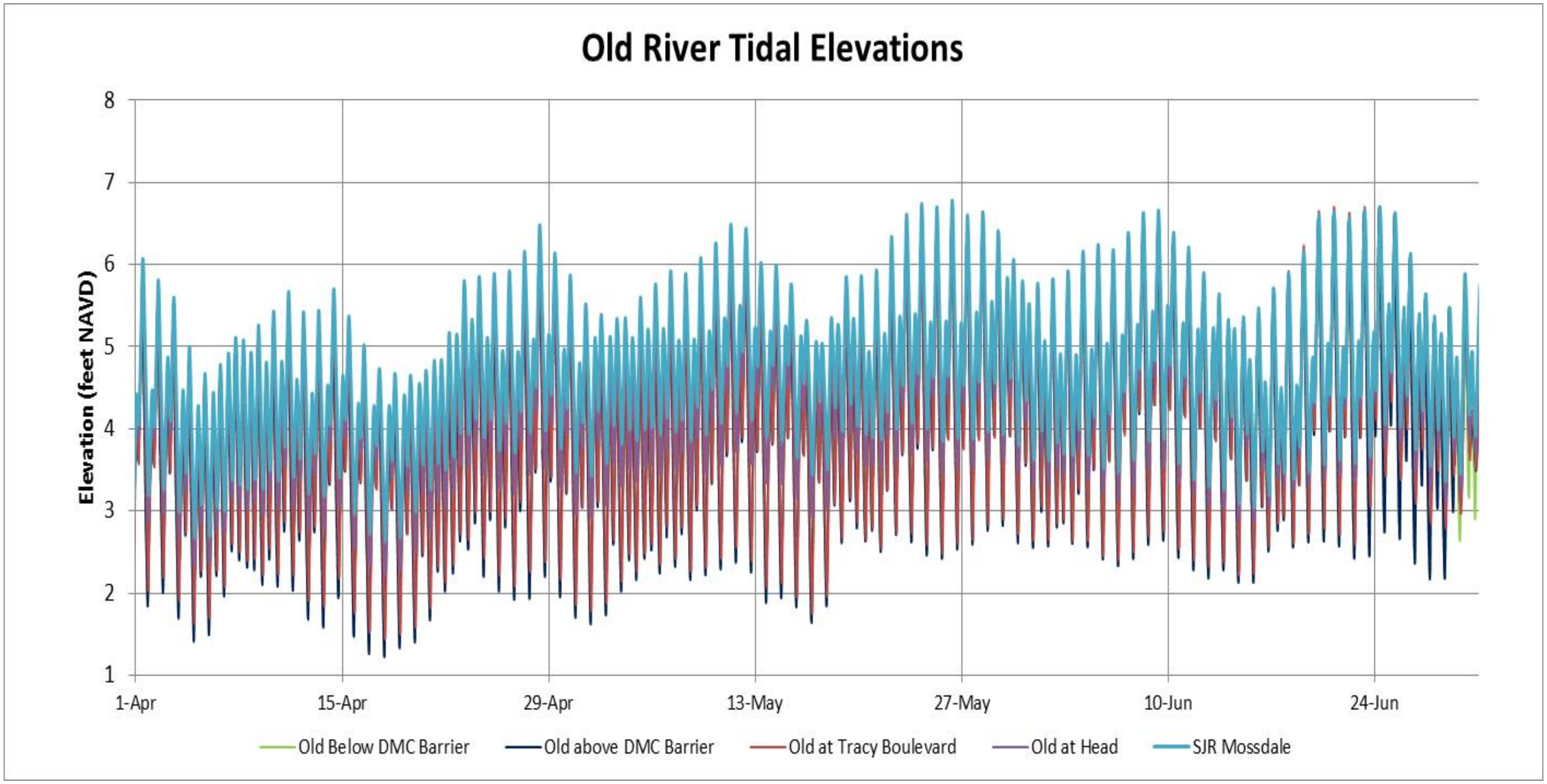
The calculated tidal movement was greatly reduced at both stations during the period with temporary barriers. Very little upstream tidal movement was measured at the DMC barrier location. The upstream tidal movement in Grant Line Canal was also much less than full tidal flows (without the barriers). Additional Old River EC profiles, together with EC profiles in Paradise Cut, Tom Paine Slough-Sugar Cut, and Grant Line Canal should be collected to confirm the location and magnitude of south Delta salt sources and to verify the tidal movement of water and salt in Old River and in Grant Line Canal. Based on the velocity measurements in Grant Line Canal, a salinity gradient similar to the EC gradient observed in Old River upstream of the DMC barrier would be expected about 5 km upstream of the mouth of Grant Line Canal without the barriers, and would be expected about 2-3 km upstream of the mouth of Grant Line Canal with the barriers installed.



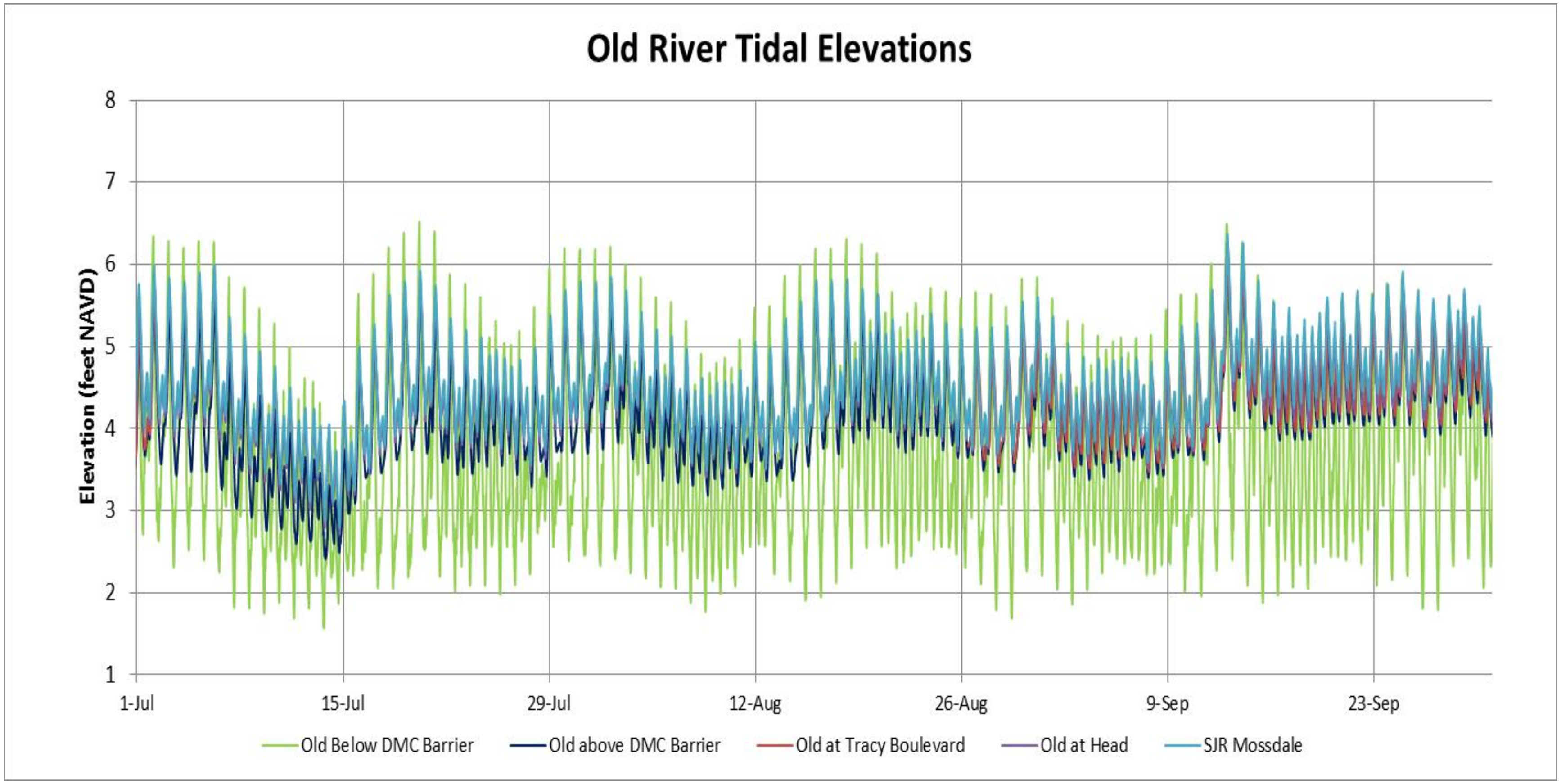
The tidal flow measurements in the south Delta channels are collected with a 15-minute interval. The primary measurements are the water elevations (green line, left scale) and the tidal velocity (purple line, left scale). The cross-section area, which is measured independently as a function of the water 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.



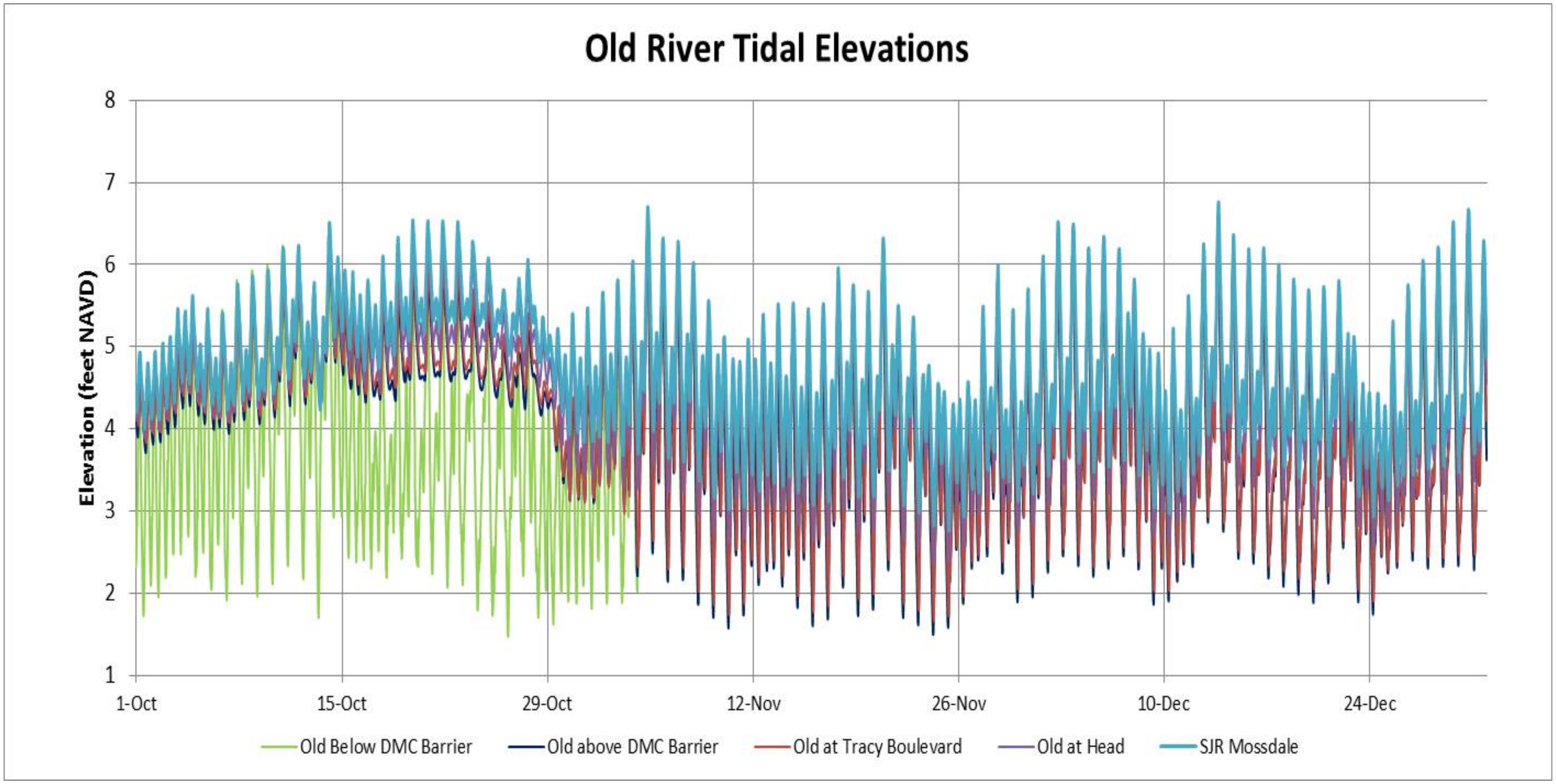
Because of low SJR flows (1,000-2,000 cfs), the tidal elevations in Old River were very uniform in the January-March period. The spring-neap tidal cycle can be detected with a tidal range of 2 feet to 5 feet during neap tides and a tidal range of 2.5 feet to 6 feet during spring tides. The graphs have a 14-day vertical grid, so there is a spring-neap cycle within each grid. The minimum tidal elevations in the SJR at Mossdale (light blue line) are about 0.5 feet higher than the head of Old River minimum elevations. Tidal elevations in Old River at Tracy Boulevard, above the DMC barrier location, and below the DMC barrier locations are very similar.



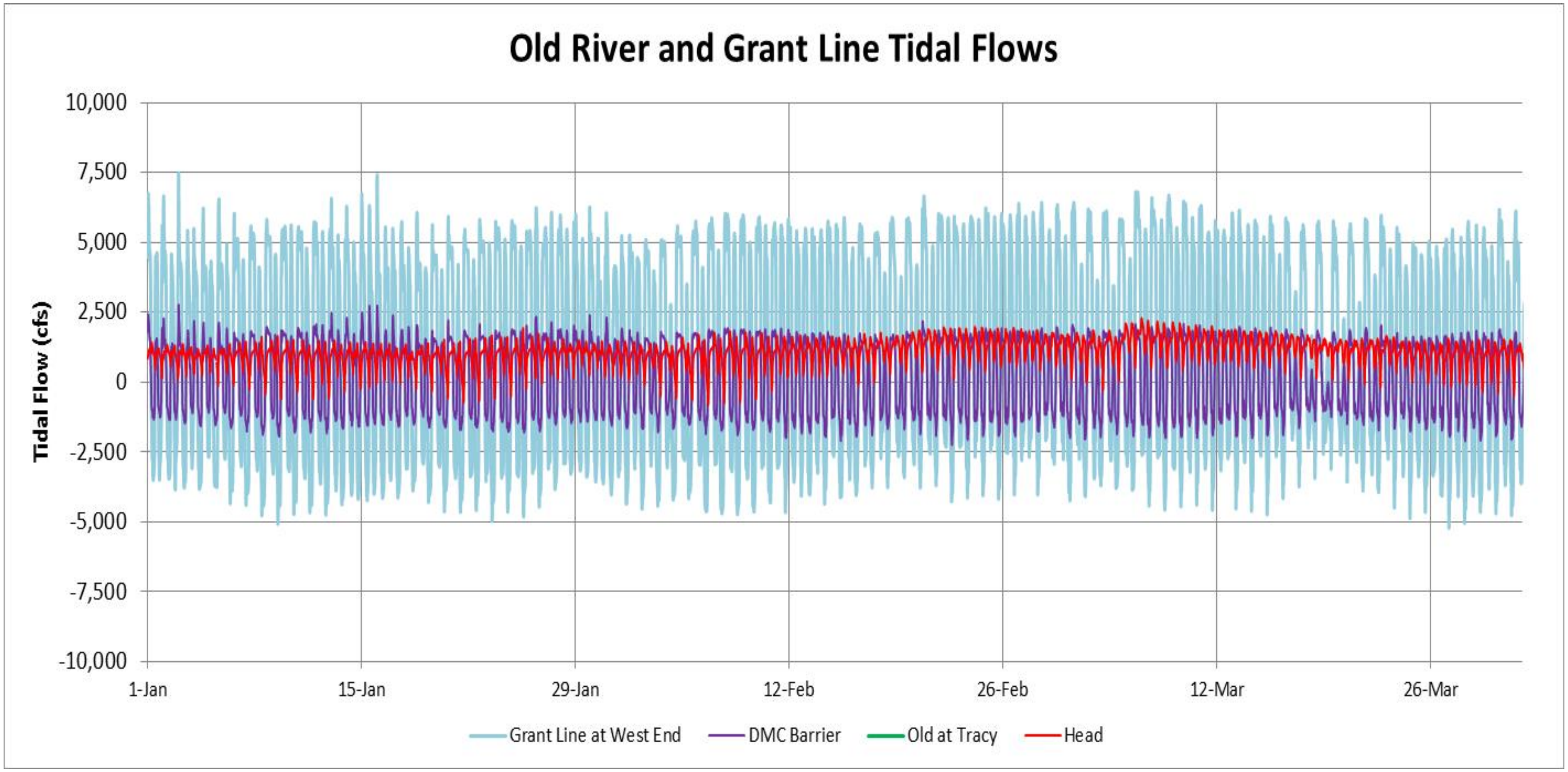
The slightly higher SJR flows in April-May increased the Mossdale elevations slightly, but did not raise the Old River elevations. The temporary barriers were installed in June but the flap gates were not closed until the end of June, increasing the minimum elevations at Tracy Boulevard (red line).



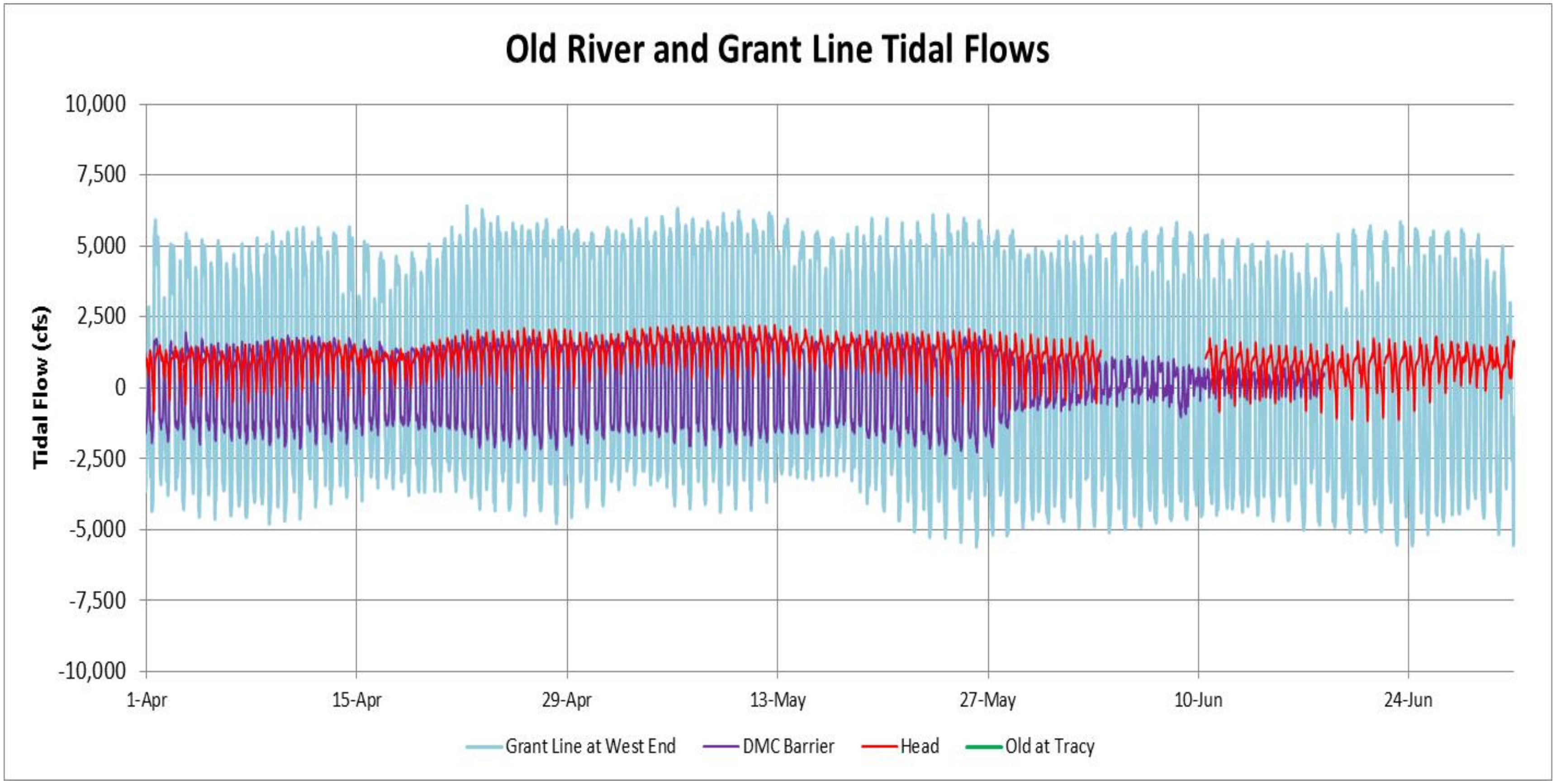
The full effects of the temporary barriers with flap gates operating were observed from early July through October. The tidal elevation range was reduced upstream of the barriers, with a tidal range of 1.5-2 feet. Although there was a net downstream flow of about 500 cfs at the head of Old River and in Grant Line Canal, and about 50 cfs in Old River, the tidal flushing of salt from Paradise Cut and Sugar Cut was greatly reduced when the tidal range was restricted by the temporary barriers.



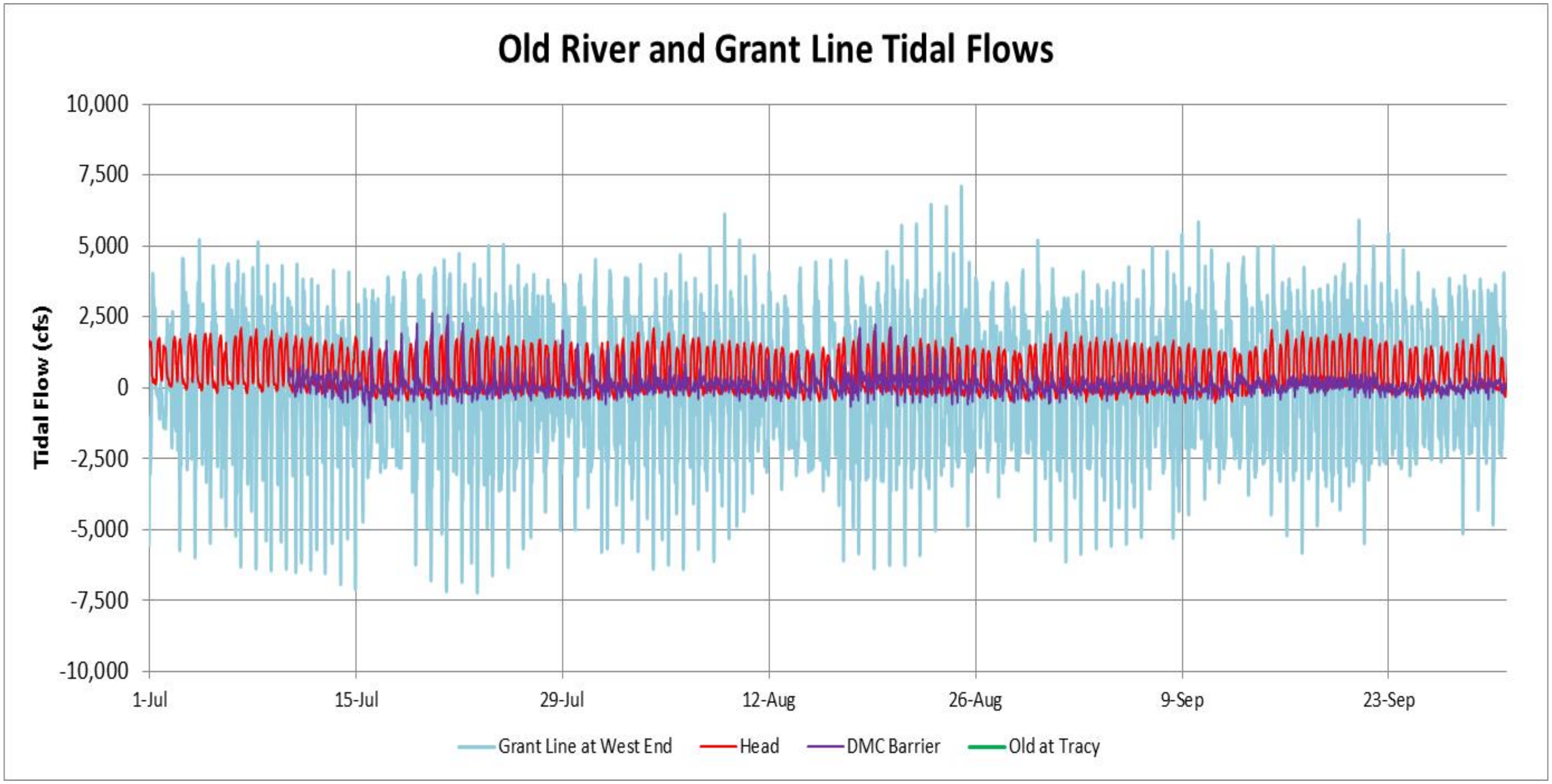
The minimum elevations upstream of the temporary barriers were increased in October, because irrigation diversions were reduced. The temporary barriers were removed at the end of October. Tidal elevations were again uniform throughout the south Delta channels, with a tidal range of 2 feet to 6 feet during spring tides.



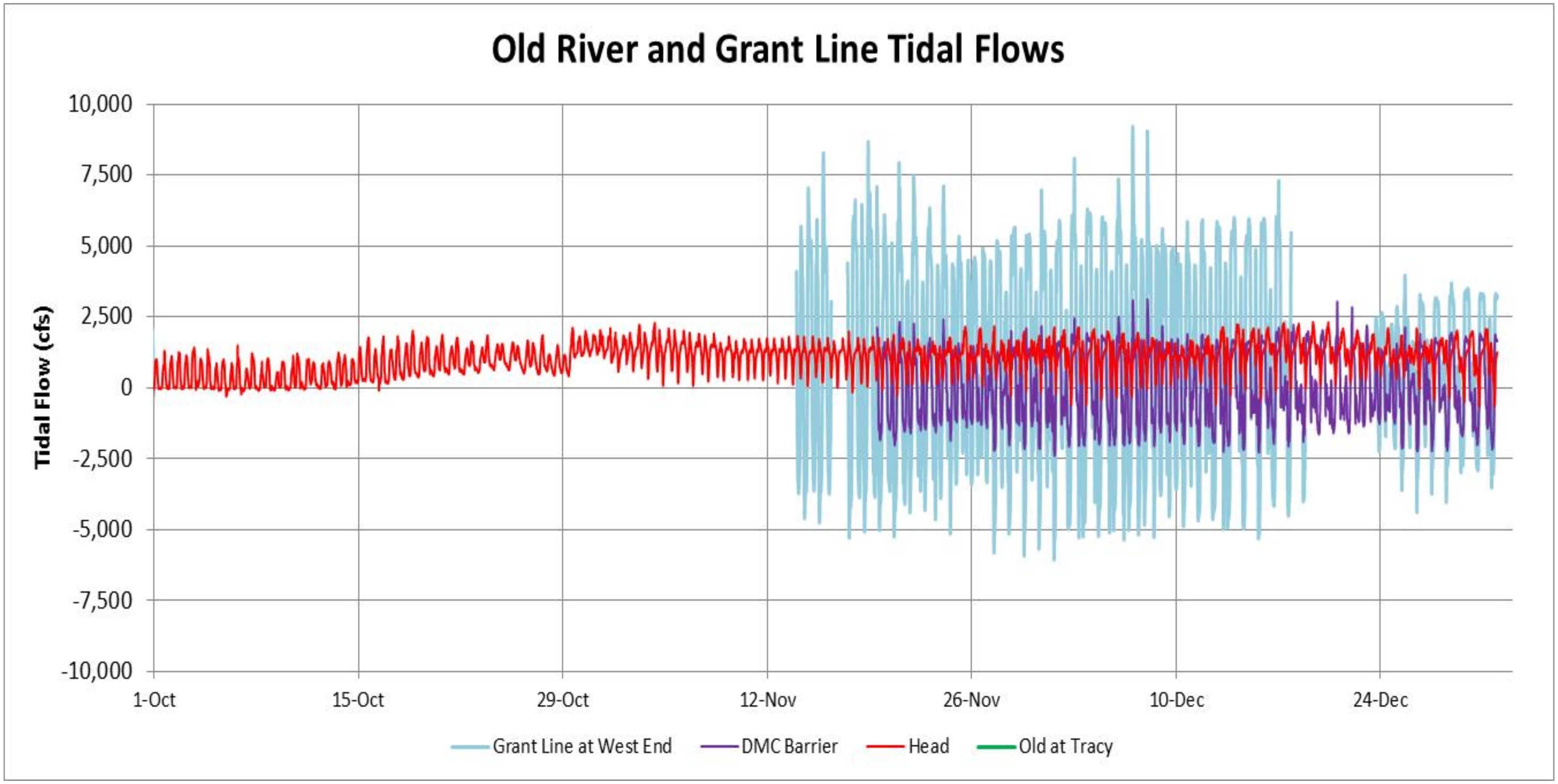
Tidal flows measured at the western end of Grant Line Canal and in Old River at the DMC barrier location indicate the maximum tidal flows in these south Delta channels during the January-March period, with no temporary barriers installed. Tidal flows in Old River at Tracy Boulevard were not measured in 2009. Tidal flows at the western end of Grant Line Canal (light blue line) varied from -4,000 cfs to 6,000 cfs (tidal range of about 10,000 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 locations varied from about -2,000 cfs to 2,000 cfs (tidal range of about 4,000 cfs), with an average flow of less than 250 cfs. Most of the south Delta tidal flow upstream (east) of the CCF and DMC intakes moves through the western end of Grant Line Canal.



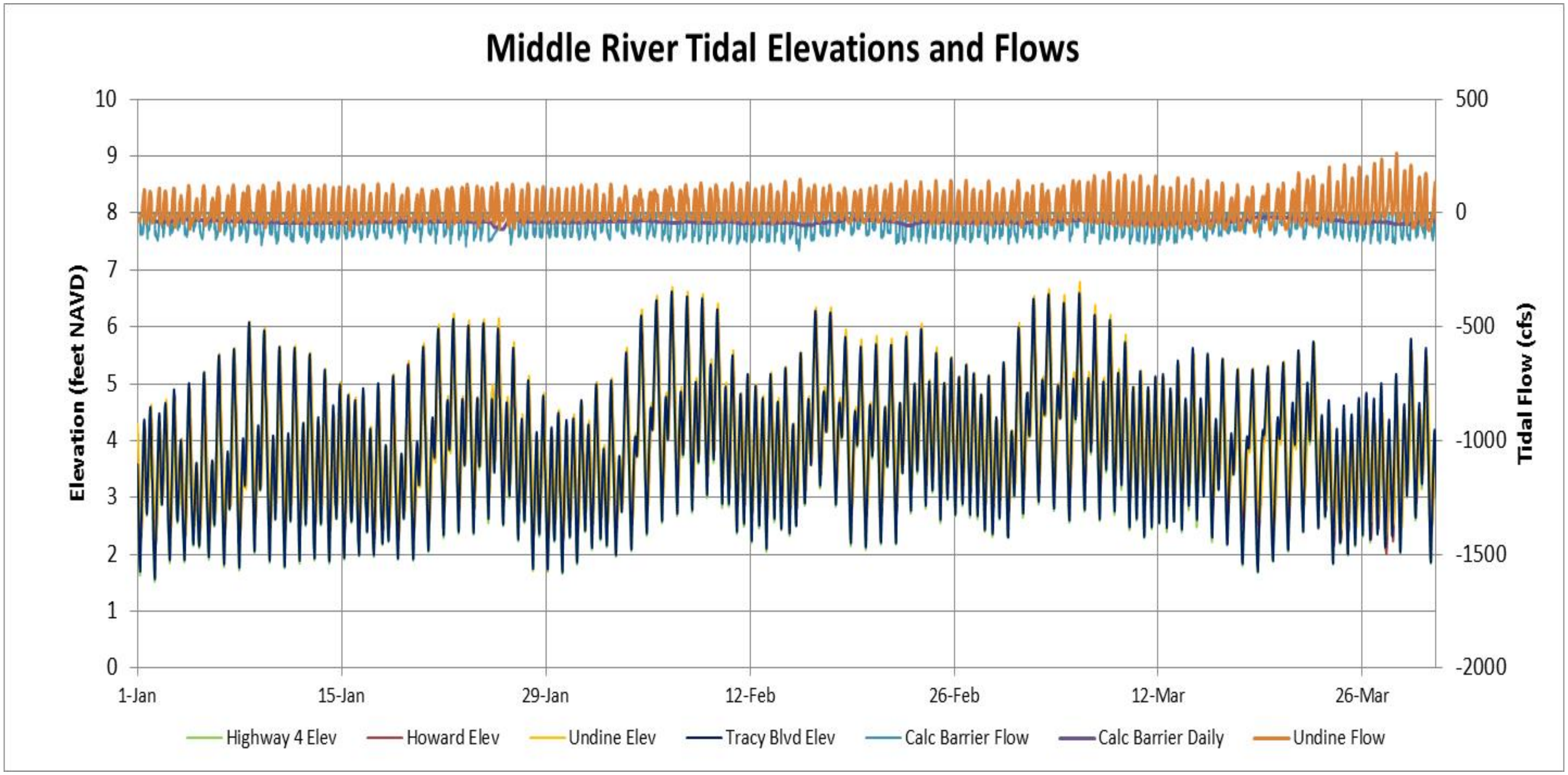
The effects of the Old at DMC temporary barrier (with flap gates open) were observed in the tidal flows at the DMC barrier during May. The tidal flows at the western end of Grant Line Canal and at the head of Old River were similar to the tidal flow in January-March.



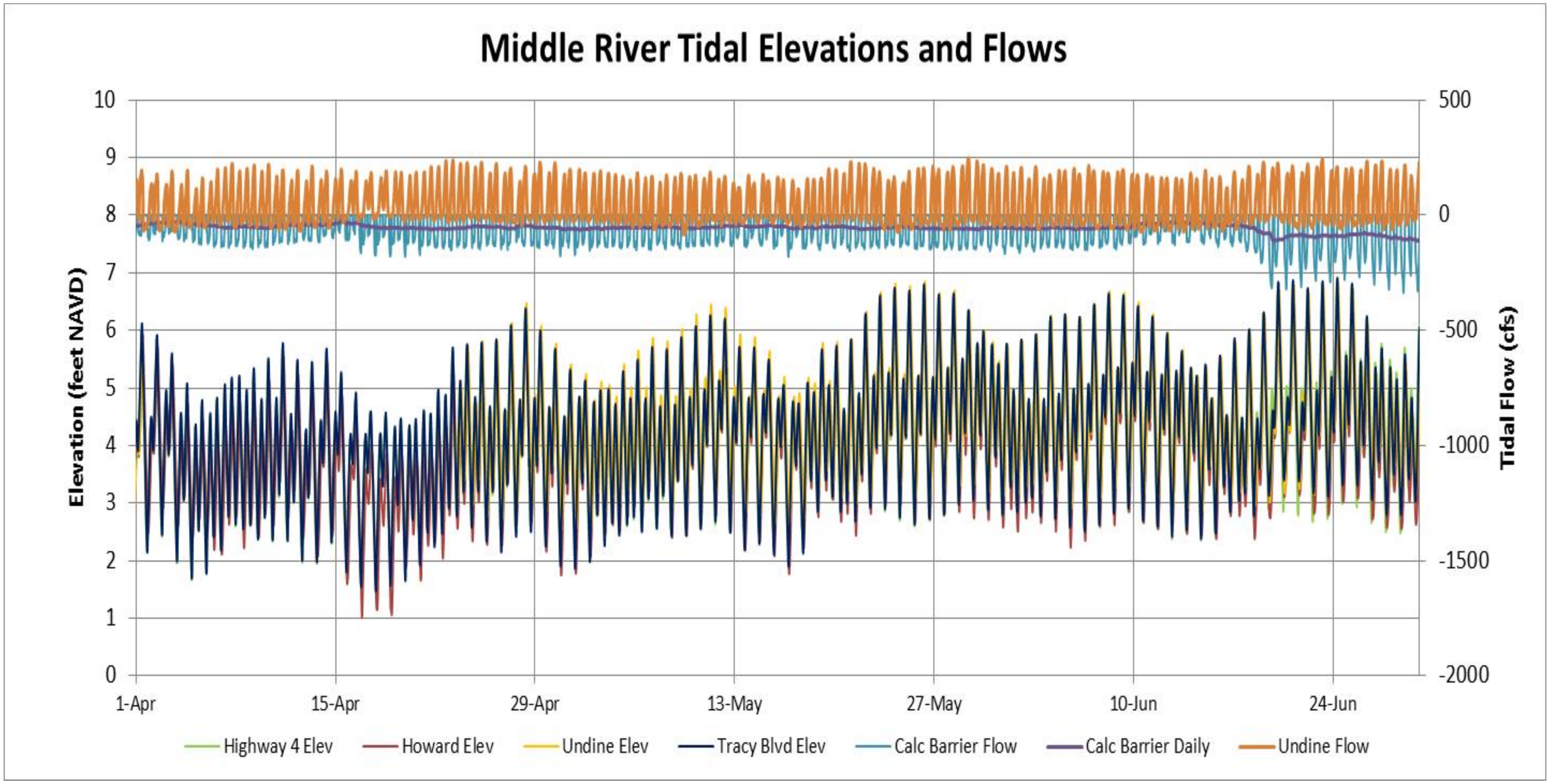
The full effects of the temporary barriers were observed in July-September, with all flap gates operating. The tidal flows at the western end of Grant Line Canal were reduced by the temporary barriers and perhaps by the increased exports (10,000 cfs in July). The tidal flows in Old River at the DMC barrier were limited to upstream flows through the flap gates or over the barrier at higher tides. The temporary barriers raised the minimum elevations upstream of the barriers somewhat, but nearly eliminated tidal flow variations.



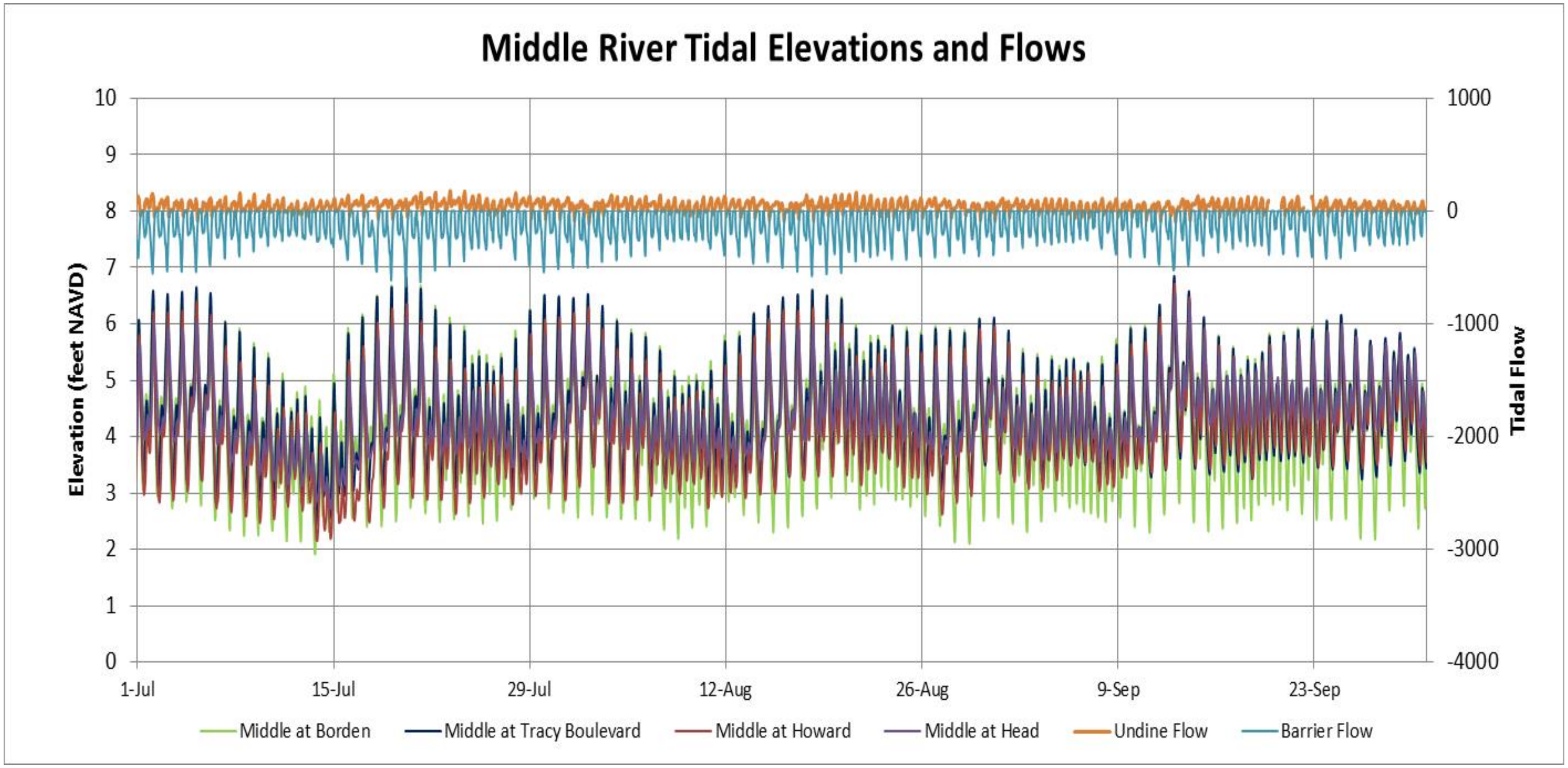
The temporary barriers were removed at the end of October, and full tidal flows were observed in November. Tidal flows at the head of Old River were increased by the pulse flow in the second half of October.



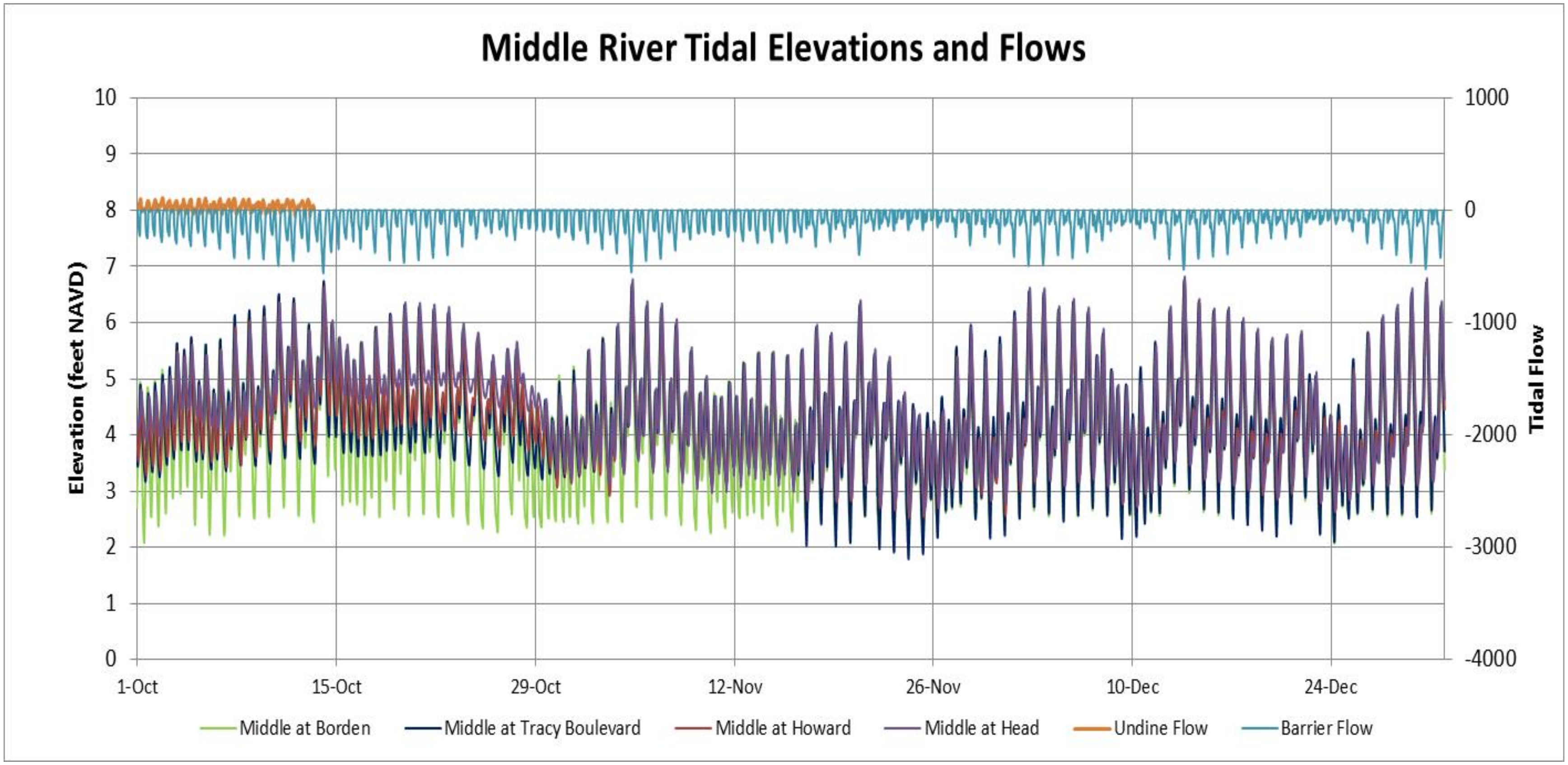
Middle River tidal elevations were similar to tidal elevations in all other south Delta channels from January through March. The tidal flow at Undine Road (brown line) was measured, with maximum tidal flows of 100-200 cfs. The flood-tide flows at Undine Road were small. The Middle River barrier was not installed during this period, but the calculated barrier flow (light blue line) indicates that the maximum upstream tidal flow (with a barrier) would have been less than 500 cfs.



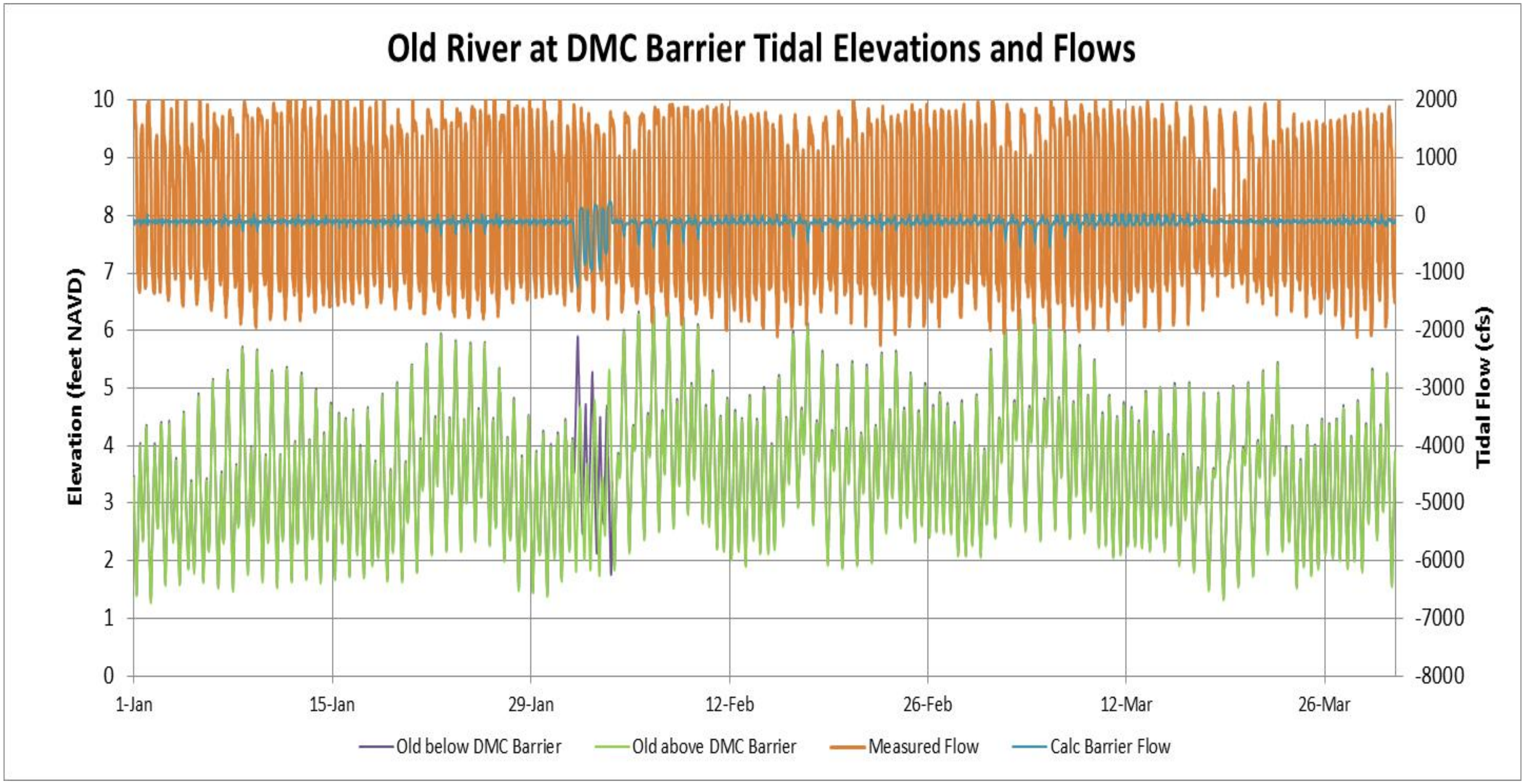
The Middle River barrier was not installed until mid-June, and the flap gates were not closed (operated) until early July. The calculated upstream barrier flow in June was less than 500 cfs, with similar downstream flows (not calculated or shown). The maximum tidal flows measured at Undine Road, near the head of Middle River, were about 150-200 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.



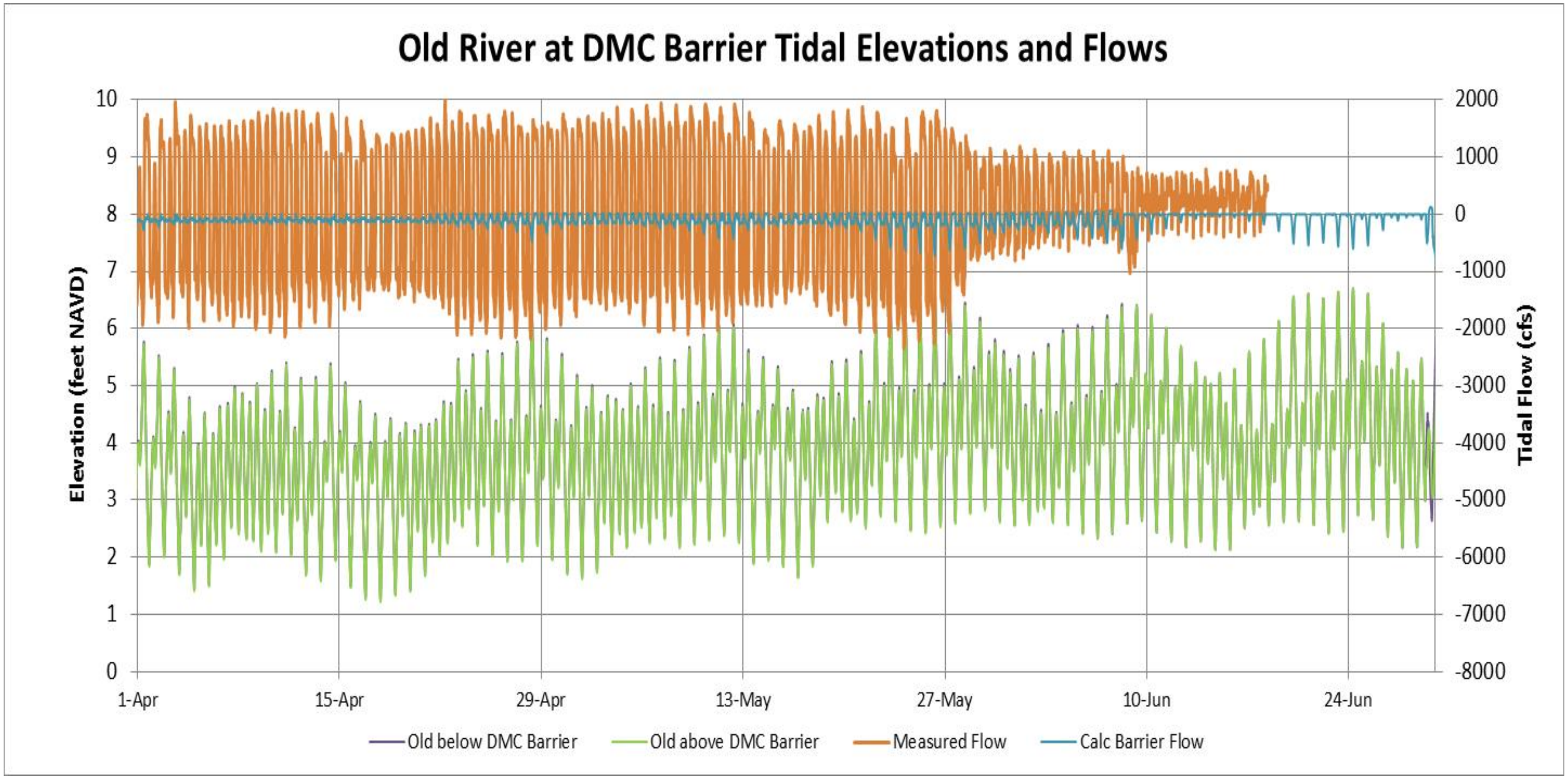
During the July-September period when the three temporary barriers were installed, but minimum tidal elevations in Middle River upstream of the barrier were less than 1 feet higher than the minimum elevations at Borden (Highway 4). The measured tidal flows at Undine Road were positive yet small (50 cfs), and the estimated tidal flows at the barrier were negative (upstream) with maximum flood tide of 500 cfs with an average of about 150 cfs, so flow was entering this 10 mile (17 km) reach of Middle River from both ends to supply irrigation diversions of about 200-250 cfs.



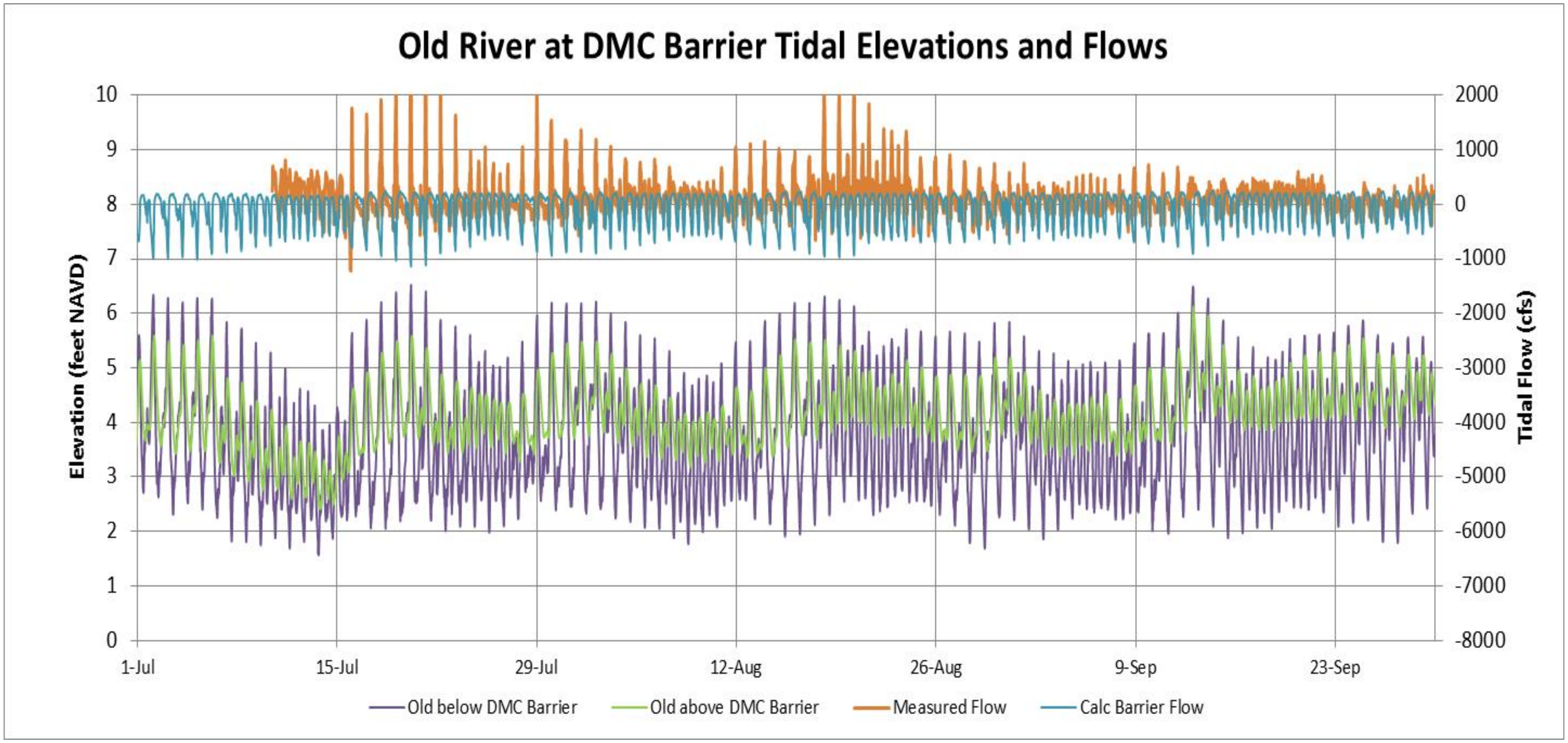
The Old at DMC and Grant Line Canal barriers were removed at the end of October, but the Middle River barrier was not removed until the middle of November. The full range of tidal elevations was measured at the Middle River stations in the second half of November and December. The measured tidal flows at Undine Road were very low (measurements not available after October 15). 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.



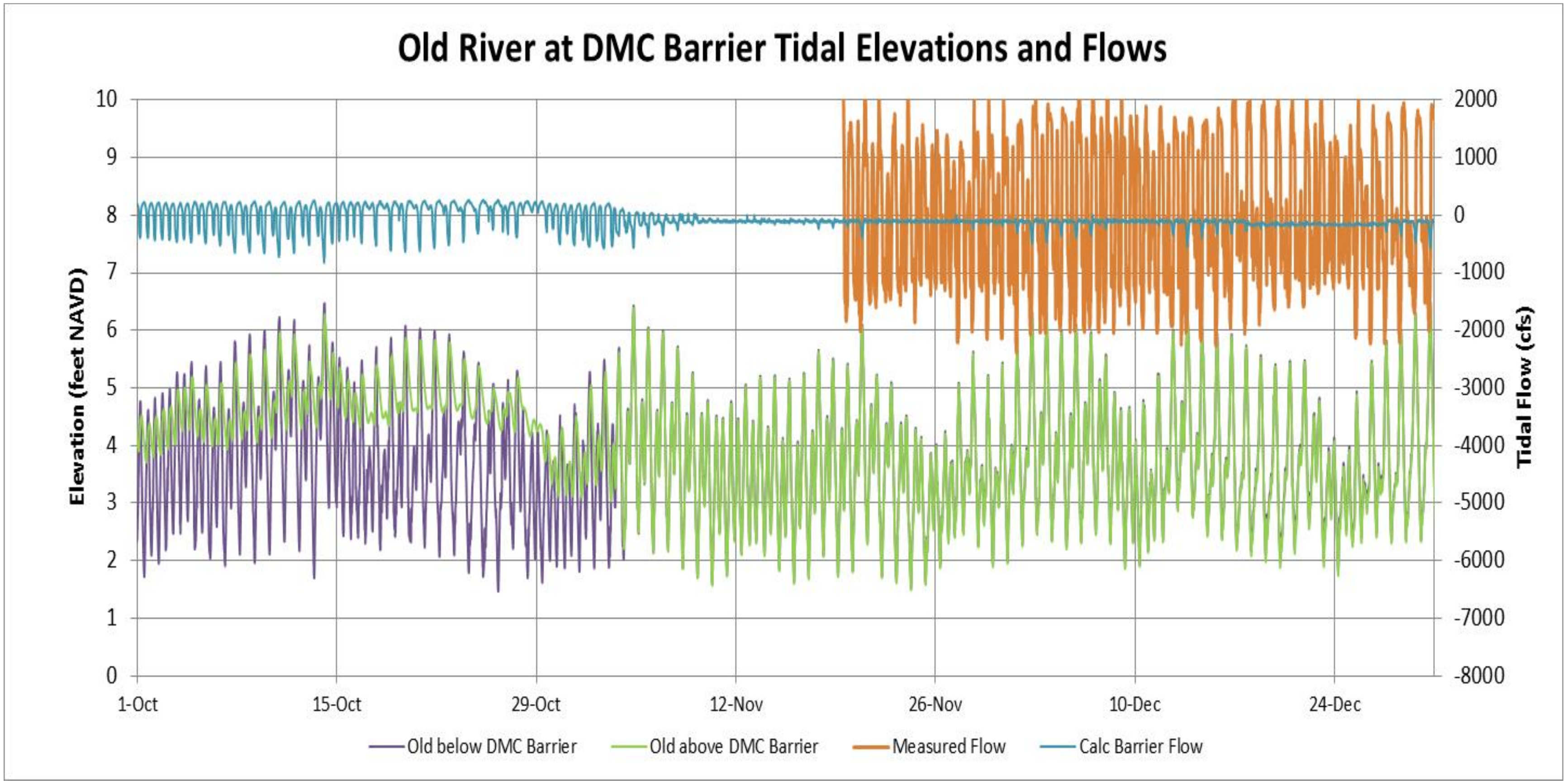
The measured tidal flows (brown line) in Old River at the DMC barrier were consistent with the tidal elevation changes, and fluctuated from about 1,500 cfs during ebb-tide to about -1,500 cfs during flood-tide. The calculated tidal flows (light blue line) were dependent on an elevation difference between downstream and upstream.



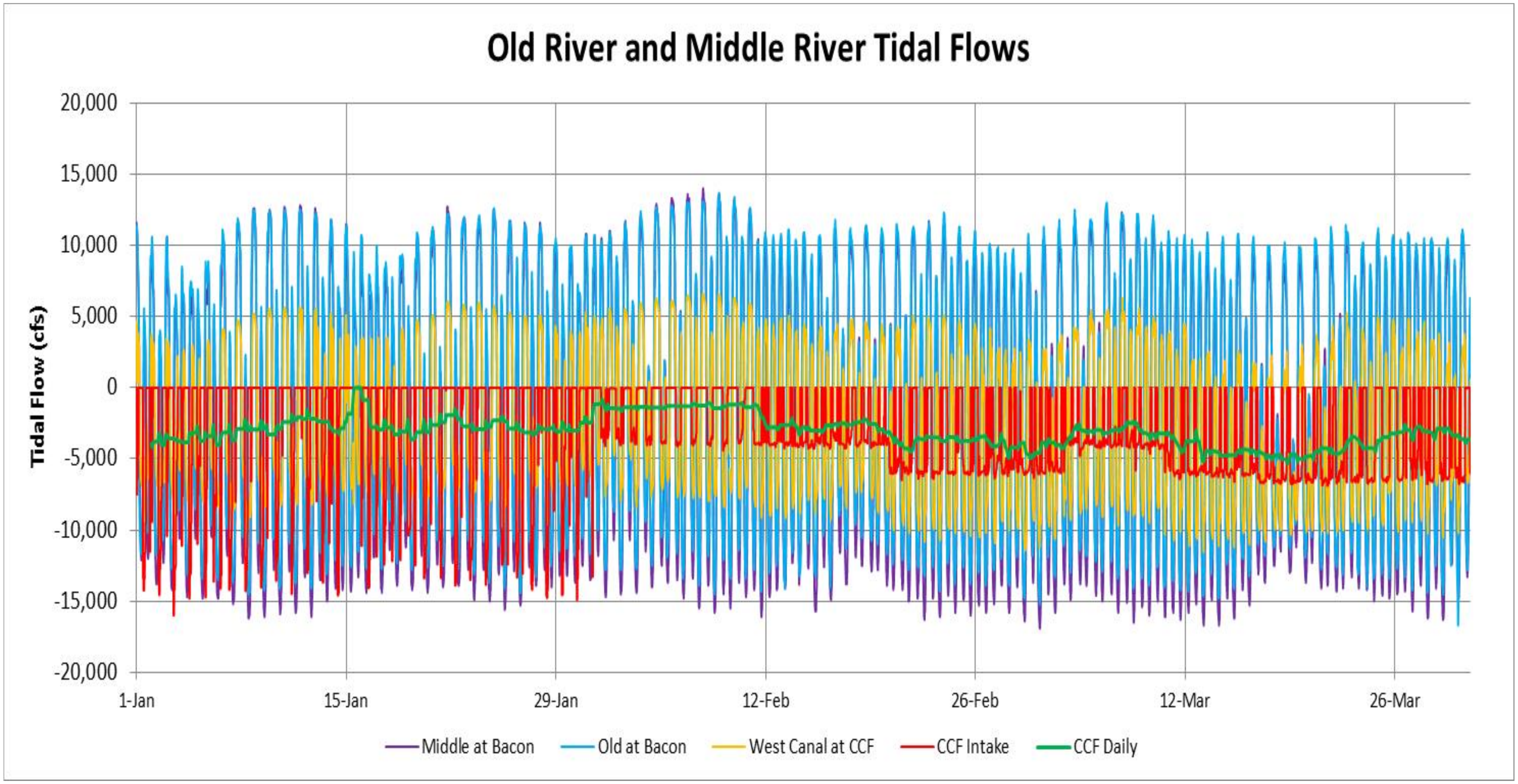
The Old at DMC barrier was installed during June but the flap gates were held open until mid-July. Therefore, the measured tidal flows (brown line) were progressively reduced in June (station out after June 18) but the tidal elevations upstream and downstream remained similar through June. The calculated tidal flows (light blue line) assumed the flap-gates were operating (flood-tide only) were less than 500 cfs and were only calculated at the higher tides (overtopping weir crest at 4.5 feet NAVD).



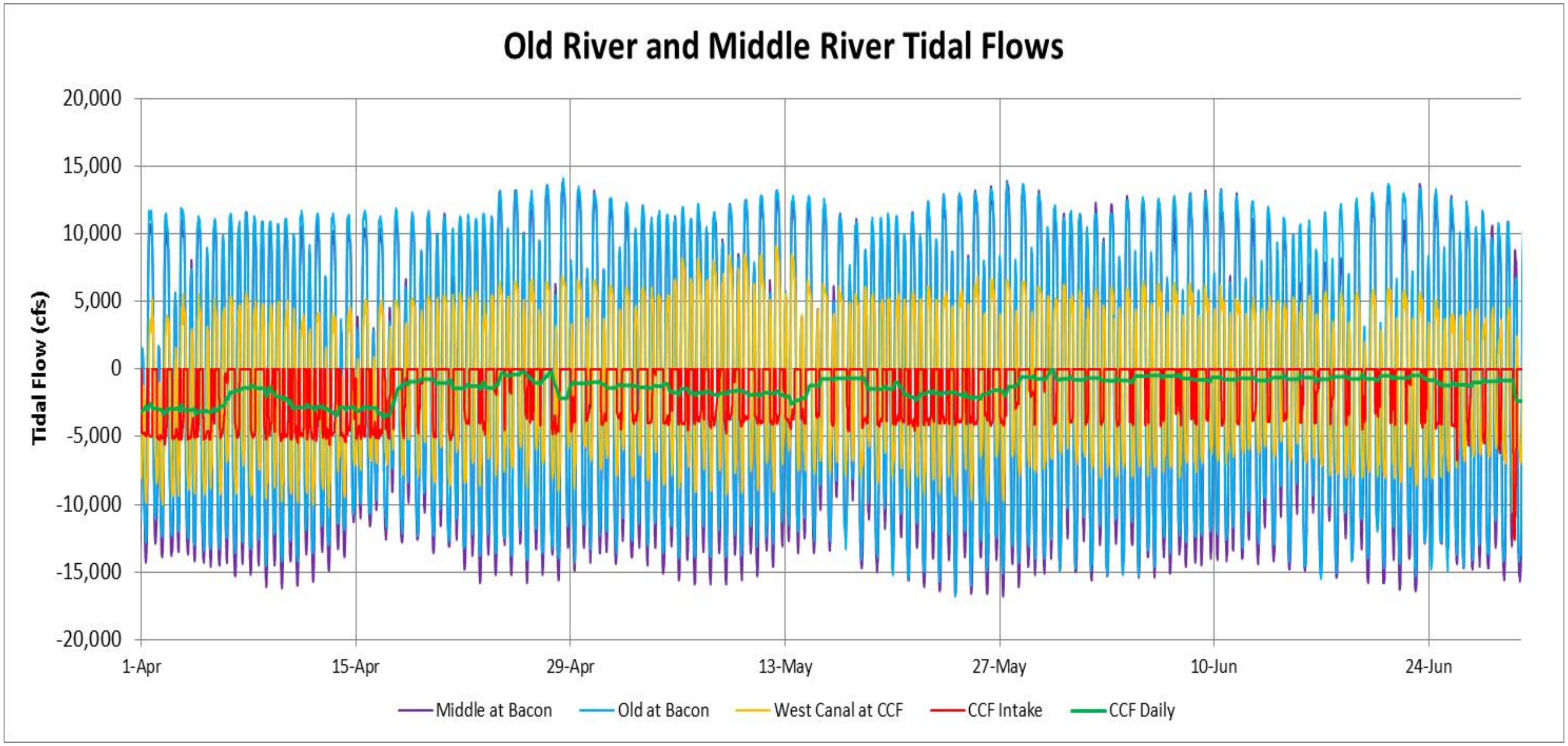
The tidal elevations are much different upstream of the barrier during the July-September period. The maximum flood-tide flows through the culverts and over the weir crest at 4.5 feet were -500 cfs to -1,000 cfs and matched the measured tidal flows. The measured ebb-tide flows of 1,000 cfs or more in July and August are unexplained.



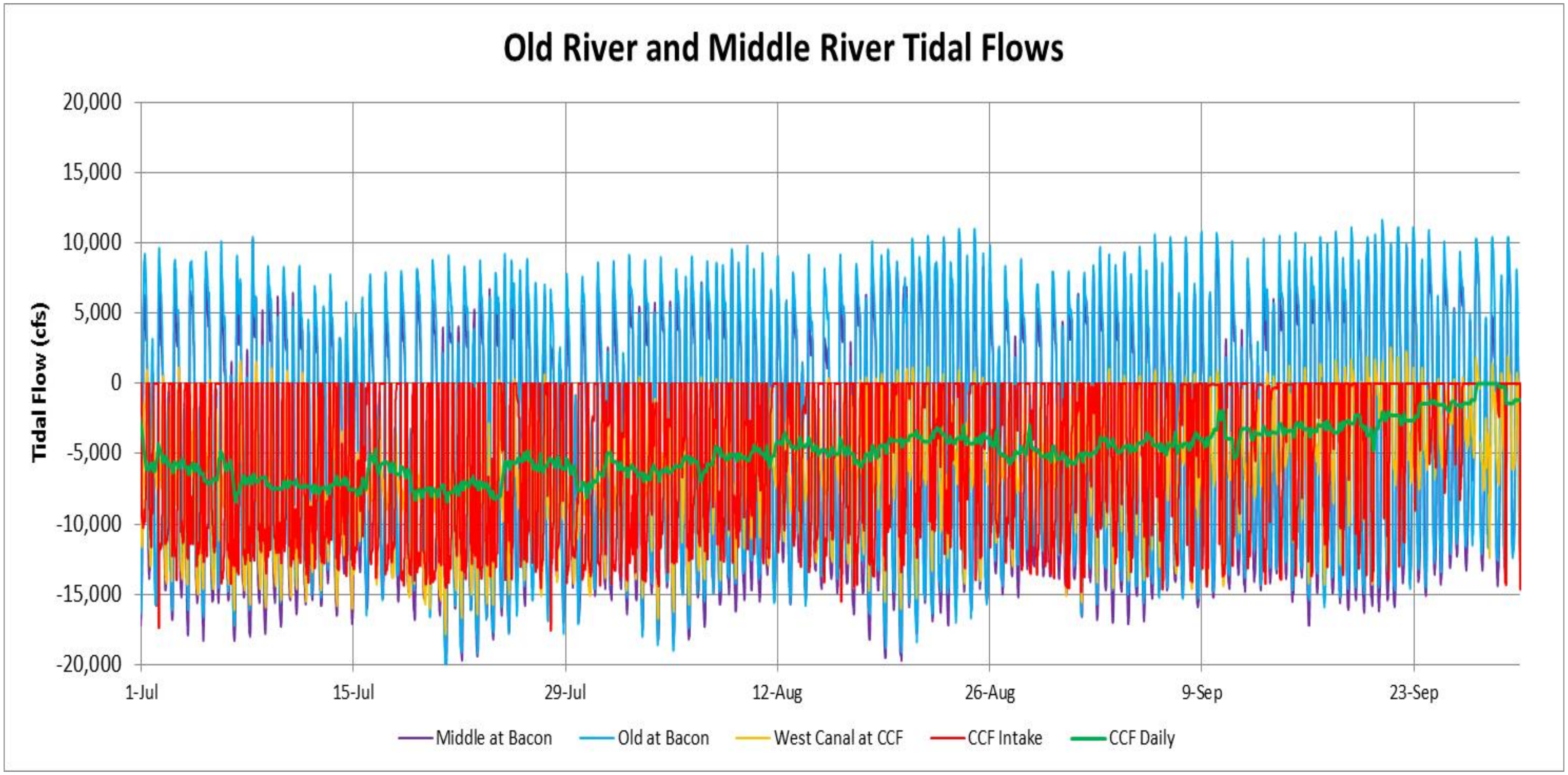
The tidal elevations are much different upstream of the barrier during October until the barrier was removed. The maximum flood-tide flows through the culverts and over the weir crest at 4.5 feet were about -500 cfs. The maximum measured tidal flows of about 1,500 cfs for ebb-tide and about -1,500 cfs for flood-tide were similar to the tidal flows measured in the January-May period.



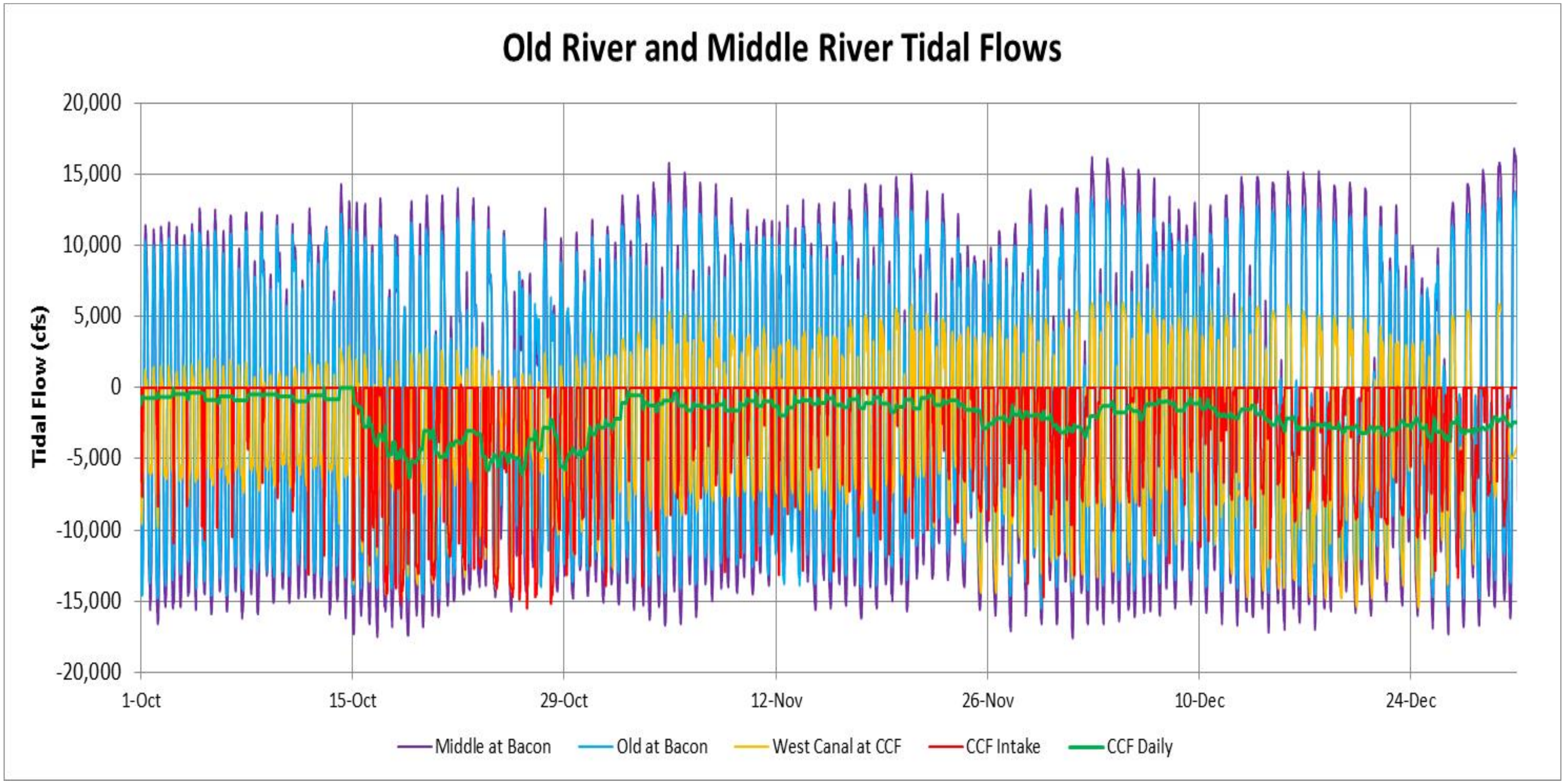
Tidal flows in Middle River at Bacon Island (purple line) and in Old River at Bacon Island (blue line) were similar, although the tidal flows in Middle River were about 5% higher. The tidal flows in West Canal at the CCF gates were about 25% of the combined Old and Middle River tidal flows. The flood 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 CCF gates were partially closed in February and March to limit the inflow to CCF.



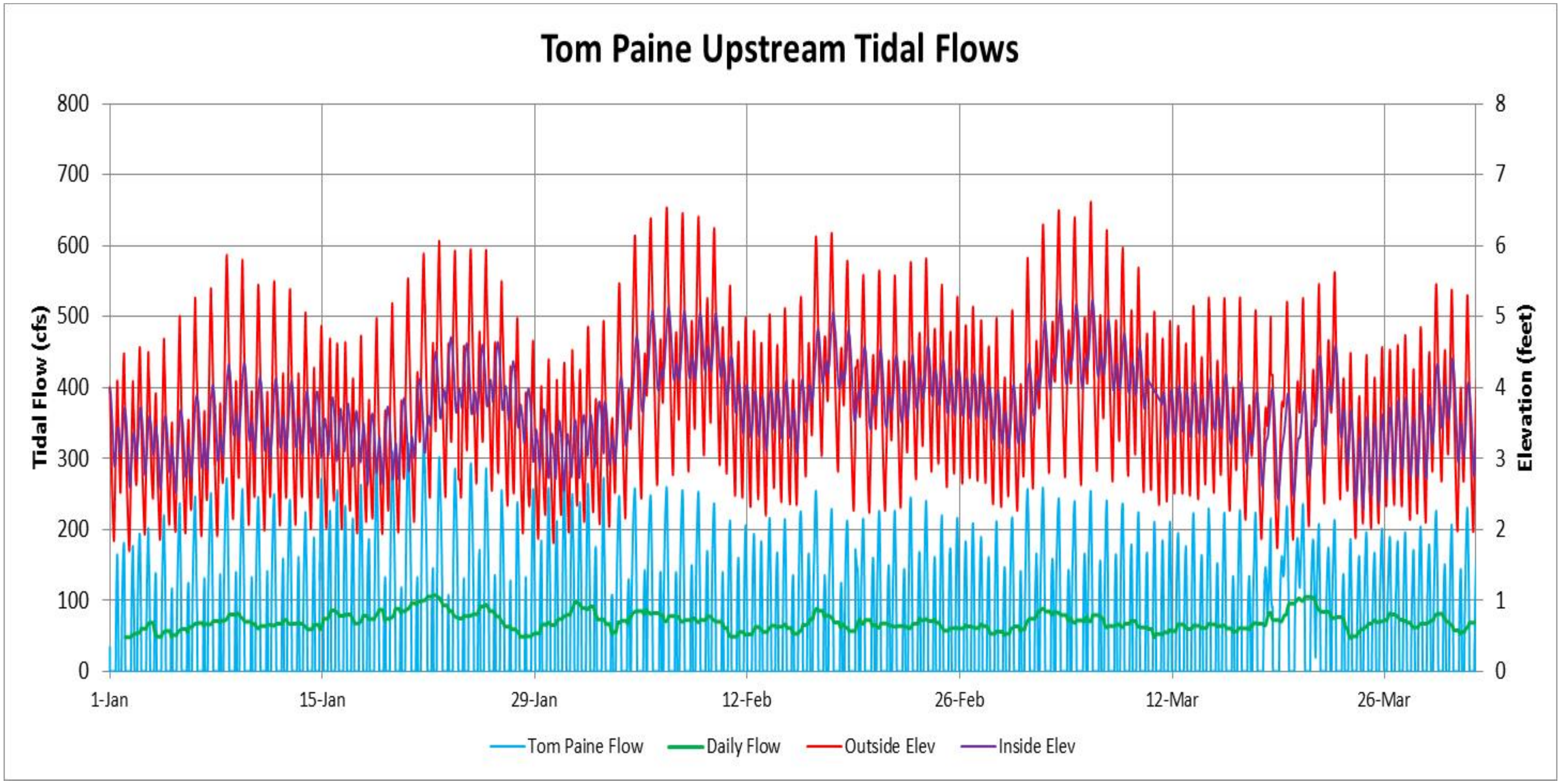
The CCF diversions were reduced considerably in the April-June period for SJR fish protection; the NMFS RPA restricted CVP and SWP pumping to 1,500 cfs during a 60-day period (mid-April to mid-June) and about half of this was at the CVP Jones pumping plant. During this period of low pumping, the flood-tide and ebb-tide flows in Old River and in Middle River were nearly identical (-12,500 cfs to 12,500 cfs).



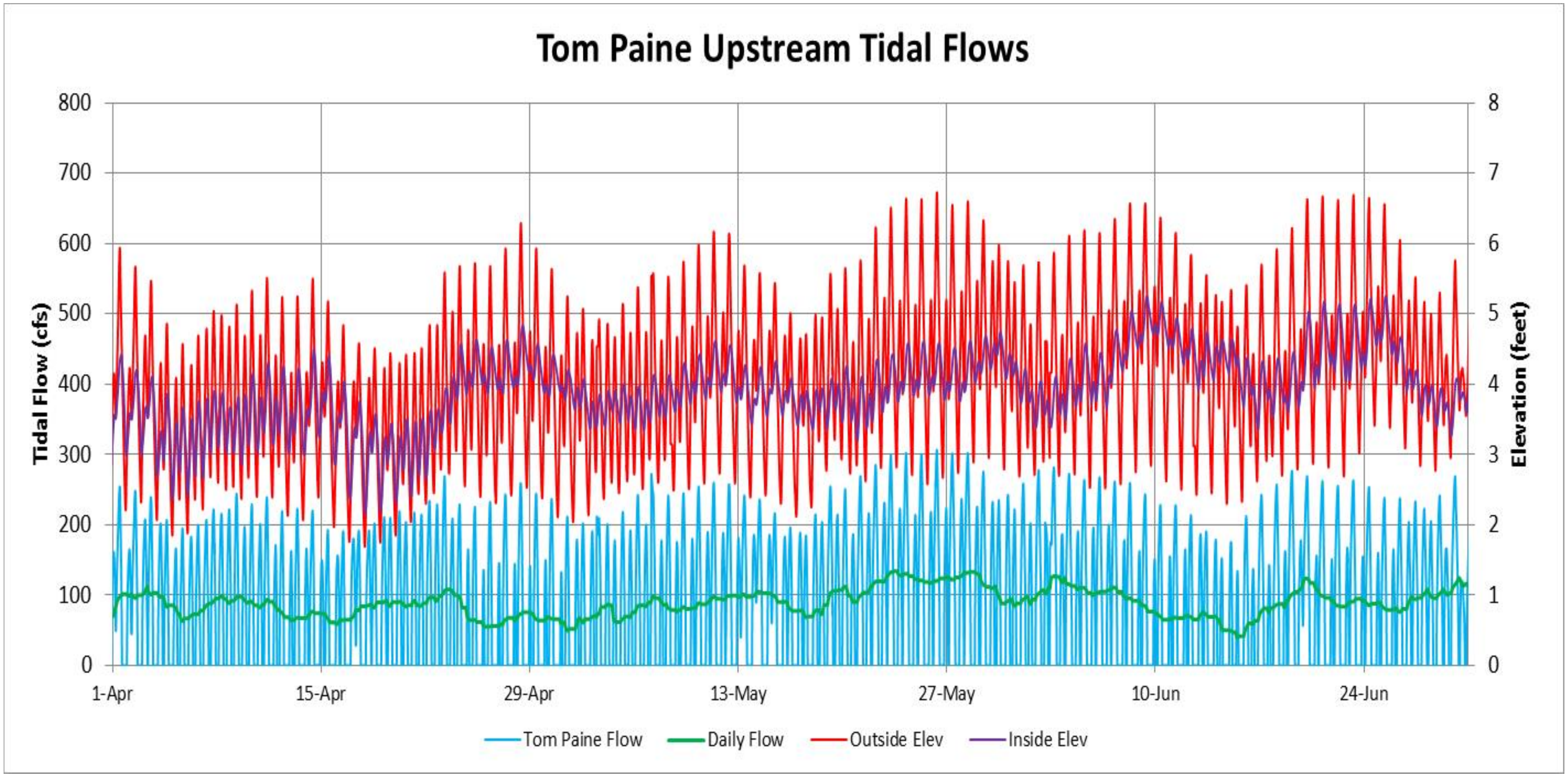
CCF diversions and DMC diversions were increased to maximum pumping of about 10,000 cfs in July, with reduced pumping of about 7,500 cfs in August and about 5,000 cfs in September. Nevertheless, there was a moderately strong ebb tide (downstream) flow of 5,000 cfs to 10,000 cfs during the major ebb tide 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.



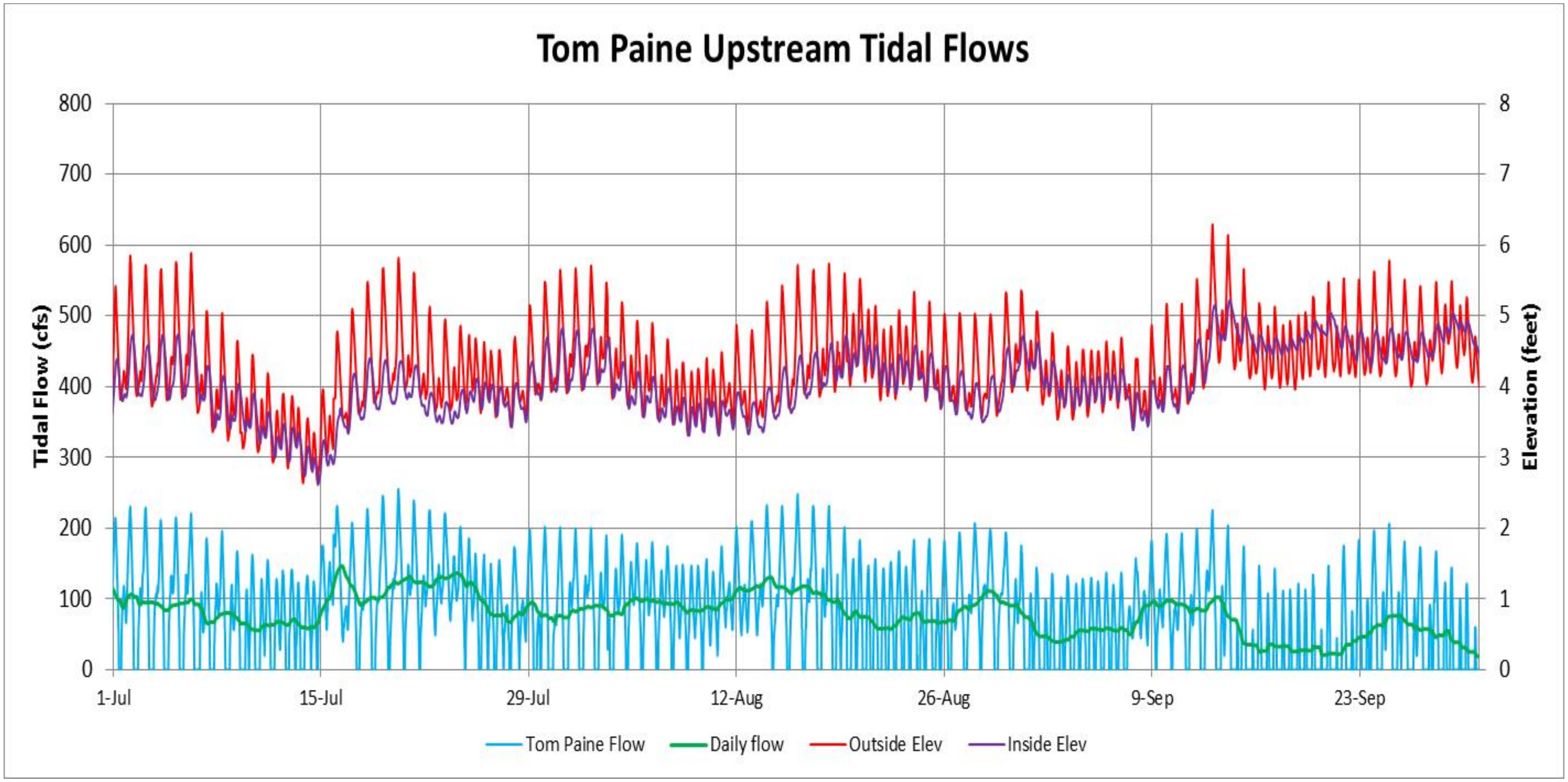
The flow into the CCF is controlled by five tidal gates (each 20 feet wide and 15 feet tall), with a maximum flow of about 15,000 cfs. The inflow is controlled by partially closing the five gates to prevent scour from flows of greater than 15,000 cfs or to close the gates during the higher high flood tide period (to preserve the higher high tide elevation), or when the CCF elevation is higher than the West Canal (Old River) elevation. The effects of opening the CCF gates can be seen in the West Canal tidal flows, but are difficult to identify in the much higher tidal flows in Old River at Bacon and in Middle River at Bacon.



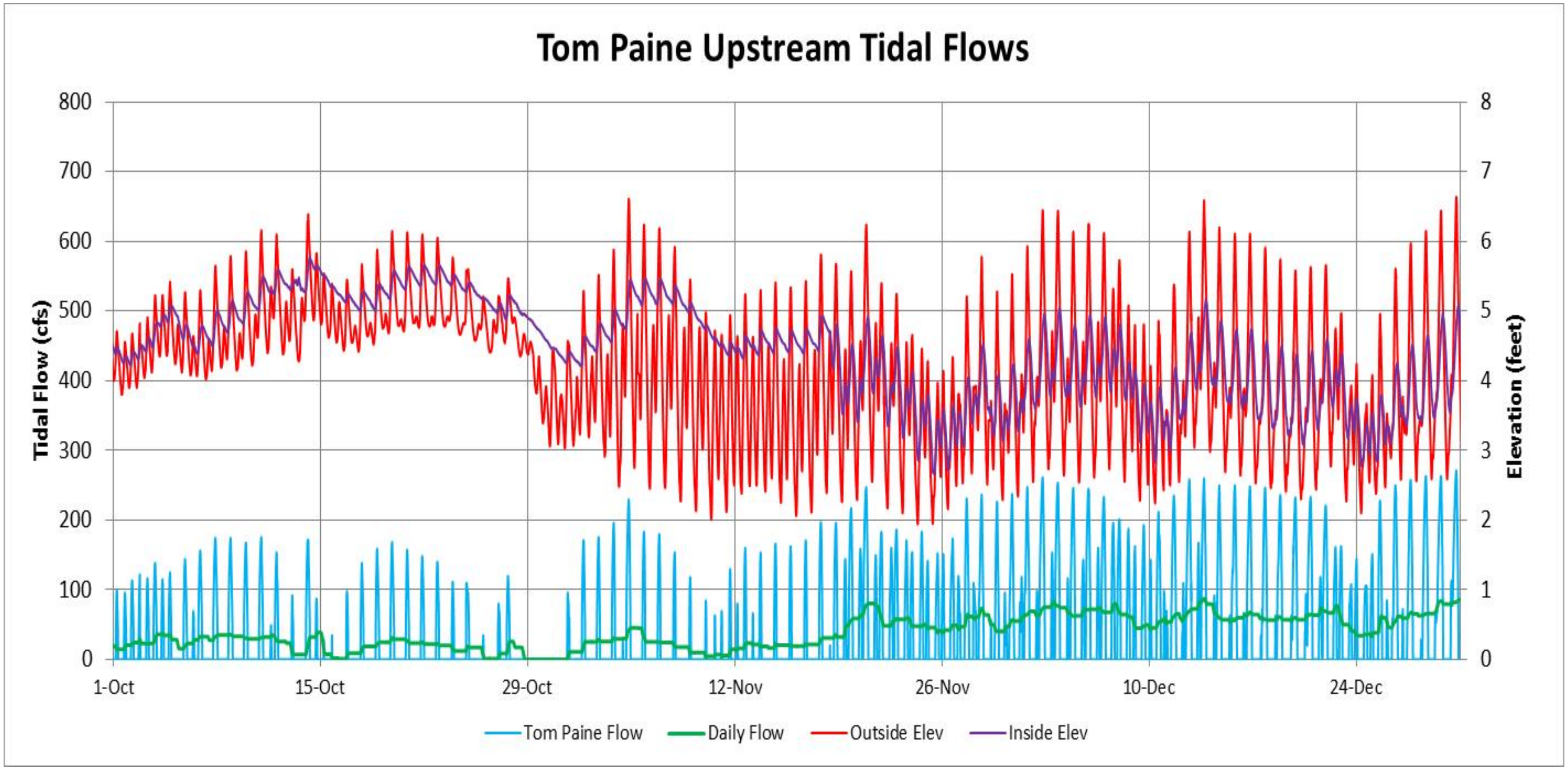
Tidal elevations in Tom Paine Slough are controlled by two box culverts and four siphons with flap gates. Diversions do not usually begin until April, and the upstream elevation (purple line) would remain higher if the flap gates were operating (upstream flow only). The upstream flow (with flap gates) 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, and the tidal elevations would fluctuate around mean tide, as they did for the January-March period; the flap gates were likely open during this period.



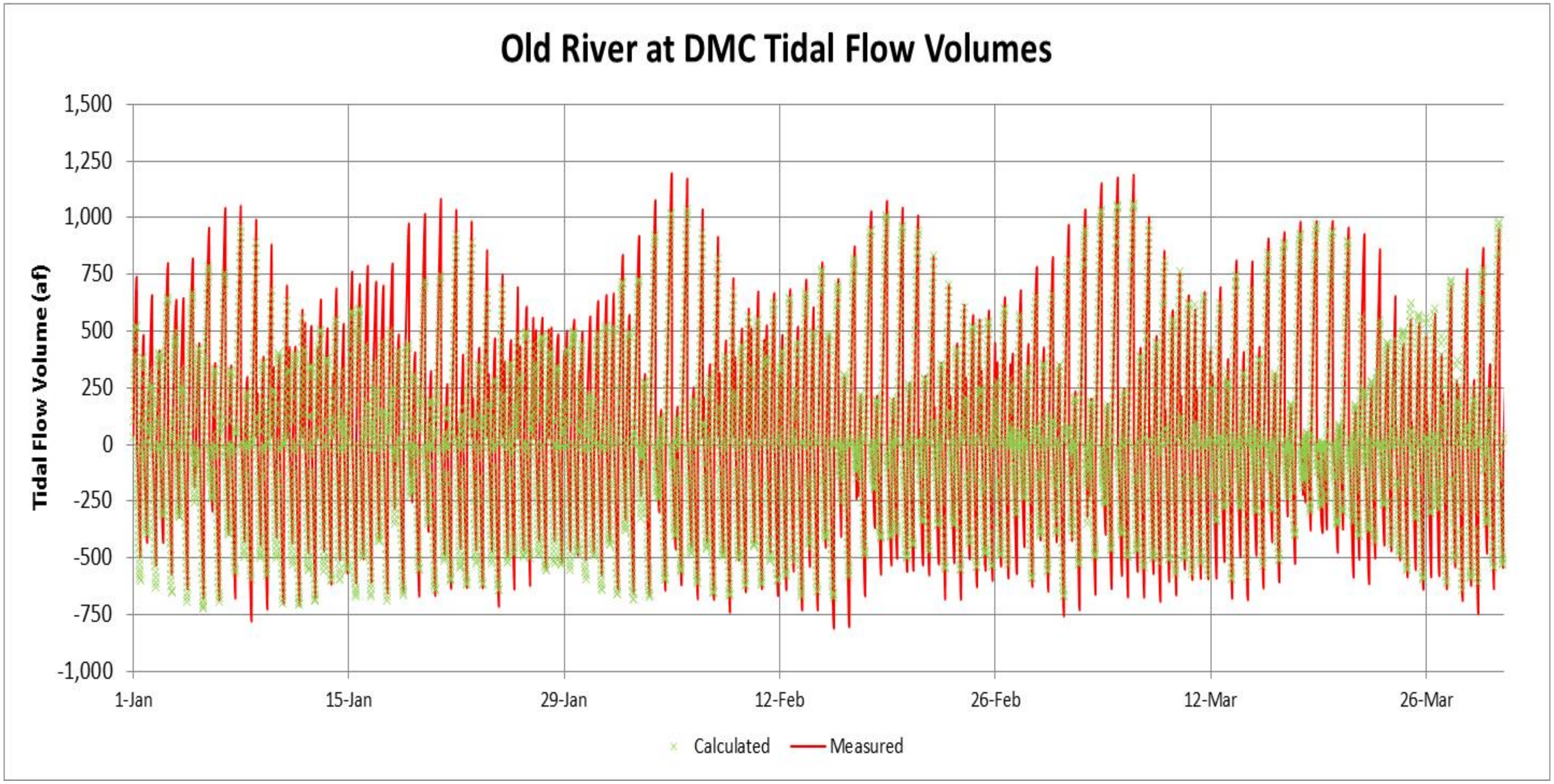
The upstream tidal range (purple line) remained near the mean of the downstream tidal elevations (red line). If the flap gates were closed (operating) the diversions from Tom Paine Slough were not large. The calculated upstream tidal flows (bright blue line) would have provided an average flow of 100 cfs (green line). Diversions from Tom Paine Slough were likely less than 100 cfs because the upstream elevations remained above 3 feet. A diversion flow of 100 cfs would be much larger than the average salt source flow to 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.



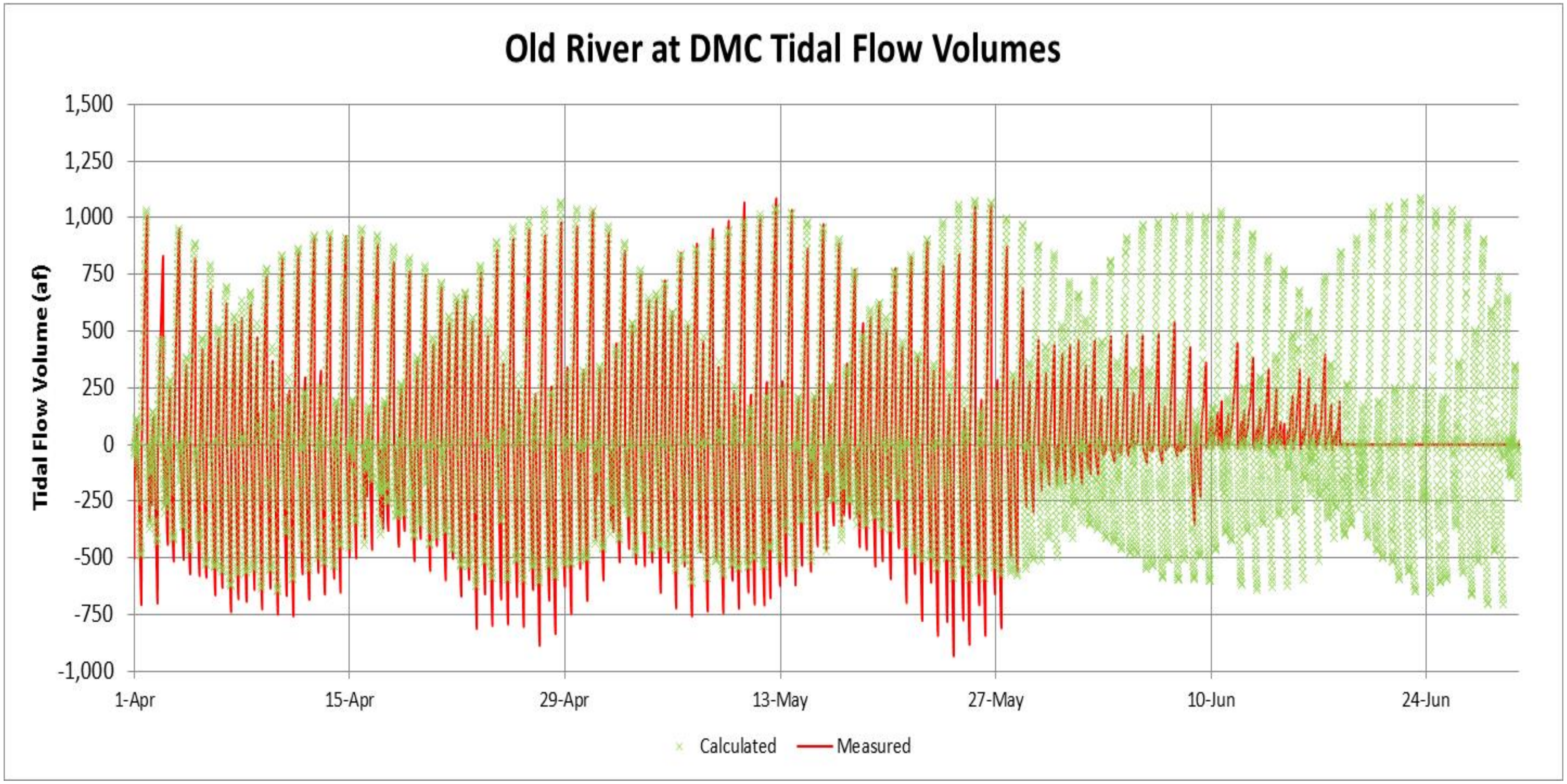
The tidal range in Old River and in Sugar Cut (at Tom Paine Slough) was substantially reduced by the temporary barriers in the summer months. The minimum elevations upstream of the Tom Paine siphons remained close to the minimum downstream elevations (greater diversion flow would have been possible with lower elevations). The daily average diversions into Tom Paine Slough (siphons) were limited to less than 100 cfs during this period; 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.



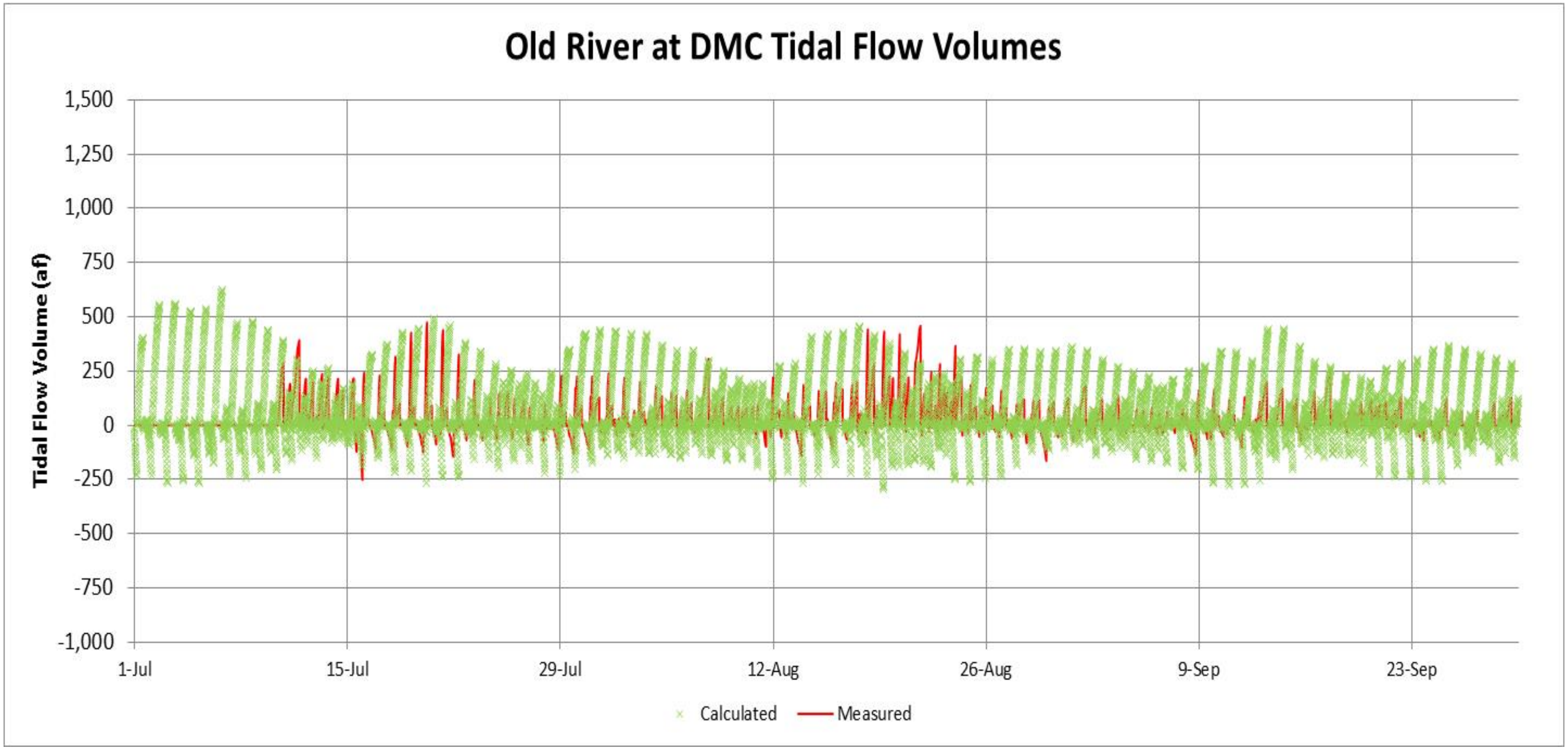
Diversion from Tom Paine Slough had likely ceased in the October-December period, and the flap gates were still open (operating), because the upstream tidal elevations remained high. The decreasing upstream water elevations (2-3 inches per day) are difficult to explain unless one of the flap-gates might have been opened. The other flap gates must have been opened on November 20, because the variation in the upstream tidal elevations increased, yet remained near the average of the downstream elevations. The calculated daily average diversions were less than 25 cfs in October and the first half of November, and the calculated upstream diversions were about 75 cfs in the second half of November and December; and equal downstream flow (flap gates open) is indicated by the tidal fluctuation in the upstream elevations.



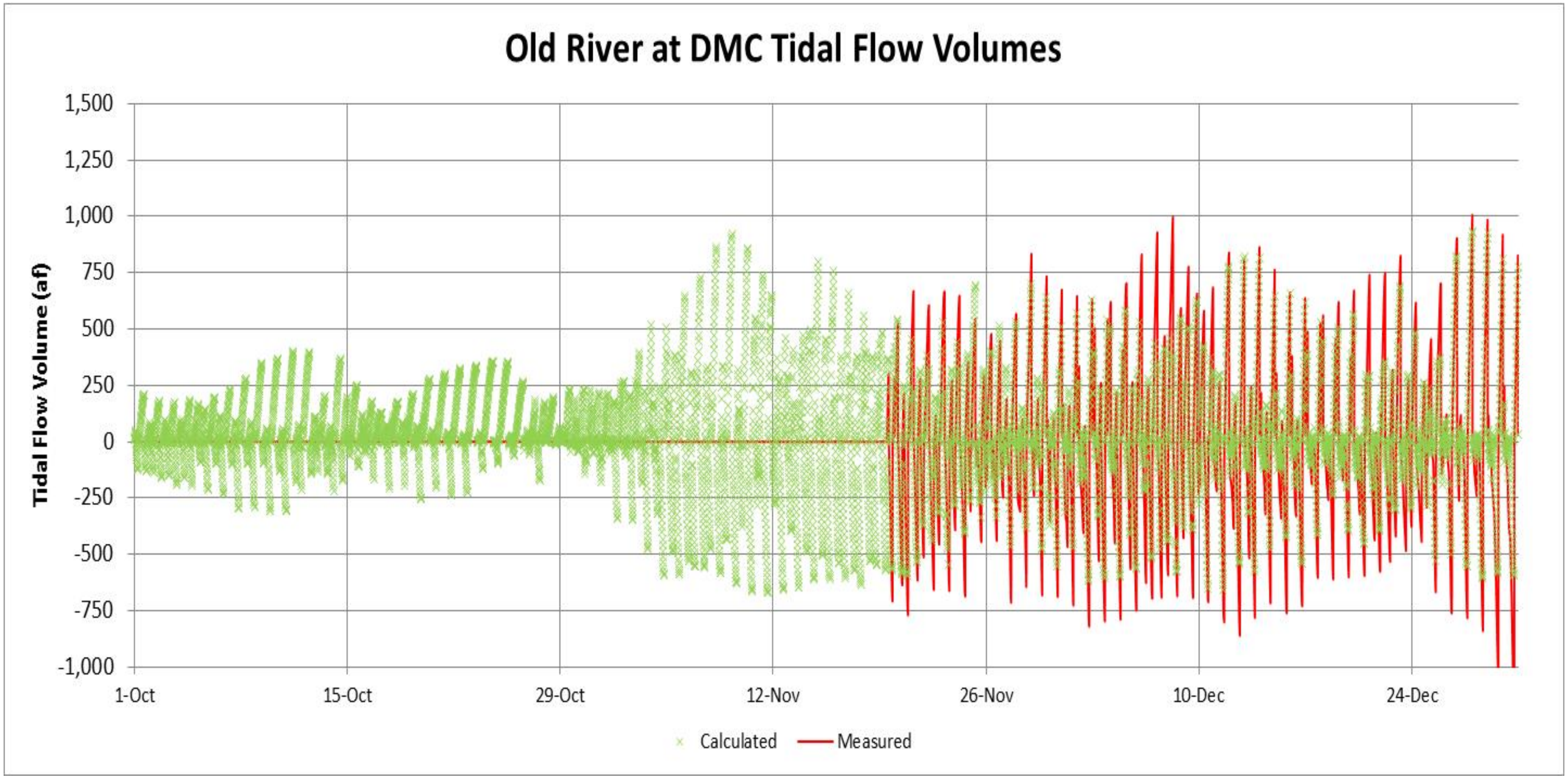
The tidal flow volume can be estimated as the change in tidal elevation times the upstream surface area that is filling or draining. For Old River at the DMC barrier, the upstream area is estimated as 250 acres. A net flow of 10% of the head of Old River was added to the tidal volumes, so that the ebb 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.



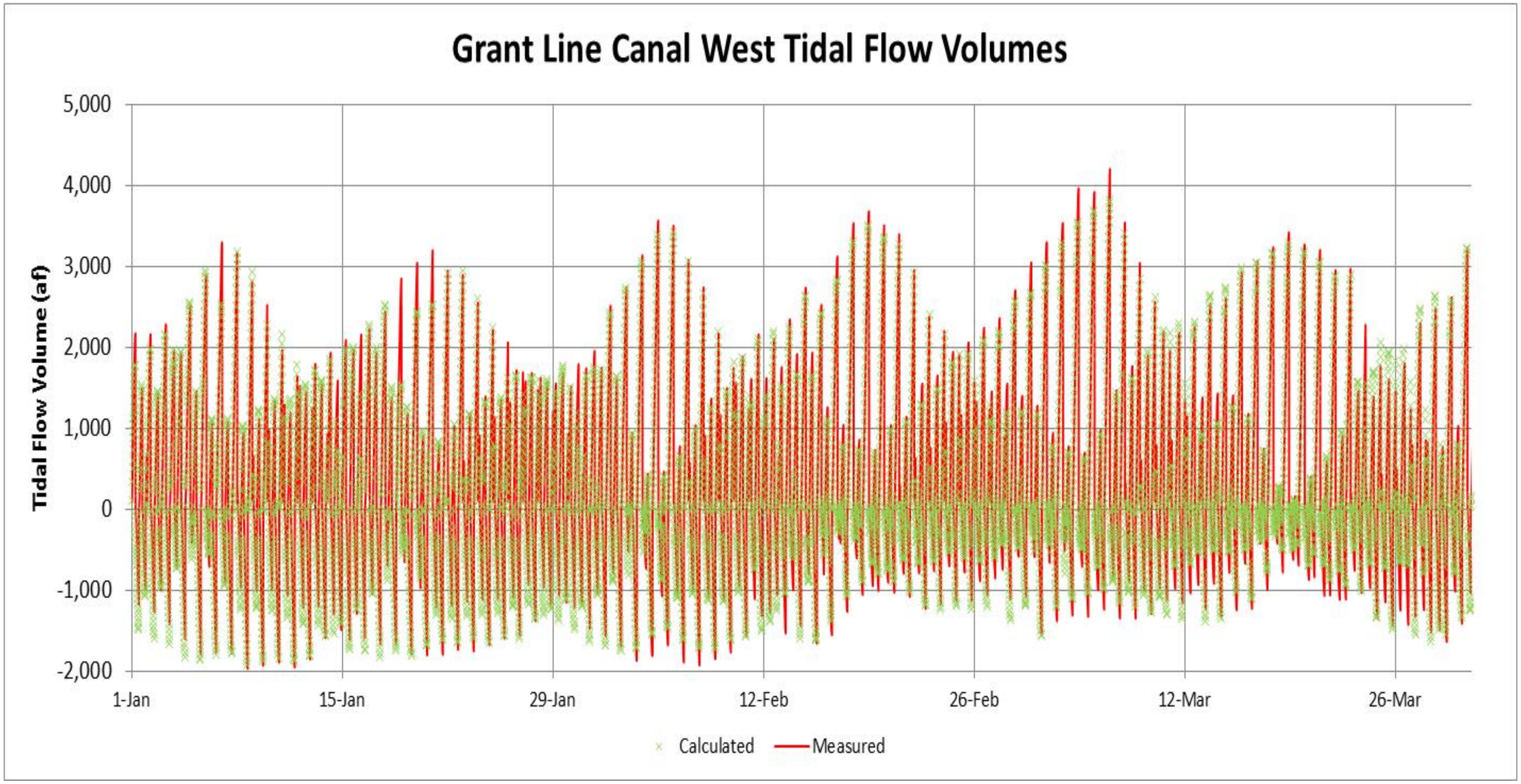
The calculated tidal flow volumes for Old River at the DMC barrier did not match the reduced measured tidal flows, because the barrier blocked most of the tidal flow, although the upstream elevations were not reduced.



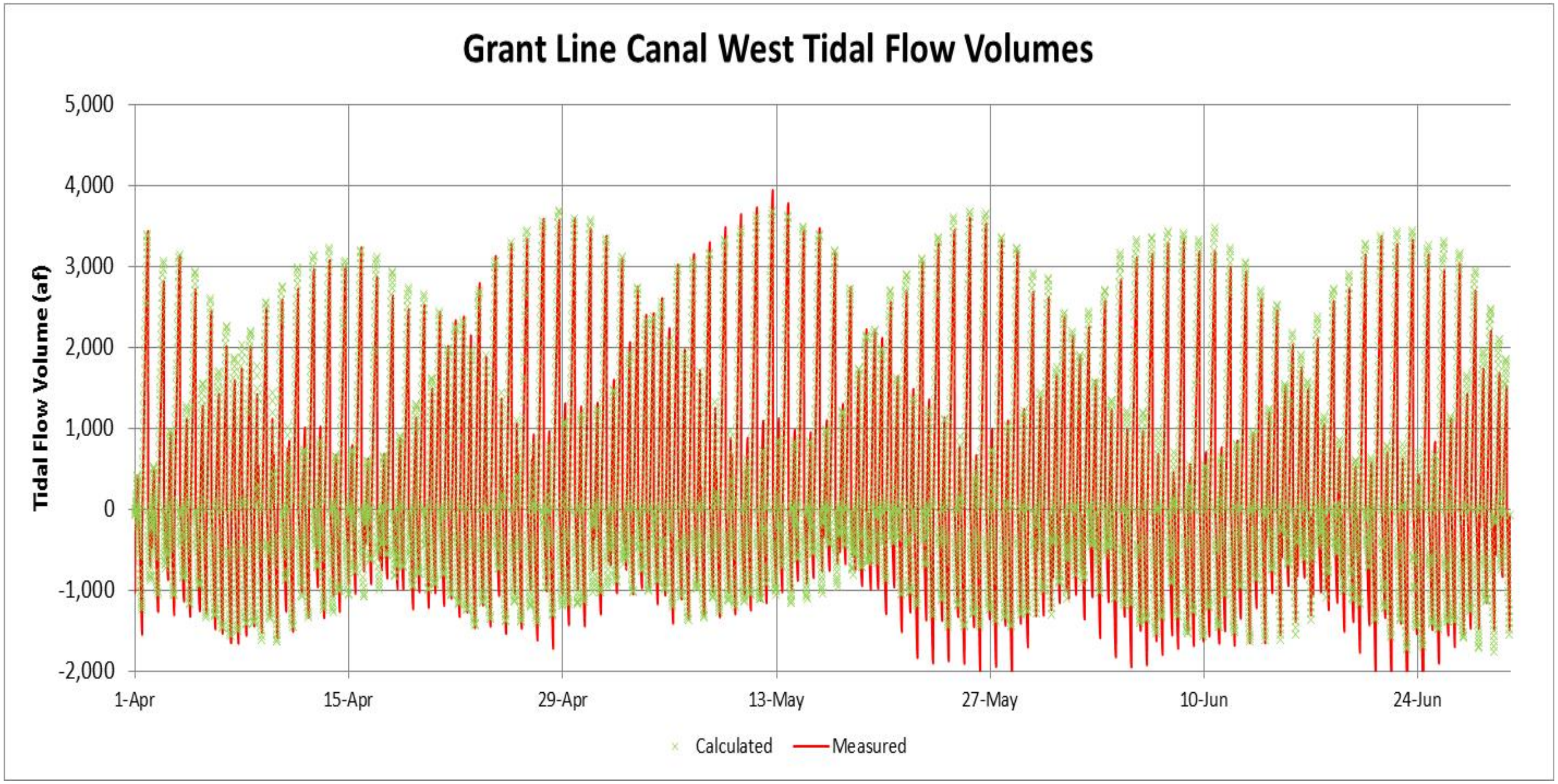
When the flap-gates were closed (operated) in July, the minimum tidal elevations upstream were increased and the maximum tidal elevations were reduced, so the calculated tidal flows were generally cut in half. The measured tidal flows downstream of the barrier were even lower, suggesting that some of the tidal flows upstream of the barrier were reversed (flood-tide flow from upstream and ebb-tide flow to upstream).



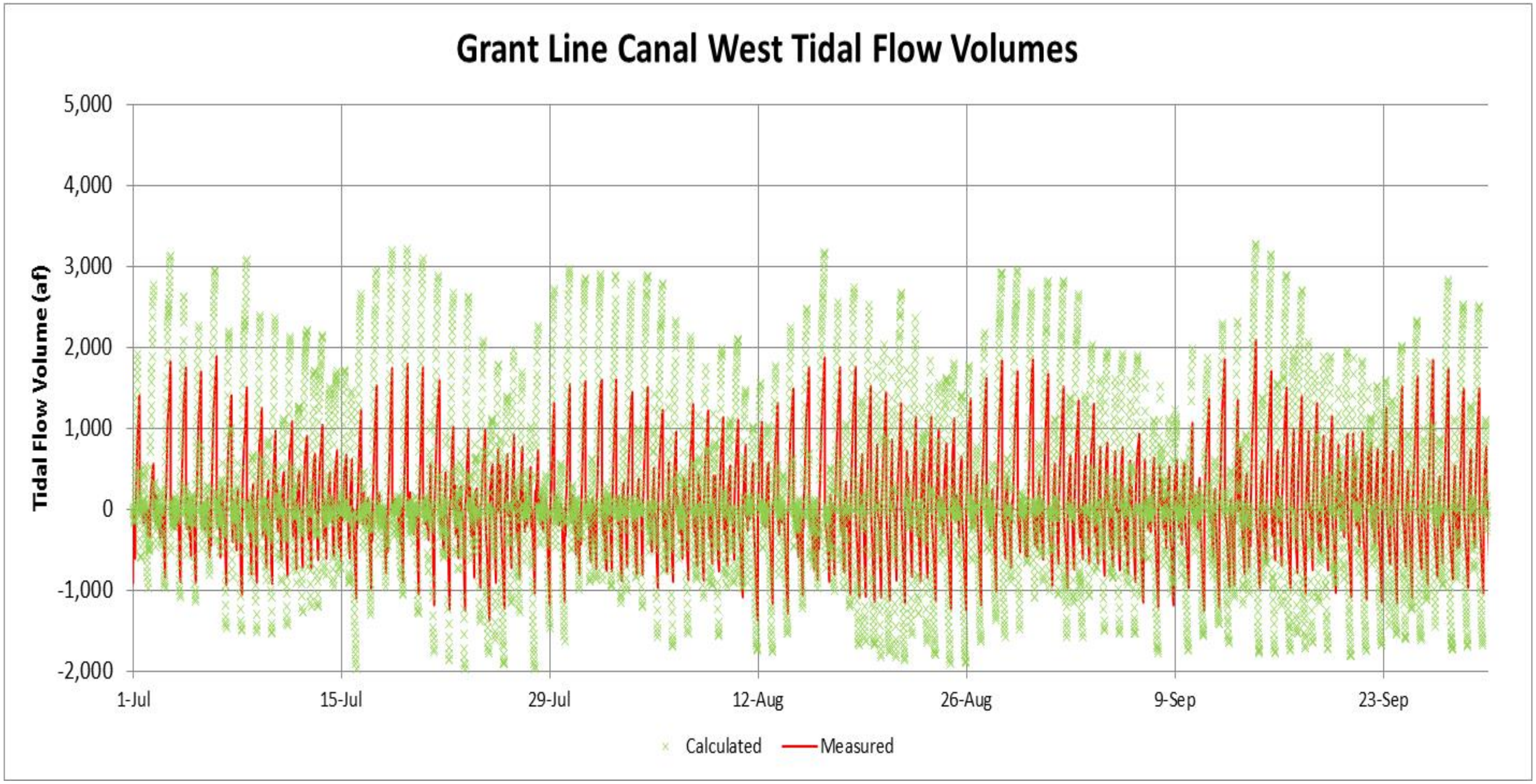
Once the Old at DMC barrier was removed at the end of October, the calculated tidal flow volumes increased to about 500-750 af. When the tidal flows were measured at the end of November, the calculated and measured tidal flow volumes matched reasonably well, although the assumed net flow of 10% of the head of Old River flow shifted the flood-tide flow volumes to be less than the measured flood-tide.



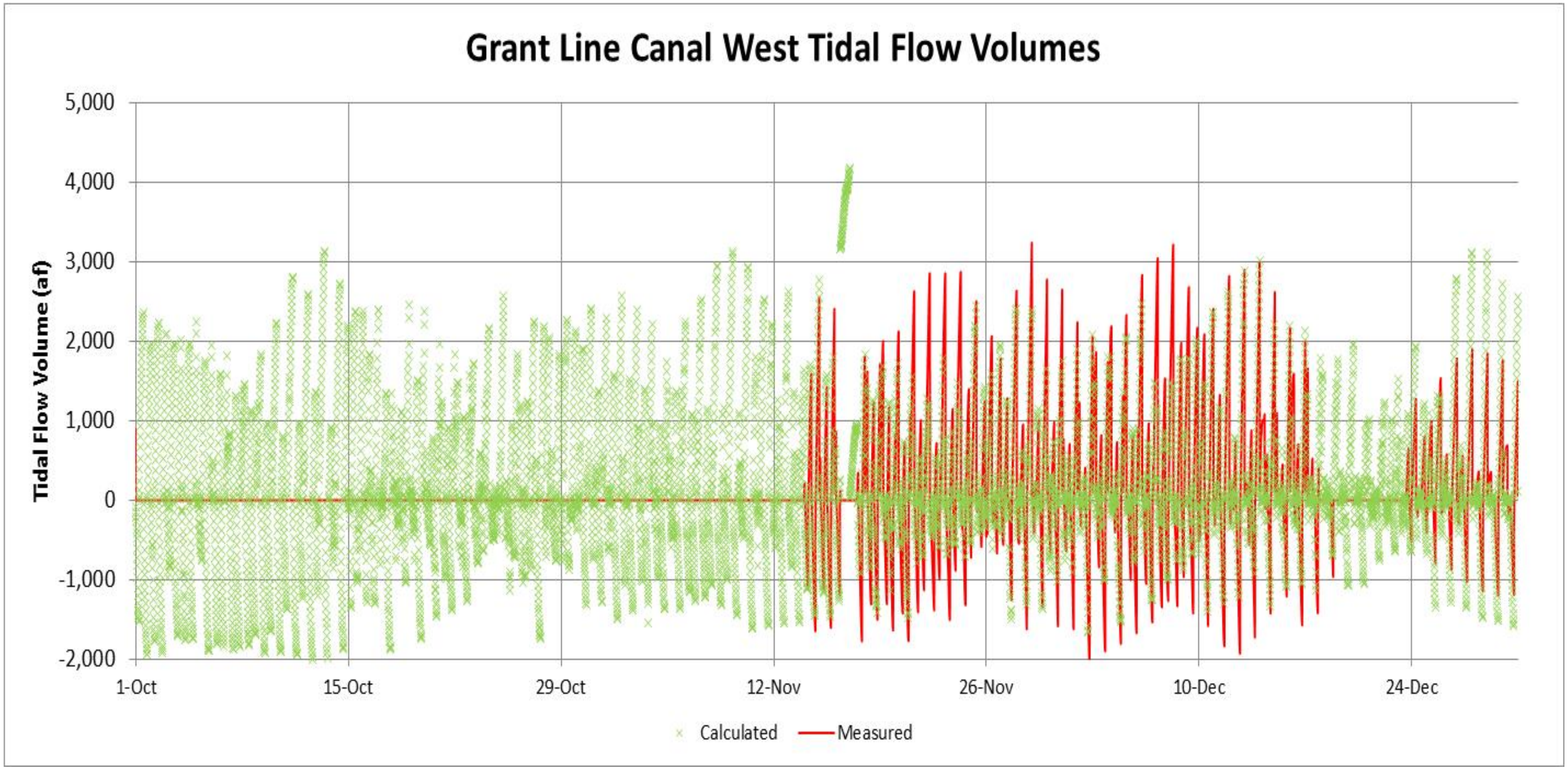
The Grant Line Canal tidal flow volumes were estimated with the tidal elevations and an upstream surface area of 750 acres, with a net flow of 85% of the Head of Old River flow. The match between the calculated tidal flow volumes and the measured tidal flow volumes is remarkable.



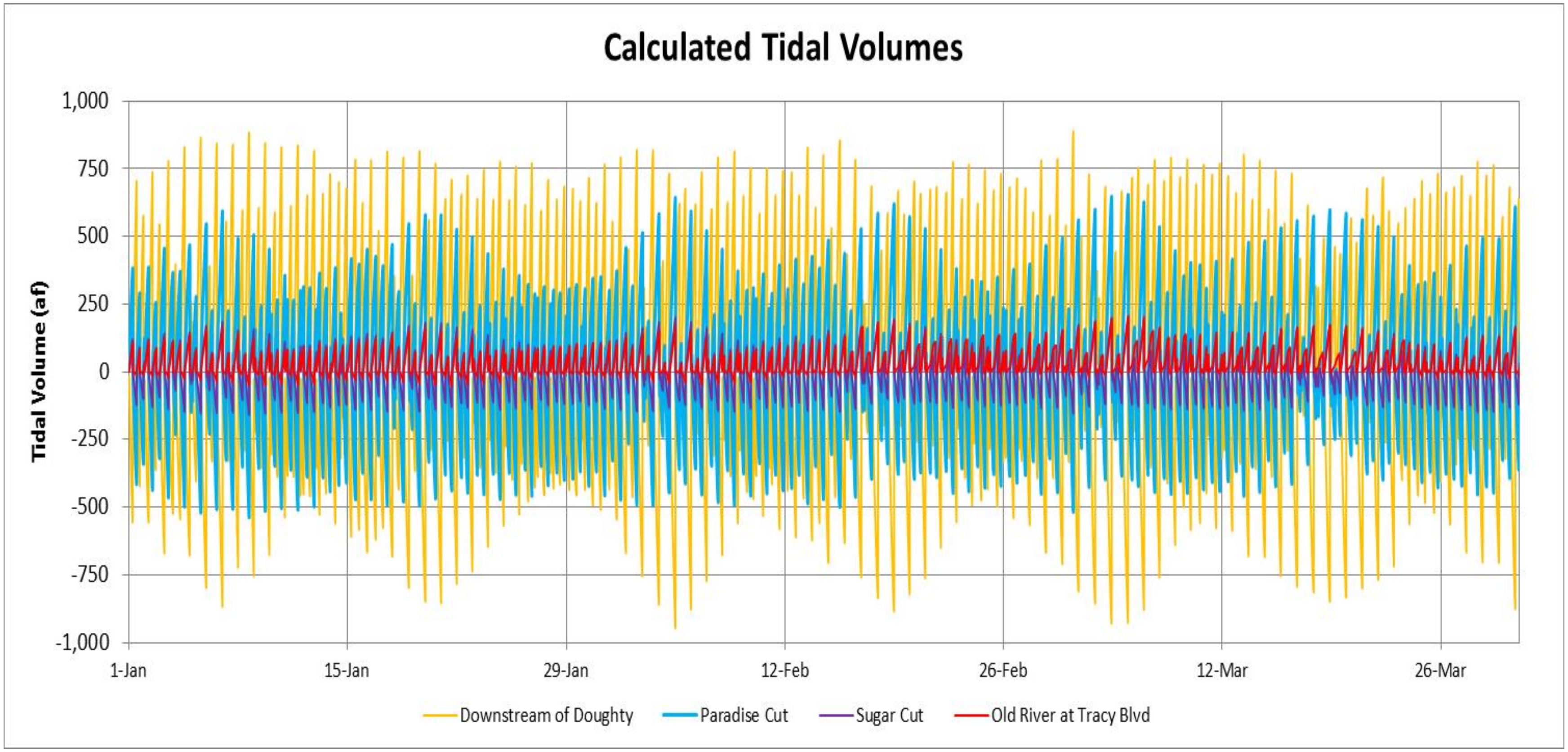
The measured flood-tide flows in Grant Line Canal were increased in June compared to the calculated tidal flows, because the Old River at DMC barrier blocked most of the flood-tide flows in Old River.



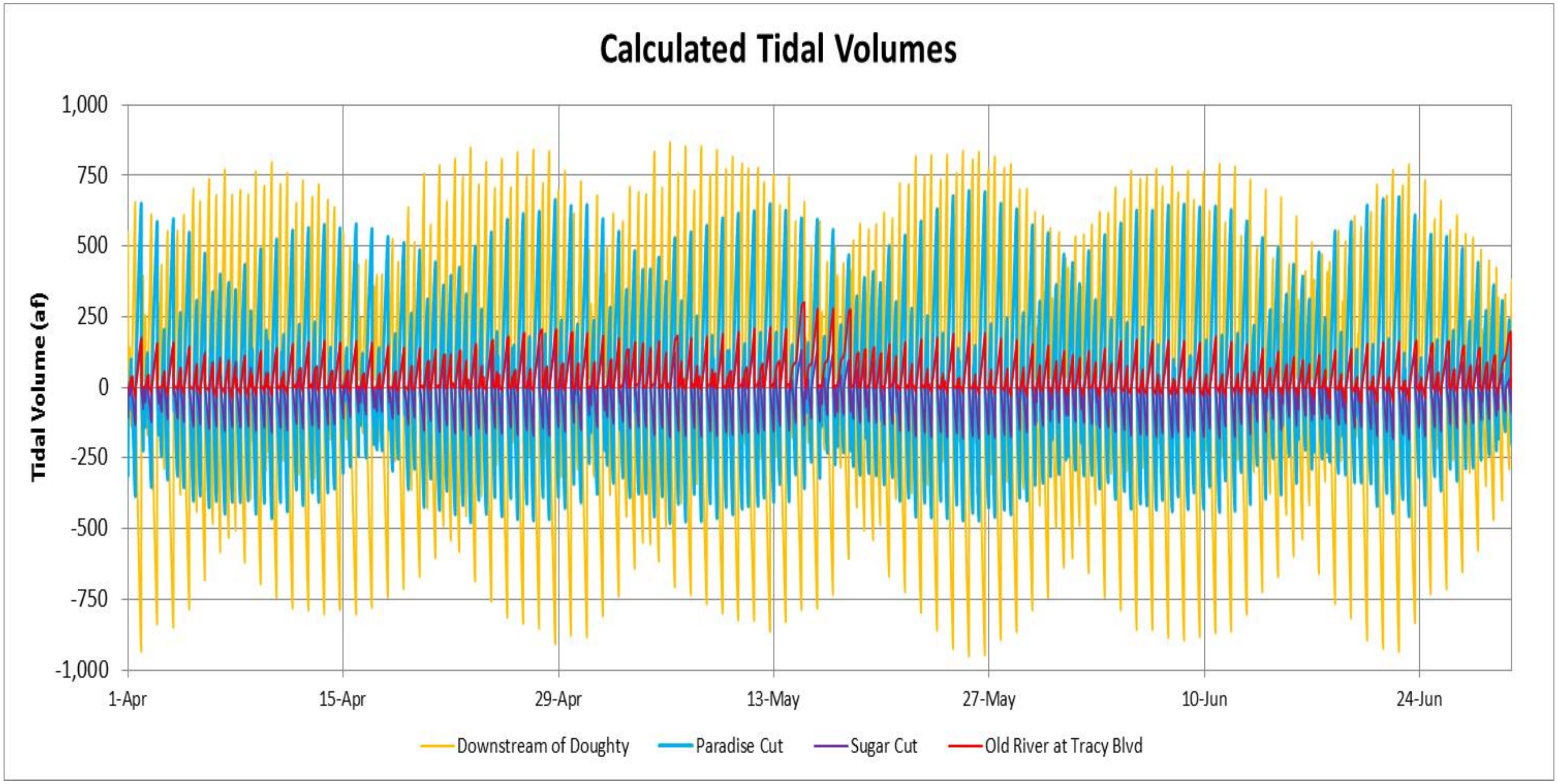
The measured tidal flow volumes in Grant Line Canal were reduced to about half after the barriers were installed with flap-gates in July. However, the tidal elevations at the west end of Grant Line Canal were nearly the same, so the calculated tidal flows were too high (using 750 acres of surface area). This suggests that the upstream surface area being filled and drained by tidal flow in Grant Line Canal was reduced by about half; a substantial portion of the tidal flow was blocked by the Grant Line Canal barrier, located upstream at Tracy Boulevard.



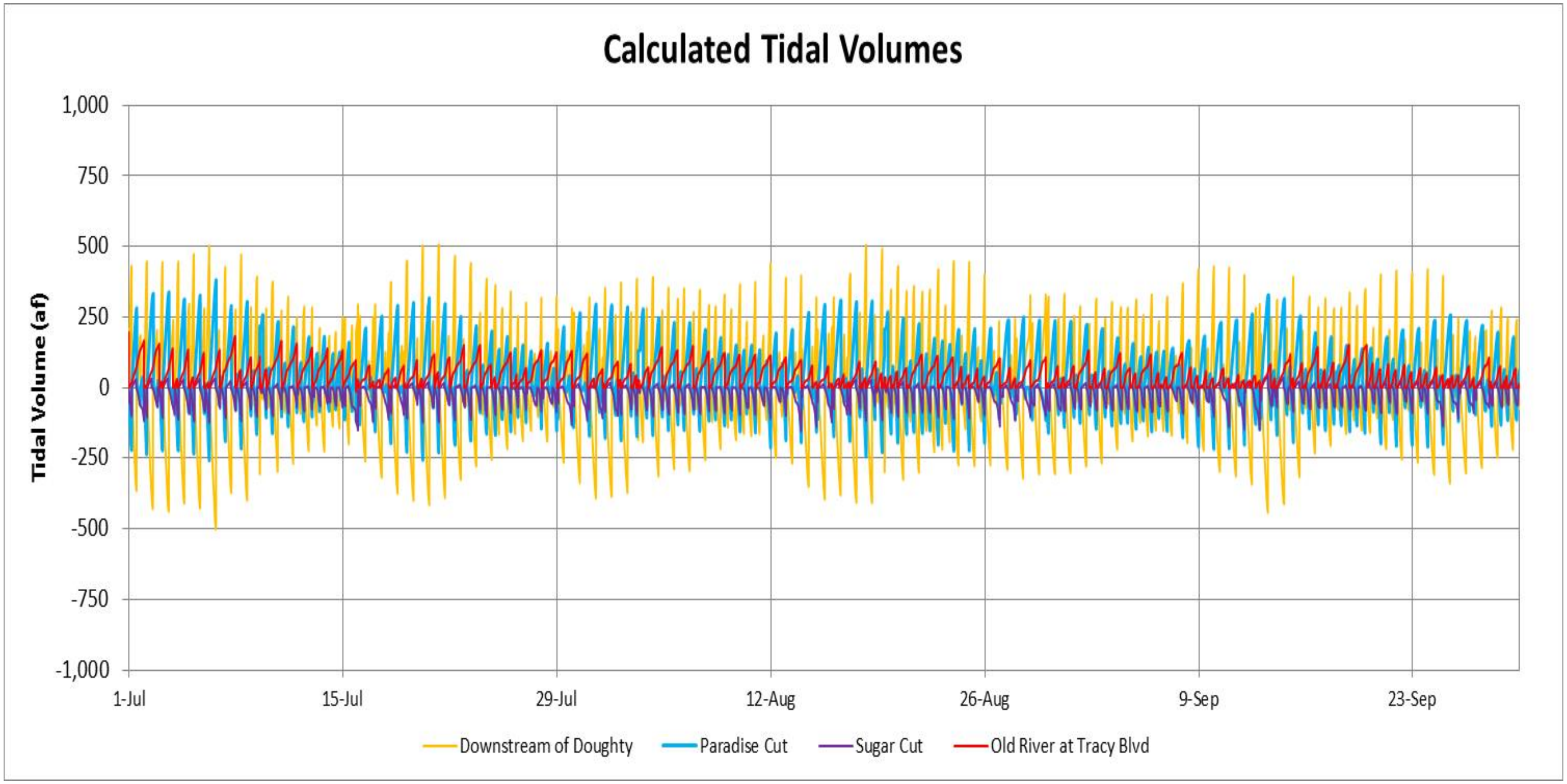
The calculated tidal flows in Grant Line Canal matched the measured tidal flows in November and December after the barrier was removed.



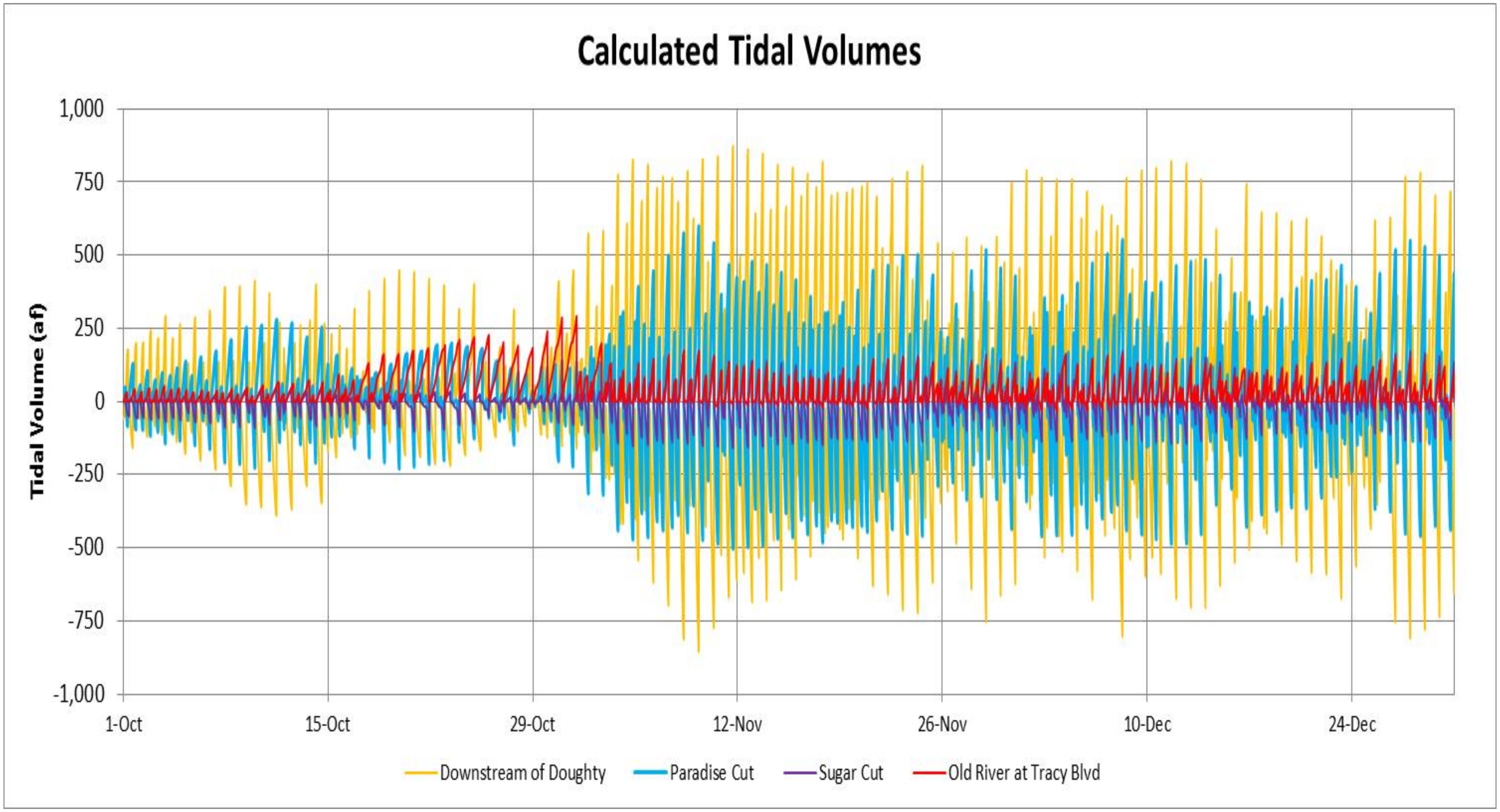
Tidal flow calculations for Old River at Doughty Cut, Paradise Cut, Sugar Cut, and Old River at Tracy Boulevard illustrate the movement of water from Paradise Cut and Sugar Cut during ebb tide (positive). Most of the ebb tide flow volumes from Paradise Cut and Sugar Cut move into Old River and upstream to Doughty Cut. However, a portion of the ebb tide volume that enters Old River at lower tide elevations flows downstream in Old River to 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.



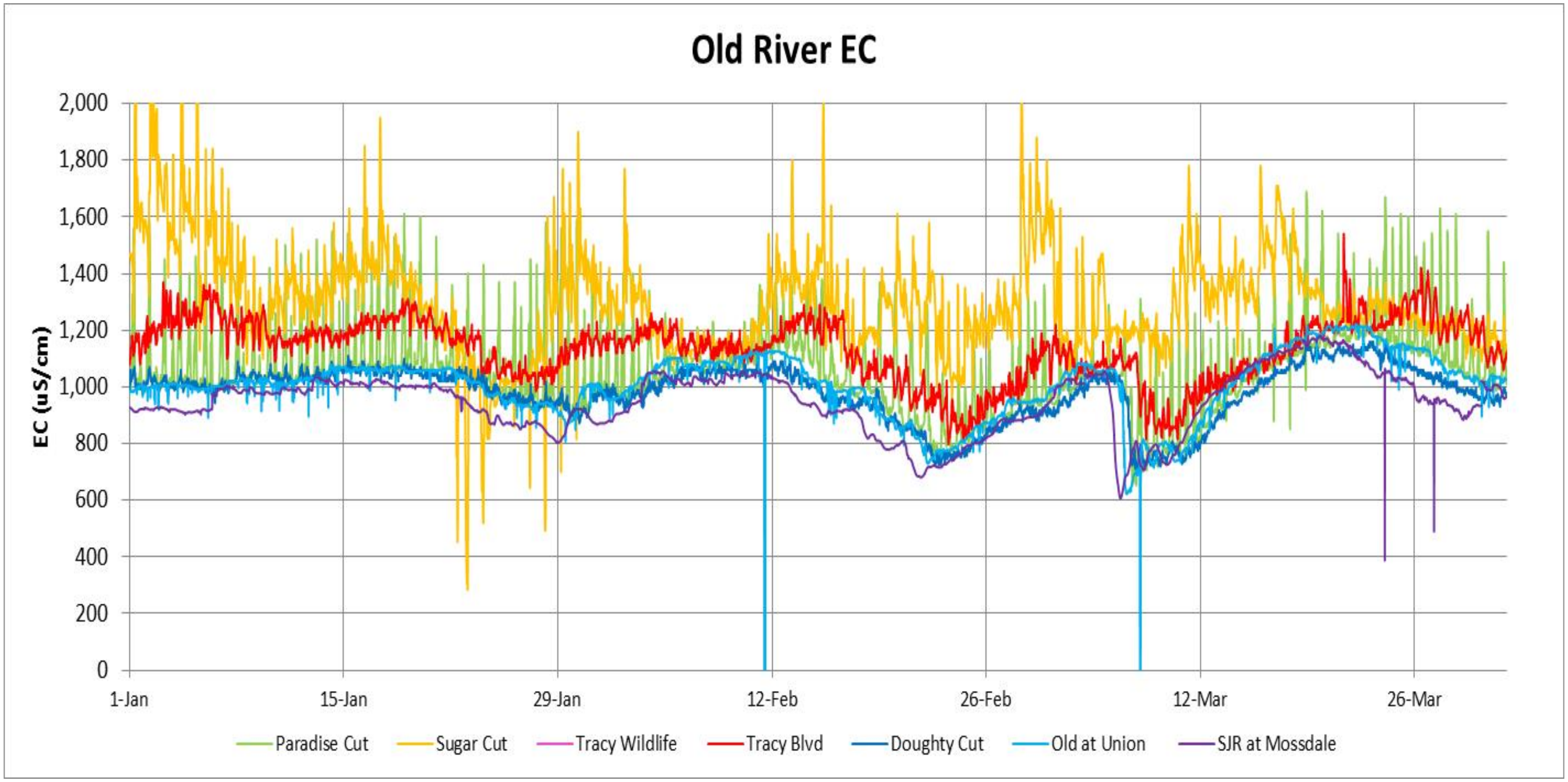
The calculated tidal flow volumes at Doughty Cut, Paradise Cut, Sugar Cut, and Old River at Tracy Boulevard for April-June were similar to the tidal flow volumes in January-March. Most of the ebb tide flow volumes from Paradise Cut and Sugar Cut move into Old River and upstream to Doughty Cut. However, a portion of the ebb tide volume that enters Old River at lower tide elevations flows downstream in Old River to 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.



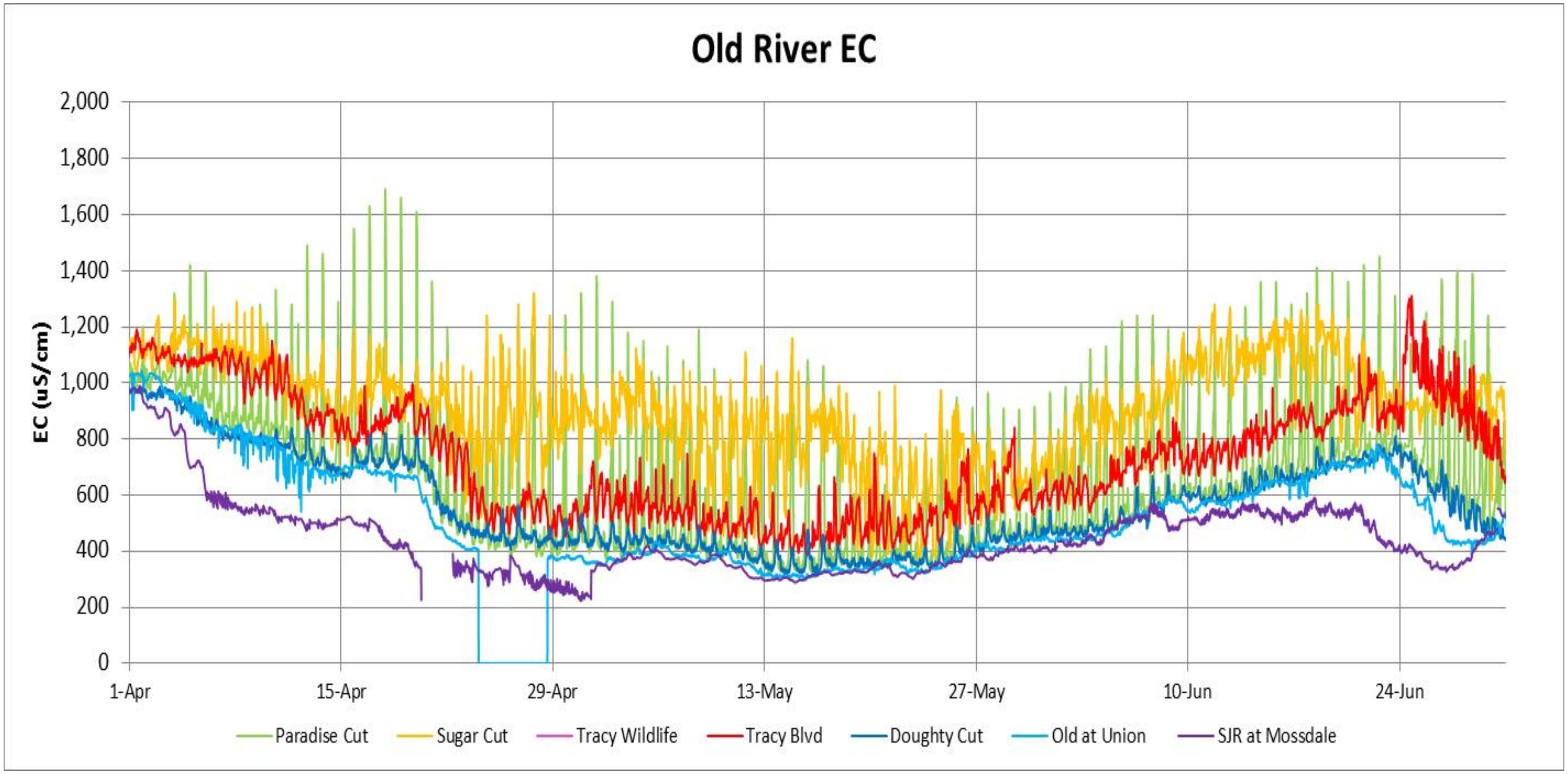
The calculated tidal flow volumes at Doughty Cut, Paradise Cut, Sugar Cut, and Old River at Tracy Boulevard for July-September were much less than the tidal flow volumes in January-June because the temporary barriers reduced the tidal flows upstream of the barriers. The details of the tidal flows in 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.



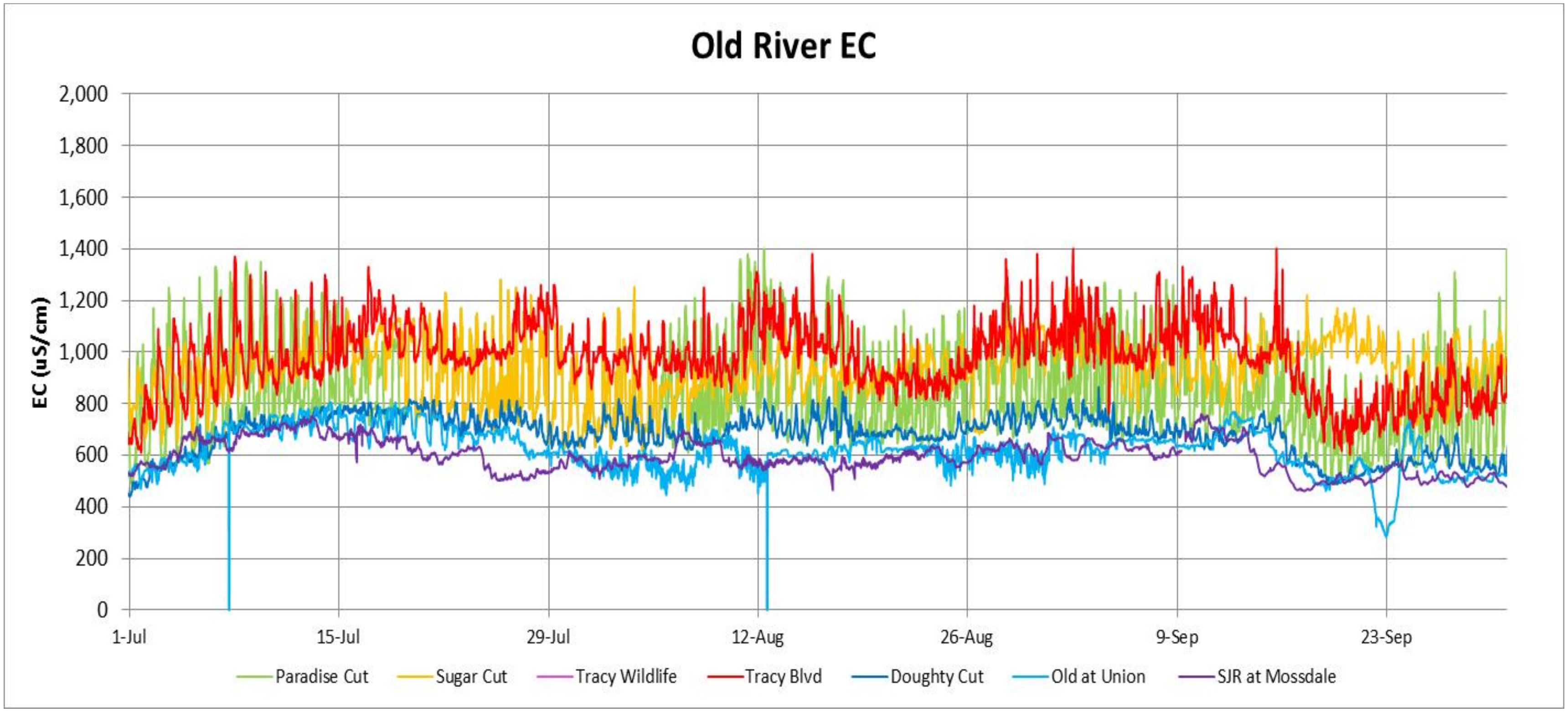
The calculated tidal flow volumes at Doughty Cut, Paradise Cut, Sugar Cut, and Old River at Tracy Boulevard for October were much less than the tidal flow volumes in November and December because the temporary barriers reduced the tidal flows upstream of the barriers. The details of the tidal flows in 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.



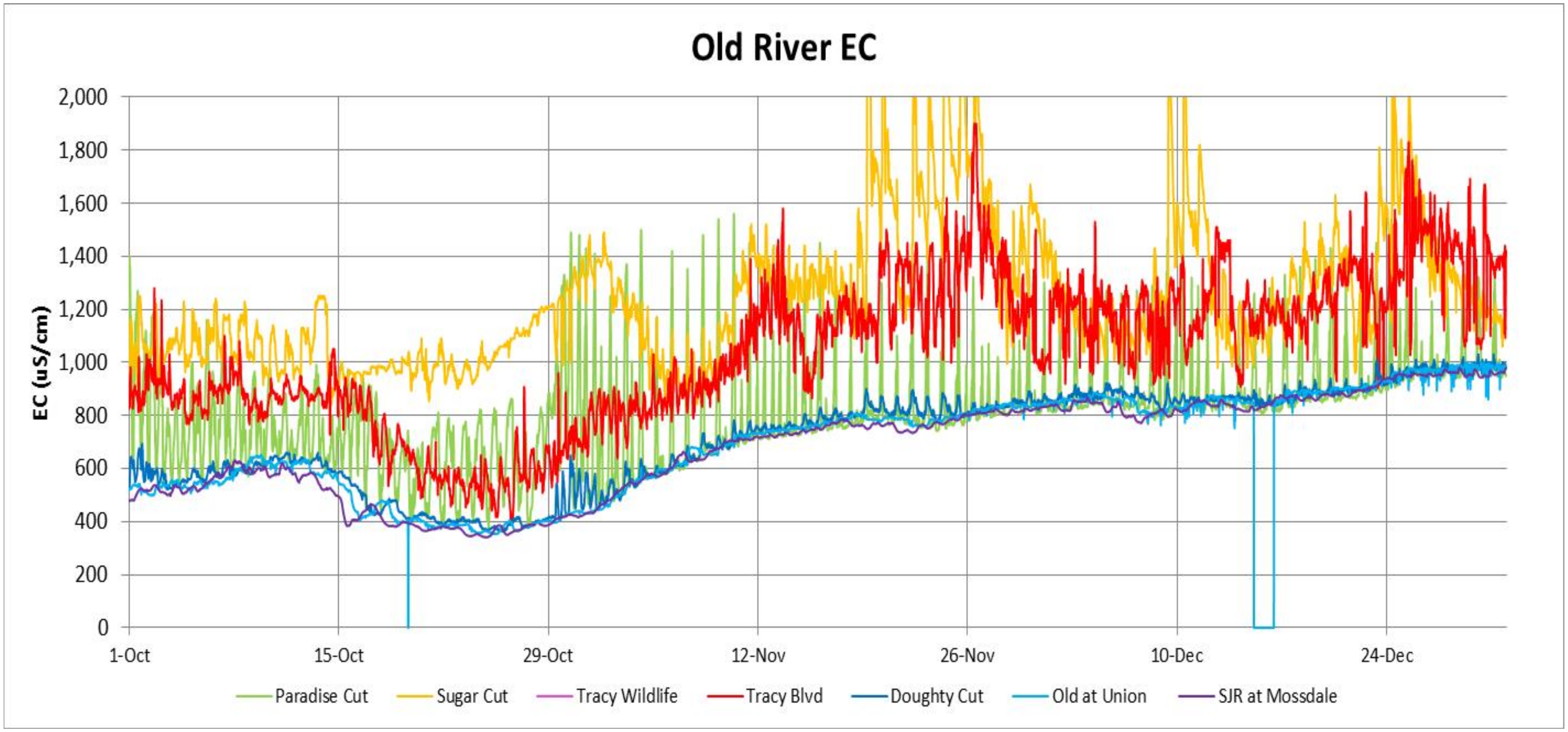
The Old River EC is generally controlled by the SJR EC (flow dilution). The SJR at Mossdale EC (purple line) and the Old at Union EC (light blue line) and the Doughty Cut EC (dark blue line) were similar in the months of January-March, ranging from 800 uS/cm to 1,200 uS/cm. The EC in Old River at Tracy Boulevard (red line) was 50-250 uS/cm higher than the EC at Mossdale, Union, and Doughty Cut, and had a tidal variation of 100-200 uS/cm. The Old at Tracy Boulevard EC was often 200-250 uS/cm greater than the upstream Old River EC. The Paradise Cut EC (green line) had a tidal variation of 400-600 uS/cm, with maximum EC of 1,400-1,600 uS/cm. The Sugar Cut EC was generally higher than the upstream Old River EC and often higher than the Tracy Boulevard EC, with a fluctuating tidal variation that was sometimes small (less than 100 uS/cm) and sometimes much higher(400-600 uS/cm).



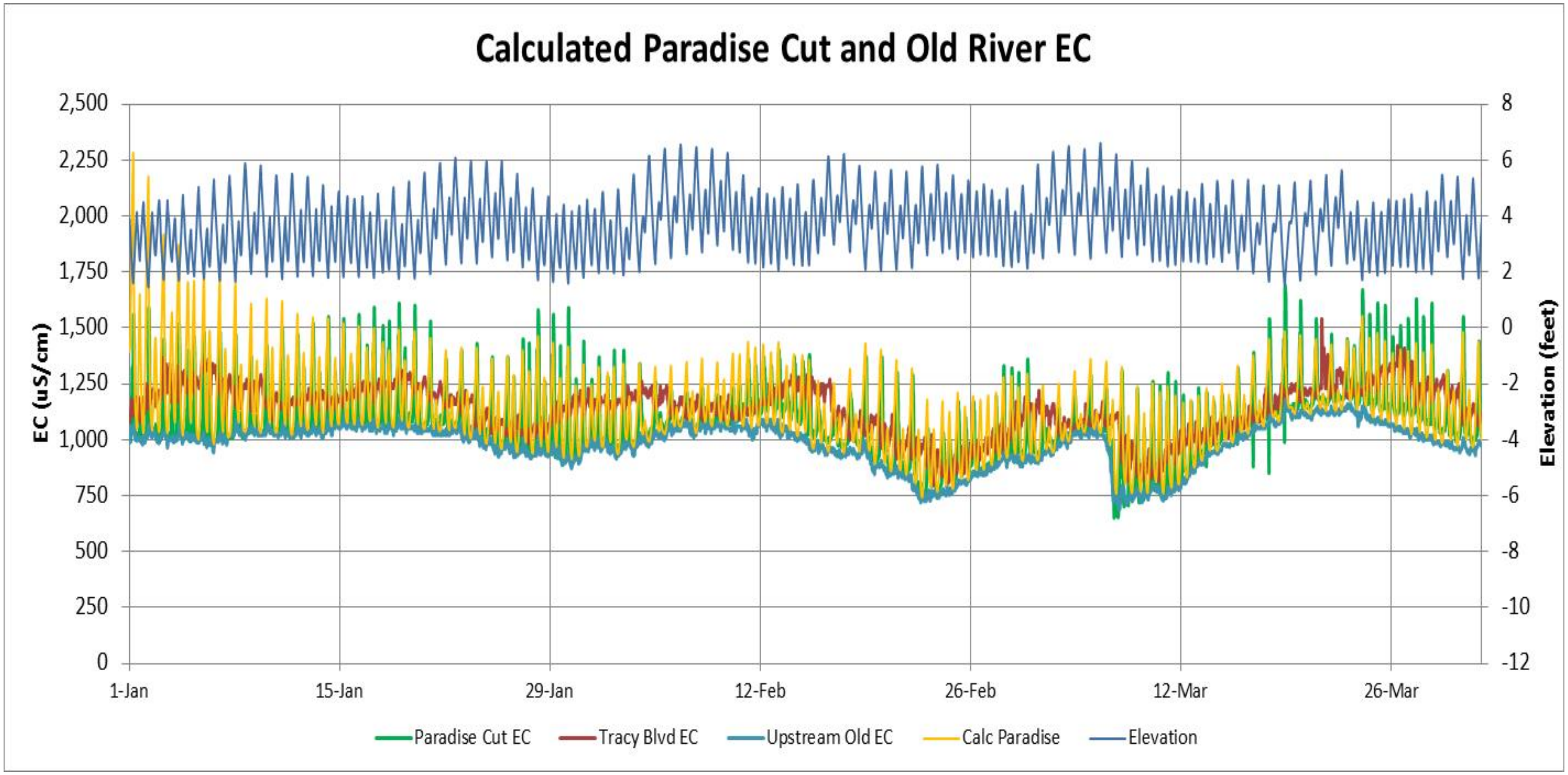
The Old River at Union EC was similar to the Doughty Cut EC and SJR at Mossdale EC in May (Mossdale EC data problems in April and June). The Old river EC was reduced to about 400 uS/cm during the pulse flow in late-April and May. The Old River at Tracy Boulevard EC was 100-200 uS/cm higher than the Union and Doughty EC. The Paradise Cut EC tidal variation was 400-800 uS/cm during the April-June period (similar to the EC variation in January-March), and the Sugar Cut EC was higher than the upstream Old River EC, and usually higher than the Old River at Tracy Boulevard EC (similar to the EC variation in January-March).



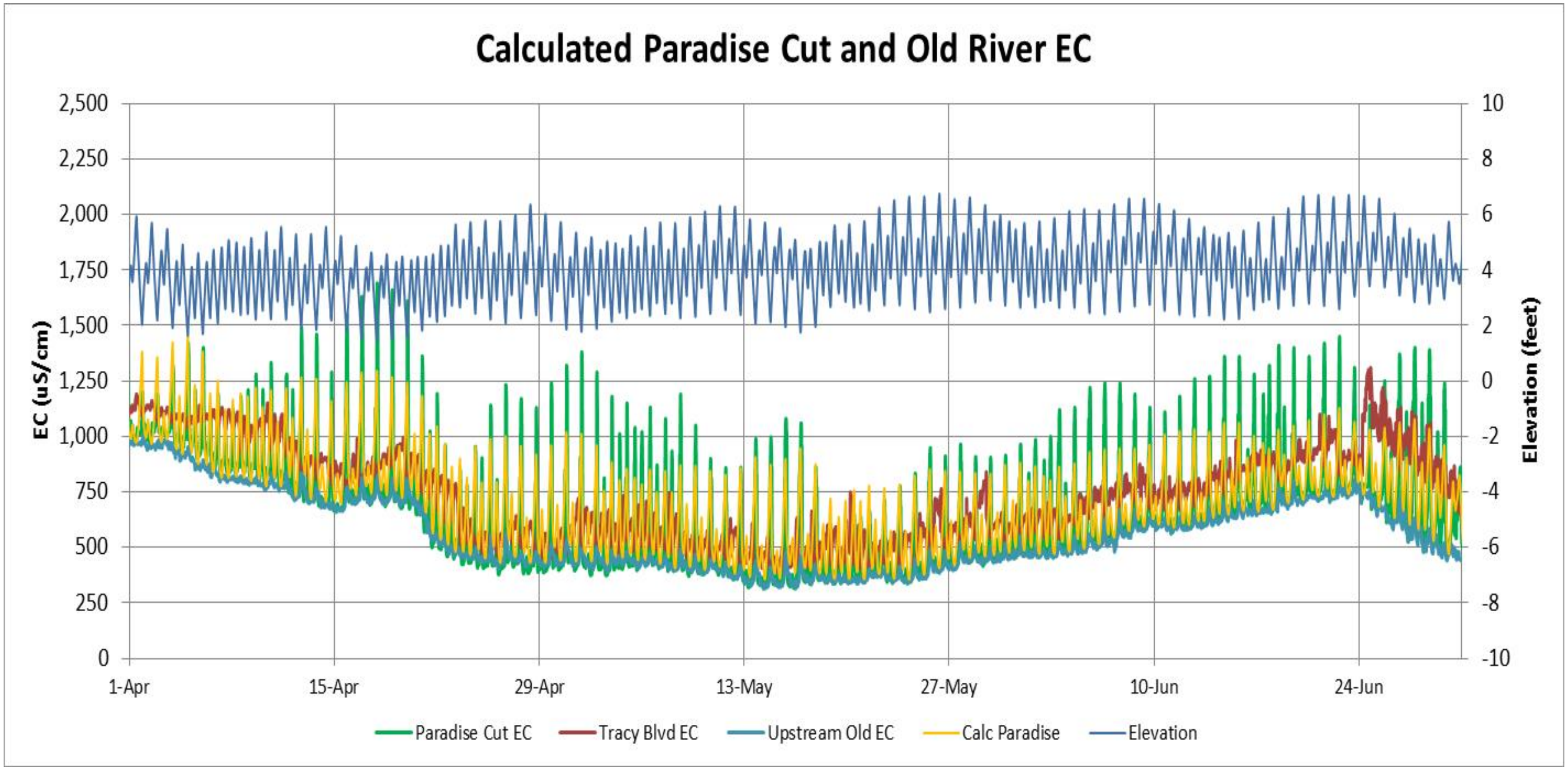
The SJR at Mossdale and Old River at Union EC and Doughty Cut were quite uniform at 600-800 uS/cm during the summer months. The tidal variations in Paradise Cut EC were 200-600 uS/cm during these summer months, suggesting that the (unidentified) salt source was relatively constant. The Old River at Tracy Boulevard EC was 200-400 higher than the Doughty Cut EC and the tidal variations were 50-200 uS/cm, suggesting that the salinity in Old River was higher upstream and lower downstream of Tracy Boulevard. The EC in Sugar Cut was higher than the EC in Old River, and sometimes remained higher throughout the tidal cycle, but sometimes the tidal variation in Sugar Cut was similar to the tidal variation in Paradise Cut, with the lowest EC similar to the upstream Old River EC (tidal flushing). The Paradise Cut EC station is close to the mouth (near Old River) and measures Old River EC during flood tides. The Sugar Cut EC measurement station is upstream of Tom Paine Slough. The lower minimum EC in Sugar Cut during July may have been caused by the larger diversions into Tom Paine Slough.



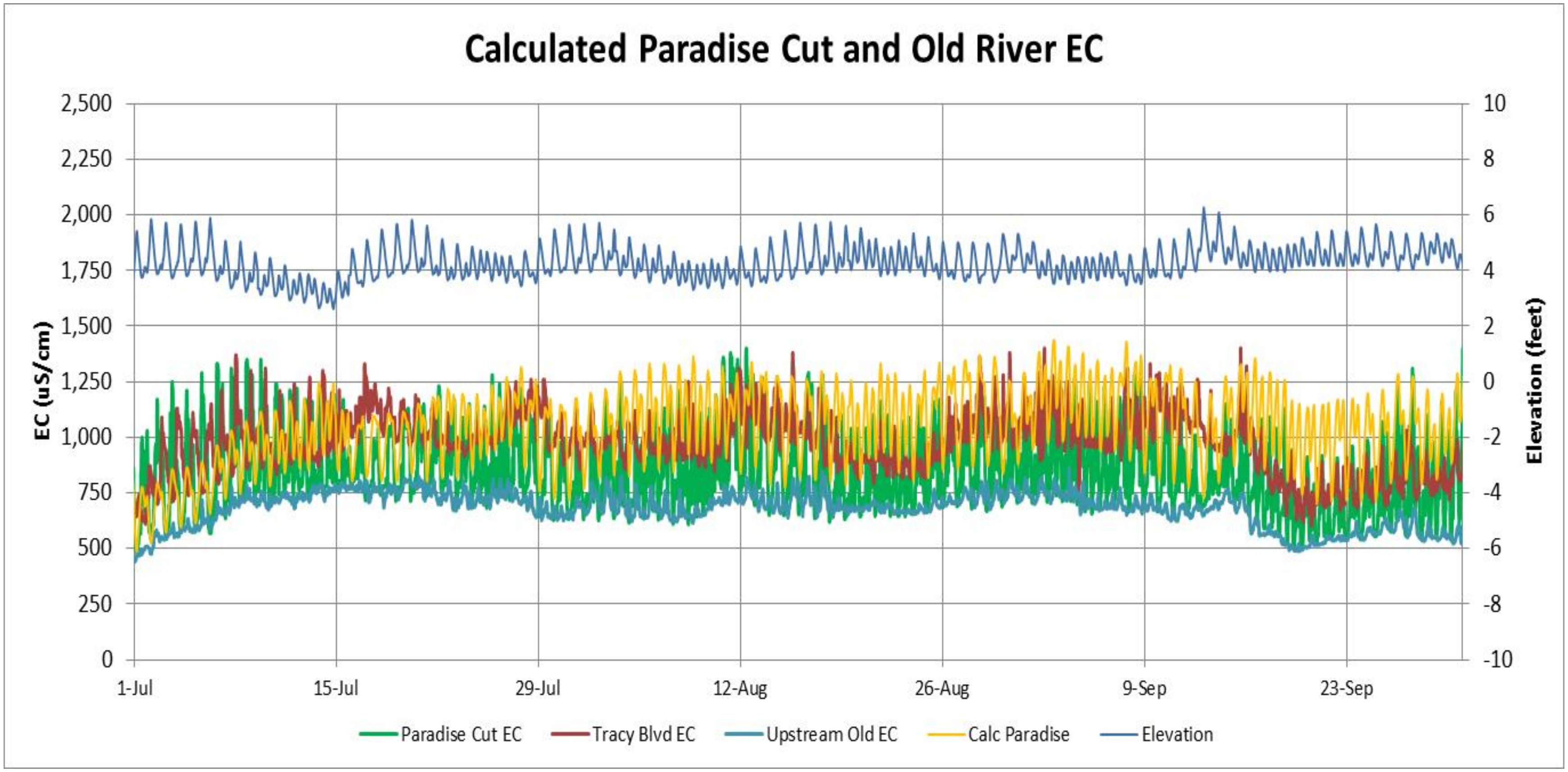
The SJR at Mossdale and Old River at Union and Doughty Cut EC were reduced to about 400 uS/cm by the pulse flow at the end of October (for adult Chinook salmon attraction) and then increased to about 1,000 uS/cm at the end of December. The Old River at Tracy Boulevard EC was 200-400 uS/cm higher than the Old River at Union or Doughty Cut EC. The tidal variations of Paradise Cut EC and of Sugar Cut EC remained similar to the variations seen in the January-June period without temporary barriers. The tidal flushing of Paradise Cut EC (with Old River water) was more uniform, while the tidal flushing of Sugar Cut EC was greatly reduced (Sugar Cut EC remained 200-1,000 uS/cn higher than upstream Old River EC. Additional EC stations located upstream in Paradise Cut and near the mouth of Sugar Cut may provide additional information about the salt sources and tidal flushing of these tidal sloughs.



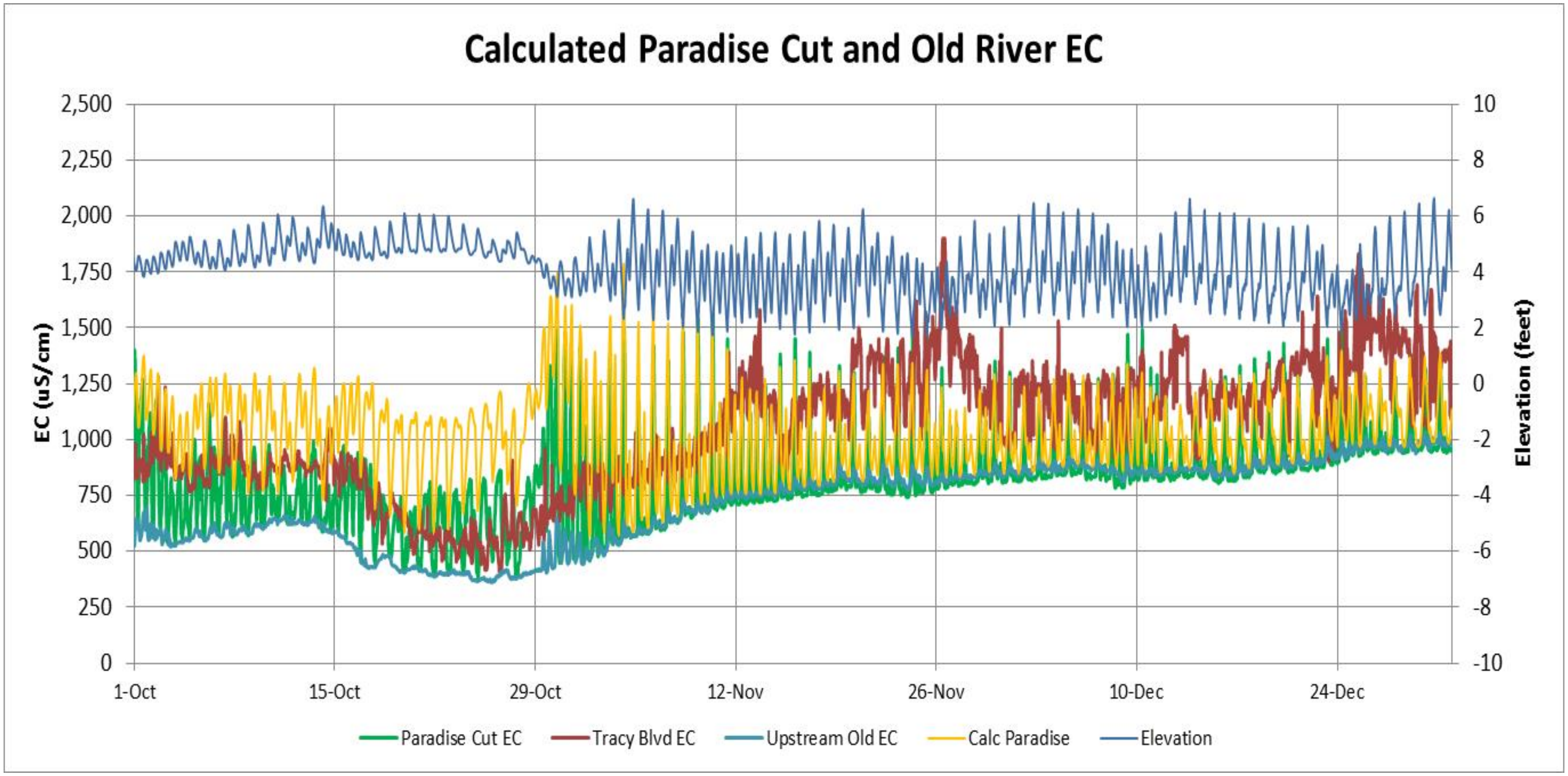
The Paradise Cut EC was calculated from the measured tidal elevations (blue line) and assumed geometry segments for Paradise Cut. The salt source was assumed to enter at the upstream end with an EC of 3,000 cfs and a constant flow of 10 cfs (52.5 tons/day). Paradise Cut discharged water and salt to Old River during ebb tides and filled with Old River water and salt during flood tides. The calculated fluctuations of EC through this period without temporary barriers was generally 500-1,000 uS/cm, and generally matched the measured EC variations. The measured and calculated Paradise Cut EC suggests that the salt source was relatively constant.



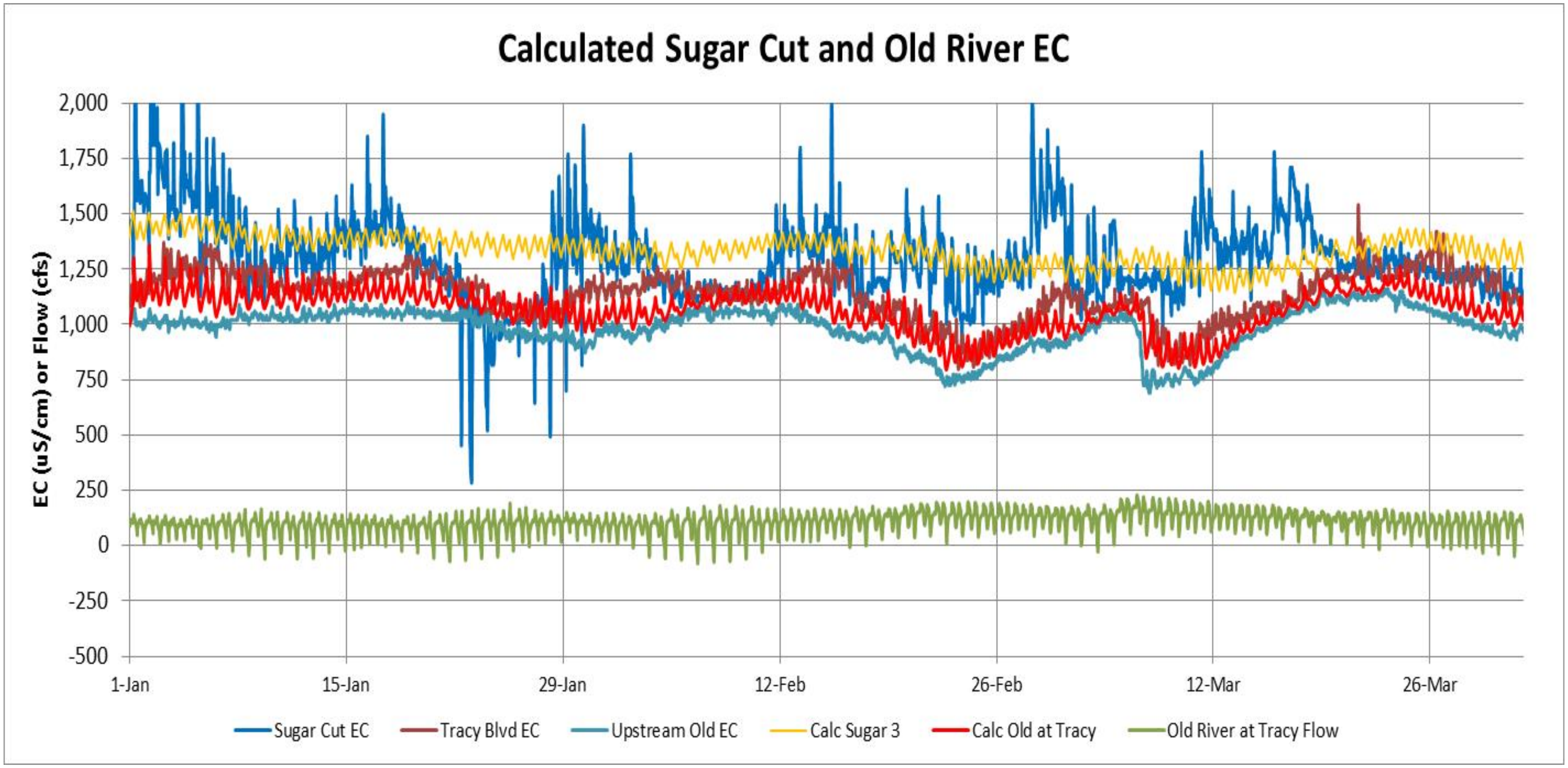
Paradise Cut was filled with Old River water during flood tide periods and the minimum Paradise Cut EC was therefore similar to the upstream Old River EC. The maximum Paradise Cut EC was controlled by the calculated tidal flushing of the assumed salt source; the maximum EC was greatest during neap tide 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.



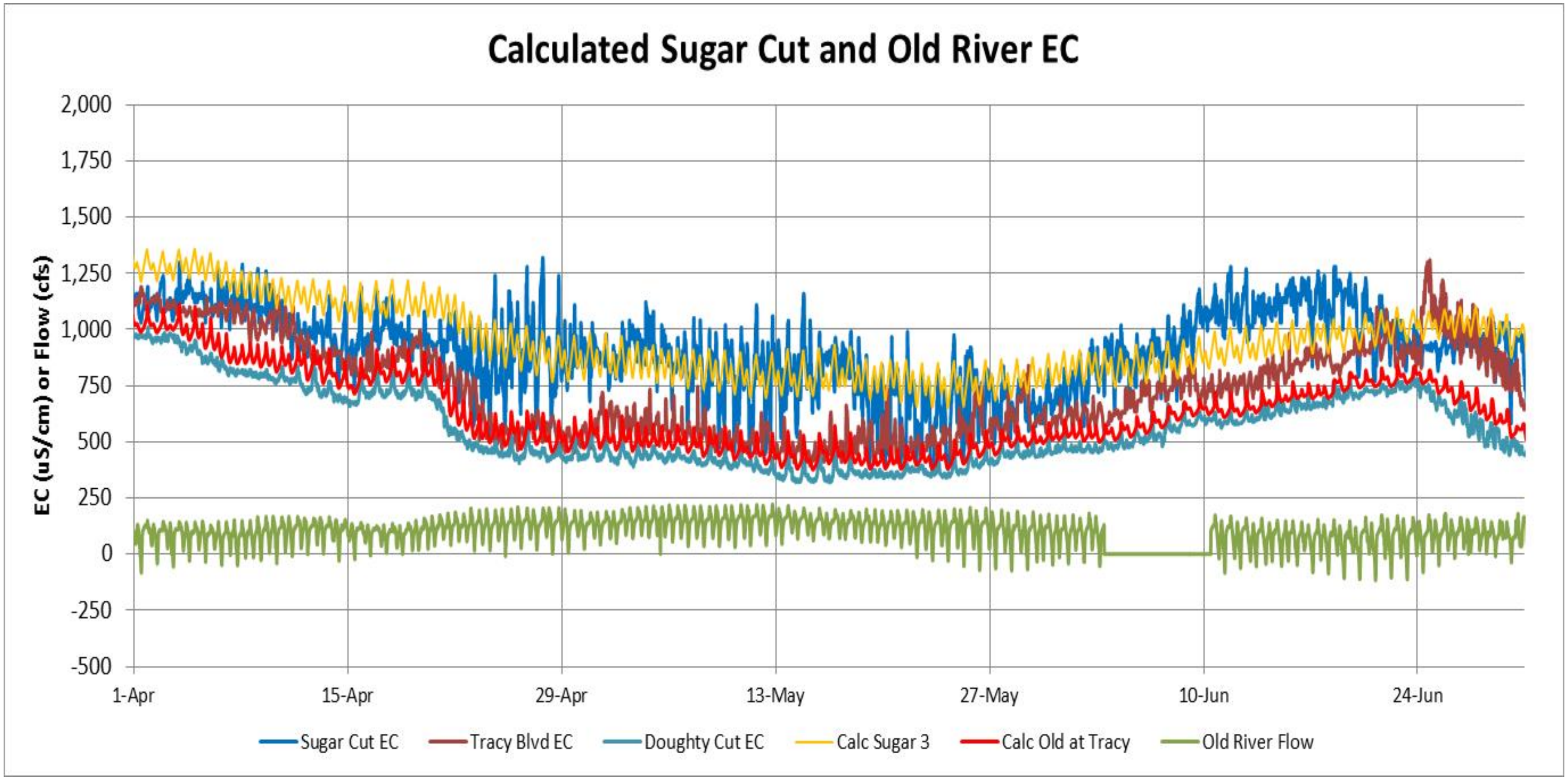
The tidal elevation variations were very small during the summer period when the Old River, Grant Line Canal and Middle River temporary barriers were installed. During this period the calculated EC variations in Paradise Cut of 250-500 uS/cm were similar to the measured EC variations, but the calculated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



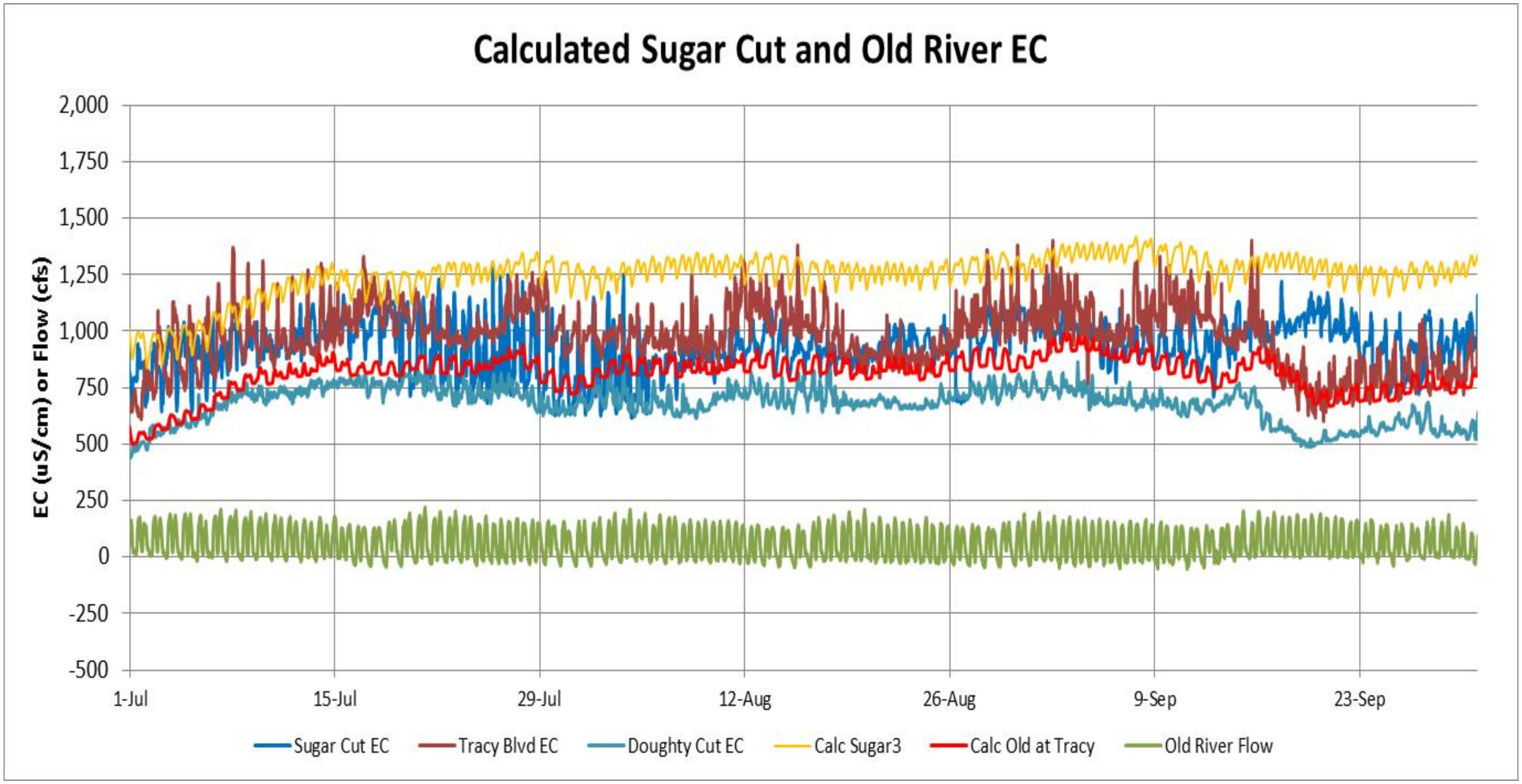
The transition back to full tidal variations and larger tidal variations in the measured Paradise Cut EC were generally matched with the calculated Paradise Cut EC. The assumed constant source of salt at the upper end of Paradise Cut appears to be confirmed by the general match with the measured EC throughout the year. The relatively simple tidal slough flushing calculations appear to provide a generally 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).



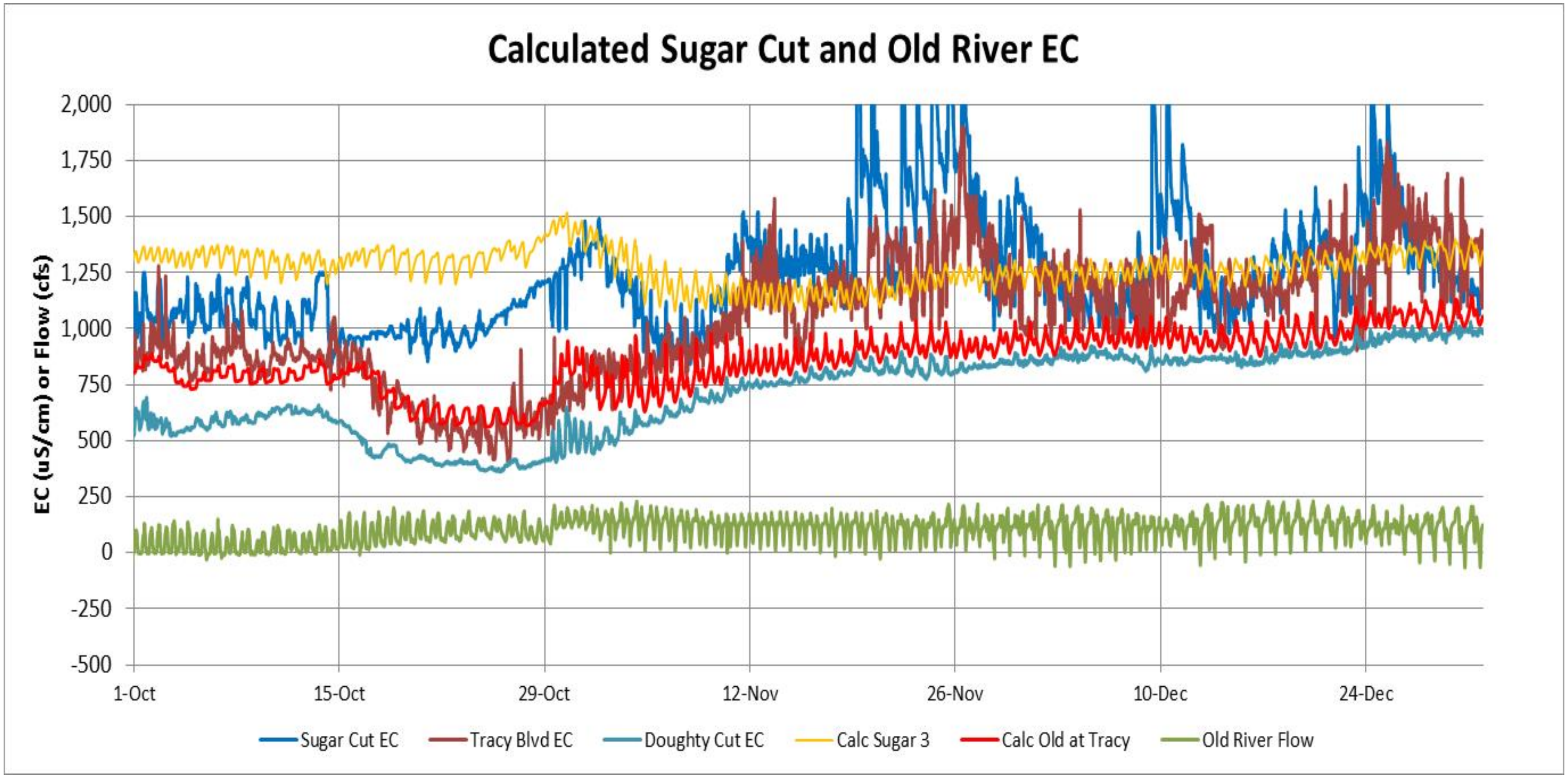
The measured Sugar Cut EC (dark blue) fluctuations were more variable than the Paradise Cut EC fluctuations, and the minimum Sugar Cut EC was usually higher than the upstream Old River EC. This was likely caused by the EC measurements being further upstream (less flood tide flushing) of the Sugar Cut EC. The assumed Sugar Cut salt source had an EC of 2,000 uS/cm with a flow of 10 cfs (35 tons/day). The calculated Sugar Cut EC (gold line) had less tidal variation than the measured EC, and remained higher than the Old River EC. The Old River at Tracy Boulevard tidal flows were not measured in 2009; Old River at Tracy Boulevard tidal flows (green line) were estimated as 10% of the head of Old River tidal flow. The calculated effects of the ebb tide flows 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).



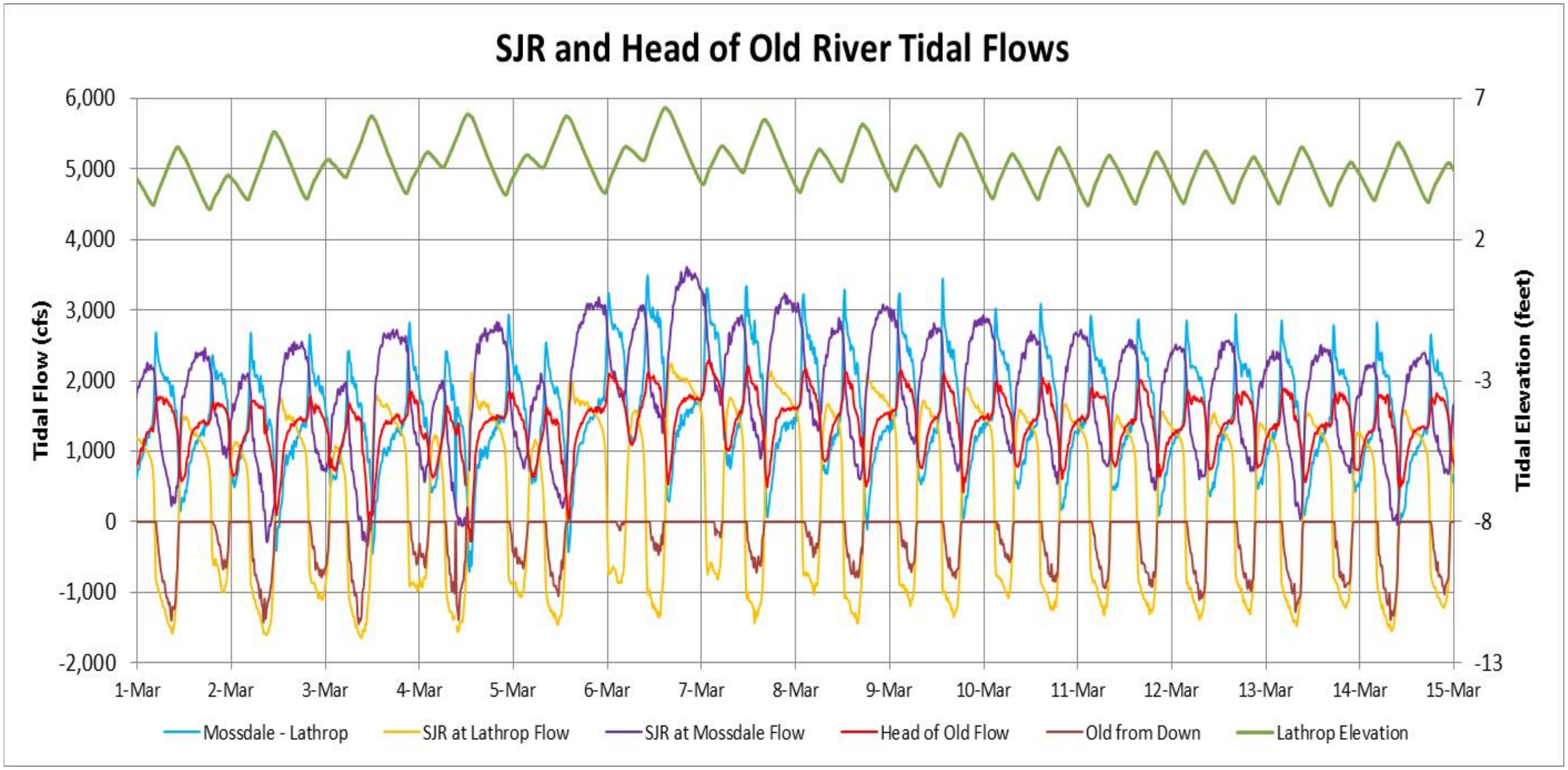
The upstream Old River EC decreased from about 1,000 uS/cm to less than 500 uS/cm with the higher flows in May. The calculated tidal variation in the Sugar Cut EC was very uniform (about 100-150 uS/cm) during the April-June period, with an average EC that remained 250-500 uS/cm higher than the Old River EC. The calculated Old River at Tracy Boulevard EC (red line) was smaller than the measured EC at Tracy Boulevard (brown line), suggesting that the estimated flow at Tracy Boulevard (10% of head of Old River) may have been too high.



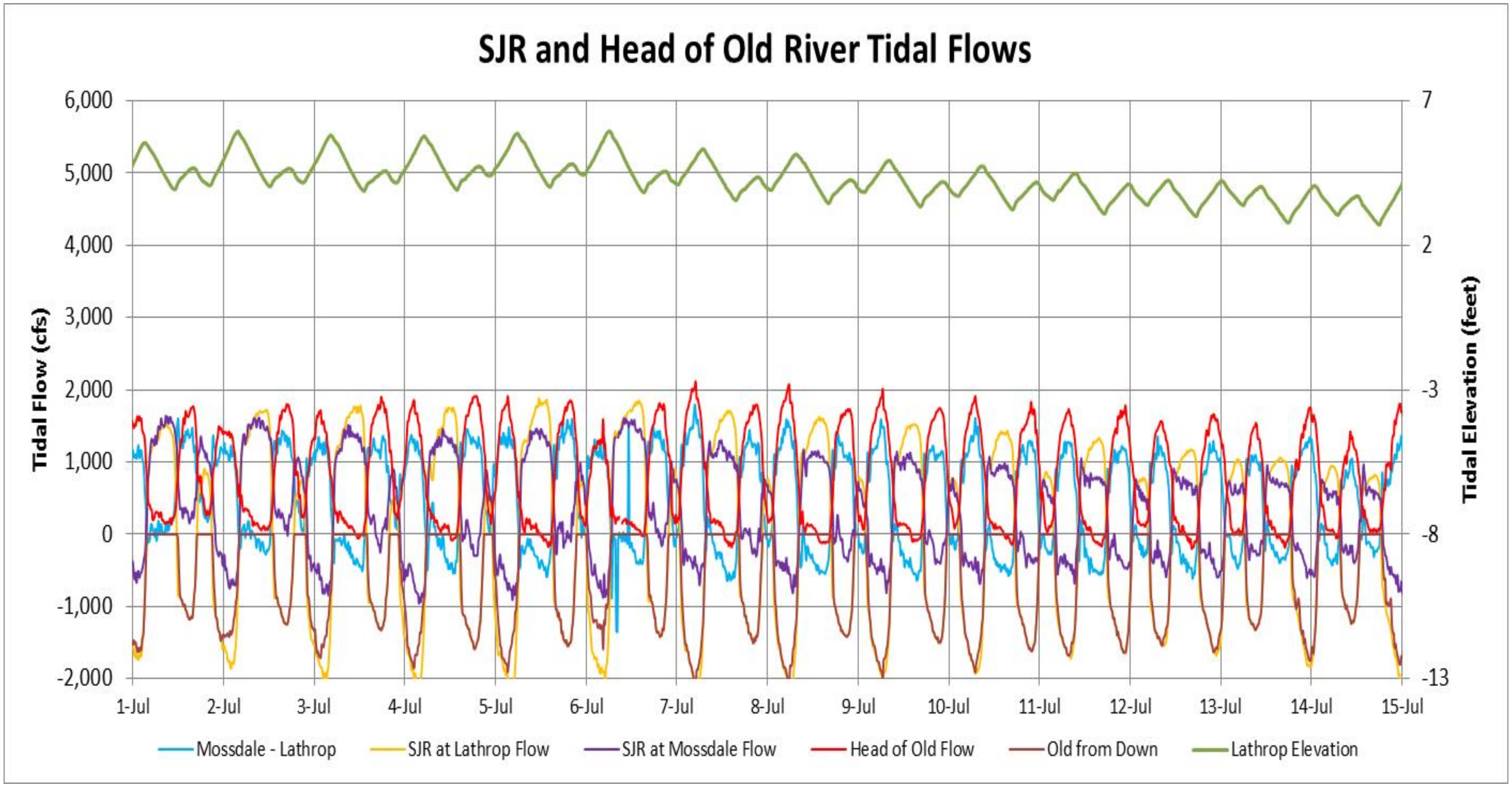
The calculated Sugar Cut EC was about 1,250 uS/cm, higher than the measured Sugar Cut EC of about 1,000 uS/cm during the July-September period when the temporary barriers were installed. However, the calculated Old River at Tracy Boulevard EC was less than the measured EC at Tracy Boulevard, suggesting that the estimated flows were too high.



The calculated Sugar Cut EC in October was too high (like July-September), but the calculated Sugar Cut EC in November-December matched the average measured EC but did not match the higher measured EC during neap tide periods (reduced tidal elevations). The calculated Old River at Tracy Boulevard EC was not as great as the measured EC at Tracy Boulevard, suggesting that the estimated Old River at Tracy Flow was too high. The calculations demonstrate 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. Various alternatives for reducing the Old River at Tracy Boulevard are being investigated.



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 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 1,000-2,000 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 Mossdale flow plus the upstream flow (negative) from Lathrop (brown line). However, there was some unresolved differences between the Mossdale minus Lathrop flow (bright blue line) and the measured Old River flow (red line).



During July 2009 the SJR flow at Mossdale (purple line) was about 250 cfs (extremely low), and the tidal flow variation was 1,000-2,000 cfs with some periods of reverse upstream flow of -250 to -1,000 cfs. 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 greater than the Mossdale flow minus the Lathrop flow (bright blue line), suggesting that the Mossdale tidal flow was too low. 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.