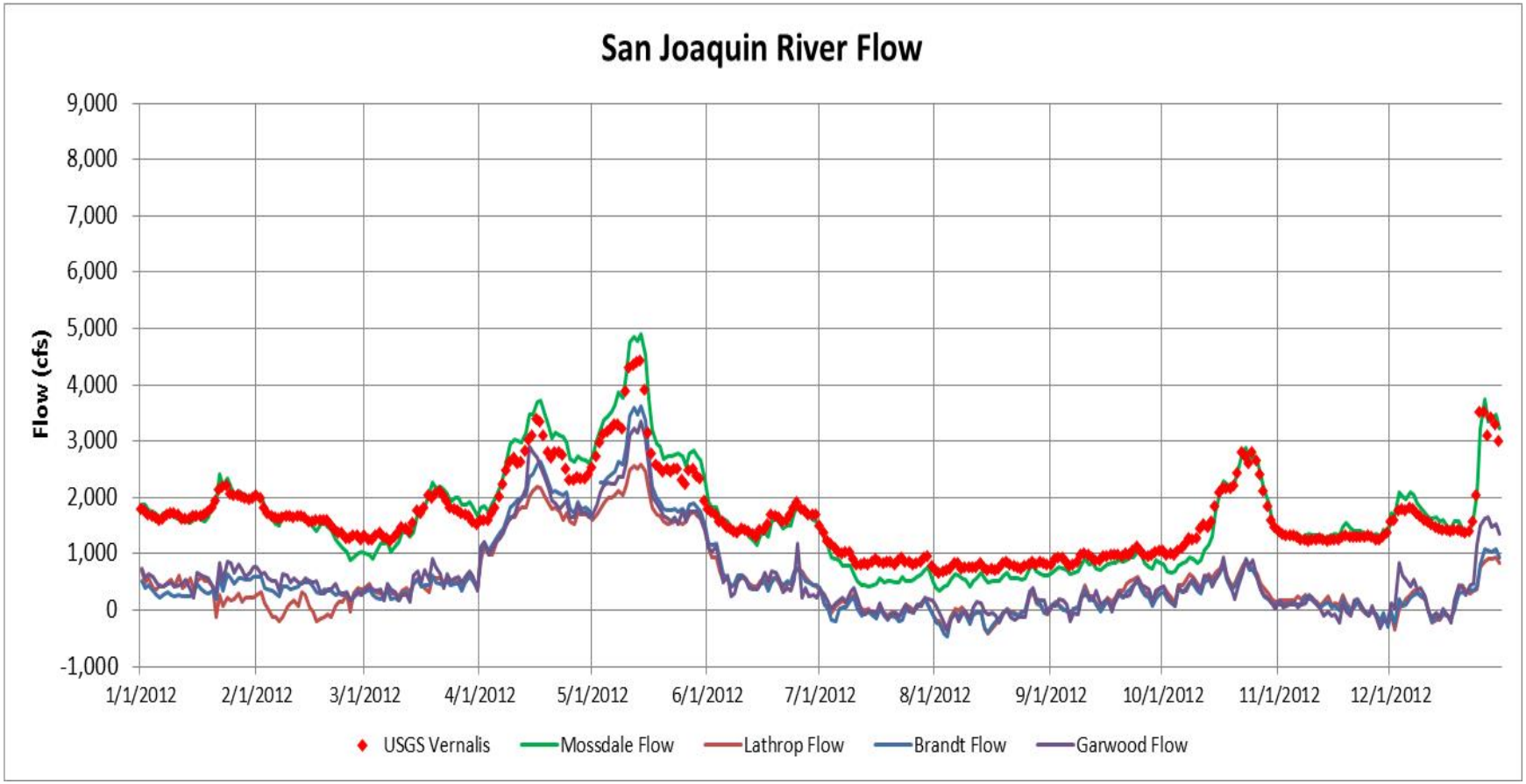
South Delta Tidal Data Atlas Graphs for Calendar Year 2012

This South Delta Data Atlas for 2012 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 2012. 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.

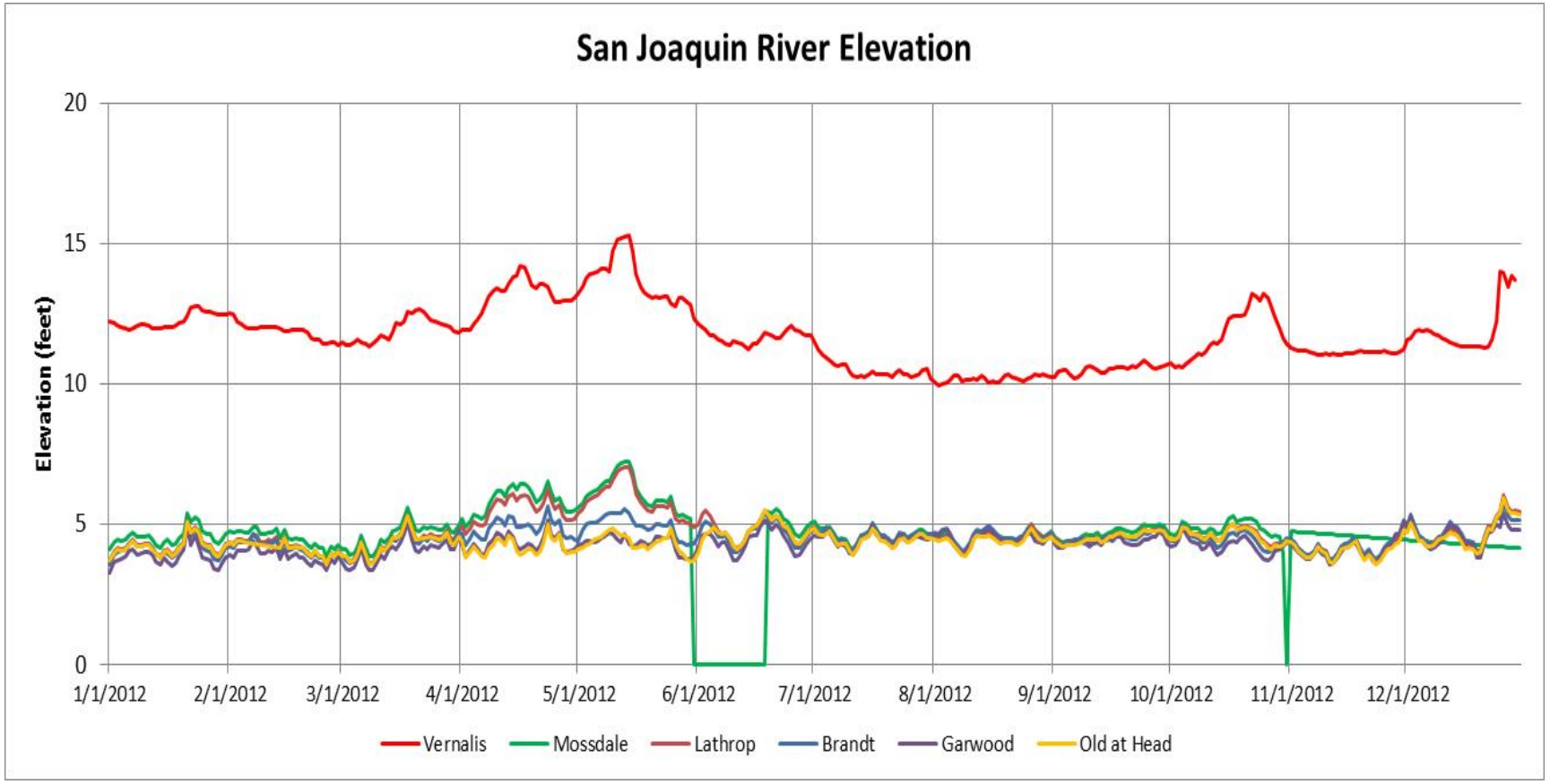
South Delta Data Atlas excel files have been compiled to support the review and summary of data patterns and relationship for 2009-2013. This year (2012) included relatively low SJR flows (2,000-3,000 cfs) and low exports (1,000-3,000 cfs) in the January-June period with low SJR flows (1,000-2,000 cfs) and high exports (6,000-10,000 cfs) in the summer and fall. A temporary barrier at the head of Old River was installed with open culverts in April and May, so the flow diversions from SJR to Old River of about 500 cfs were observed.

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 2012. 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.

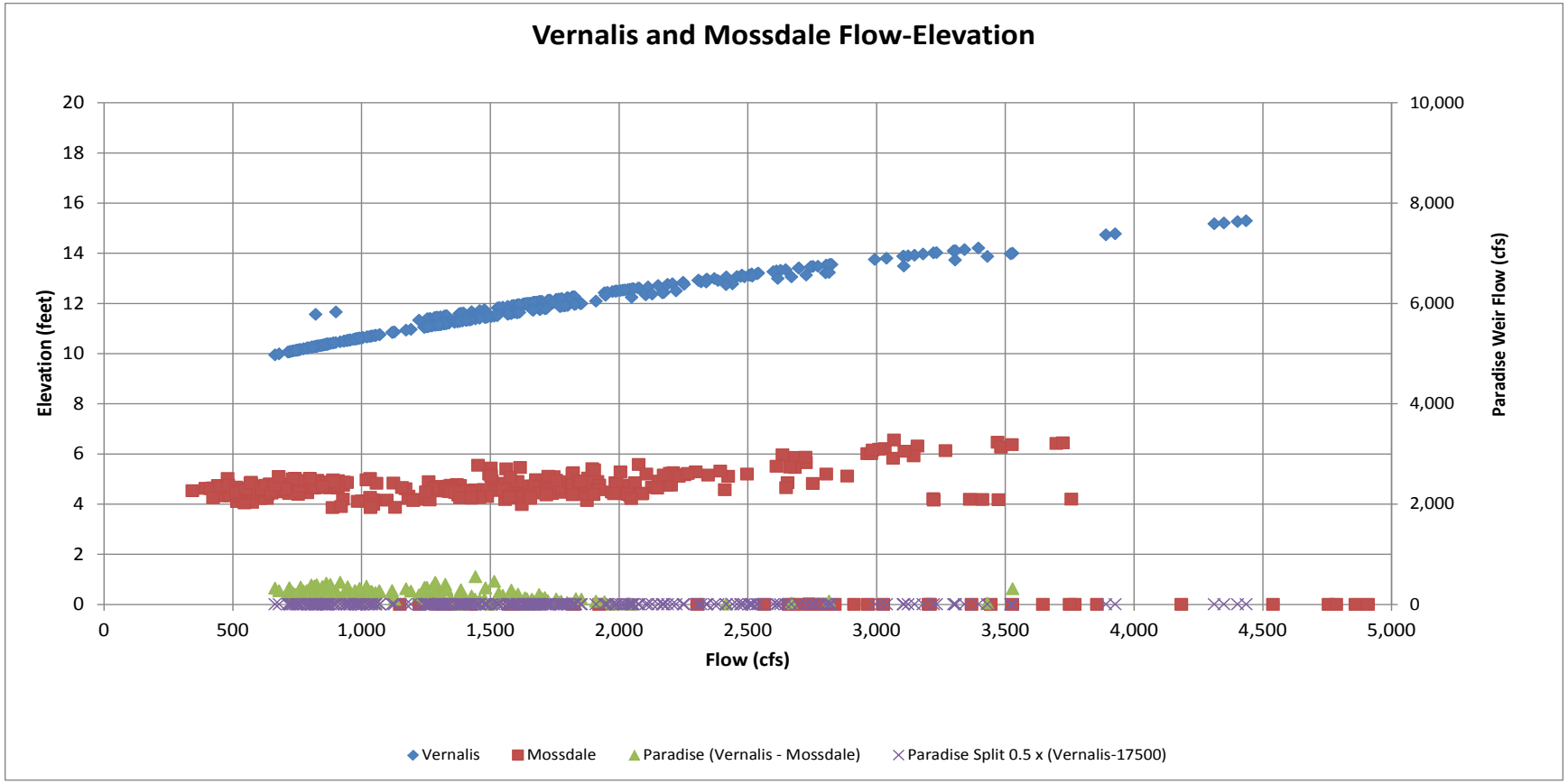
The basic flow splits in the south Delta are evaluated, and the effects of the temporary barriers on tidal elevations, tidal flows, and net downstream flows are described in the graphs. The tidal elevations and tidal flows in Old River at Tracy Boulevard provide the framework for evaluating the effects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



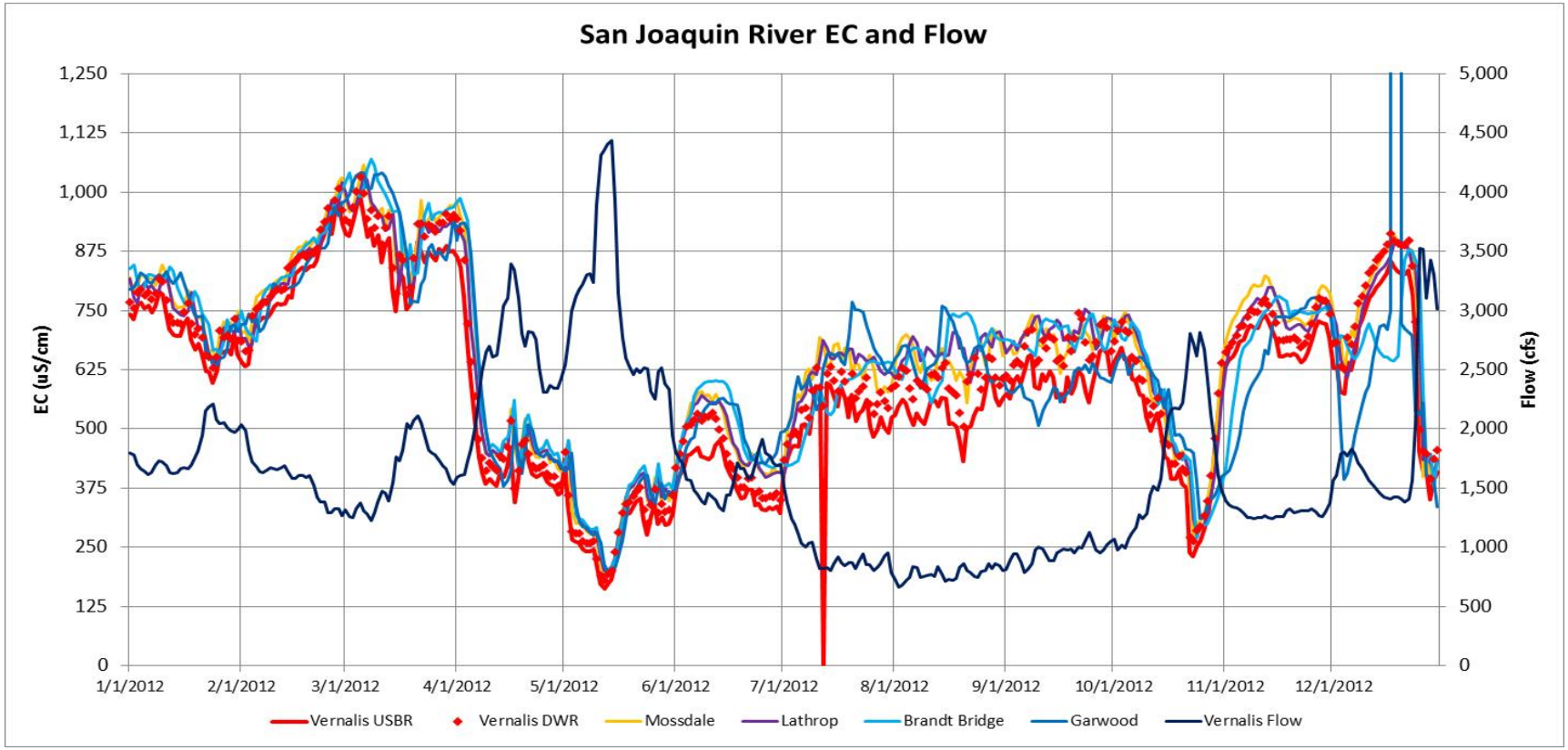
San Joaquin River flow in 2012 was very low, less than 2,000 cfs in January-March and slightly increased to about 3,000 cfs in April and May. The SJR flow was about 1,000 cfs from July through mid-October, when a pulse flow of about 2,500 cfs for fish attraction was released from the tributary reservoirs (Stanislaus, Tuolumne, and Merced Rivers). 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 was negative (i.e., upstream) in July-September and in November. A temporary barrier at the head of Old River was installed in April and May; the diversions to Old River were limited to about 500 cfs (through eight 4-feet diameter culverts) and most of the SJR flow remained in SJR at Lathrop, Brandt and Garwood.



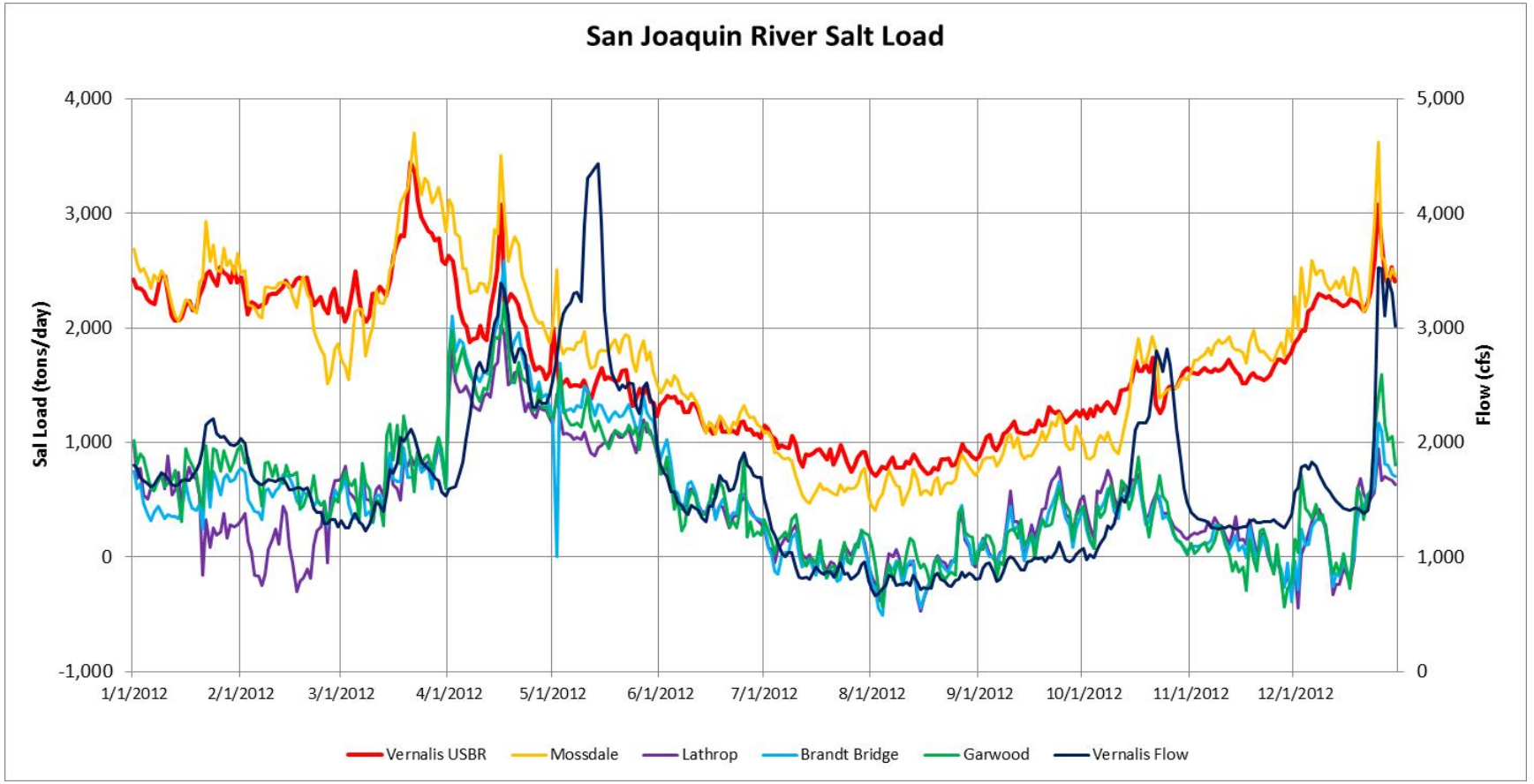
Only during April and May of 2012 were the SJR elevations at Mossdale increased slightly. Because the head of Old River barrier was installed during this same period, the effects of higher flow and the temporary head of Old River barrier on SJR elevations cannot be easily separated. Elevations at Mossdale, Lathrop, Brandt, and Garwood indicate a slight elevation gradient (slope) only when flows are greater than 2,500 cfs at Vernalis (elevation of greater than 12.5 feet). Average tidal elevations in the SJR downstream of Mossdale were about 4 to 5 feet throughout the year.



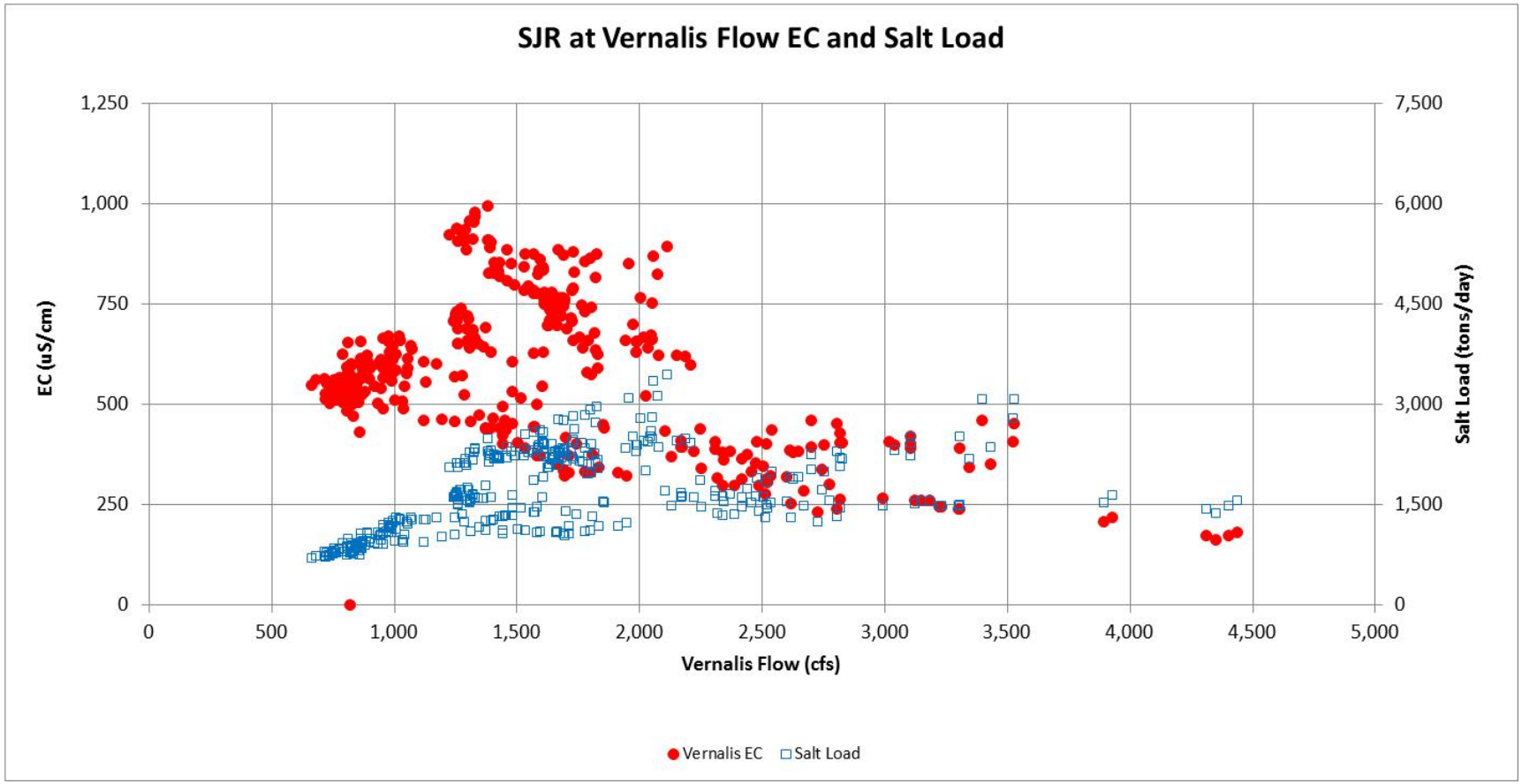
The flow-elevation relationships (rating curves) at Vernalis and Mossdale are compared. The rating curve at Mossdale indicates that the river elevations are increased (above the tidal average of 5 feet) when flows are greater than 2,000. The rating curve at Vernalis is checked periodically (generally every 6-8 weeks) and small shifts in the elevation-flow curve are applied throughout the year. The elevation at Vernalis increases from about 10 feet at a flow of 750 cfs to about 14 feet at a flow of 3,250 cfs; the elevation increases by 1.6 feet for each 1,000 cfs of increased flow at this low end of the rating curve.



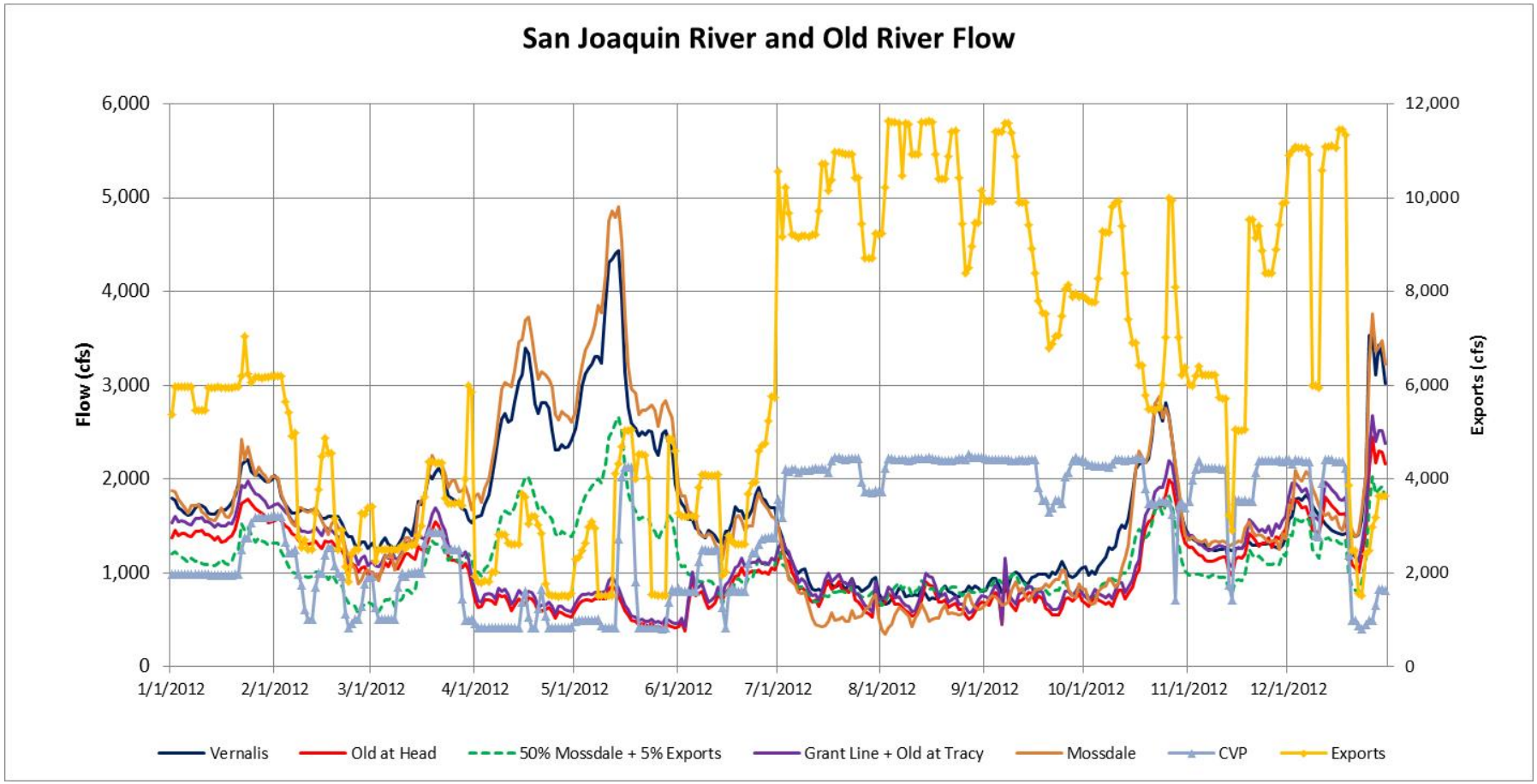
The SJR salinity (EC) at Vernalis is controlled by the combination of the salt load entering the SJR from high salinity groundwater seepage, agricultural drainage (e.g., Salt and Mud Sloughs), and surface runoff during storms, and the dilution of these salt sources by the SJR flow and the major tributary flows (Merced River, Tuolumne River, and Stanislaus River). The SJR minimum EC was about 250 uS/cm during the moderate flow of 4,500 cfs in May and during the pulse flow of 2,500 cfs for fish attraction in late October (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 2012 was about 1,000 uS/cm in March, when the SJR flow at Vernalis was about 1,250 cfs. Because the SJR flows were low (<1,000 cfs) in the summer months of July through August, the downstream changes in EC were moderately high (i.e., 125 to 250 uS/cm). There was also considerable variability between the DWR EC and the USBR EC during these months.



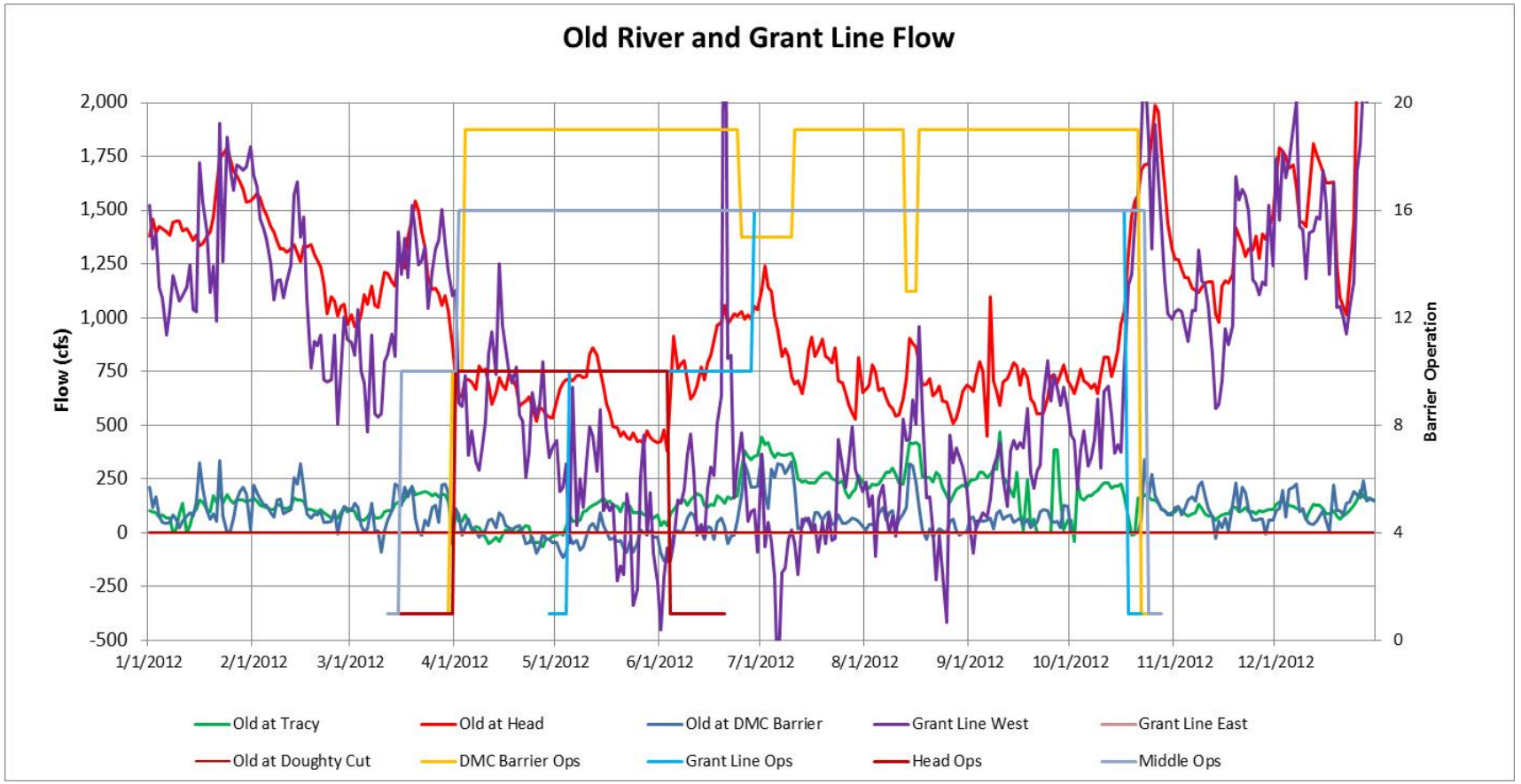
The SJR salt load is estimated as: Salt Load (tons/day) = flow (cfs) x EC (uS/cm) x 0.00175. The SJR salt load at Vernalis was relatively constant (2,000 to 3,000 tons/day) during the winter and spring months of January to April, declined to a minimum of about 1,000 tons/day in July-September, and increased slightly in October-December with increased flow and increased EC. Because the SJR flow and the SJR EC did not change appreciably between Vernalis and Mossdale, the SJR salt load did not change substantially. But the salt load was reduced to about half downstream of Old River because about half of the SJR flow (and salt) was diverted into Old River. Most of the salt load remained in the SJR in April and May when the head of Old River barrier was installed. The SJR salt load downstream of Old River was negative (flow moving upstream) in July-September and in November-December because of low SJR flows with high export pumping.



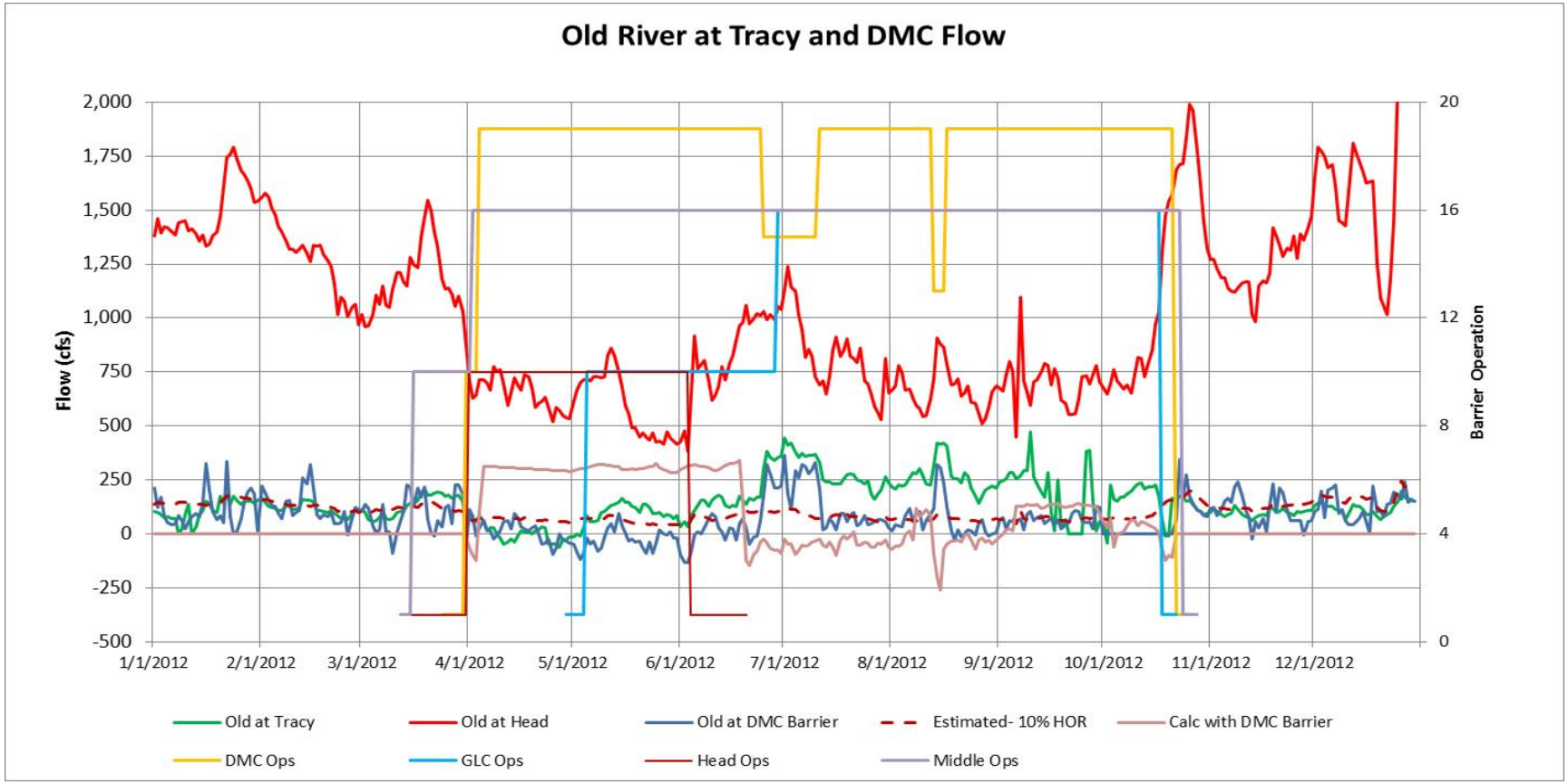
The relationship between the SJR at Vernalis flow and the Vernalis EC depends on the upstream salt loads. The salt load for a given flow was lower if the flows were released from the tributary reservoirs (lower EC) while higher flows from runoff generally increased the SJR salt load (salt flushing from increased runoff). 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 SJR EC showed a wide range during the relatively low flows in 2012; the EC ranged from 500-750 uS/cm when the flow was less than 1,000 cfs, and ranged from 250-1,000 uS/cm when the flows were 1,000 cfs to 2,000 cfs.



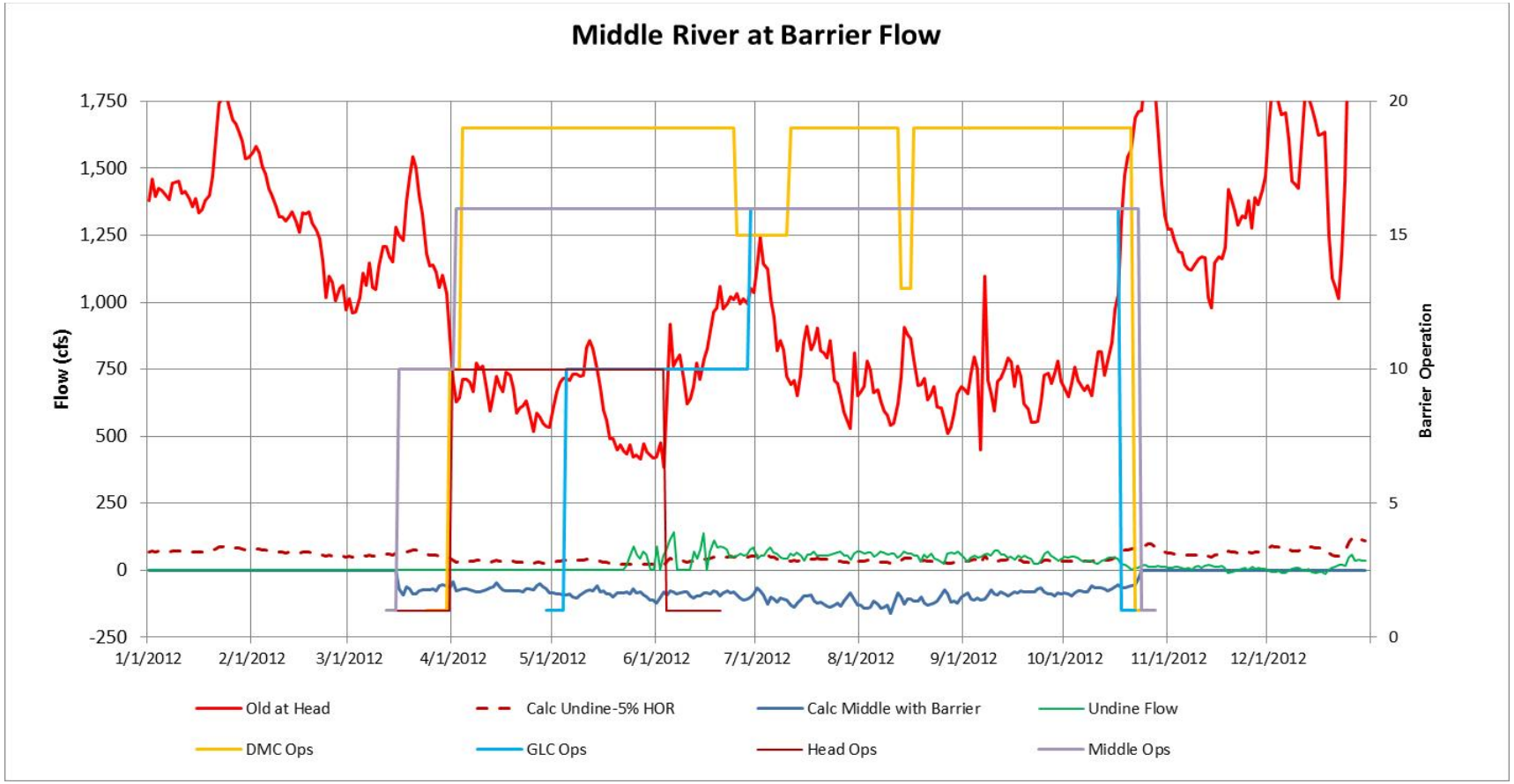
The SJR at Mossdale flow diverted into Old River was measured at the head of Old River (red line) and estimated (dashed green line) with the basic relationship for Old River Diversion = 50% Mossdale + 5% of the CVP and SWP combined exports (shown in gold). The measured Old River flows were higher than the estimated Old River flows in January-March and in November-December. Because the head of Old River barrier was installed in April and May of 2012, the flow (through the eight 4-feet diameter culverts) was about 500-750 cfs. The Grant Line flow plus Old at Tracy flow estimate of the Old River at head flow 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 in 2012, except when the head of Old River barrier was installed in April and May.



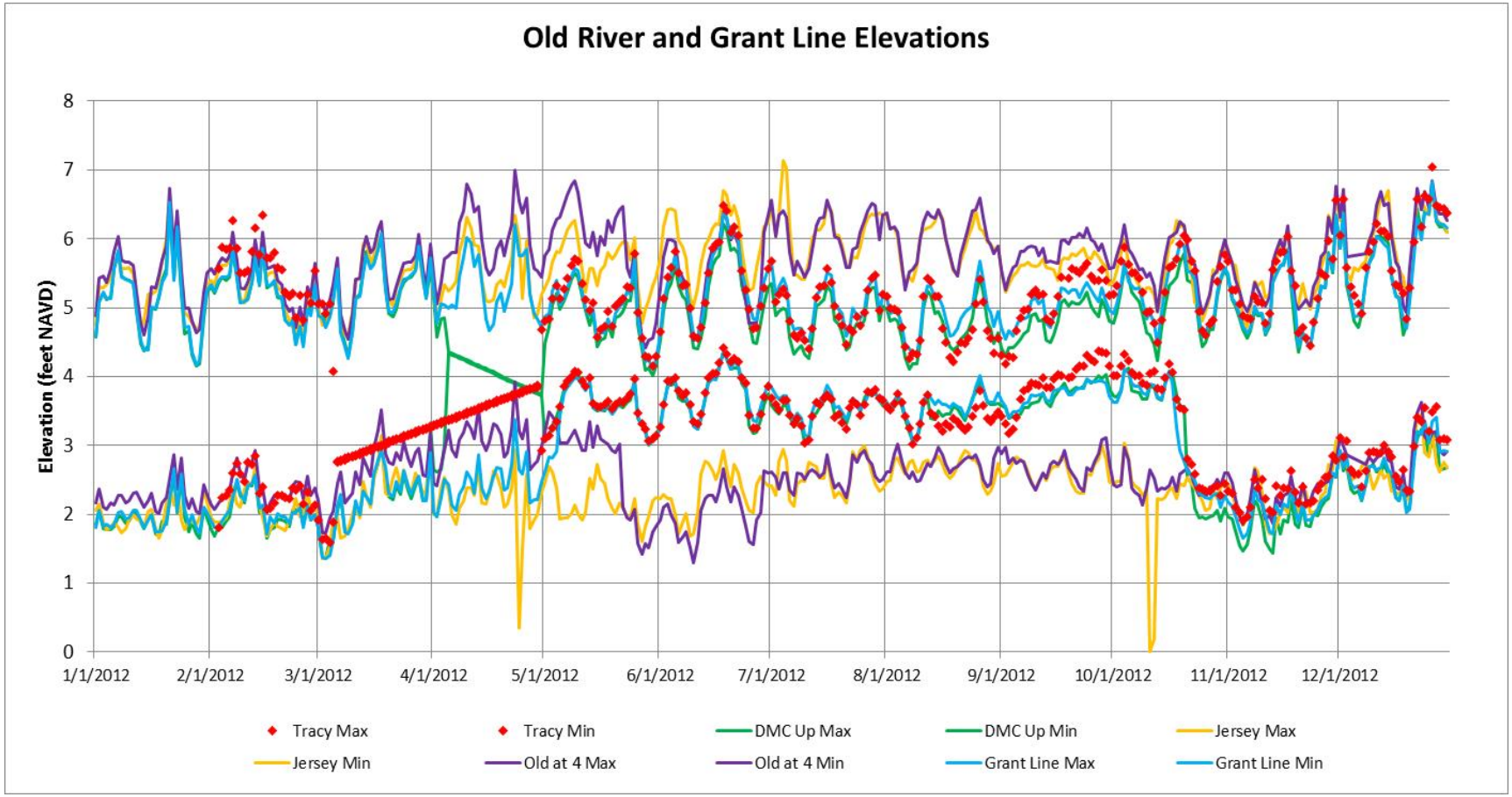
A barrier operation value of 5 (right scale) indicates barrier installation was initiated, a value of 10 indicates the weir was closed but the culverts were open, and higher values indicate the number of flap gates that were operational (10 + flap gates). The Old River flow at the head (red line) was generally confirmed by the Grant Line Canal flow (purple line) in January-March and in November and December, when temporary barriers were not installed. The majority of the Old River flow was diverted at Doughty Cut to the Grant Line Canal. The Grant Line Canal flows were 250-750 cfs less than the head of Old River flows in the May-September period, because of high agricultural diversions in Old River and Grant Line Canal. The Old River flow at Tracy Boulevard (green line) was similar to the Old River flow at the DMC barrier (blue line) during the months without temporary barriers (with limited agricultural diversions). There is considerable variation in the daily average tidal flows at these locations.



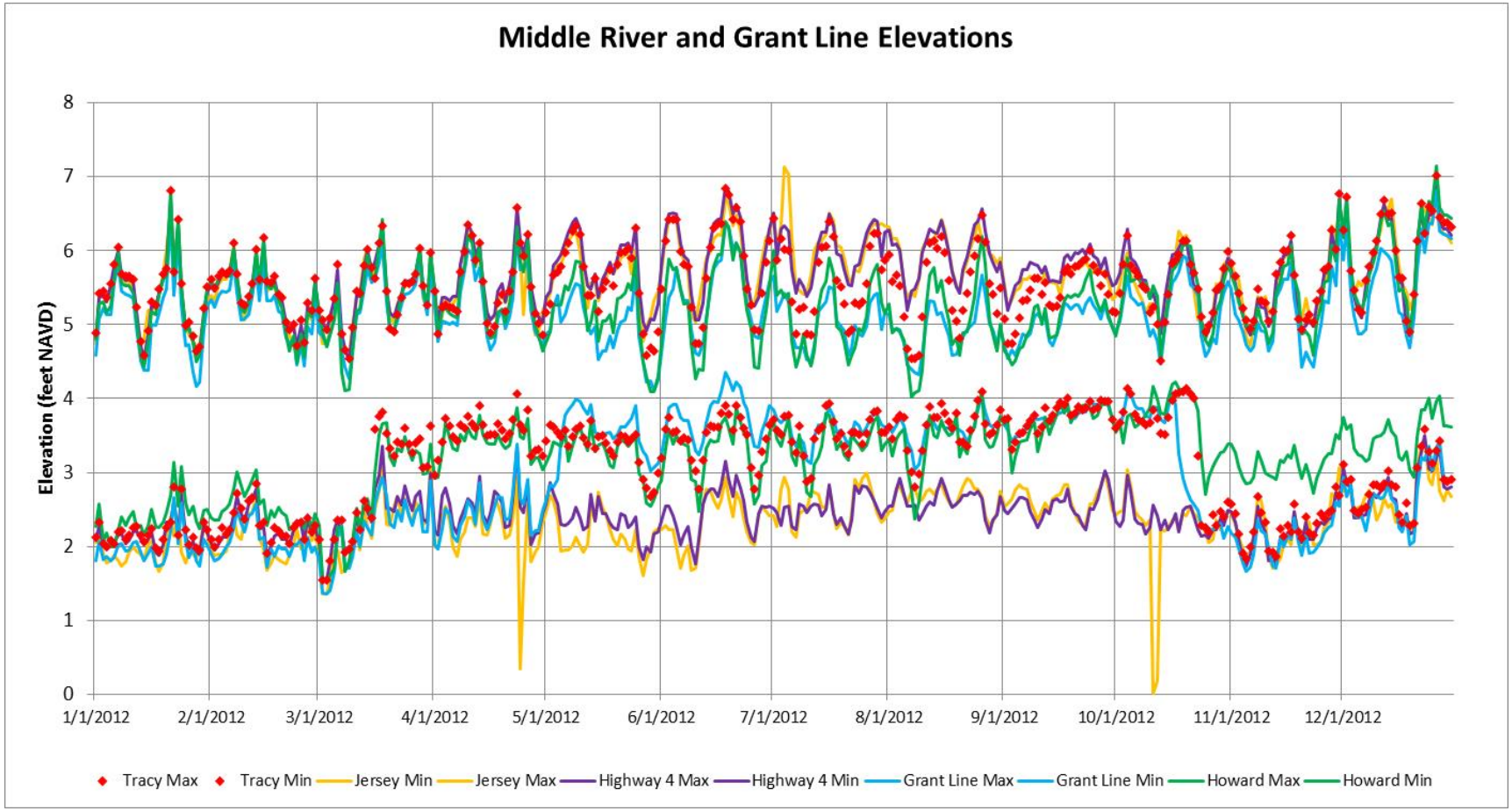
For the salinity analysis in Old River at Tracy Boulevard, it is important to measure (or accurately estimate) the Old River at Tracy flow (green line) and Old River at the DMC barrier flow (blue line). The multiple flow measurement locations in 2012 indicate the Old River flow at Tracy Boulevard can be estimated as 10% of the head of Old River flow (dashed brown line), when the Grant Line Canal barrier was not installed (January-April and late-October to December). When the Grant Line barrier was installed with the culverts closed (blue line, operation index of 16) in July, the Old River at Tracy flow increased to about 30% of the head of Old River flow. Installing the Grant Line Canal barrier without the Old River at DMC barrier would likely provide a higher net flow in Old River at Tracy Boulevard, and allow greater tidal flushing upstream of the DMC barrier location.



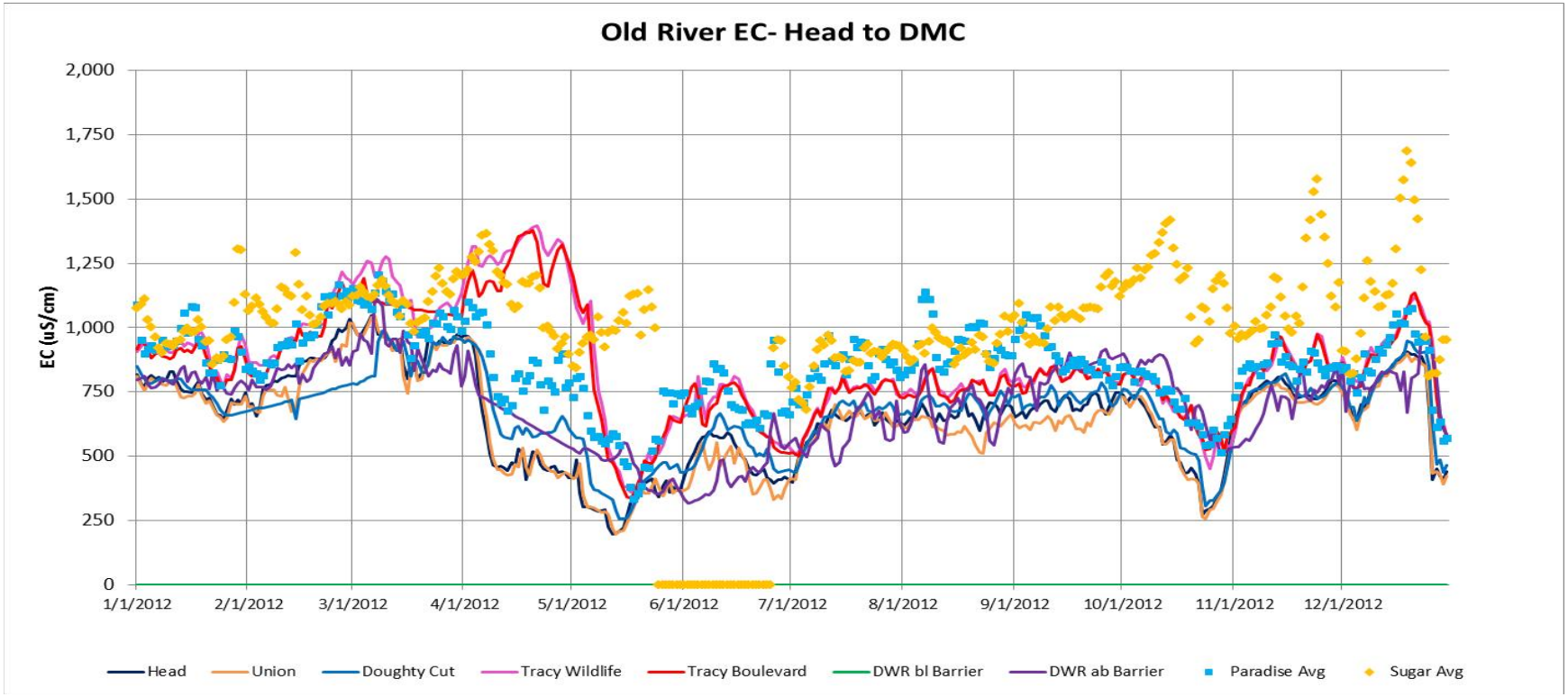
The Middle River flow at Undine Road was about 5% of the head of Old River flow during the months when the Middle River barrier was installed (grey line, operational index of 16). Based on previous DSM2 modeling and flow measurements, about 5% of the head of Old River flow was estimated to be diverted into Middle River (dashed brown line). The calculated net daily upstream flow at the Middle River barrier (based on drop in elevation over the barrier) is also 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 about 100-200 cfs, so inflows to Middle River come from both upstream and downstream with the barrier installed from April to October (corresponds to irrigation season).



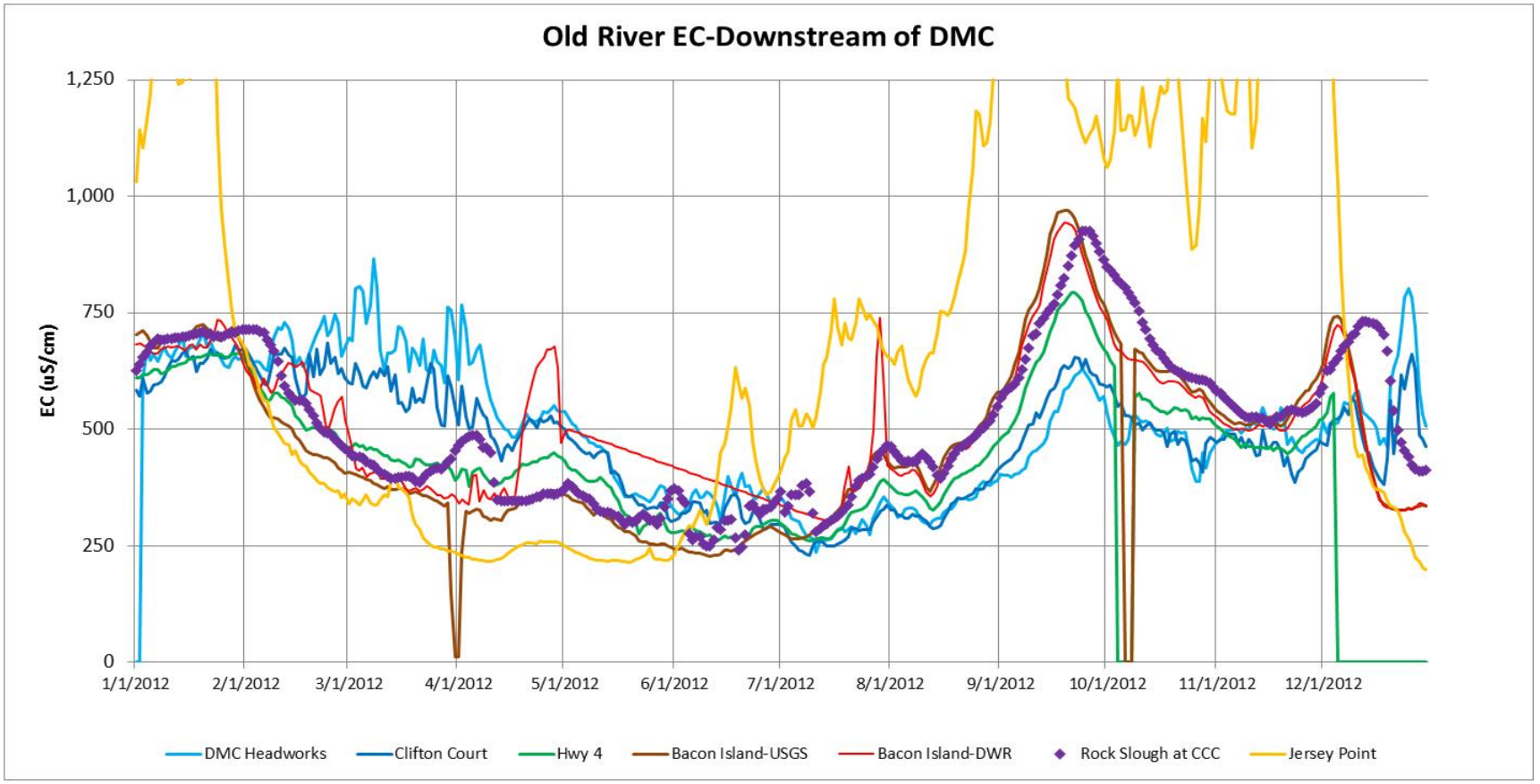
The Old River at Highway 4 minimum and maximum elevations (purple lines) indicate that the tidal elevations generally range from 2 feet to 6 feet. The minimum elevations in Old River at Tracy Boulevard were likely increased slightly to about 3 feet in April when the DMC barrier was installed. Several data problems in April and May make it difficult to separate the influence of each barrier. The minimum elevations in Grant Line Canal were increased to between 3 feet and 4 feet from May to mid-October when the Grant Line Canal temporary barrier was installed. But the tidal elevation range in Old River and in Grant Line Canal was reduced to less than 2 feet (reduced tidal flows) from May to mid-October.



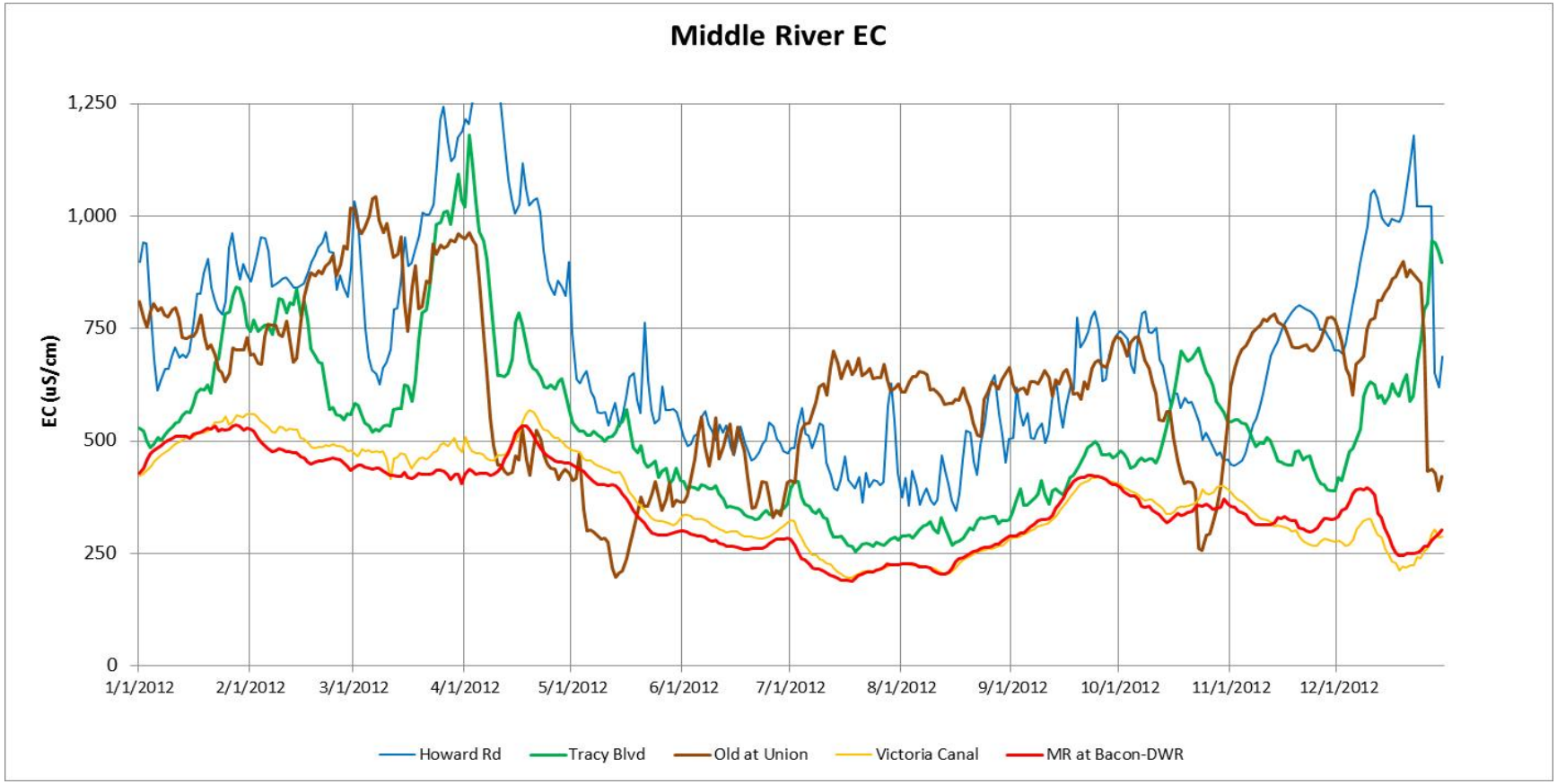
The Middle River Barrier, with a weir crest of about 4.5 feet, was installed in mid-March. The minimum elevations in Middle River at Tracy Boulevard (red diamonds) were increased by 1 to 1.5 feet compared to the Highway 4 elevations in March-October. The minimum elevations were slightly higher in September and October, perhaps because of reduced irrigation diversions. The high tides in Middle River at Highway 4 were not reduced at Tracy Boulevard during spring tides (highest tides) but were reduced slightly during neap tides (lower maximum tides); the maximum tides were more uniformly reduced by about 1 feet at Howard Road (green line) with the barrier installed. The tidal range in Middle River at Howard Road was very similar to the tidal range in Grant Line Canal with the Grant Line Canal barrier installed (May-October).



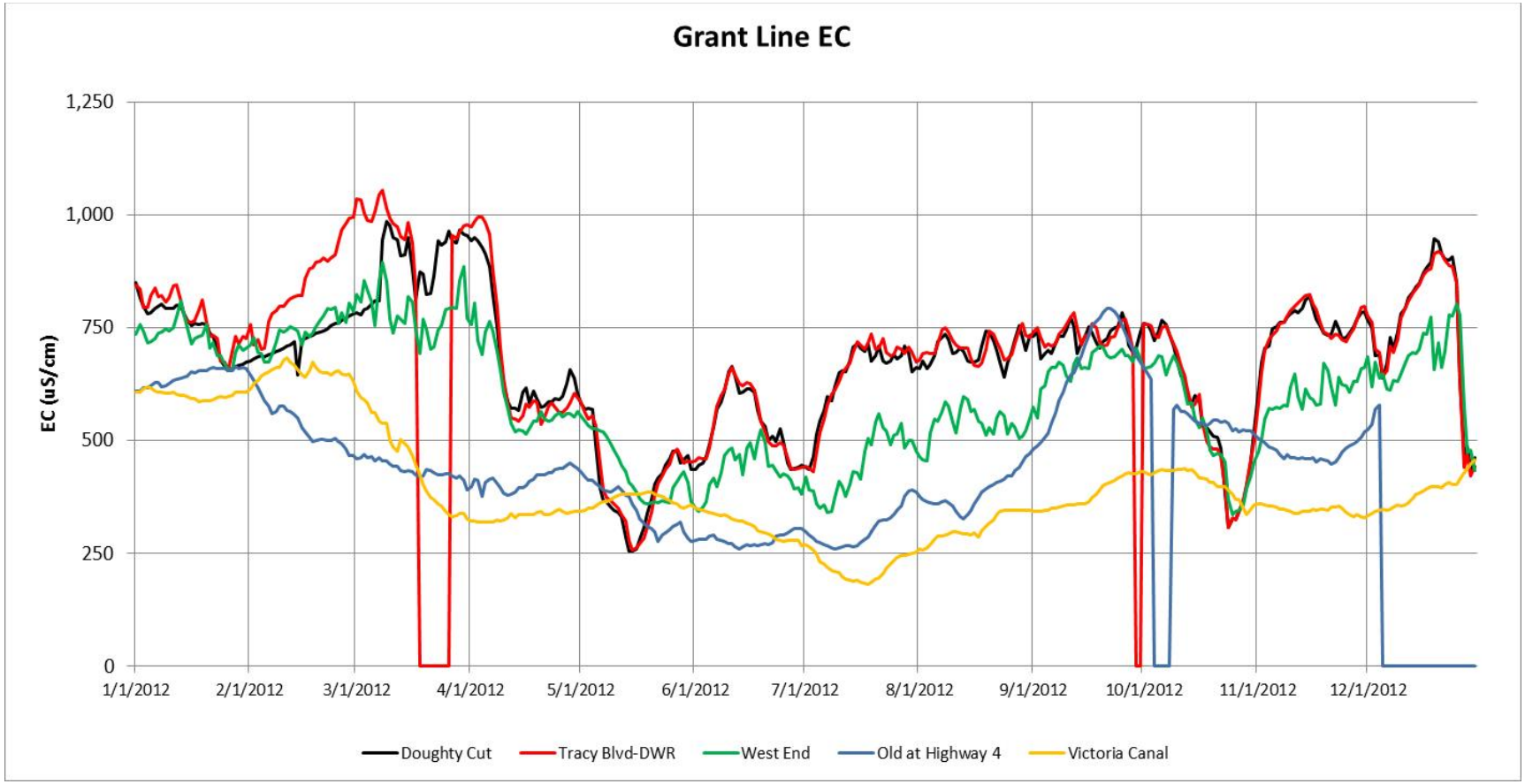
The Old River EC was measured at several locations between the head and the DMC barrier. The most dramatic EC increases were measured between Doughty Cut and Tracy Boulevard (a distance of about 2 miles). The EC in Old River at Tracy Boulevard was highest (1,250 uS/cm) in April, when the head of Old River barrier (and the Old River at DMC and Middle River barriers) was installed. The high EC at Tracy Boulevard (red line) was confirmed with the Tracy Wildlife EC (pink line). Because the head of Old River barrier was installed in April and May, the Old River flow at the head was only 500-750 cfs, and the Old River at Tracy Boulevard flow was less than 50 cfs (sometimes negative). The EC at Tracy Boulevard was generally 50-150 uS/cm higher than the EC at Doughty Cut, but was 750 uS/cm higher in April, when the SJR EC was reduced to 500 uS/cm. 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-August, indicate sources of higher salinity because the EC remained higher than the Old River EC. In April, the Tracy Boulevard and Tracy Wildlife EC remained high, while the Paradise Cut EC was reduced to about 250 uS/cm higher than the Old River EC by the lower SJR and Old River EC (flow dilution).



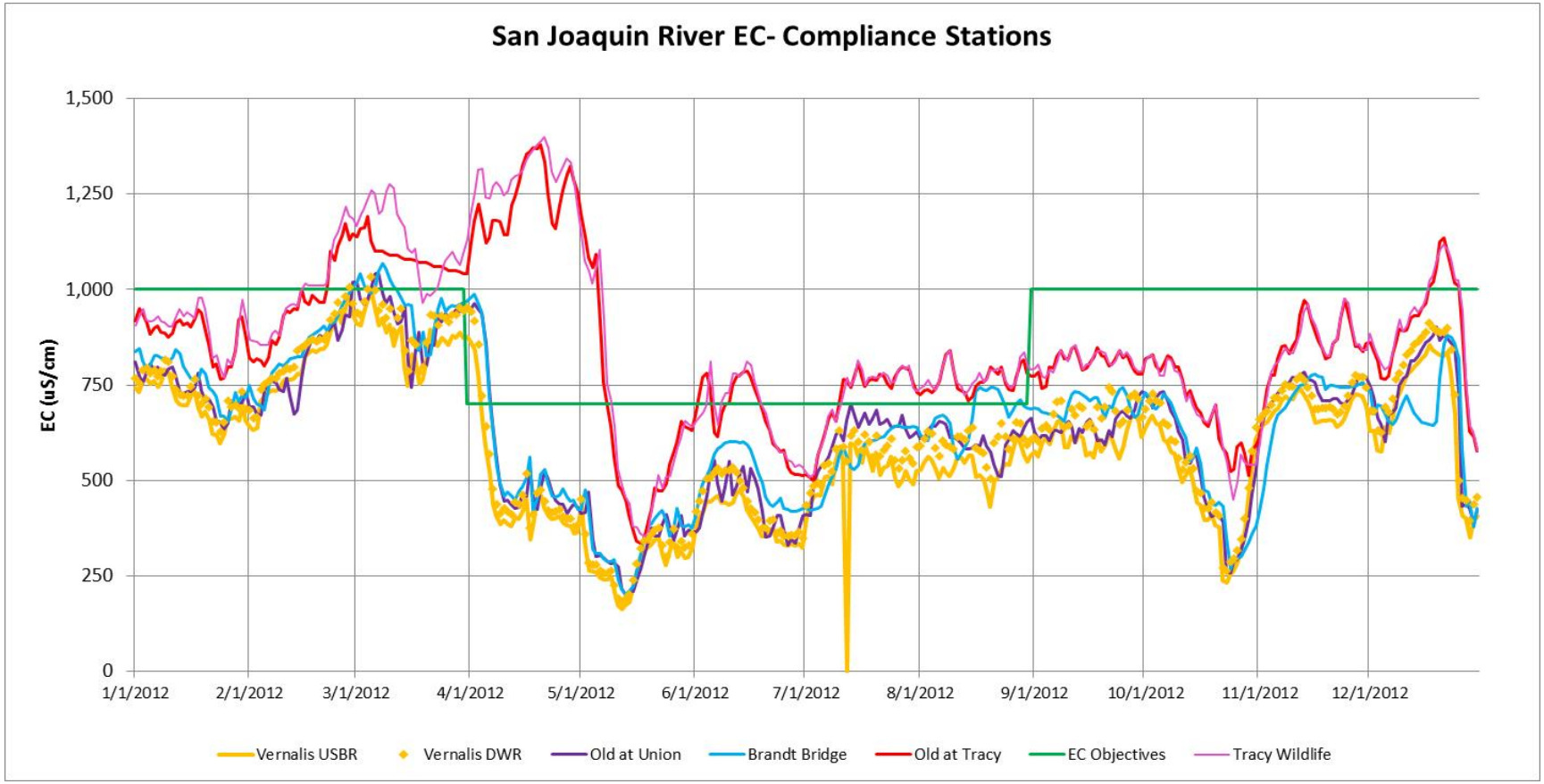
The Old River EC downstream of the DMC intake may have an increasing salt gradient when seawater intrusion is high during periods of low Delta outflow (January and September-November of 2012). The SJR at Jersey Point EC (gold line) is highest when seawater intrusion is greatest. False River, located 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 (and other upstream locations) will increase. Because of moderate outflow in 2012, the Old River at Bacon EC was about 700 uS/cm in January, and decreased slowly to about 250 uS/cm in June and July, increased to a peak of 1,000 uS/cm in mid-September, and was reduced to about 500 uS/cm in November and December. 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 CVP and SWP EC were less than 500 uS/cm only from May through August.



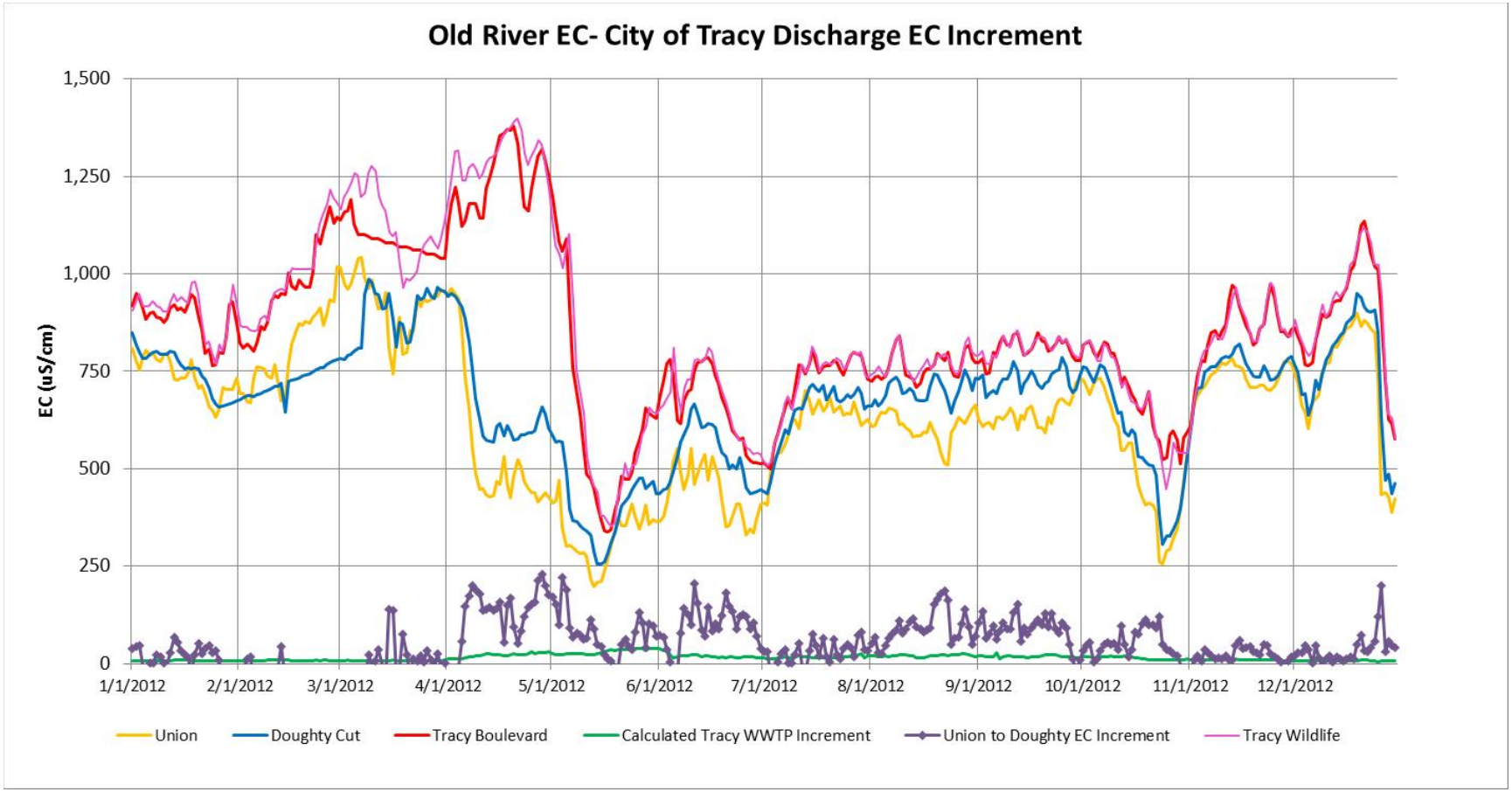
The Middle River EC downstream of the barrier at Victoria Canal or at Bacon Island was about 500 uS/cm in January-April, and was reduced to 250 uS/cm in June-August, and was about 300-400 uS/cm for the remainder of 2012. The EC at the head of Middle River (Union) was 750-1,000 uS/cm in January-March (similar to SJR EC) but was reduced to about 500 uS/cm in April and about 250 uS/cm in May, and increased to 500 uS/cm in June and was generally 500-750 uS/cm for the remainder of the year. The EC at Tracy Boulevard (green line) was variable, sometimes similar to the upstream EC (Union) and sometimes similar to the downstream EC (Victoria and Bacon). The EC at Howard Road (blue line) was higher than the EC at Union in March-May, suggesting salt sources (e.g., salt leaching prior to irrigation) in Middle River and reduced flushing flow (head of Old River was installed in April and May). The Tracy Boulevard EC appears to remain 50-100 uS/cm higher than the Victoria Canal EC when the Middle River barrier was installed (April-October).



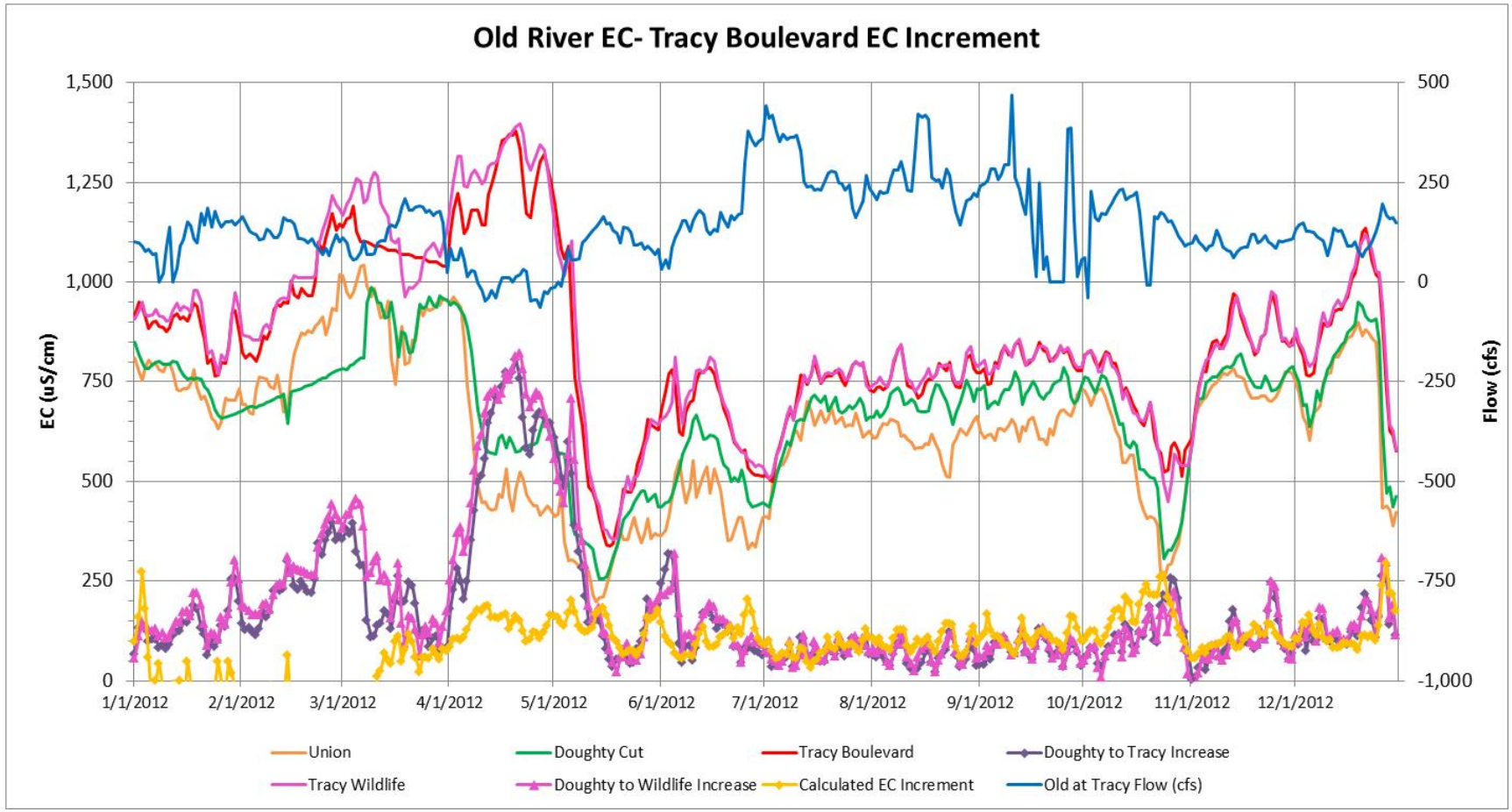
The Grant Line Canal EC at Doughty Cut and at Tracy Boulevard followed the SJR EC pattern that was controlled by the SJR flows. The Grant Line Canal EC at the western end (green line) was often lower than the EC at Doughty Cut and at Tracy Boulevard because of the influence of lower EC from Old River at Highway 4 (blue line) and Victoria Canal (gold Line). Flood-tide flows move upstream about 5 km in Grant Line Canal and provide tidal flushing (salinity gradient) in the downstream portion of Grant Line Canal.



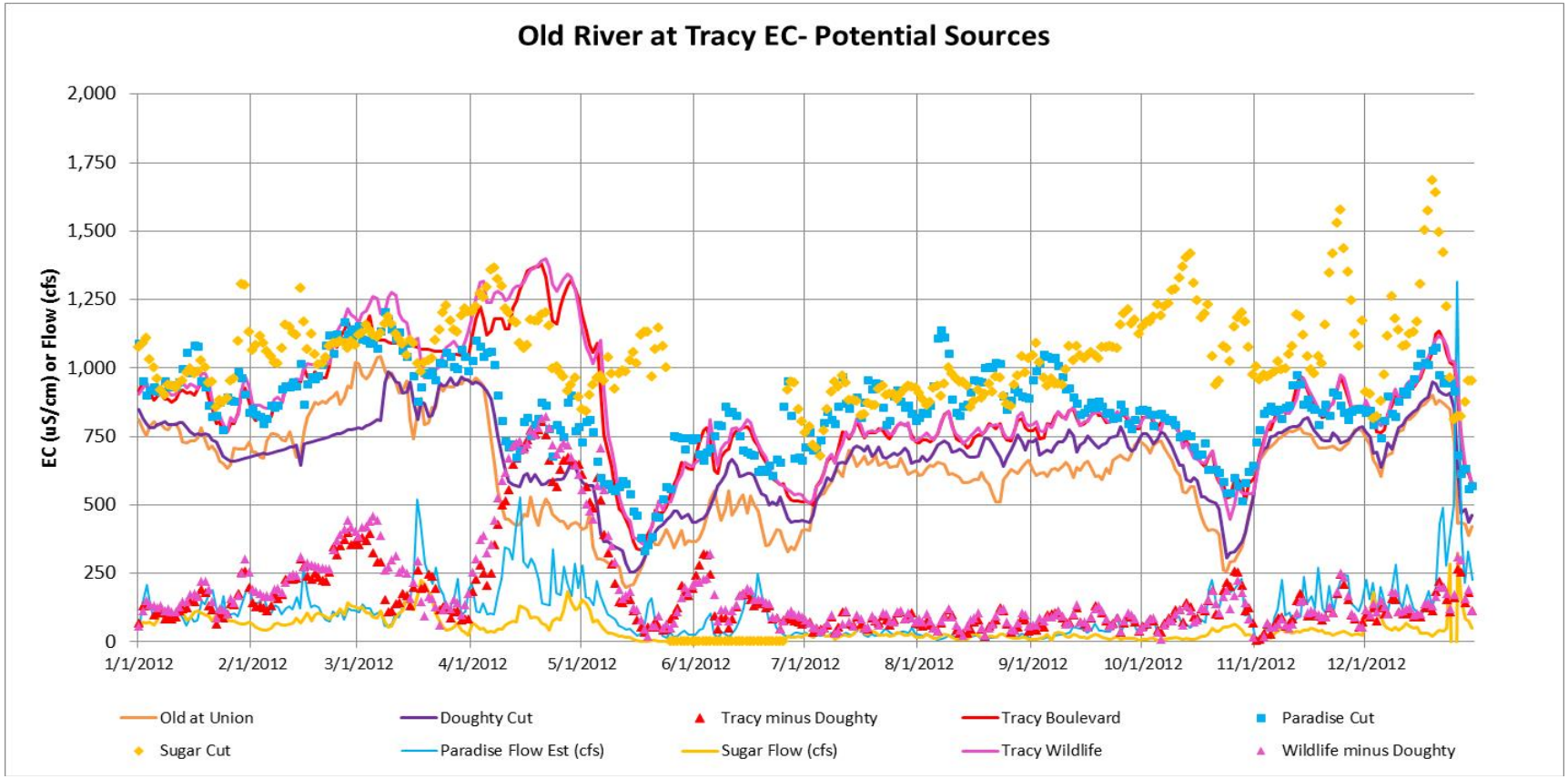
The SJR at Vernalis and the south Delta EC Objectives are 700 uS/cm from April through August and 1,000 uS/cm from September through March (30-day running average). The Old River at Tracy Boulevard EC and Tracy Wildlife EC were often 100-250 uS/cm higher than the Old at Union EC, located 7 miles upstream. There appears to be a major source of higher EC water in the vicinity of Old River at Tracy Boulevard. The higher EC was measured both during periods with the temporary barriers installed (April-October of 2012) and during periods without barriers. The EC increments in April 2012 were remarkably high (750 uS/cm), likely caused by a combination of low flows in Old River (because of the head of Old River barrier), reduced Old River EC upstream of Doughty Cut (from increased SJR flows), and nearly stagnant conditions in Old River at Tracy Boulevard (because the DMC barrier was installed at the same time as the head of Old River barrier). The DMC barrier should not be installed when the head of Old River barrier is installed.



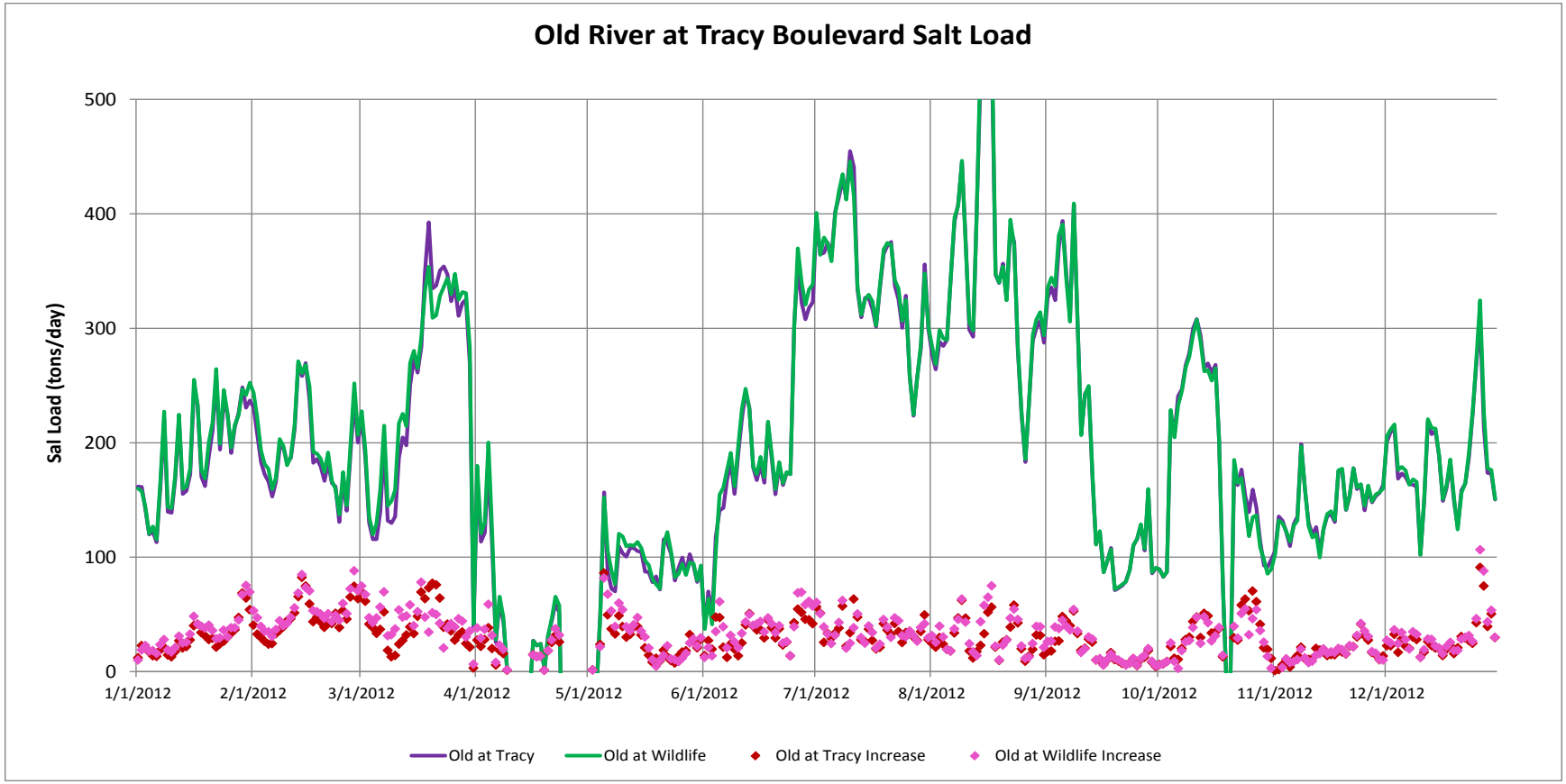
The measured daily EC increment between any two locations along Old River can be approximated with a specified source discharge (cfs) and a specified source EC. The expected EC increment between Union and Doughty Cut caused by the Tracy Wastewater Discharge (green line) was calculated as: EC increment (uS/cm) = (Tracy Discharge EC – River EC) x Tracy Discharge / (River Flow + Tracy Discharge). The assumed discharge EC was 1,250 uS/cm and the discharge flow was 15 cfs. The calculated EC increments were highest in the spring and summer when the Old River flow was lowest. The measured EC increments (purple diamonds) were much greater, suggesting that a much larger salt source was influencing the Doughty Cut EC measurements.



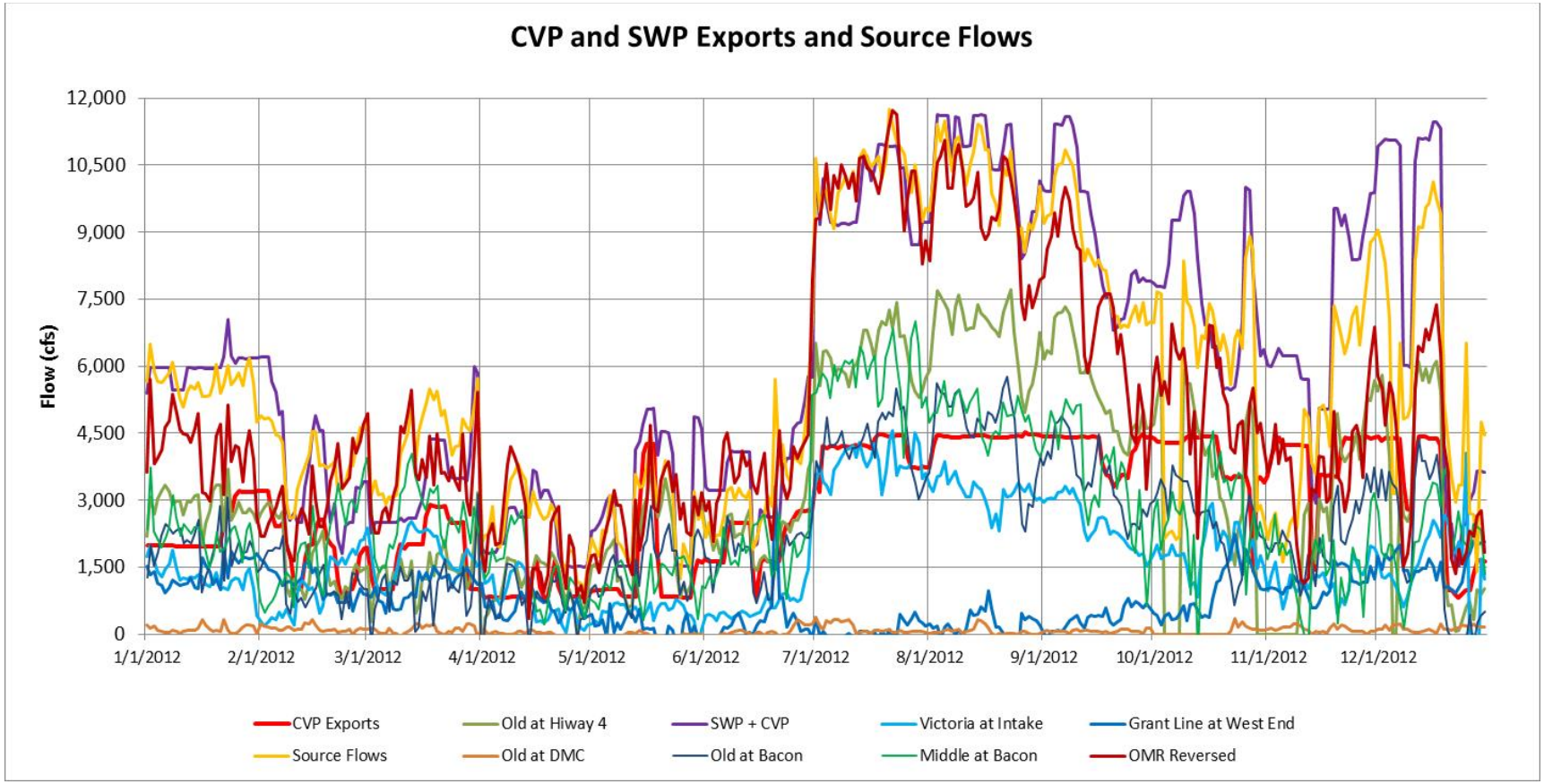
The measured Old River EC increments between Doughty Cut and Tracy Boulevard (purple diamonds) or Tracy Wildlife (pink triangles) were compared with the calculated EC increments from Paradise Cut and Sugar Cut (gold diamonds), assuming the Old River at Tracy Boulevard flow was 10% of the head of Old River flow. The 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 averaged 170 uS/cm and were highest in February and in April. The calculated EC increments were similar to the measured EC increments from June-December, but did not match the measured EC increments in January-May.



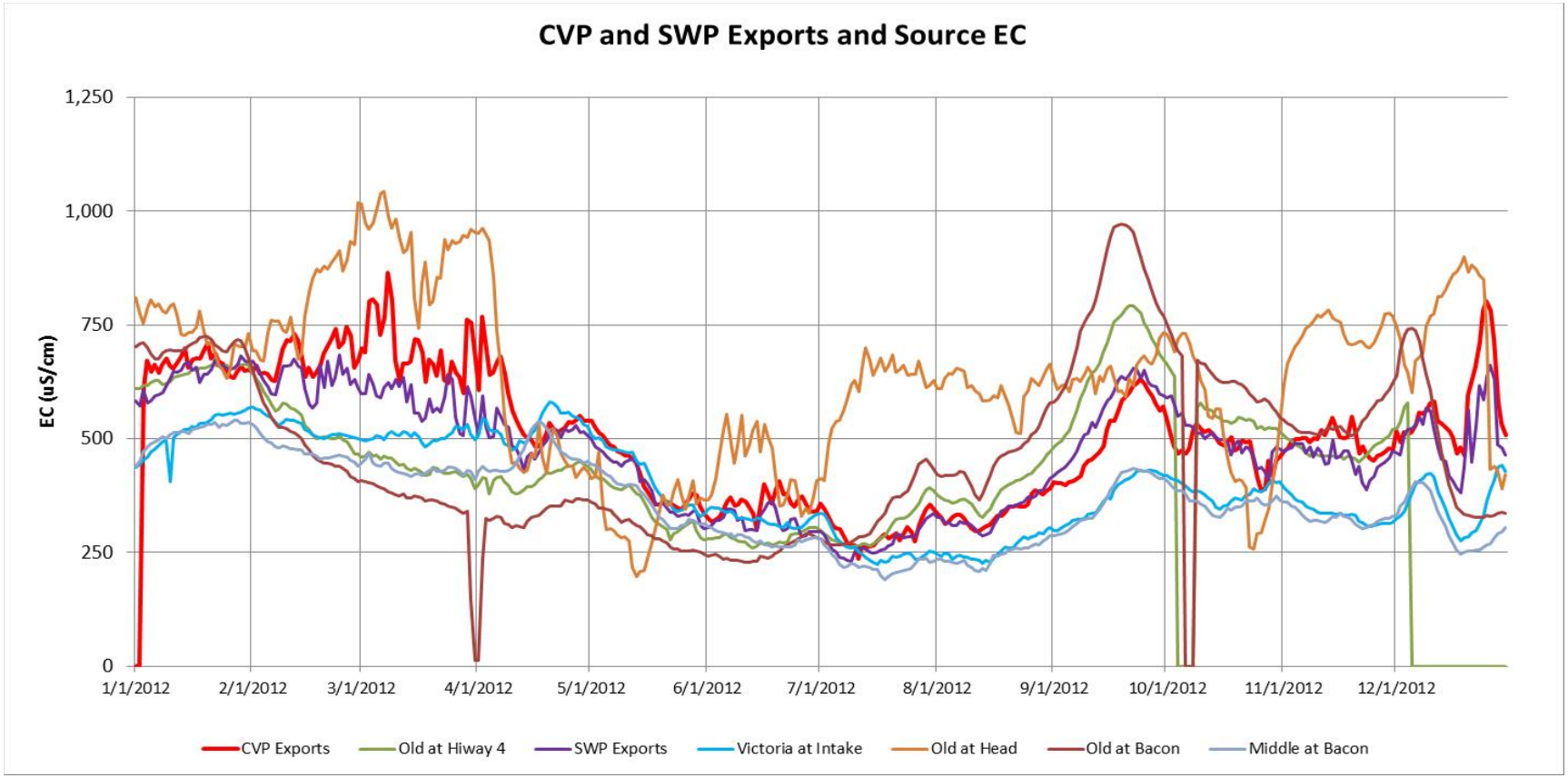
The salt source that would match the measured daily EC increment between Doughty Cut and Tracy Boulevard (or Tracy Wildlife) can be calculated as: EC increment (uS/cm) = (Source EC – River EC) x Source Discharge / (River Flow + Source Discharge). The daily Old River EC increments at Tracy Boulevard (red 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 larger and when the flow in Old River at Tracy Boulevard is higher. The estimated salt discharge from Paradise Cut would have been about 125 cfs (very high discharge) for January-April and November-December, because the average Paradise Cut 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 have been about half of the Paradise Cut flow, because the Sugar Cut EC was higher.



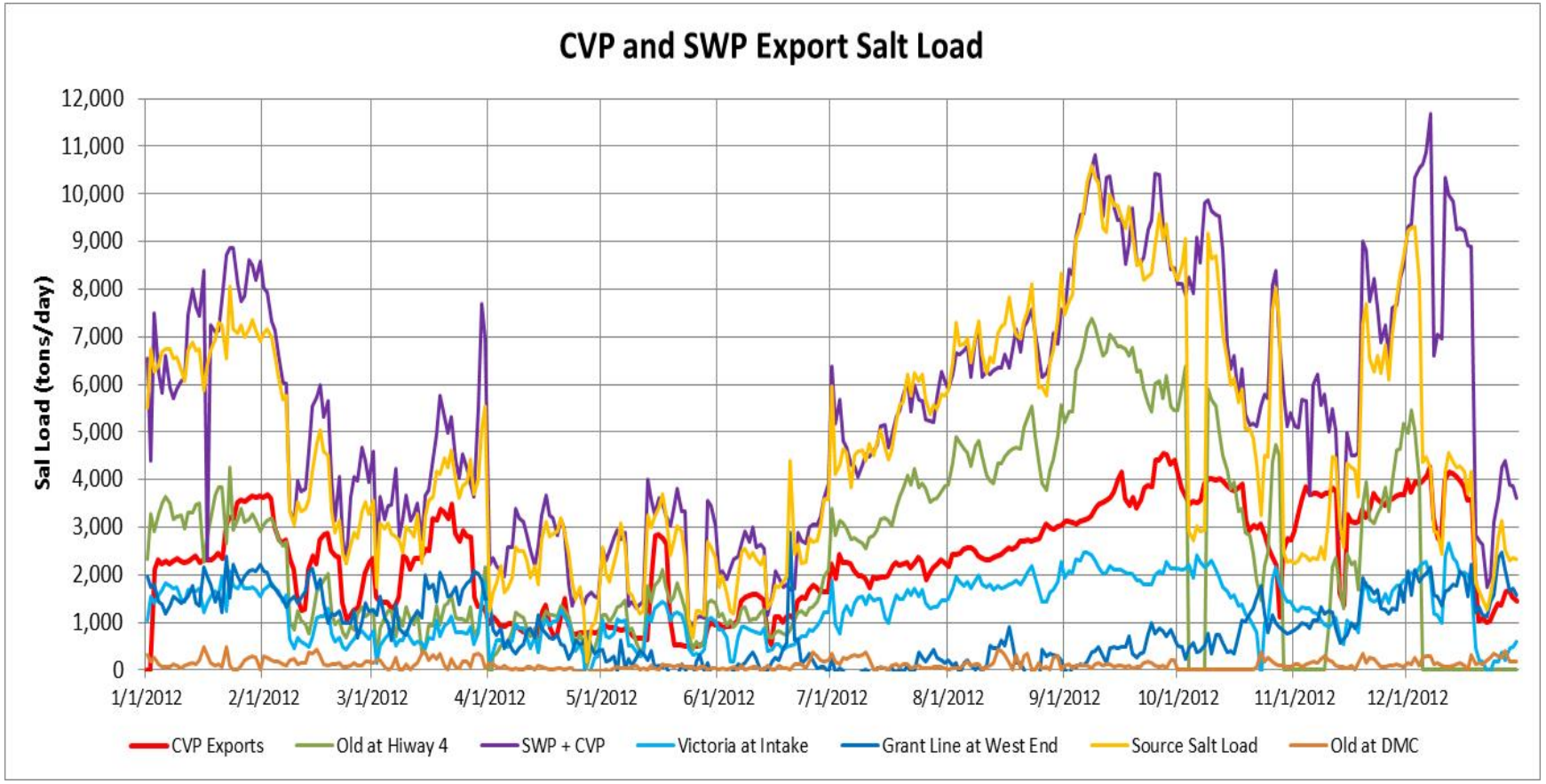
The measured salt loads in Old River at Tracy Boulevard and Tracy Wildlife (purple and green lines, respectively) were calculated from the Old River EC at these locations and estimated flow at Tracy Boulevard. The salt load increments between Doughty Cut and Tracy Boulevard and Doughty Cut and Tracy 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 30 tons/day in 2012. The EC at Tracy Boulevard and the EC at Tracy Wildlife were very similar in 2012 (replicate EC stations), so the salt load increments calculated for these two locations were about the same.



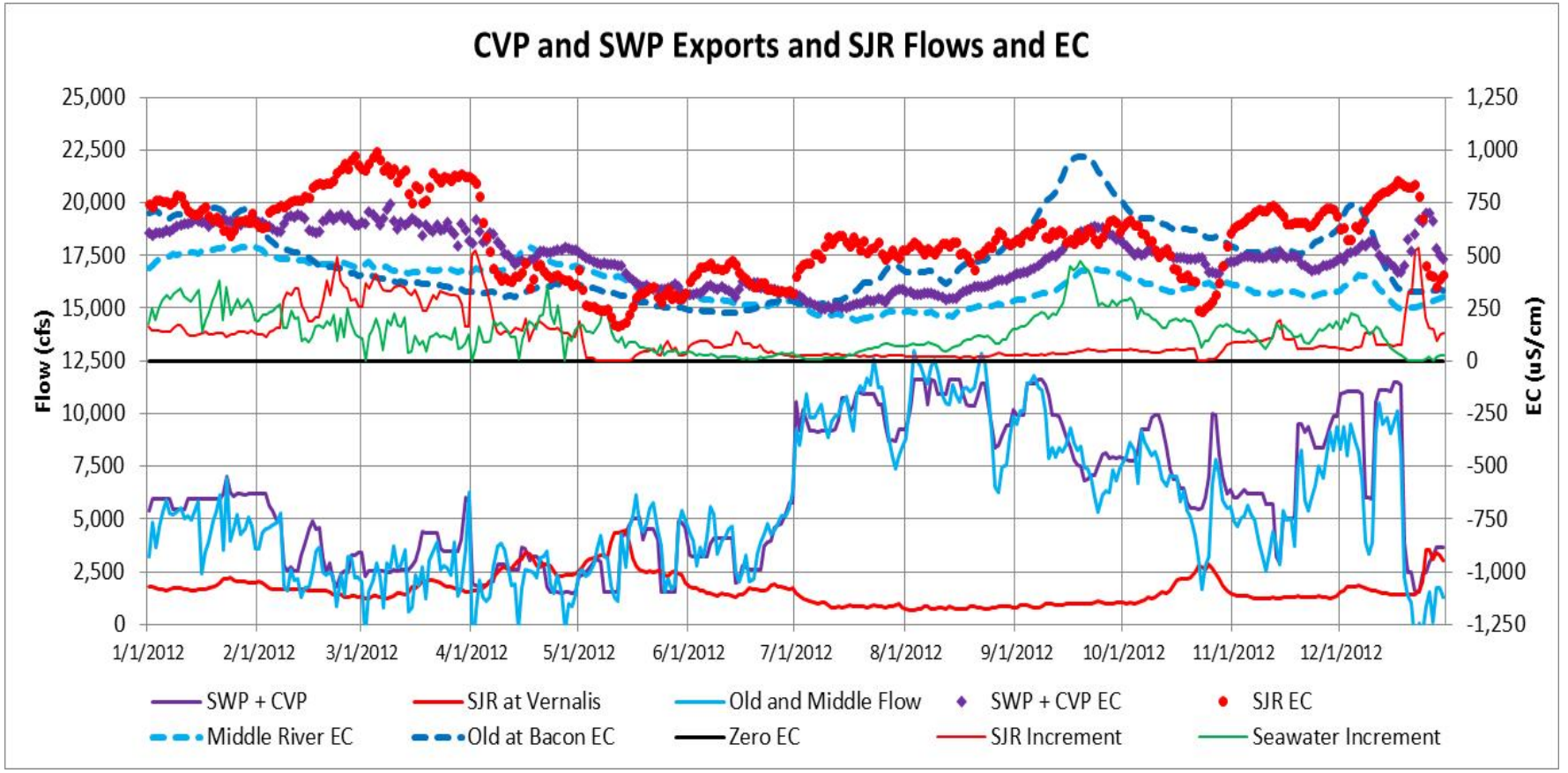
During 2012, the net tidal flows (daily average) in the south Delta channels provided an accurate match with the CVP and SWP export flows. The Old River at Highway 4 flow was the largest source of water for CVP and SWP exports; when pumping was near the maximum (permitted) of about 11,000 cfs, the Old 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 and Woodward Canal. The Grant Line Canal flow plus the Old River at DMC flow was generally less than 500 cfs during the summer months when irrigation diversions in the south Delta were greatest. The OMR flow (reversed) was similar to the exports, except when the Grant Line Canal flow was relatively high (some OMR flow measurement problems in mid-August to December).



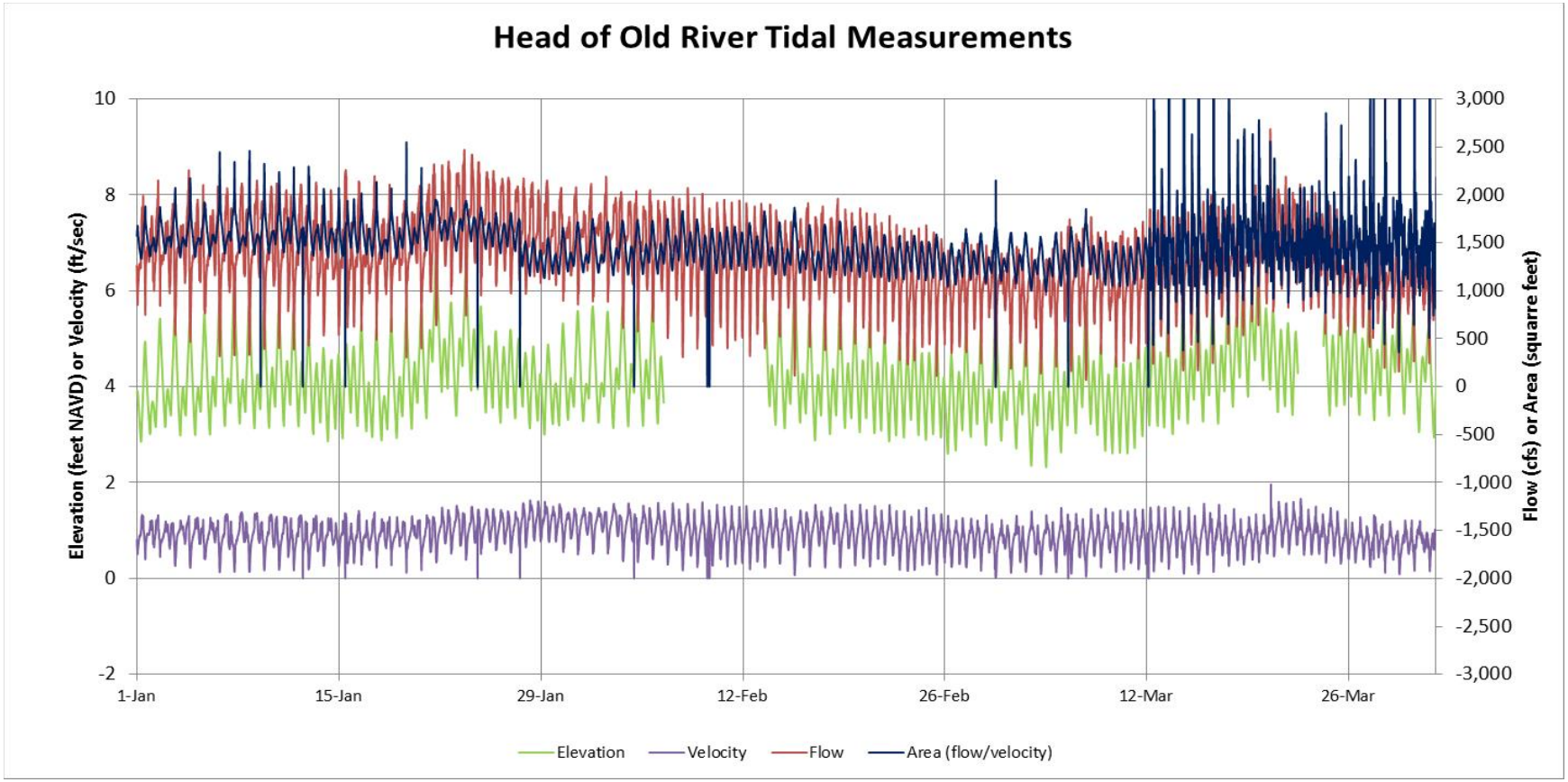
The salinity (EC) of the CVP and SWP exports was slightly different during most of the year. The CVP intake is located just one mile south of the SWP intake, but Grant Line Canal enters Old River between the two intakes. The Old at Head EC water is tidally mixed with the lower EC water from Victoria Canal and from Old River at Highway 4. The EC in Old River at Highway 4 is often higher than the EC in Victoria Canal because of seawater intrusion into Old River during periods of low Delta outflow (September 2012). The EC in Old River at Bacon Island was higher than the EC at Highway 4 in the summer and fall because of a greater influence from seawater intrusion.



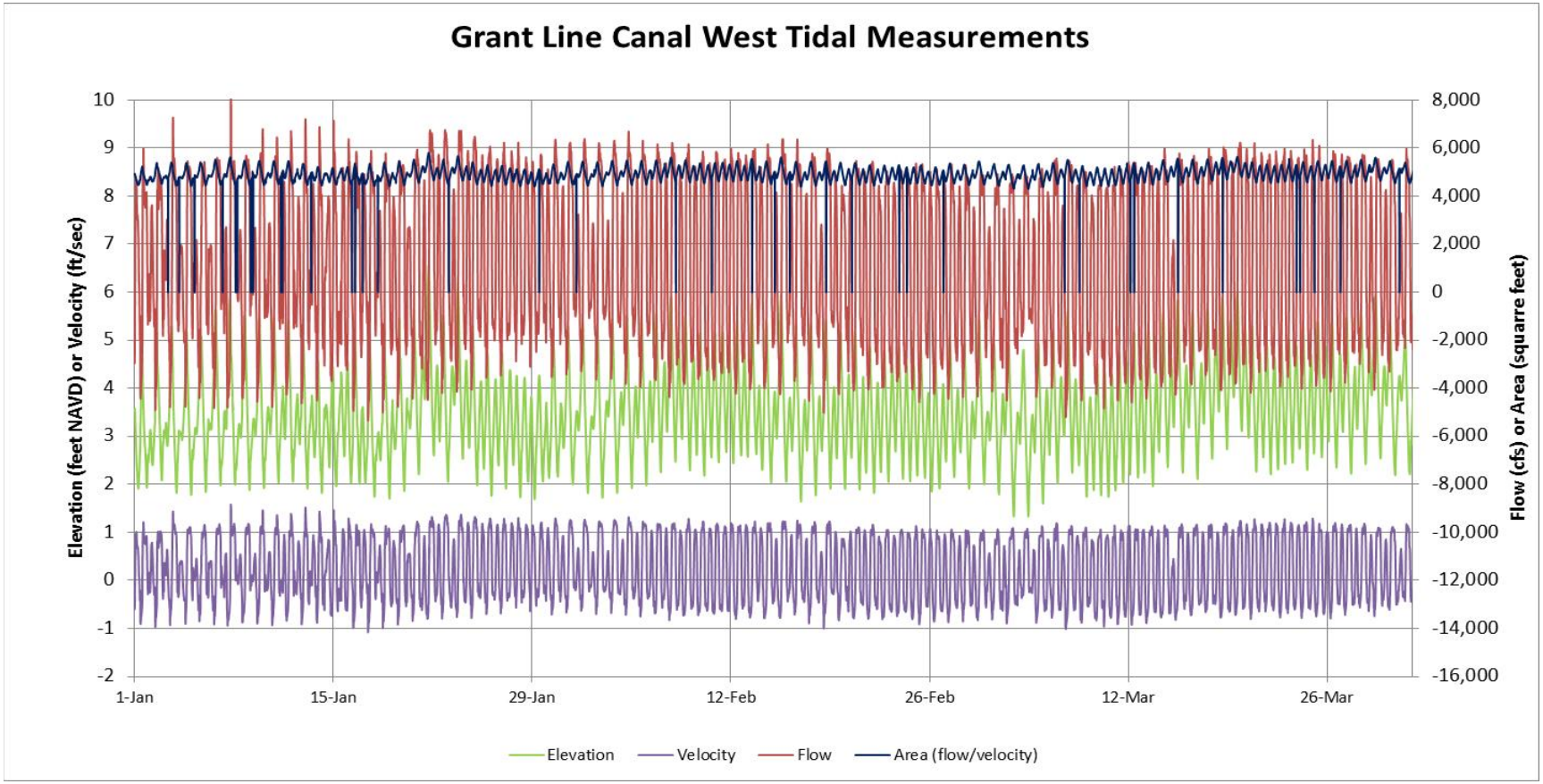
The salt load exported at the CVP (Jones) and SWP (Banks) pumping plants increases with pumping flow and with salinity (EC). The tidal flow and EC monitoring in the south Delta is comprehensive and accurate. For 2012, the net tidal flows and the daily average EC values were used to calculate the CVP and combined CVP and SWP salt loads (tons/day) as well as the salt loads from Old River at Highway 4, Victoria Canal at CCWD intake, Grant Line Canal at west end, and Old River at the DMC barrier. Although there were some periods when the Old River at Highway 4 station (green line) was out, the agreement between the source salt loads and the exported salt loads was generally within 10%. A similar agreement was calculated using Old River at Bacon (instead of Old at Highway 4) and the Middle River at Bacon (instead of Victoria Canal).



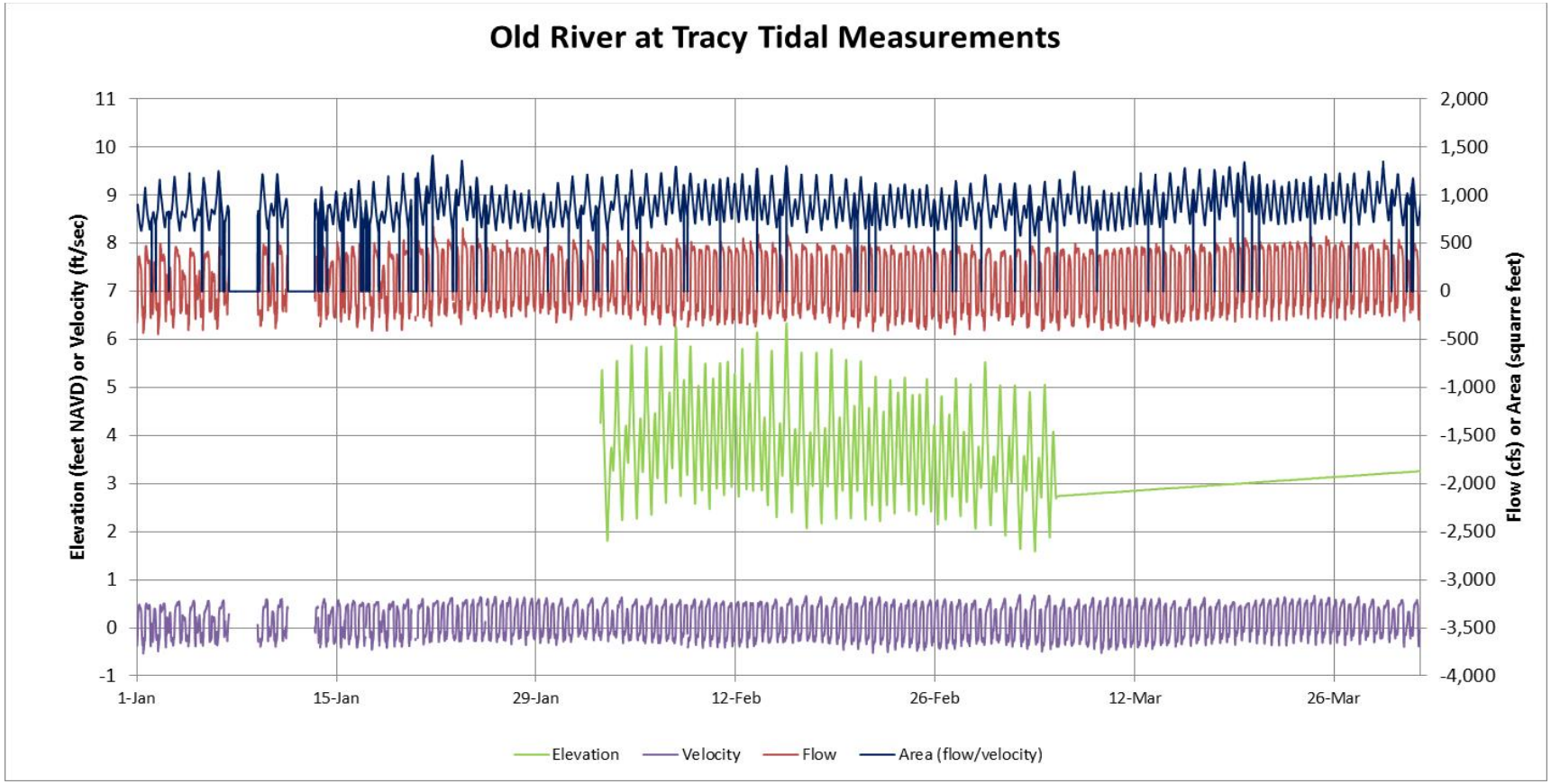
The water sources for the SWP and CVP exports can be estimated from the SJR flow at Vernalis and the Old and Middle River (OMR) flows. All of the SJR flow was exported in 2012 because the exports were greater than the SJR flows. The salt sources in the exports can be estimated from the EC increments, with a minimum of 250 µS/cm assumed from Sacramento River water. 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 µS/cm in January and April, and was 250 µS/cm in February and March. The seawater intrusion EC increment was calculated as the Old and Middle River flow fraction times the (OMR EC - 250). Seawater intrusion was 125-250 µS/cm in January-April, was greatest in September (250 µS/cm) and was about 125 µS/cm in October and November. For 2012, the average exports were 6,145 cfs and the average (flow-weighted) export EC was 460 µS/cm; the Sacramento River EC was 250 µS/cm (54%), the SJR EC increment was 118 µS/cm (26%), and the seawater EC increment was 140 µS/cm (30%).



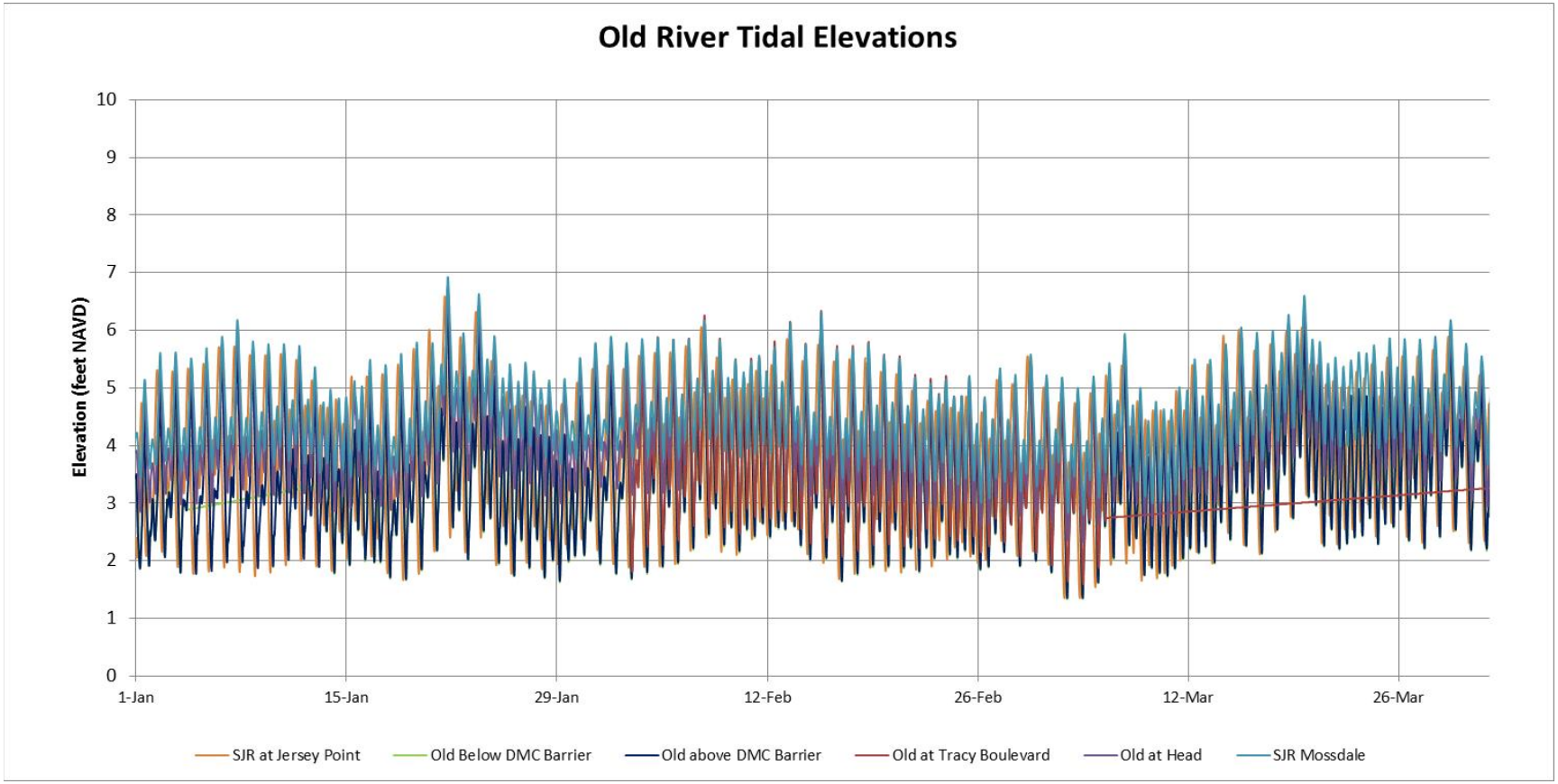
The primary tidal measurements are the water elevation (green line, left scale) and the tidal velocity (purple line, left scale). The cross-section area, which is measured independently as a function of the water elevation and programmed into the data station (but not reported), is multiplied by the velocity to calculate the tidal flow. The area for this graph was calculated by dividing the flow by the velocity; high values are calculated when the velocity is low. 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 and varies from about 1,000 ft^2 to 2,000 ft^2 between an elevation of 3 feet and 6 feet. The tidal velocity is only about 1-2 ft/sec, and the tidal flow fluctuated between about 500 cfs and 2,000 cfs during flood-tide and ebb-tide (plus the net flow).



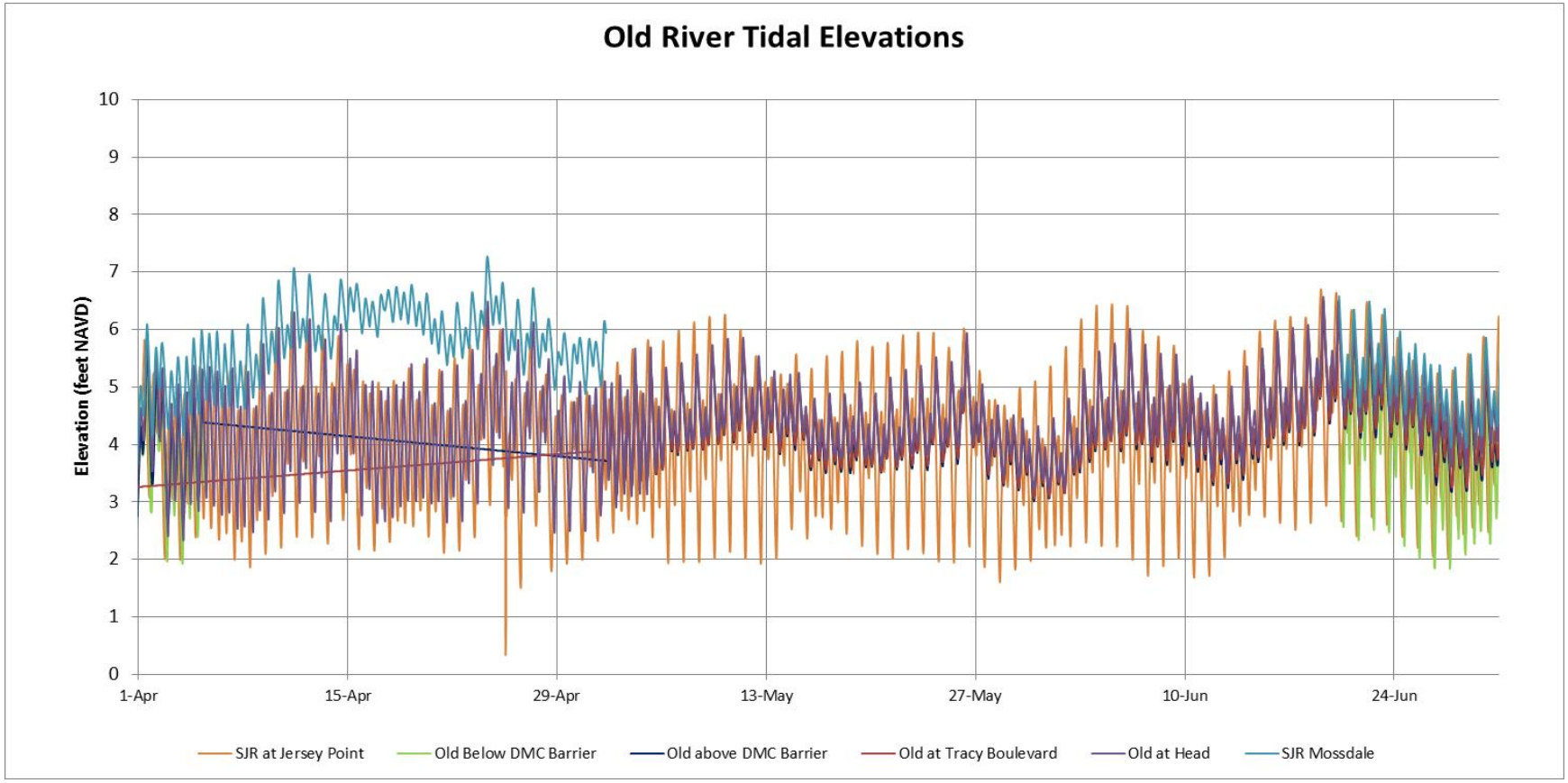
The primary tidal measurements are the water elevation (green line, left scale) and the tidal velocity (purple line, left scale). The cross-section area, which is measured independently as a function of the water elevation and programmed into the data station (but not reported), is multiplied by the velocity to calculate the tidal flow. The area for this graph was calculated by dividing the flow by the velocity; high values are calculated when the velocity is low. 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 an elevation of 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 (plus the net flow).



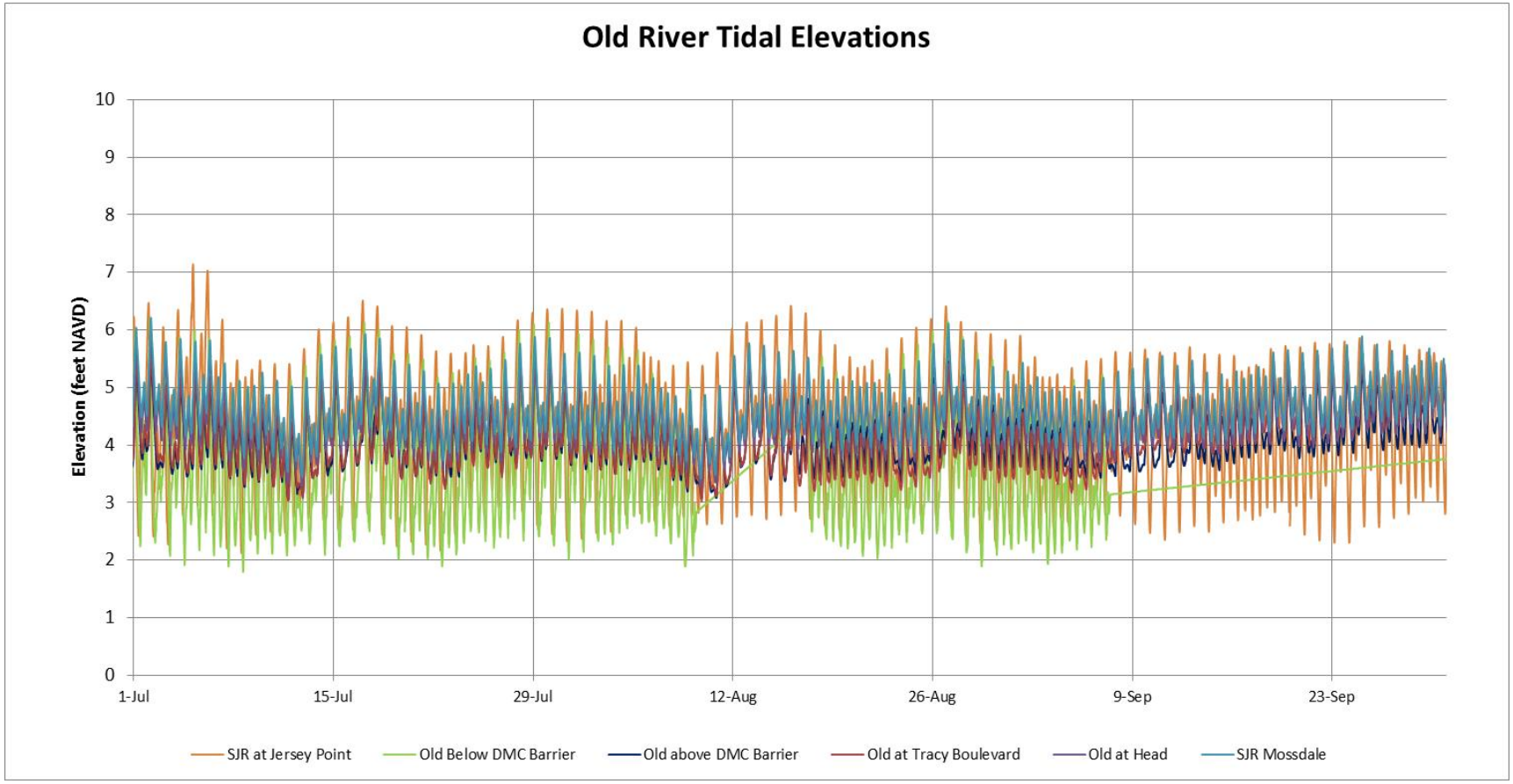
The primary tidal measurements are the water elevation (green line, left scale) and the tidal velocity (purple line, left scale). The cross-section area, which is measured independently as a function of the water elevation and programmed into the data station (but not reported), is multiplied by the velocity to calculate the tidal flow. The area for this graph was calculated by dividing the flow by the velocity; high values are calculated when the velocity is low. The fluctuation of the area with water elevation is shown on the graph (dark blue line, right scale). The Old River at Tracy Boulevard cross-section area is about 1,000 ft^2 and varies between 750 ft^2 and 1,250 ft^2 between an elevation of 2 feet and 6 feet. The tidal velocity is less than 0.5 ft/sec in Old River at Tracy Boulevard, and the tidal flow fluctuates between about 250 cfs and -250 cfs during ebb-tide and flood-tide (plus the net flow). Tidal flow measurements are more difficult when the velocity is low.



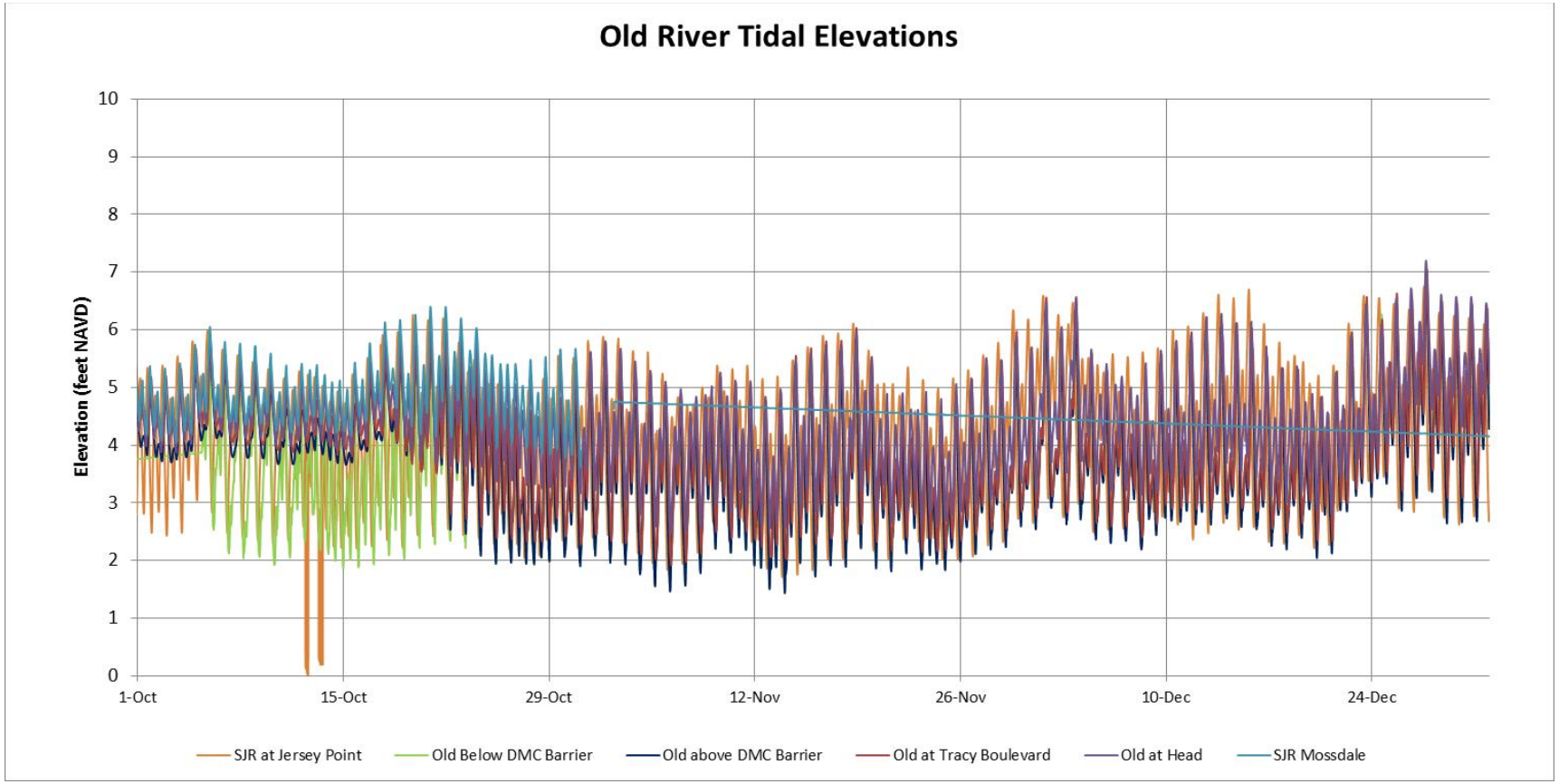
Because of low SJR flows, the tidal elevations in Old River were very uniform in the January-March period, before the temporary barriers were installed. The spring-neap tidal cycle can be detected with a tidal range of 2 feet to 5 feet during neap tides and a tidal range of 2 feet to 6 feet during spring tides. The graphs have a 14-day vertical grid, so a full spring-neap cycle requires two grids, and there are tidal variations within each cycle.



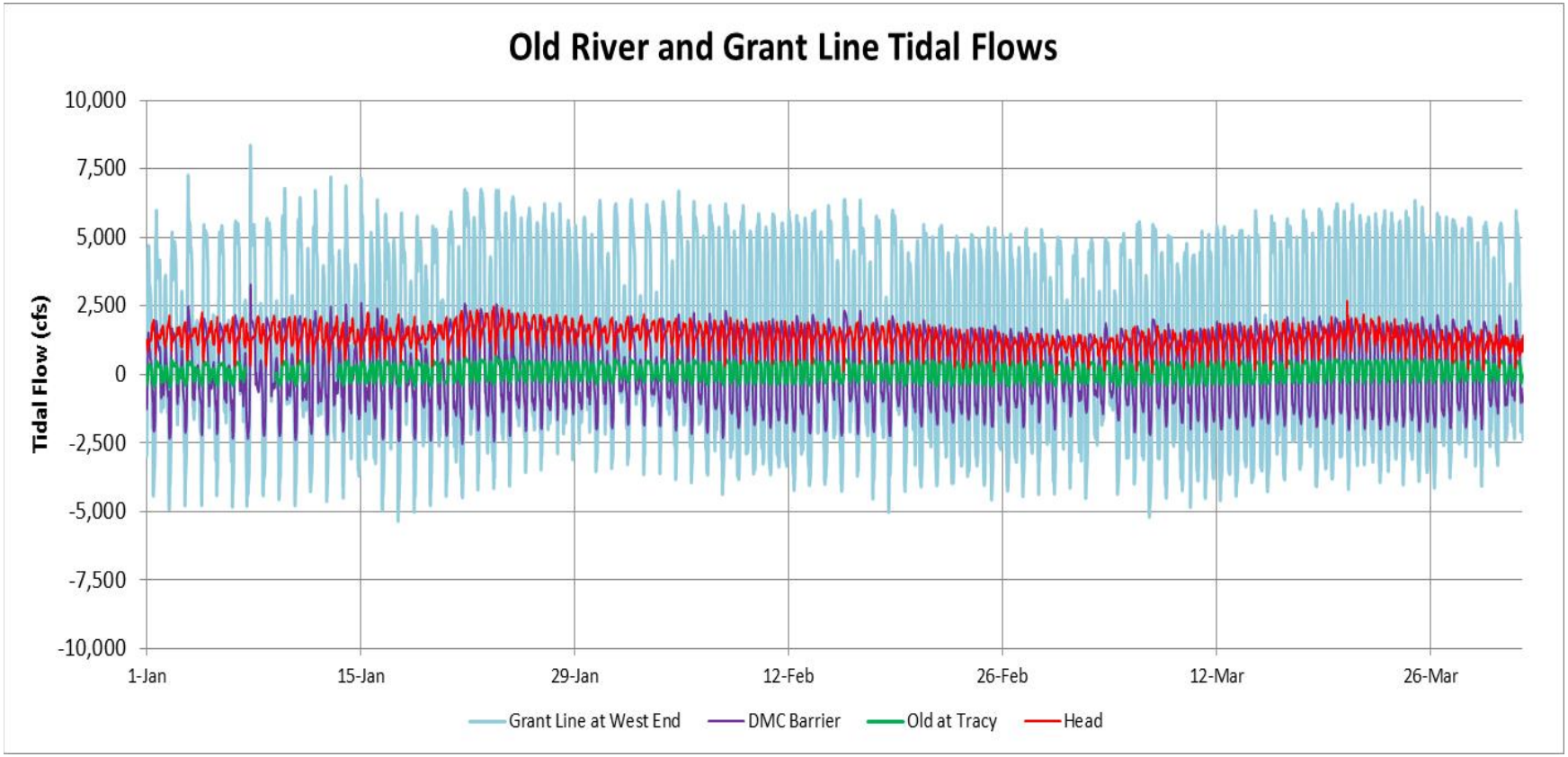
The slightly higher SJR flows in April and May did not raise the head of Old River elevations because the temporary barrier (with eight open culverts) was installed. The minimum daily tidal elevations in Old River were increased to about 3 feet in April when the DMC barrier was installed, and were increased to about 4 feet in May and June when the Grant Line Canal barrier was installed (with six 4-feet diameter culverts opened). The Old River elevations downstream of the DMC barrier (data beginning again at the end of June) indicate the effects of the DMC and Grant Line Canal temporary barriers on the tidal elevations upstream of the barriers.



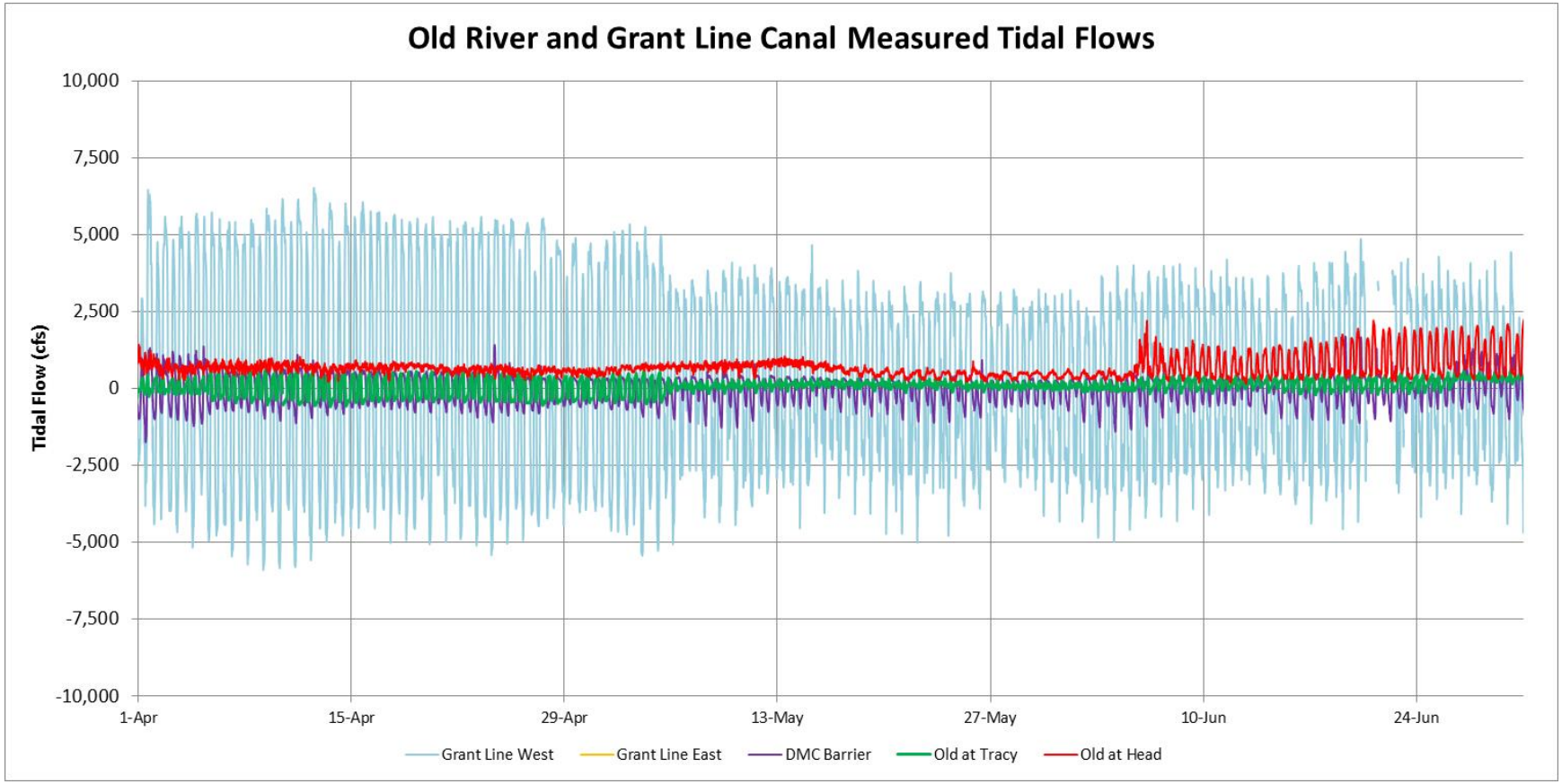
The six flap-gates on the Grant Line Canal temporary barrier were operated beginning on June 30, so the full effects of the temporary barriers with flap gates operating were observed from July to mid-October. The tidal elevation range was nearly eliminated upstream of the barriers, with a tidal range of less than 2 feet. There was a net downstream flow of about 500 cfs in Grant Line Canal and about 250 cfs in Old River, but the tidal flushing of salt from Paradise Cut and Sugar Cut was greatly reduced when the tidal range was restricted by the temporary barriers.



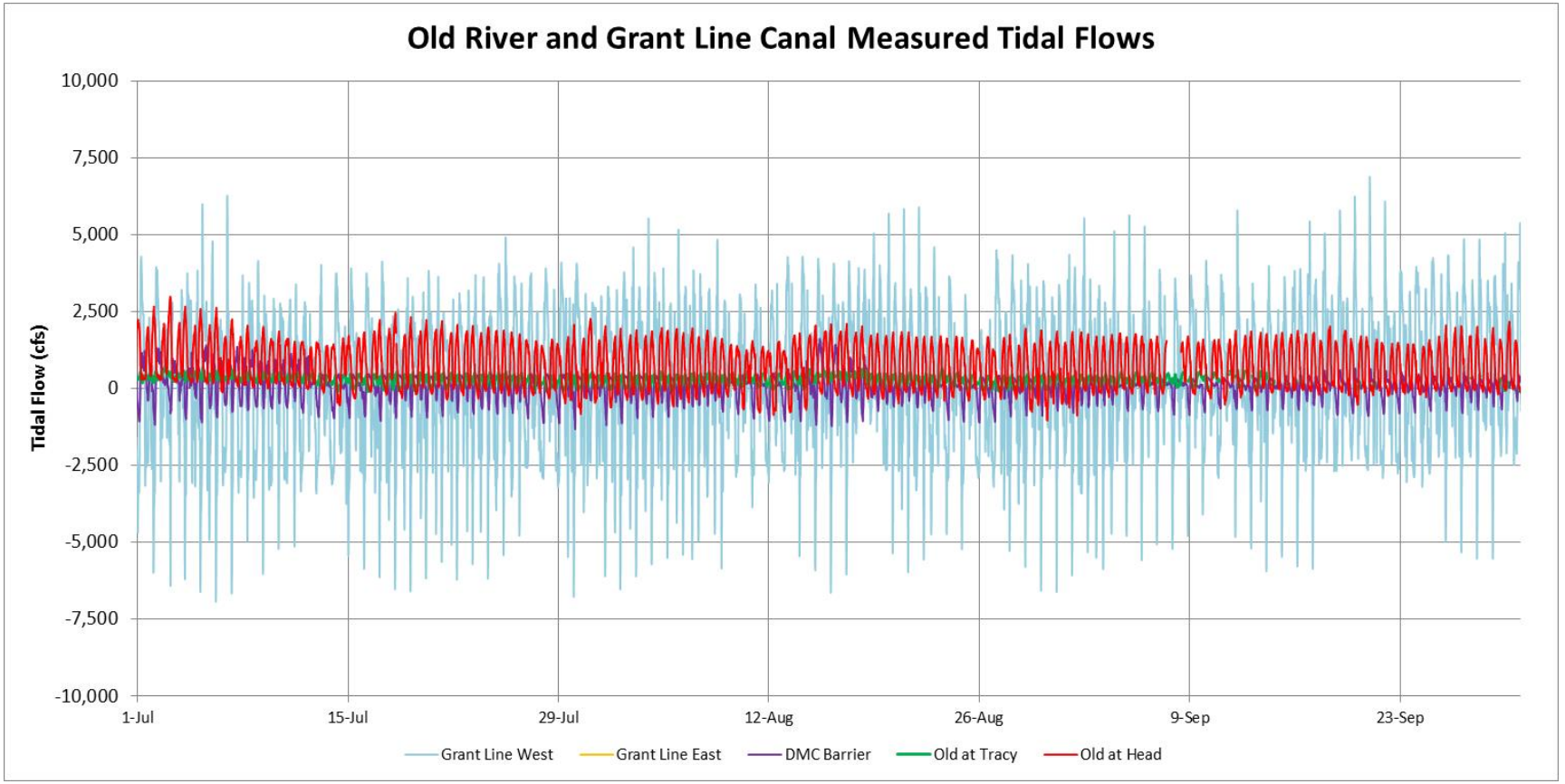
The Old River at DMC and Grant Line Canal temporary barriers were removed near the end of October. Tidal elevations were again uniform (without the temporary barriers) throughout the south Delta channels (delayed by 1-2 hours from Jersey Point), with a tidal range of 2 feet to 6 feet during spring tides.



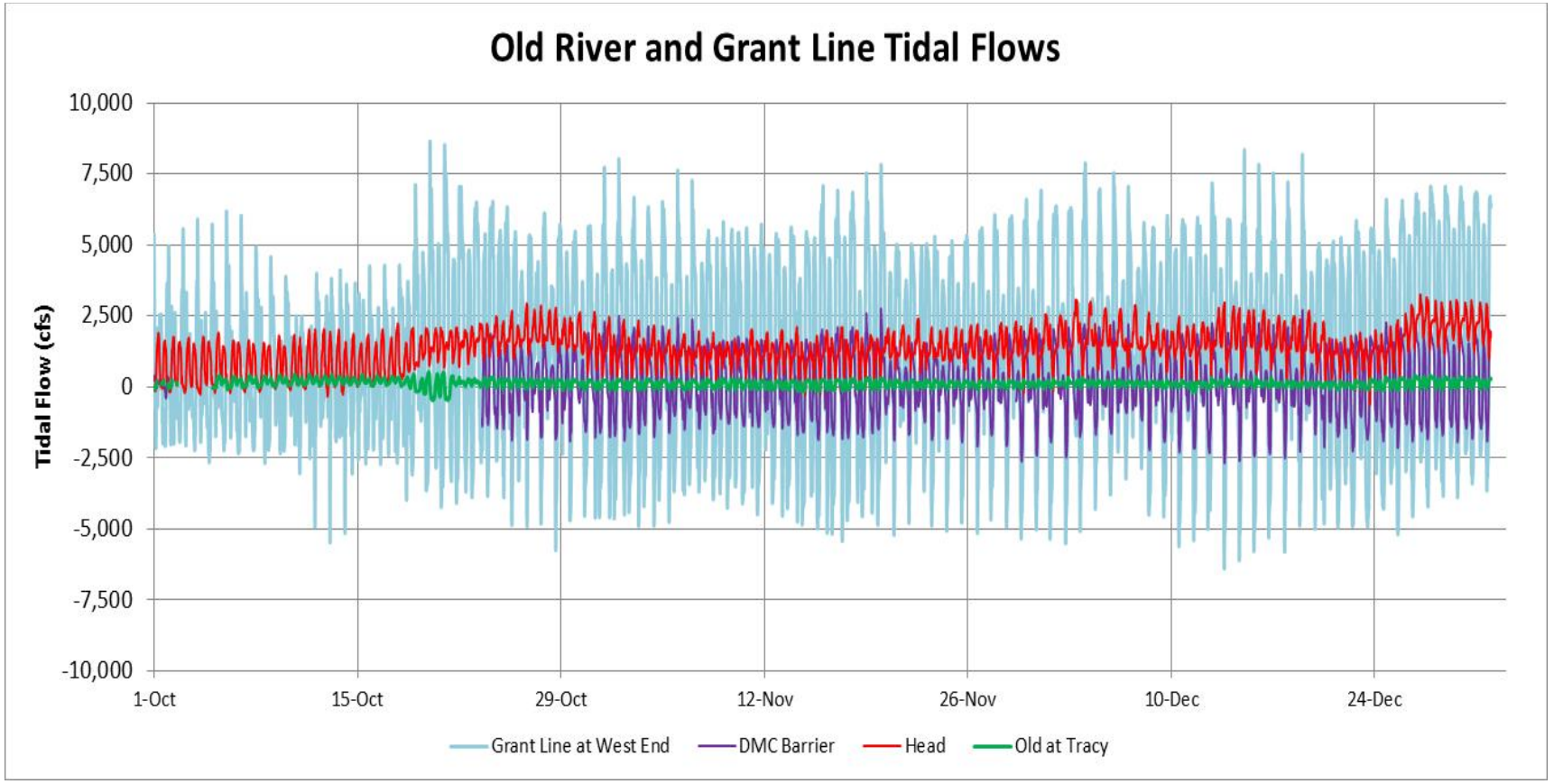
Tidal flows measured at the western end of Grant Line Canal and in Old River at the DMC barrier location indicate the maximum tidal flows in these south Delta channels during the January-March period with no temporary barriers. Tidal flows at the western end of Grant Line Canal (light blue line) varied from -5,000 cfs to 5,000 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). Tidal flows in Old River at Tracy Boulevard were much smaller and varied from -250 cfs to about 500 cfs (average flow of about 125 cfs), and The tidal flows in Grant Line Canal were large because this is the major south Delta channel; most of the tidal flow moves through the western end of Grant Line Canal.



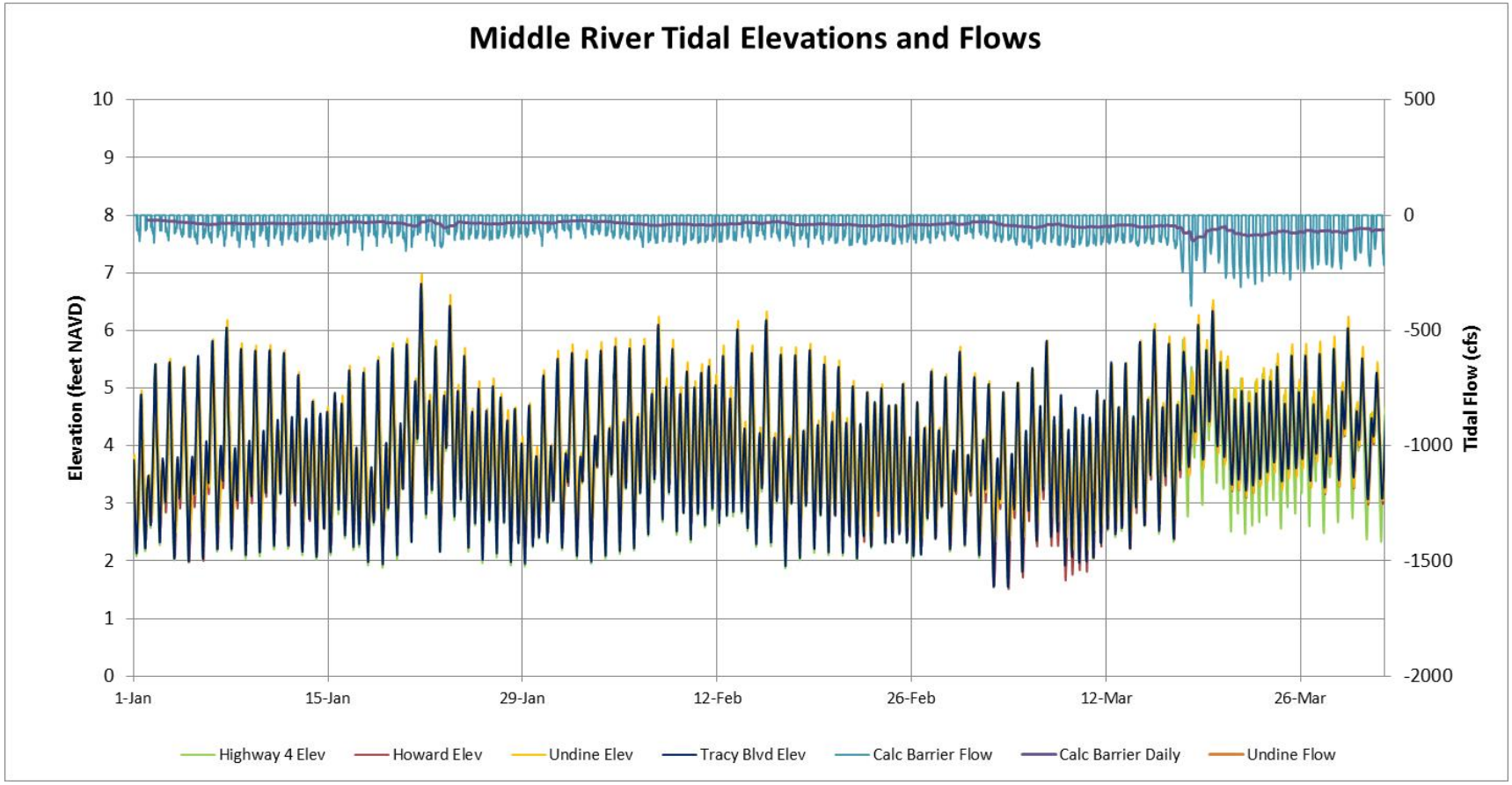
The effects of the temporary barriers were observed in the tidal flows for April May and June. The head of Old River barrier (with eight culverts open) reduced the tidal flows at the head of Old River station, and reduced the net flow to about 500 cfs in April and May. The tidal flows at the head of Old River increased when the barrier was removed in early June. The Old River at DMC barrier was installed with flap gates in early April, so the downstream tidal flows at the DMC barrier were nearly eliminated. The grant Line Canal barrier was installed with flap gates open in early May, reducing the tidal flows at the western end of grant Line Canal by about 50% (tidal range of 5,000 cfs rather than 10,000 cfs) because tidal flows were substantially reduced at the Grant Line Canal barrier near Tracy Boulevard. The Old River at Tracy flow station was not operating in these months.



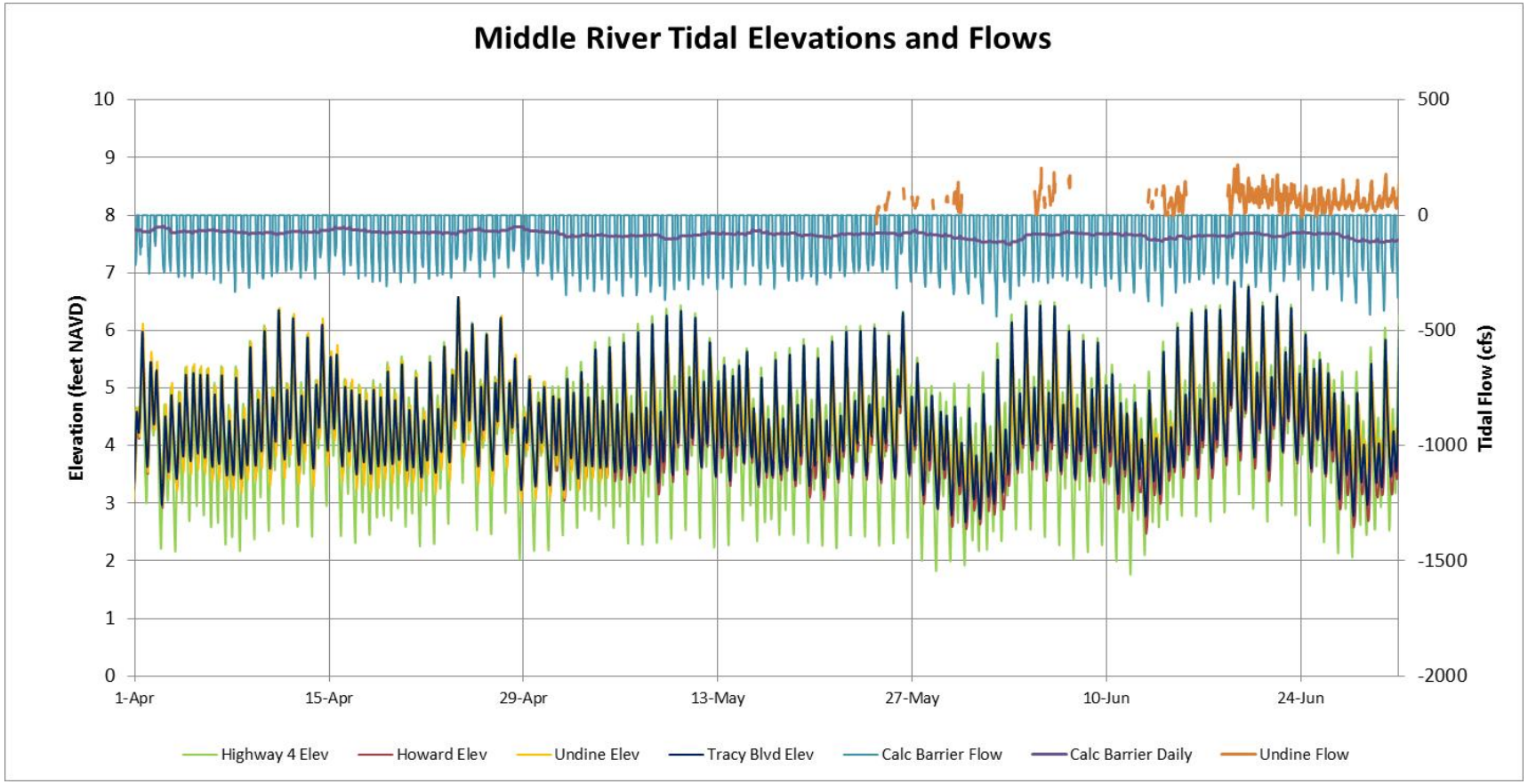
The flap gates began operating at the Grant Line Canal barrier in July, and this allowed the tidal flows in Grant Line Canal to be greater during flood tide (upstream, negative flow). The tidal flows at the head of Old River ranged from -250 cfs to 2,000 cfs with an average (net) flow of about 750 cfs in these summer months. 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, and the tidal flows at Tracy Boulevard were small (tidal range of 250 cfs. The temporary barriers raised the minimum elevations upstream of the barriers but nearly eliminated tidal flow variations.



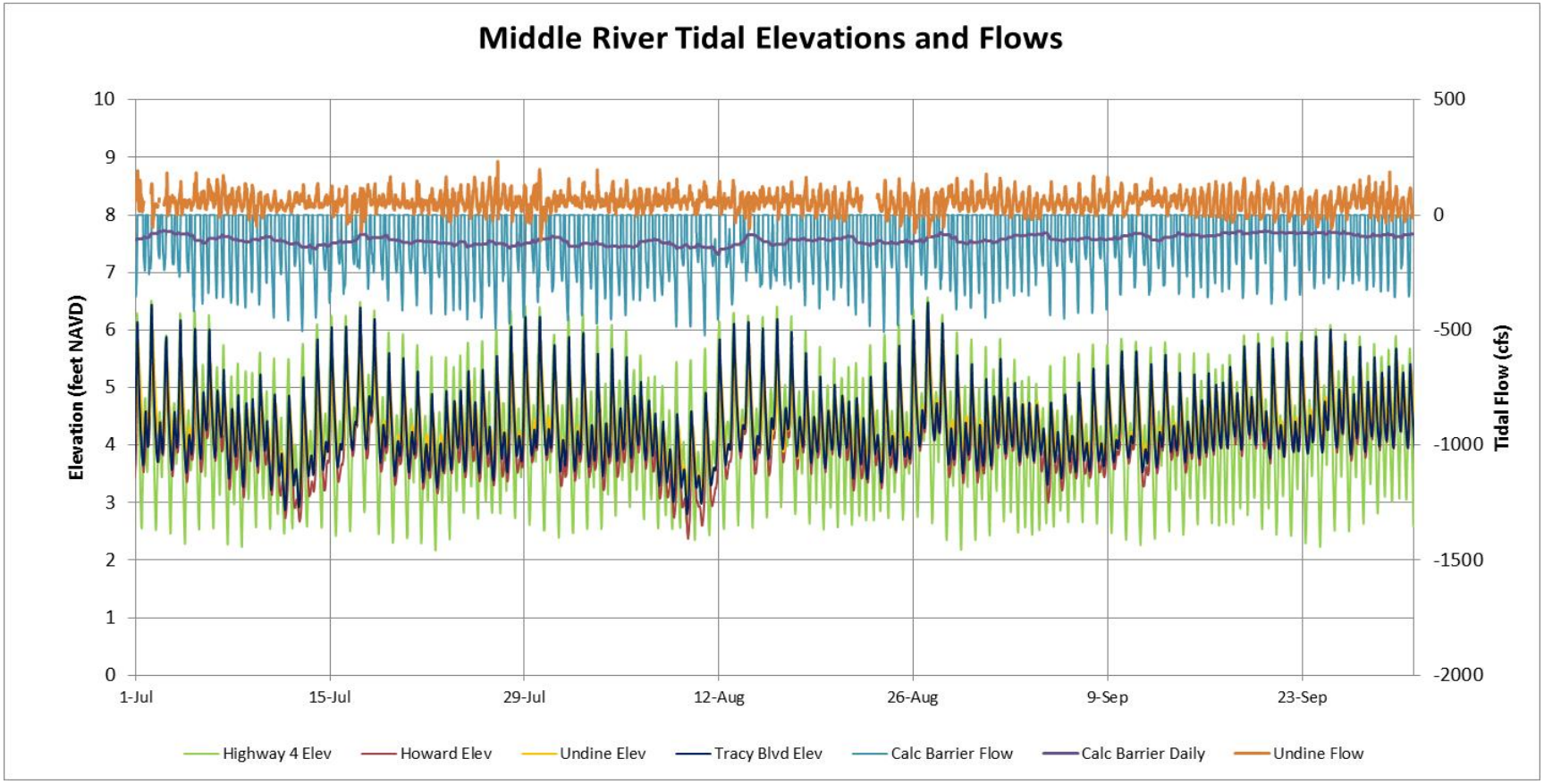
The temporary barriers in Old River at the DMC and in Grant Line Canal at Tracy Boulevard were removed in late October, and the tidal flow variations increased. The tidal flows in Grant Line Canal ranged from -5,000 cfs to 7,500 cfs in November and December, when the head of Old River (net) flow increased to 1,500 cfs and combined export pumping ranged from 5,000 cfs to 10,000 cfs. The tidal flows in Grant Line Canal were shifted to a single flood tide (filling to the higher-high tide) which is consistent with the operations of CCF gates to allow the maximum tidal elevations in the south Delta channels by closing the gates during the higher-high flood tide period.



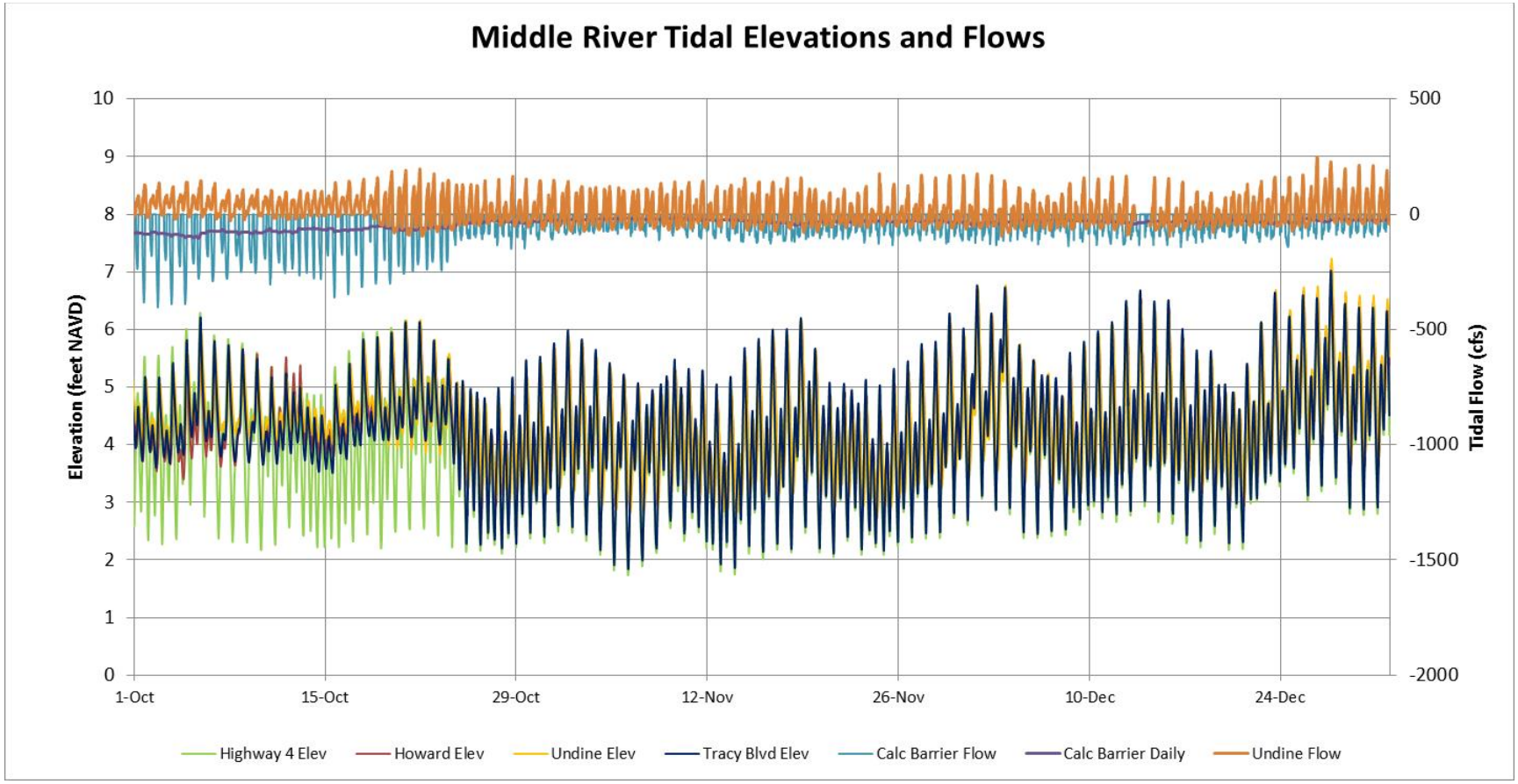
Middle River tidal elevations were similar to tidal elevations in all other south Delta channels from January through mid-March, when the Middle River barrier was constructed, although the six flap-gates were left open until April. The barrier flow was calculated assuming the flap gates were operating, with the six culverts allowing an upstream (negative) flow of about 300 cfs with an elevation difference (downstream – upstream) of 1 foot, according to a culvert equation as: flow (cfs) = 300 x elevation difference ^0.5. The tidal flows without any barrier would depend on the water slope and the conveyance area, according to the Manning open-channel flow equation as: flow (cfs) = 2,000 x elevation difference ^0.5. Although the elevation differences were generally smaller without the barrier, the tidal flows were estimated to be 500-1,000 cfs, and the net flow near the barrier was estimated to be about 10-15% of the Old River flow.



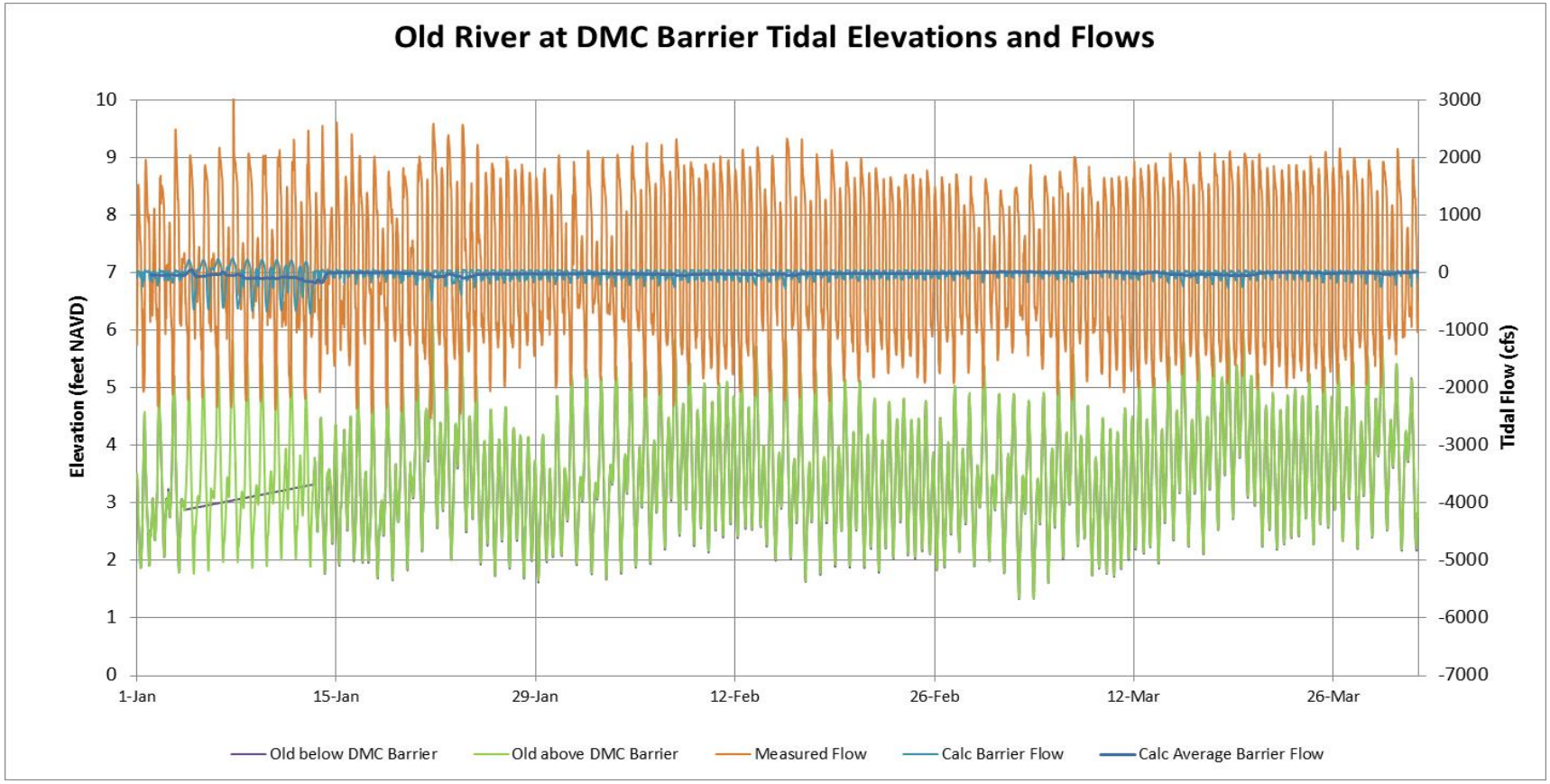
The flap gates on the six culverts were closed at the beginning of April, and the minimum tidal elevations upstream of the barrier were increased to about 3.5 feet, about 1 foot higher than the minimum elevations at Highway 4 (green line). The tidal elevations at the Head of Middle River were increased at the beginning of May when the Grant Line Canal was installed, which raised the tidal elevations in the upstream portion of Old River. The minimum elevations at Howard Road (brown line) fluctuated with the spring-neap tide, and remained about 1 foot higher than the minimum elevations at Borden. The calculated upstream tidal flow (bright blue line) through the culverts or over the weir crest (4.5 feet) were about 100-150 cfs, and the measured flow at Undine Road, near the head, were about 25-50 cfs, suggested that agricultural diversions along Middle River were a maximum of about 200 cfs. With the barrier installed, water is entering Middle River from upstream and downstream to supply agricultural diversions. The daily graphs for Middle River EC indicate that the EC was greatest at Howard Road.



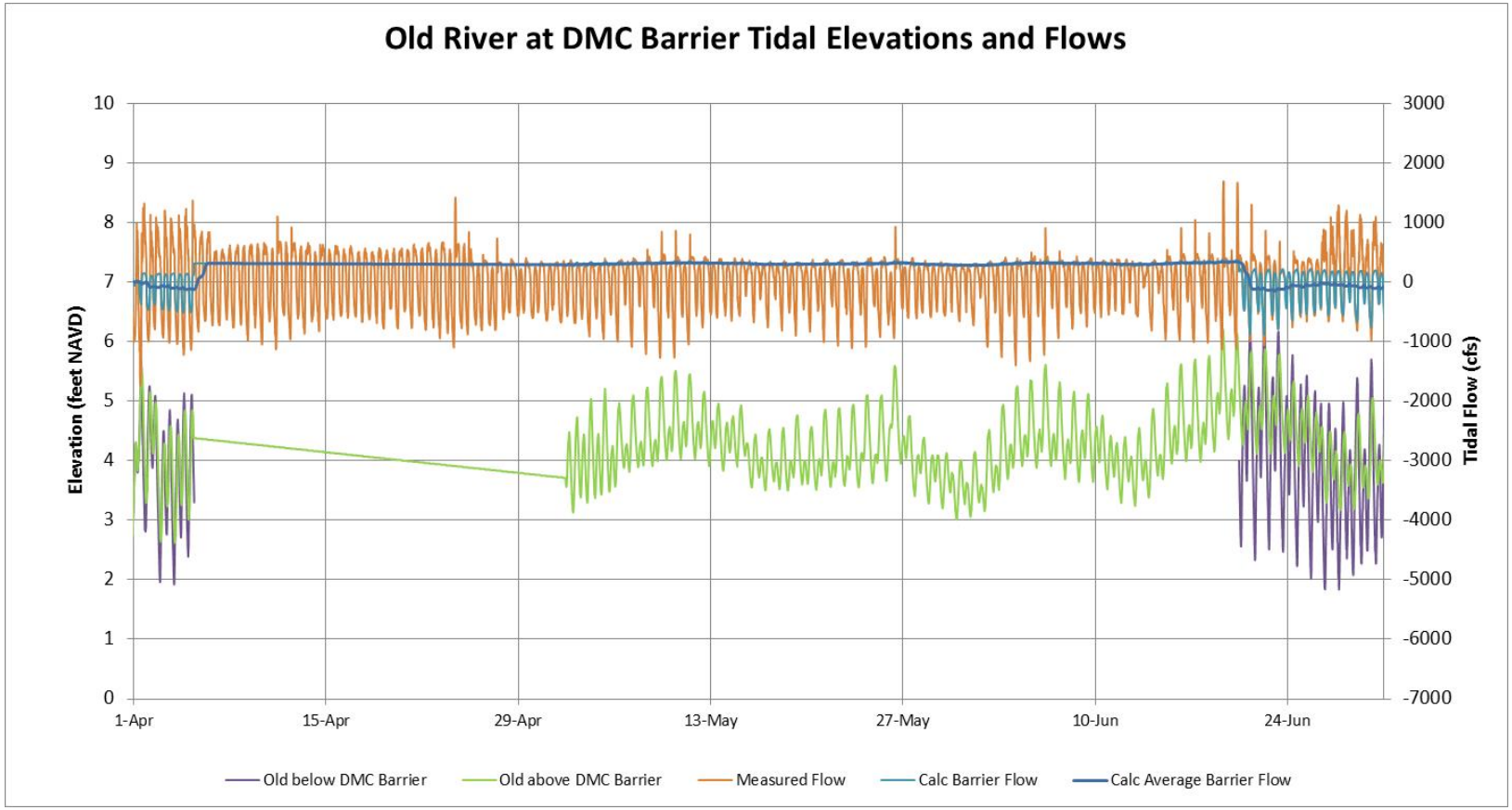
During this period when the three barriers in Middle River, Grant Line Canal, and Old River at DMC were installed, minimum tidal elevations in Middle River upstream of the barrier were about 1 to 1.5 feet higher than the minimum elevations at Highway 4. The measured tidal flows at Undine were positive, and the estimated tidal flows at the barrier are negative (upstream) so flow is entering this 10 mile (17 km) reach from both ends. Because there are several drainage pumps discharging to this section of Middle River, the EC at Howard Road is greater than the EC entering at the barrier.



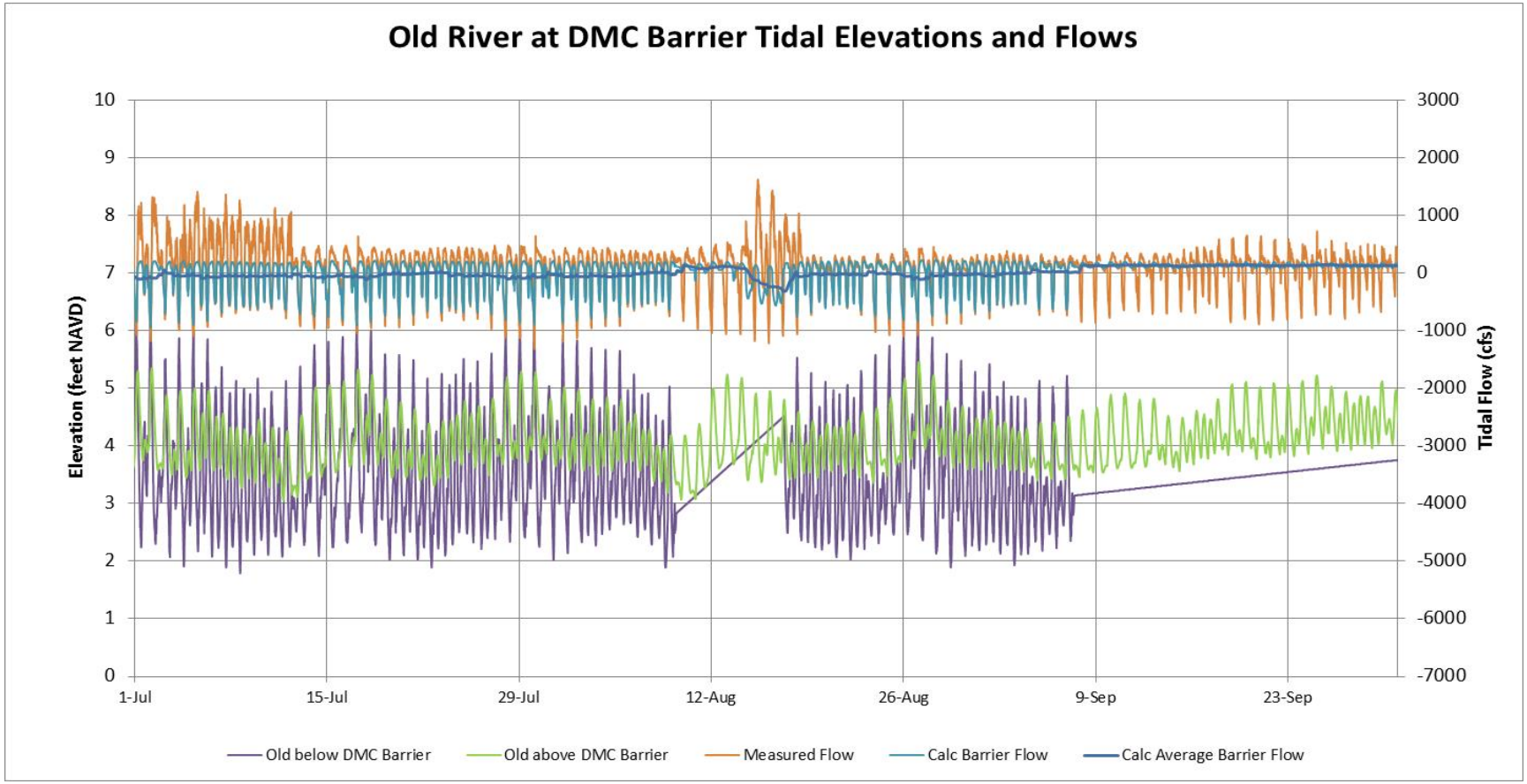
The Middle River, Old River at DMC and Grant Line Canal barriers were all removed near the end of October, and the full range of tidal elevations are measured at all Middle River stations. The measured tidal flows at Undine Road remain similar to the period with the barriers, but the estimated Middle River barrier flow (bright blue line) is not accurate- the tidal flow estimates for open channel flow are much larger (500-1,000 cfs). The benefits from the Middle River barrier (increasing minimum elevations) should be considered in relationship to the water quality effects (increased EC). Perhaps some localized dredging would allow all diversion pumps (or siphons) to be operated without the need for the Middle River barrier.



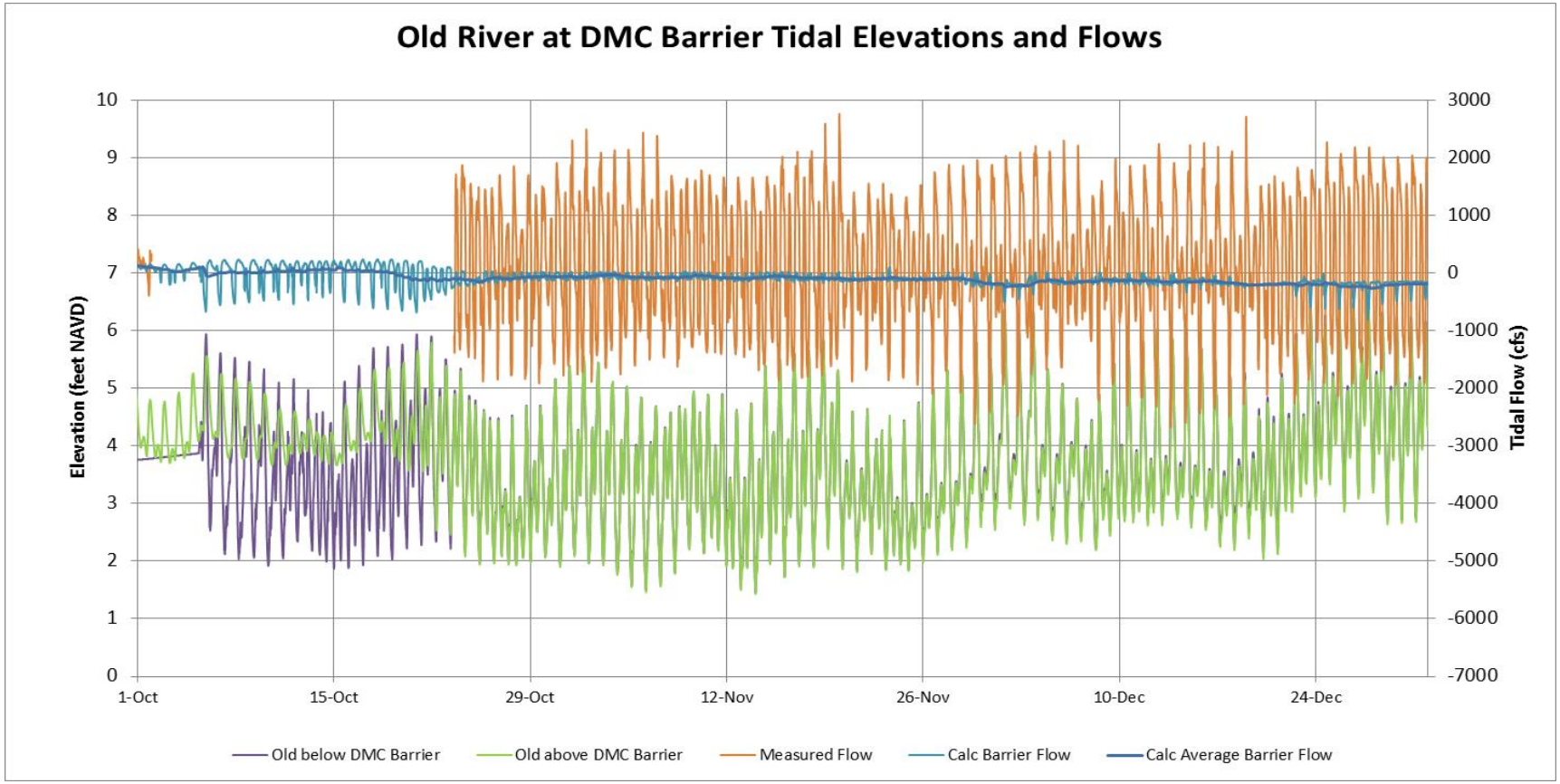
Tidal elevations at the Old River at DMC barrier were similar to tidal elevations in all other south Delta channels from January through March (below barrier elevations missing in early January). The barrier flow was calculated assuming the flap gates were operating, with the six culverts allowing an upstream (negative) flow of about 450 cfs with an elevation difference (downstream – upstream) of 1 foot, according to the culvert equation: flow (cfs) = 450 x elevation difference ^0.5. The measured tidal flows (without any barrier) ranged from -2,000 cfs to 2,000 cfs.



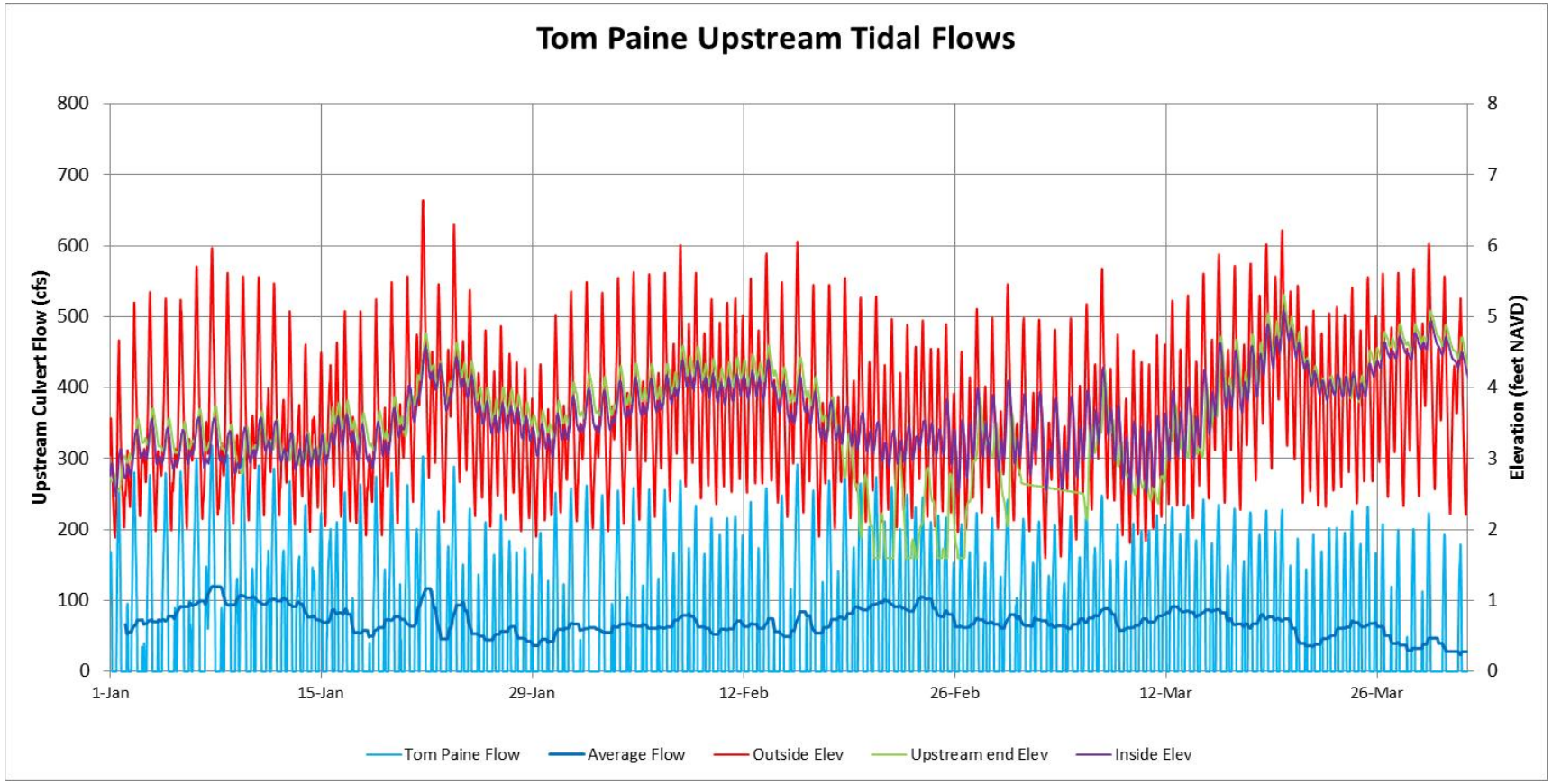
The Old River at DMC barrier was installed in early April with all 9 flap gates operating. The measured tidal flows were substantially modified; there were only a few ebb-tide flows over the barrier (4.5 feet) at high tides, and the flood-tide flows were reduced to a maximum of about -1,000 cfs. The calculated flood-tide flows (blue line) at the end of June (elevations recorded) matched the measured tidal flows well. Three of the flap-gates were opened at the end of June, allowing higher ebb-tide flows (not calculated, because the flap-gates were assumed to be operating).



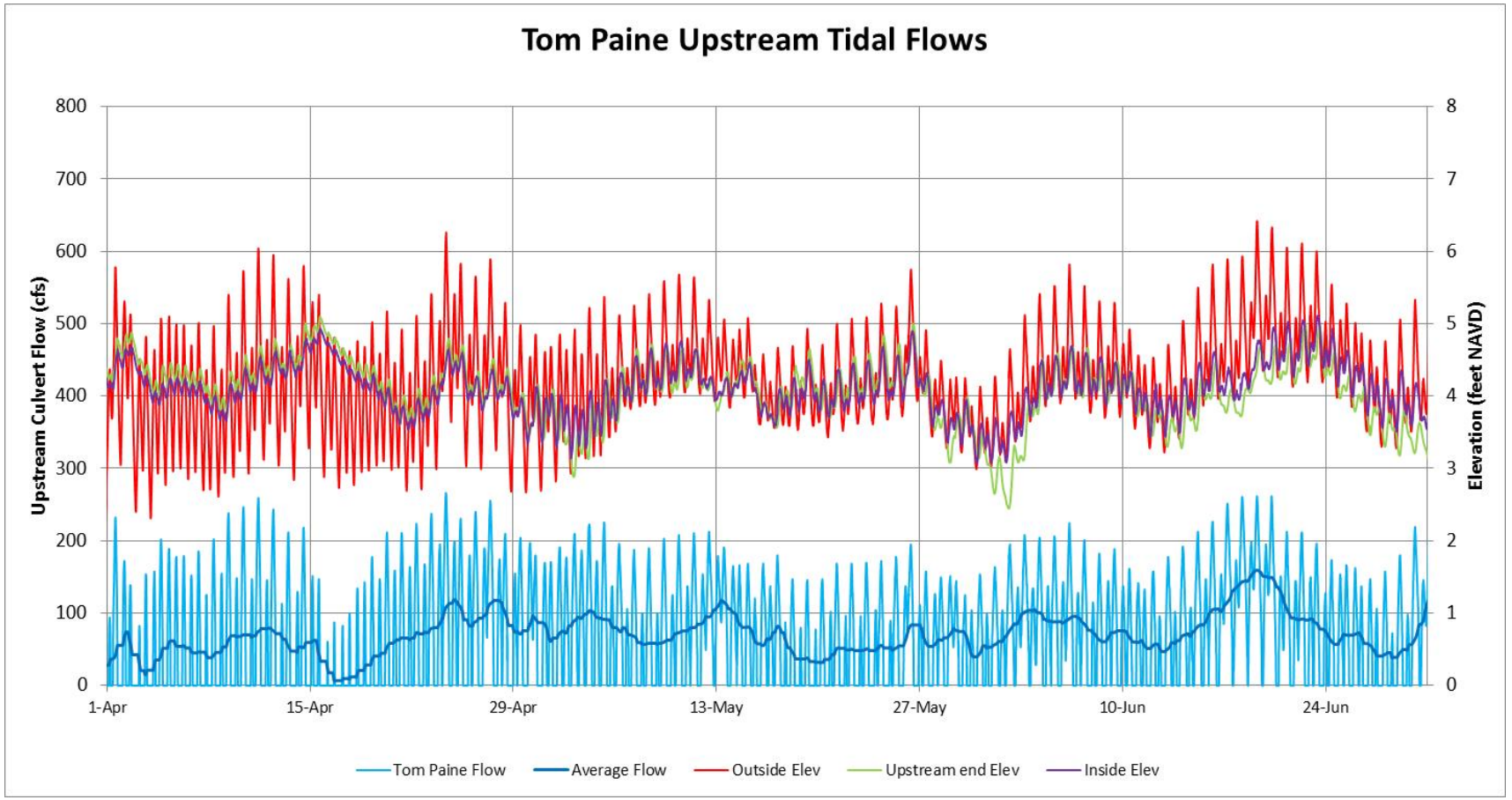
The Old River at DMC barrier had three culverts open in early July and five culverts open in mid-August; the ebb-tide flows were correspondingly increased. The measured tidal flows indicate some leakage through the ruck barrier during ebb tides, when the downstream elevations are less than the upstream elevations.



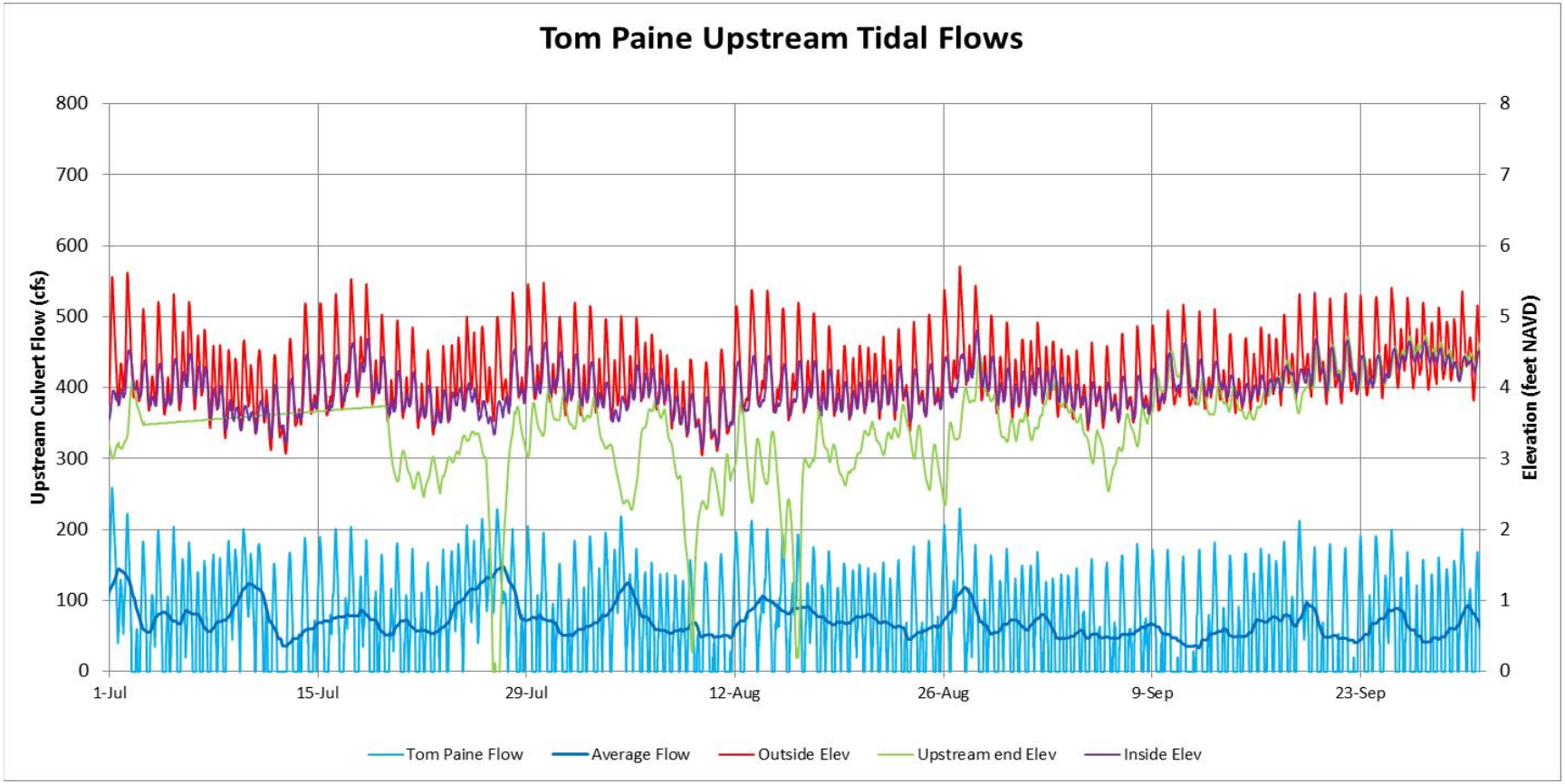
The Middle River, Old River at DMC and Grant Line Canal barriers were all removed near the end of October, and the full range of tidal elevations were measured at the Old River at DMC barrier. The benefits from the Old River at DMC barrier (increasing minimum elevations) should be considered in relationship to the water quality effects (increased EC). Perhaps some localized dredging would allow all diversion pumps (or siphons) to be operated without the need for the Old River at DMC barrier. In particular, full tidal flows in Old River at the DMC barrier would allow lower EC water to be tidally mixed upstream to the Westside ID pumping plant in Wicklund Cut.



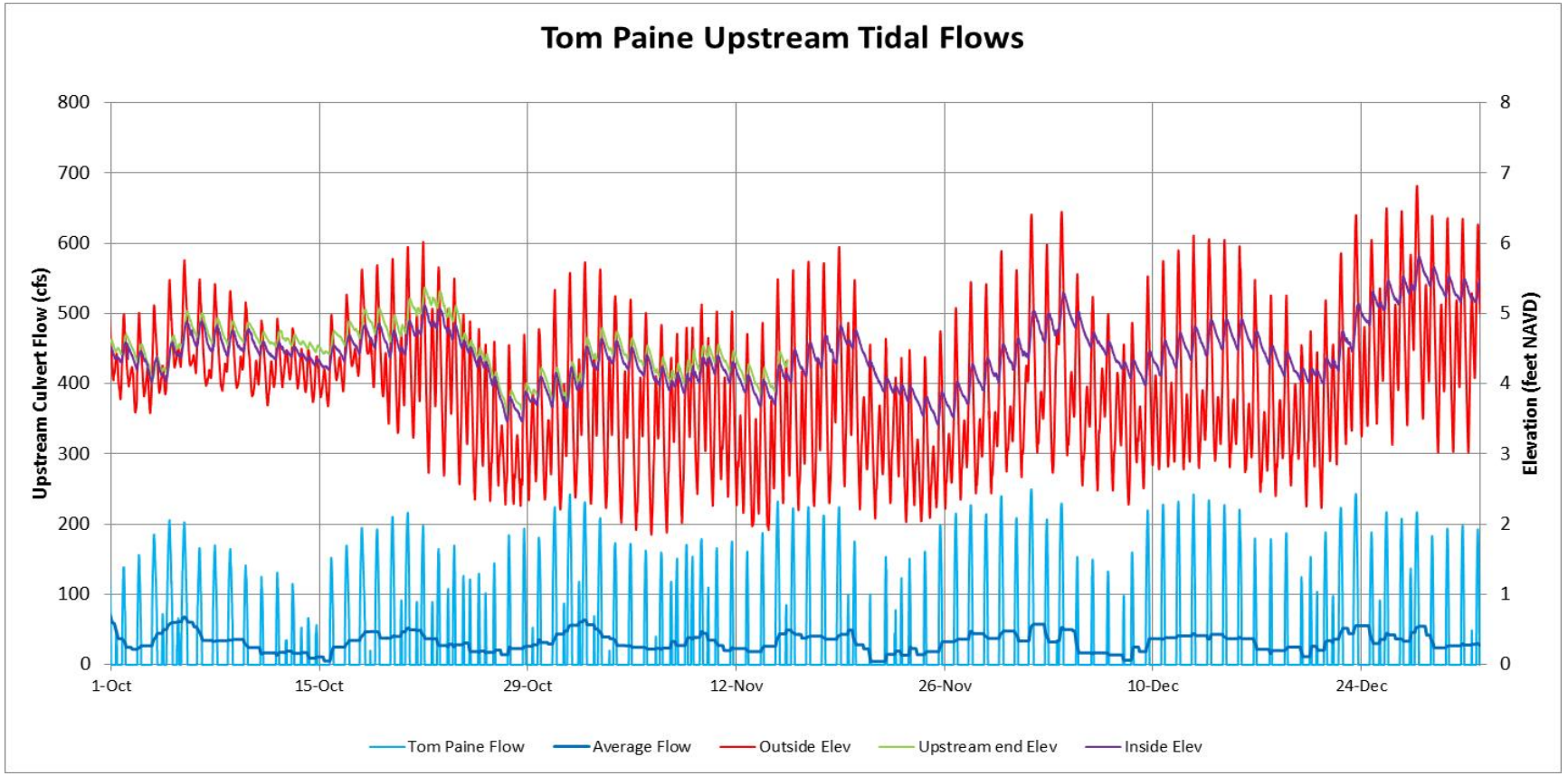
Tidal elevations in Tom Paine Slough are controlled by two box culverts and four siphons with flap gates. Diversions do not usually begin until April, so the upstream elevation (purple line) follows the average downstream tide elevation (red line). The flood tide flow was calculated as: Upstream Flow (cfs) = 300 x Elevation Difference (feet) ^ 0.5. The calculated flow was too high for this period, because the siphons would not be operated; flow would move both directions in the January-March period through the culverts because the flap gates were open.



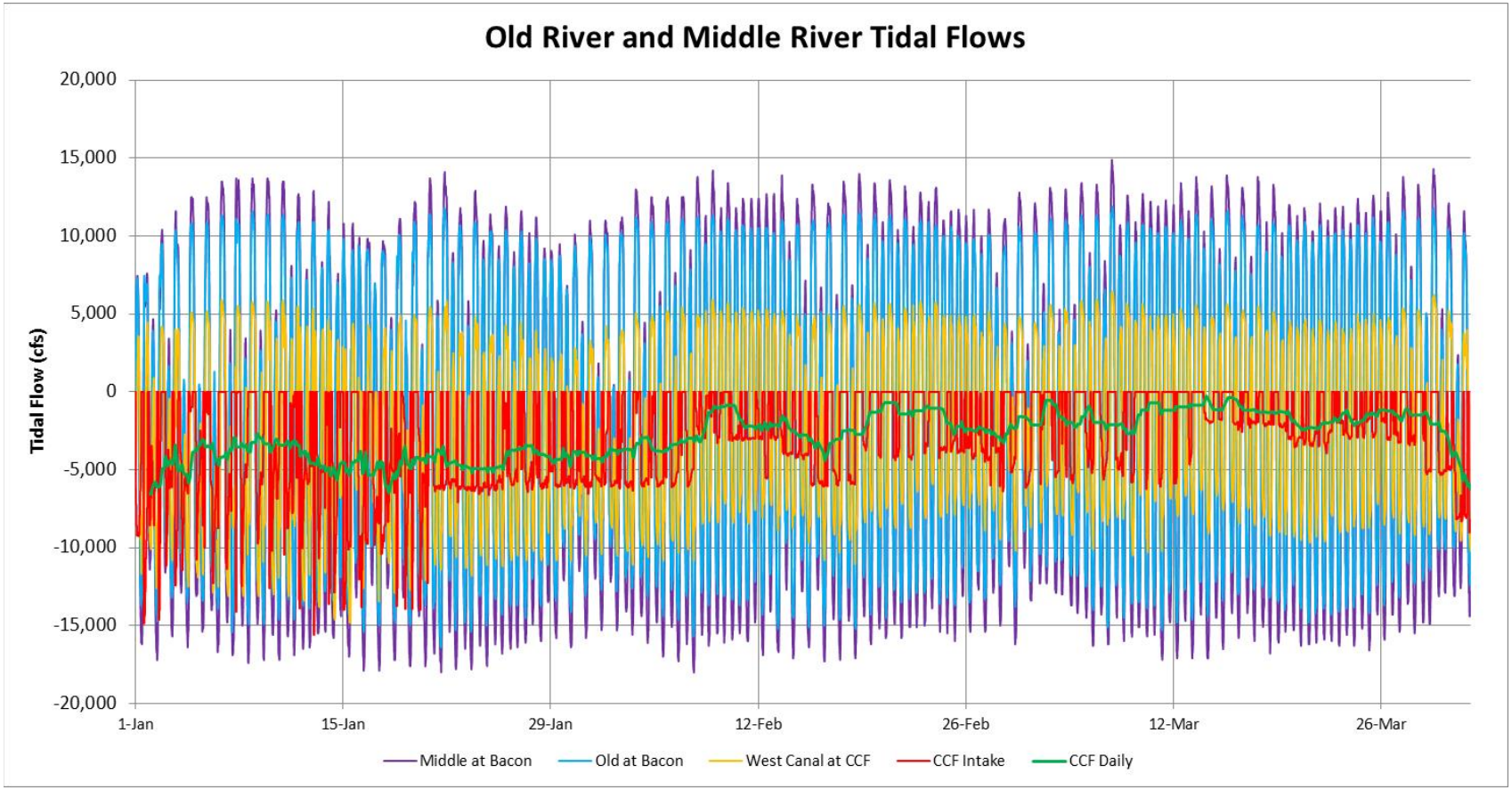
The downstream tidal range was reduced in May when the Grant Line Canal barrier was installed. Diversions from Tom Paine Slough likely began in April, because the upstream elevations declined to the minimum downstream elevations. The calculated diversions were about 100 cfs (dark blue line) and the minimum water elevations ranged from about 3 to 4 feet. A diversion flow of 100 cfs would be much larger than the higher salinity inflow (salt source) to Sugar Cut; therefore, most of the Sugar Cut salt load was likely diverted into Tom Paine Slough during the irrigation season. An EC measurement was added to the upstream Tom Paine elevation station in 2014 to confirm this condition.



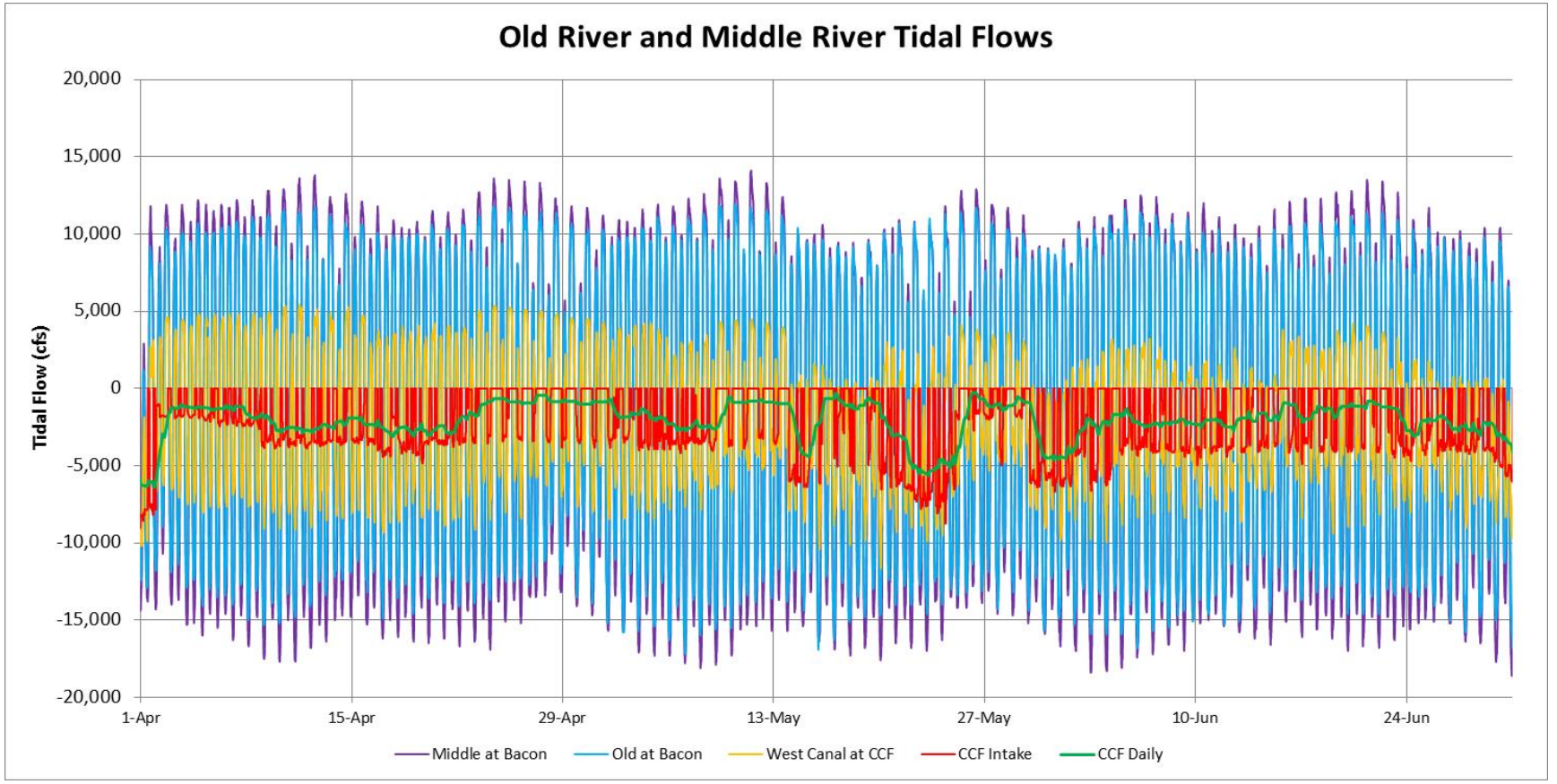
The tidal range in Old River and in Sugar Cut (at Tom Paine Slough) was substantially reduced by the temporary barriers in the summer months. The calculated tidal flows and daily average diversions into Tom Paine Slough (dark blue line) were about 100 cfs; this was likely not enough to sustain full historical deliveries from Tom Paine Slough. This negative effect of the temporary barriers on reduced high tide elevations and on reduced water supply diversion to Tom Paine Slough should be considered along with the effects on tidal flushing of salt in the south Delta channels.



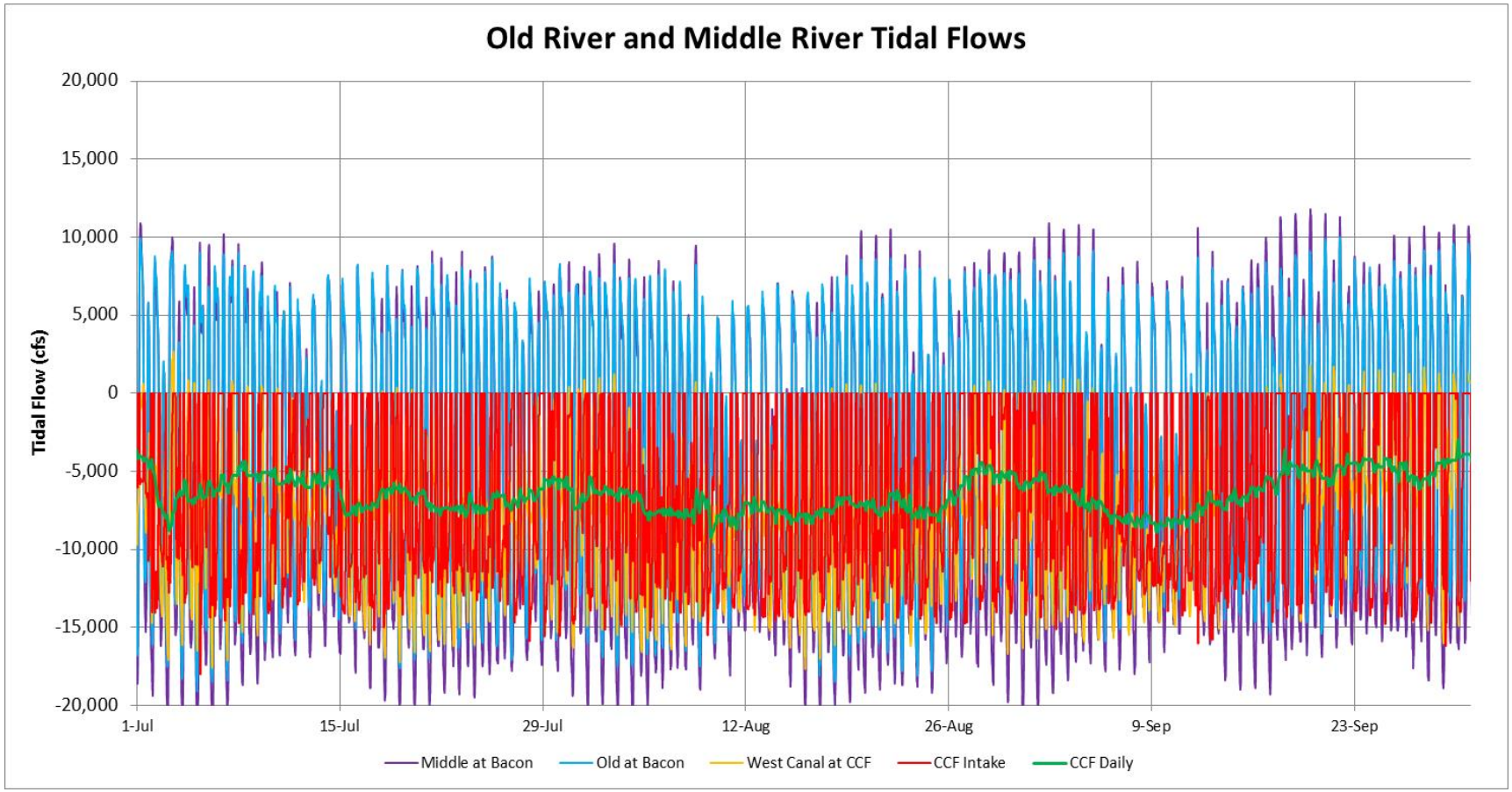
Diversion from Tom Paine Slough had likely ceased in the October-December period, because the upstream tidal elevations remained high (average of downstream elevations). The daily fluctuations in the upstream water elevations (2-3 inches per day) indicate that at least one of the culverts was open; the increasing elevations in December suggest that perhaps the other culvert flap gate was still operating (open on flood tide).



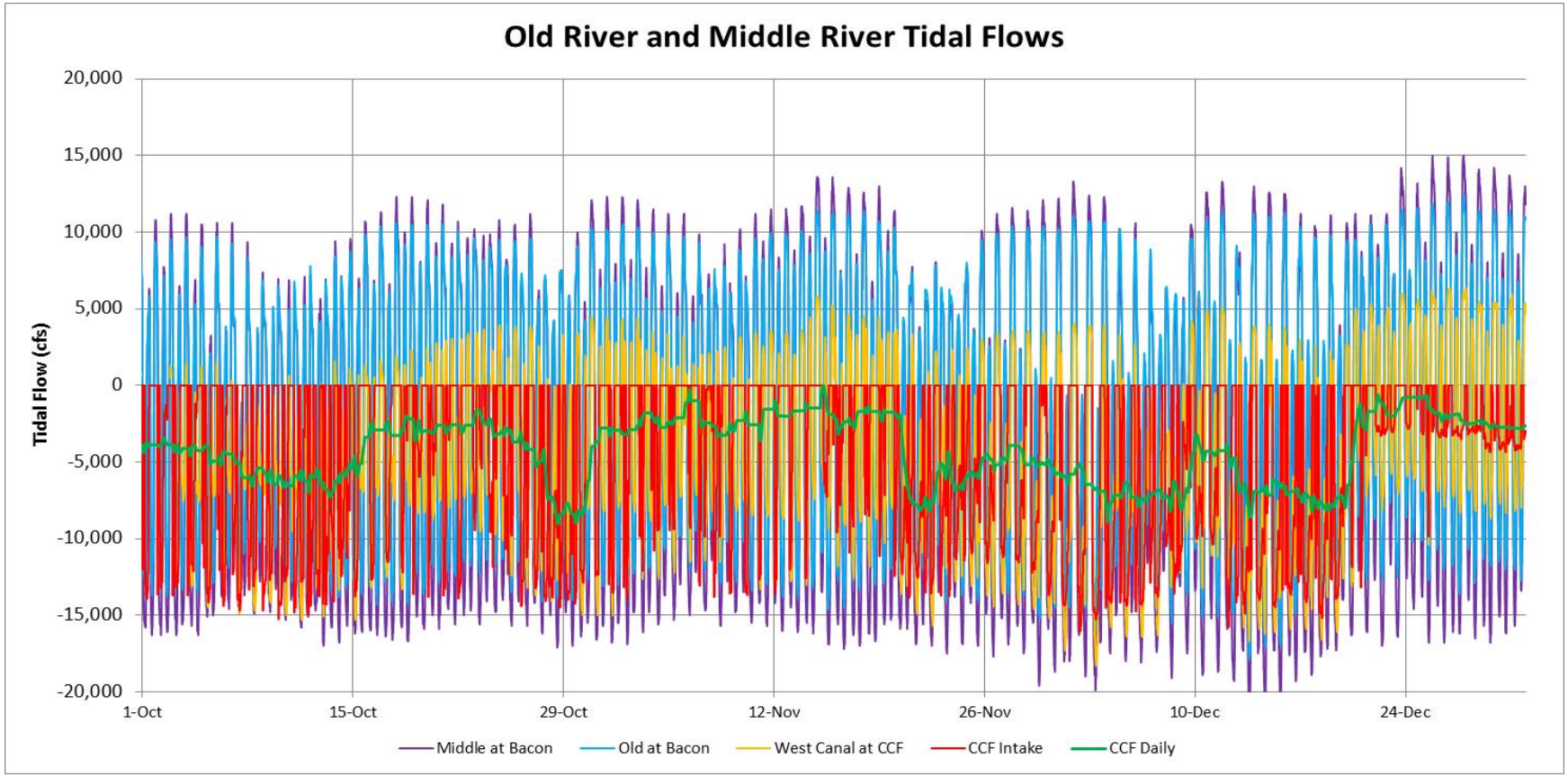
Tidal flows in Middle River at Bacon Island (purple line) and in Old River at Bacon Island (blue line) were similar, although the tidal flows in Middle River were about 10% higher. The tidal flows in West Canal just downstream of the CCF gates (gold line) were about 25% of the combined Old and Middle River tidal flows (50% of Old or 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 -1,000 cfs to -5,000 cfs (diversions, upstream flow) during this period.



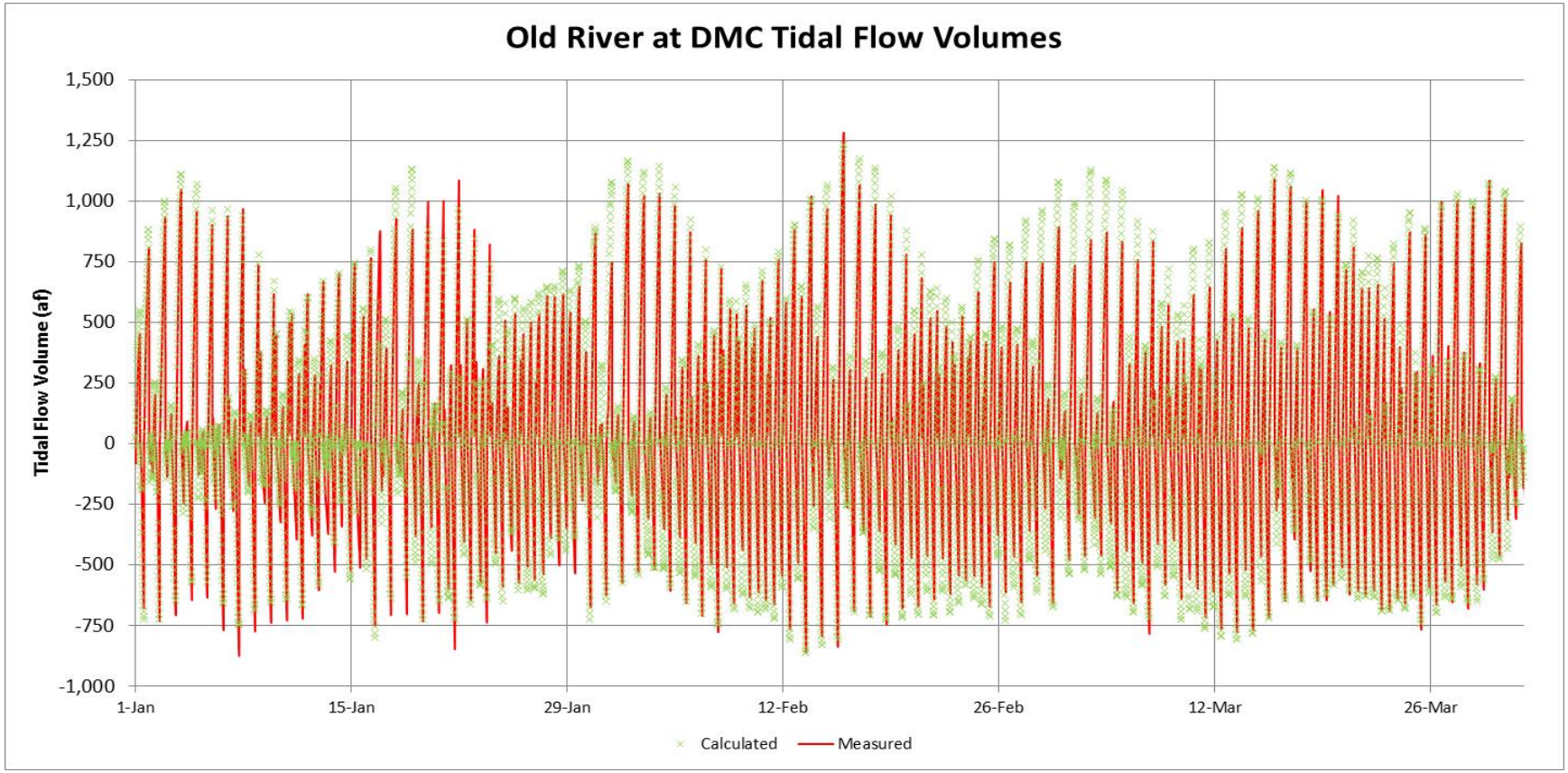
The CCF diversions were reduced considerably in the April-June period for SJR fish protection; the NMFS BiOp RPA restricted CVP and SWP pumping to 1,500 cfs and about half of this was at the CVP Jones pumping plant. The flood-tide flows in Old River and in Middle River were higher than the ebb-tide flows (-15,000 cfs to 10,000 cfs), although the average flood-tide and ebb-tide volumes. The flood-tide flows in West Canal downstream of the CCF intake were slightly higher than the ebb-tide flows (-7,500 cfs to 5,000 cfs).



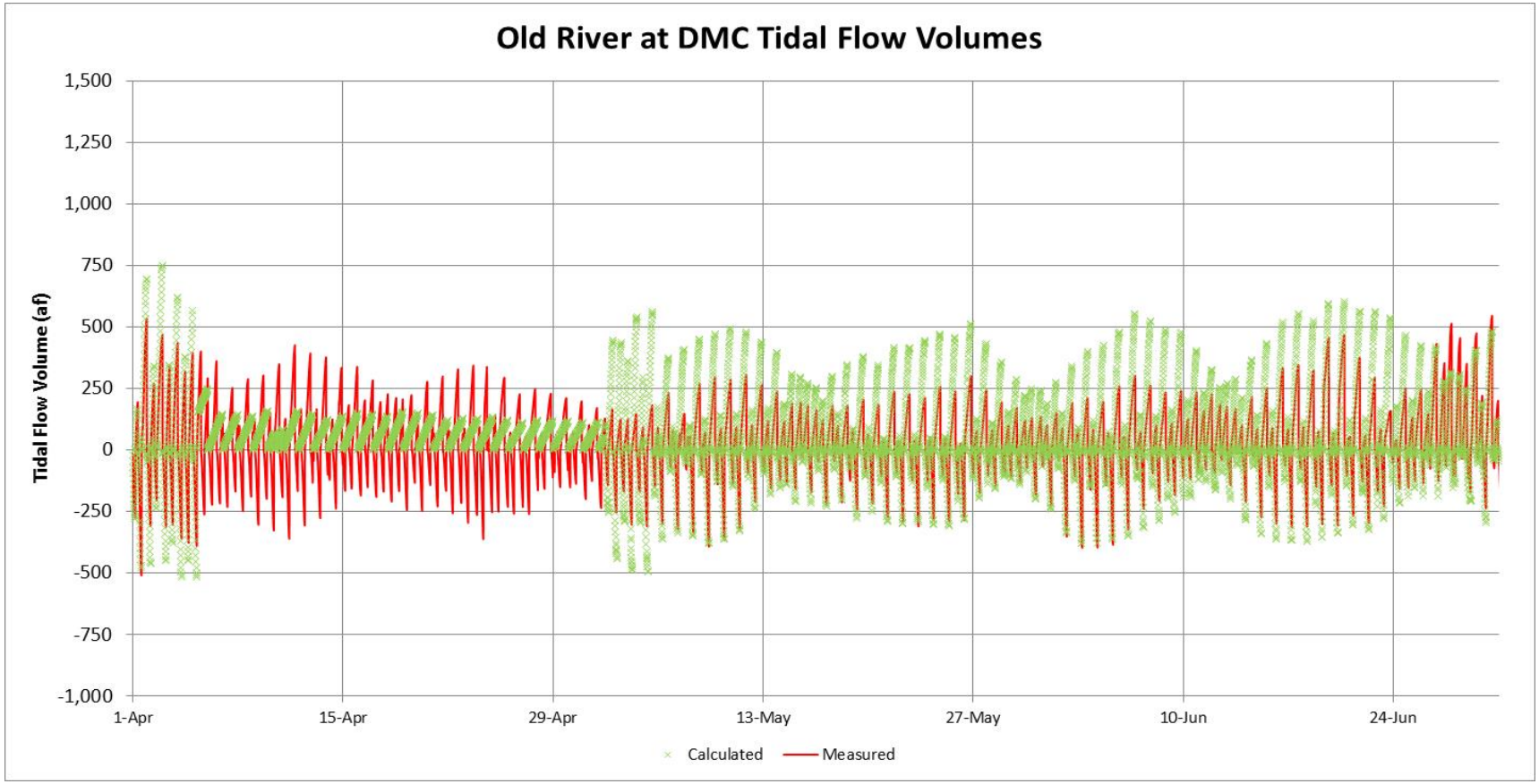
CCF diversions and DMC diversions were increased to maximum pumping of about 10,000 cfs in the July-September period. Nevertheless, there was a moderately strong ebb-tide (downstream) flow of 5,000 cfs to 10,000 cfs during the major ebb tide period each day in Old River at Bacon and in Middle River at 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 upstream into Grant Line Canal and to the DMC intake.



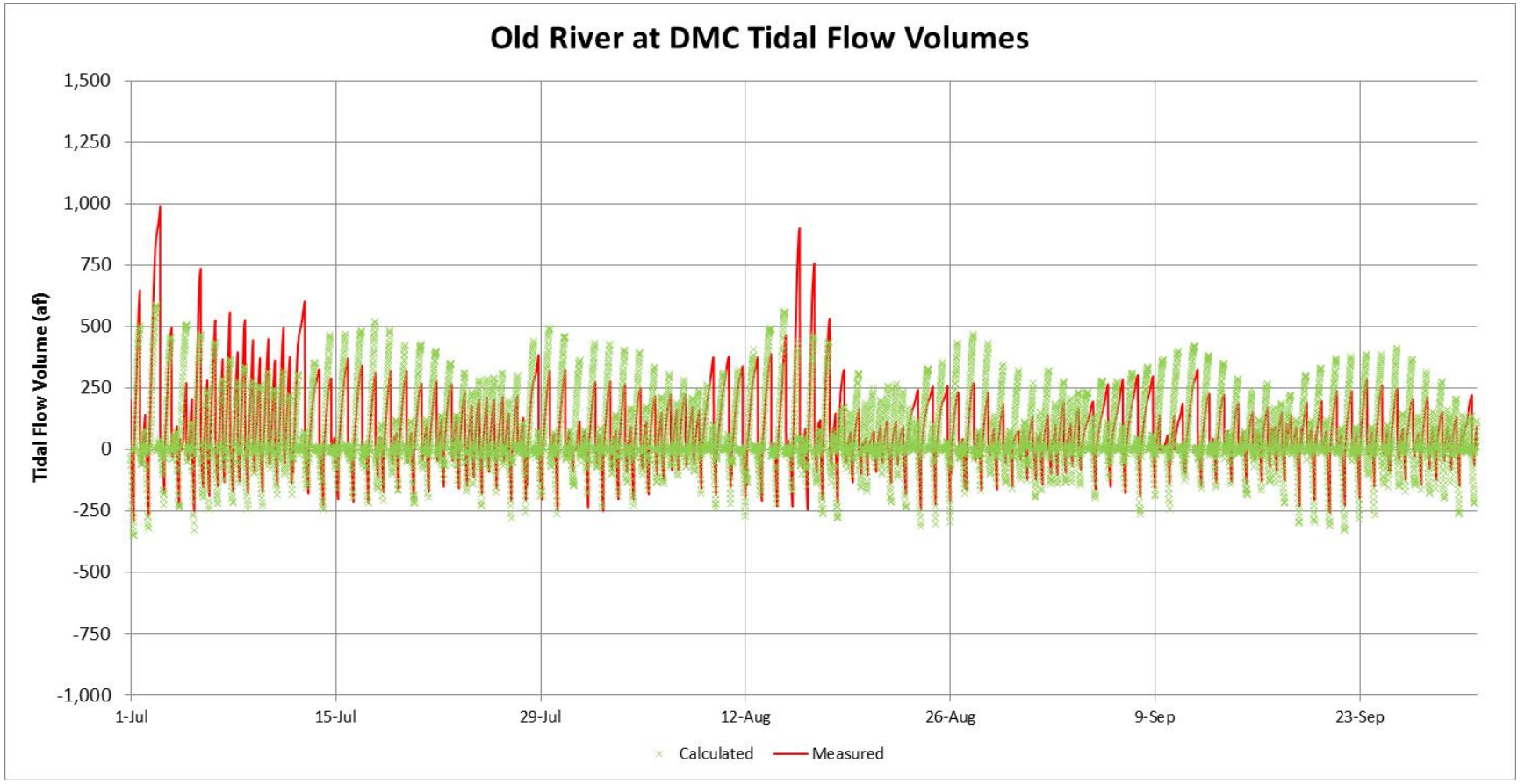
The flow into the CCF is controlled by five tidal gates (each 20 feet wide and 15 feet tall), with a maximum flow of about 15,000 cfs at a head difference of 1 foot. The inflow is controlled by partially closing the five gates to prevent scour from flows of greater than 15,000 cfs (velocities higher than 10 ft/sec) and by closing the gates during the higher-high flood tide period (to preserve the higher-high tide elevation) and when the CCF elevation is higher than the West Canal (Old River) elevation. The CCF diversions ranged from 1,000 cfs to 7,500 cfs during this period.



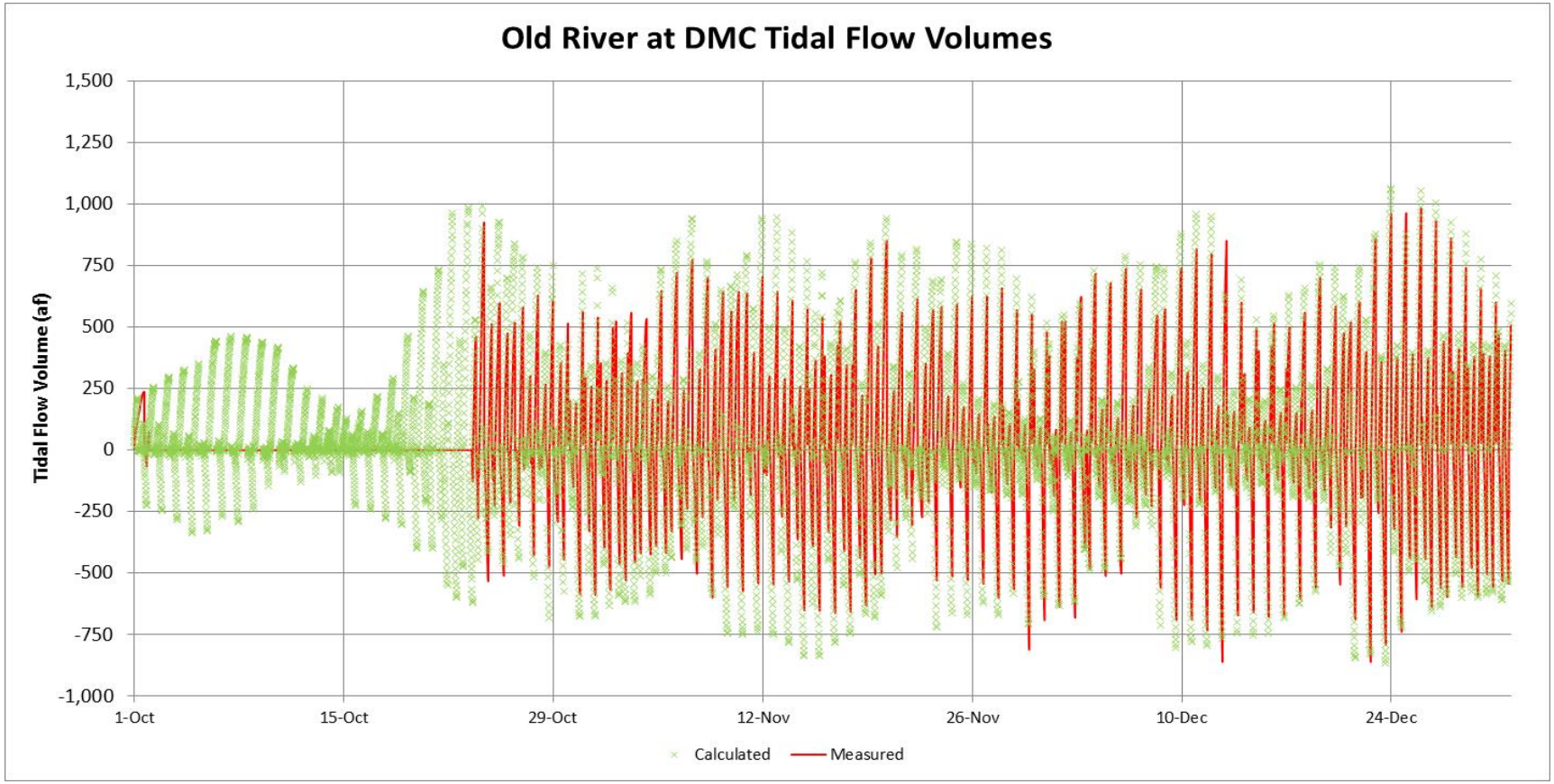
The tidal flow volume can be estimated (calculated) as the change in tidal elevation times the upstream surface area that is filling or draining. For Old River at the DMC barrier, the upstream area was estimated to be about 300 acres. A net flow of 10% of the head of Old River was added to the tidal volumes, so that the ebb-tide (positive, downstream) tidal volumes were greater than the flood-tide (negative, upstream) 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 volumes matched the measured tidal volumes (cumulative measured flow x time) reasonably well; the tidal elevation changes match the measured tidal flows, but the net downstream flows must be included in the calculations.



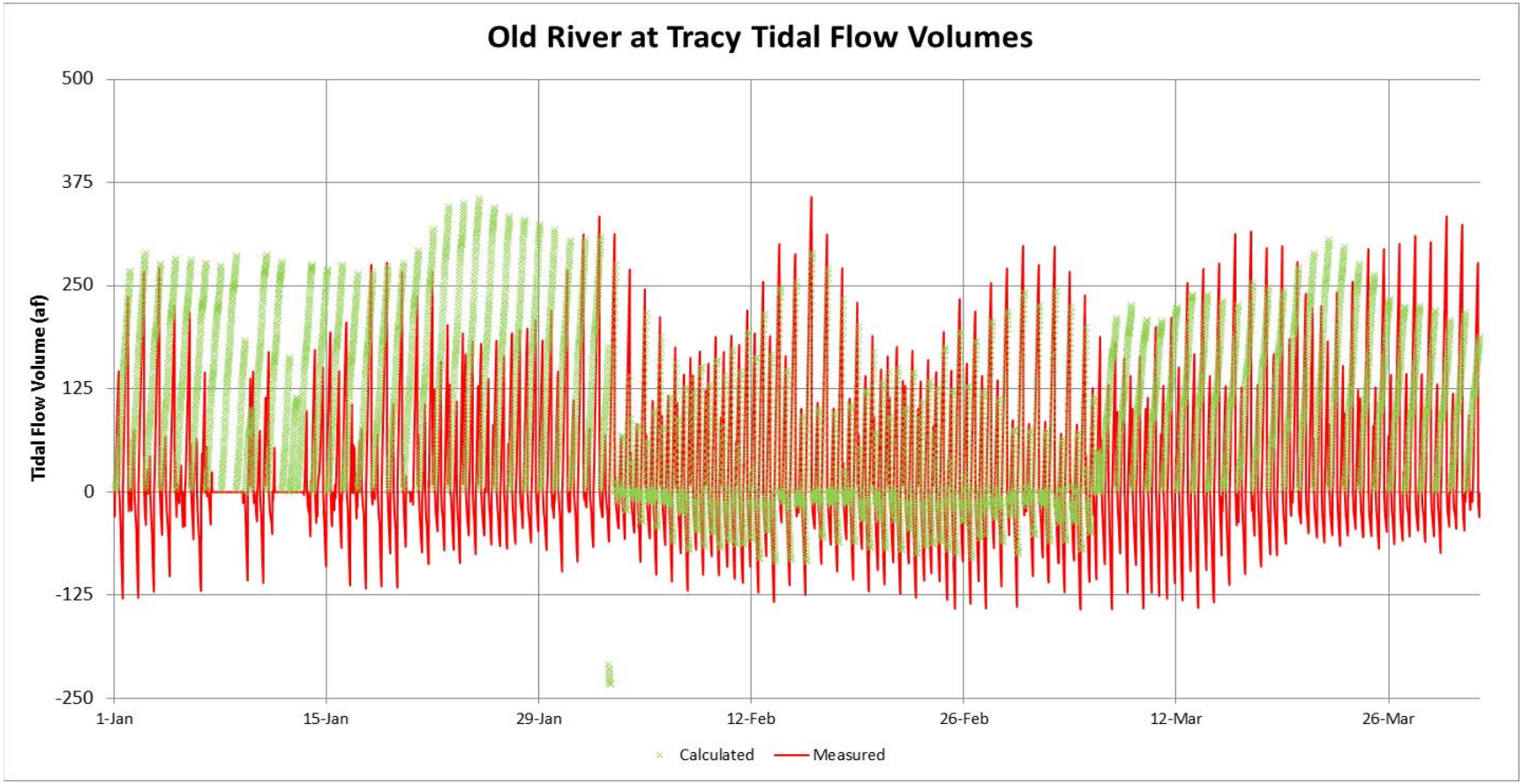
The measured and calculated tidal flow volumes for Old River at the DMC barrier were reduced dramatically in the April-June period because the Old River at DMC barrier and the head of Old River barrier were installed in April. The net flow in Old River at the DMC was reduced and the tidal flows were reduced by more than half. The calculated tidal flows were reduced in June because the barriers reduced the range of tidal elevations; they were higher than the measured tidal volumes, suggesting the upstream tidal area may also have been reduced (more of the tidal flows entering Old River from upstream through Grant Line Canal and Doughty Cut.



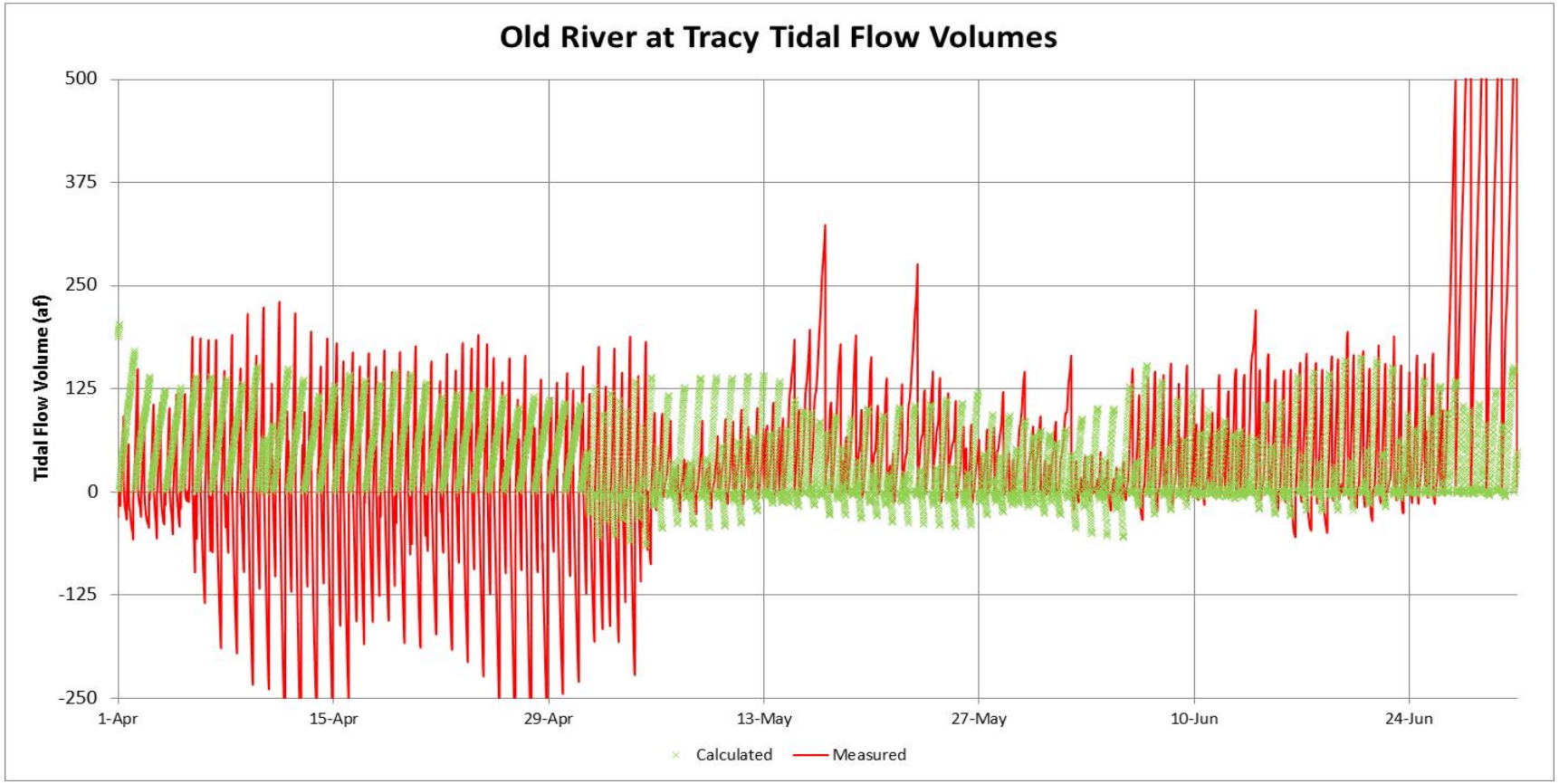
With the barriers installed and the flap-gates closed (operated), the minimum tidal elevations upstream were increased and the maximum tidal elevations were reduced, so the calculated tidal flows were generally reduced by more than half. The calculated tidal volumes matched the measured tidal flow volumes at the DMC well during most of this period; in early July and mid-August some of the culverts were opened, so the measured ebb-tide flows (positive) were higher than the calculated flows (assuming all culvert flap gates were operating).



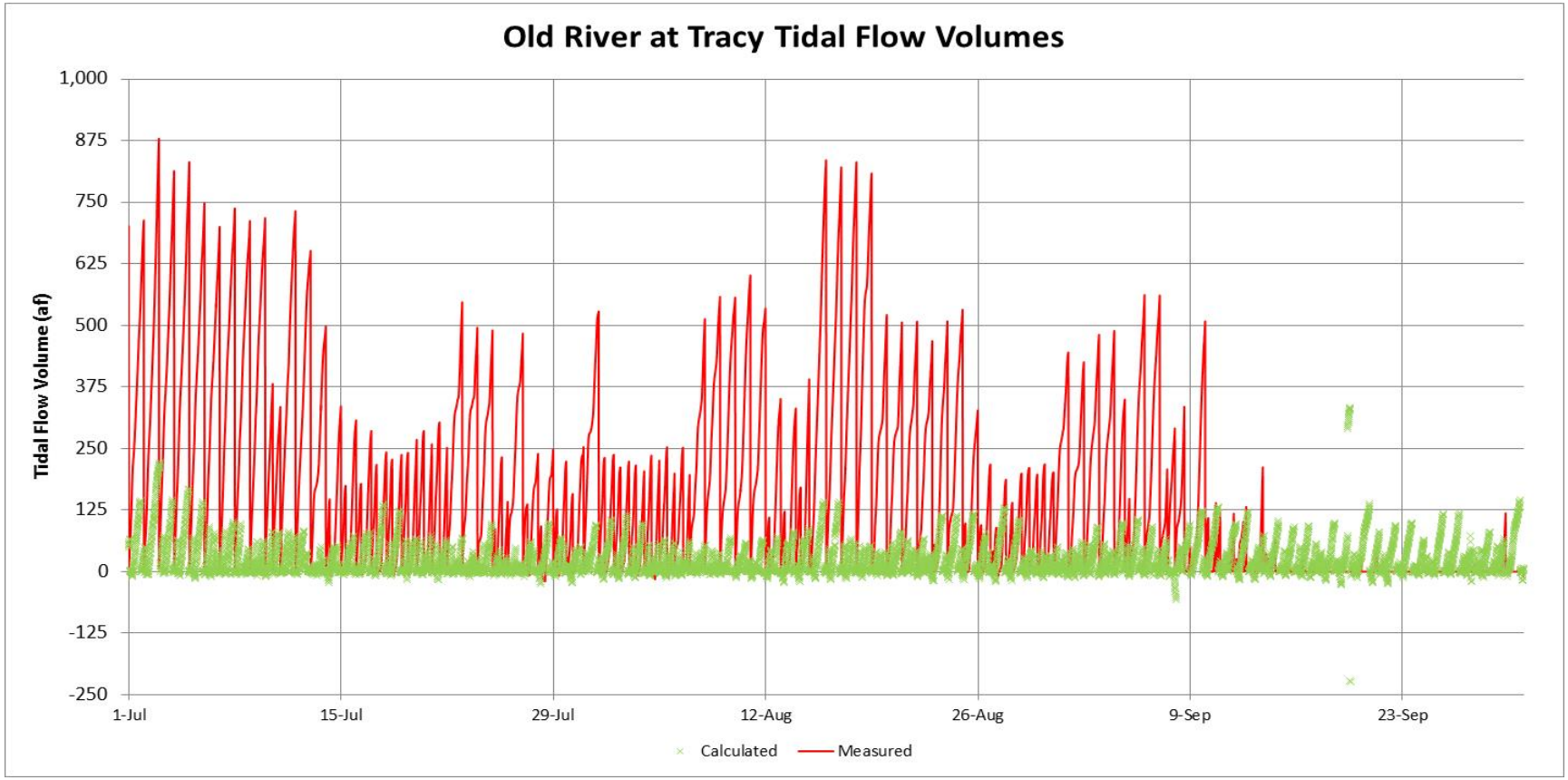
All of the temporary barriers were removed in mid-October, and the calculated and measured tidal volumes were relatively high (500-750 af). The calculated tidal volumes matched the measured tidal flow volumes reasonably well, and the assumed net flow of 10% of the head of Old River flow was small, so the flood-tide flow volumes were similar to the ebb-tide volumes.



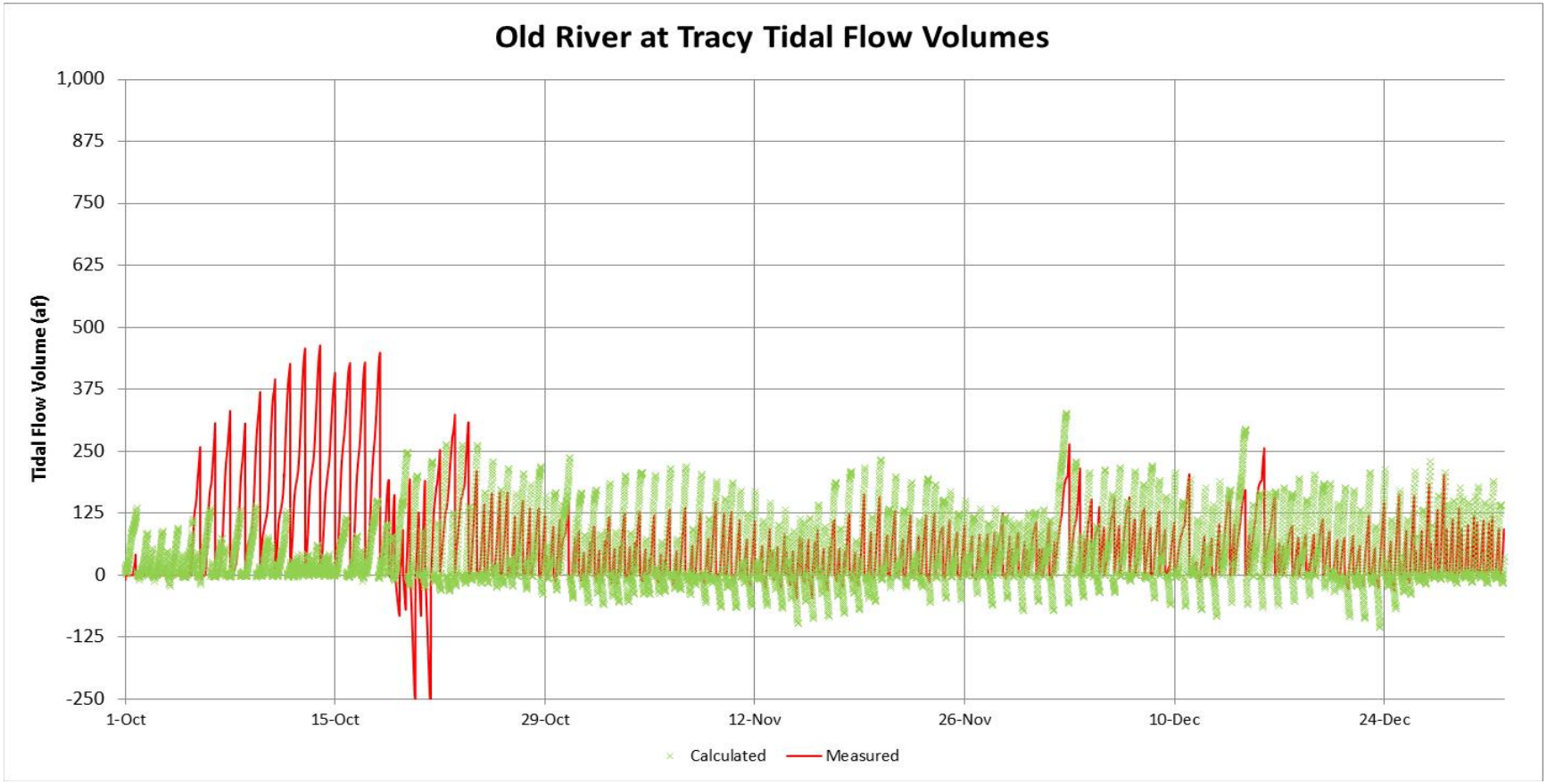
The tidal flow volume can be estimated (calculated) as the change in tidal elevation times the upstream surface area that is filling or draining. For Old River at Tracy Boulevard, the upstream area was estimated to be about 50 acres. A net flow of 10% of the head of Old River was added to the tidal volumes, so that the ebb-tide (positive, downstream) tidal volumes were greater than the flood-tide (negative, upstream) 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 volumes matched the measured tidal volumes (cumulative measured flow x time) reasonably well.



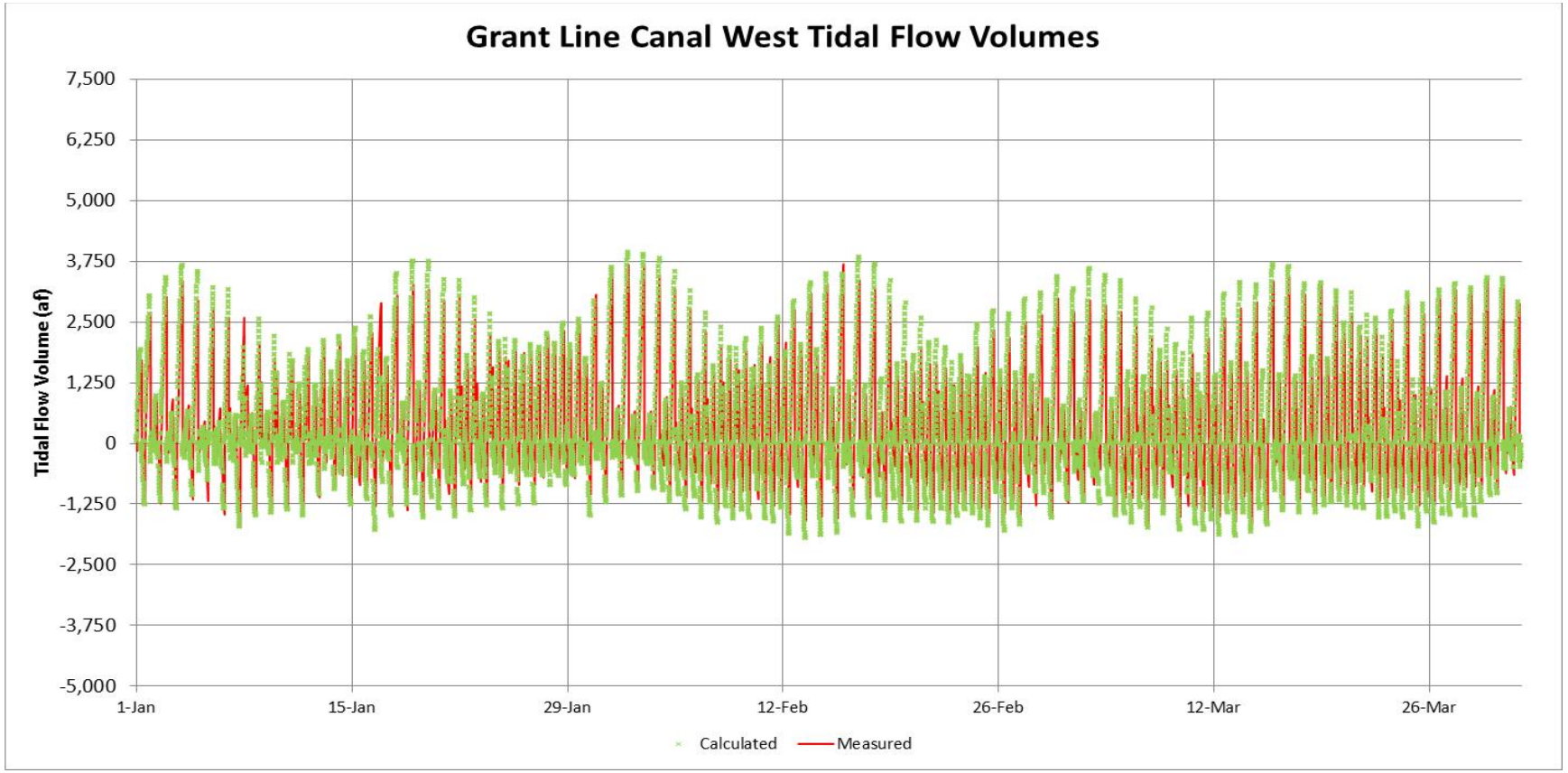
The tidal flows in Old River at Tracy Boulevard shifted in May when the grant Line Canal barrier was installed. In April the tidal flow volumes were generally balanced, but in May and June the measured and calculated tidal flow volumes were mostly downstream (ebb-tide).



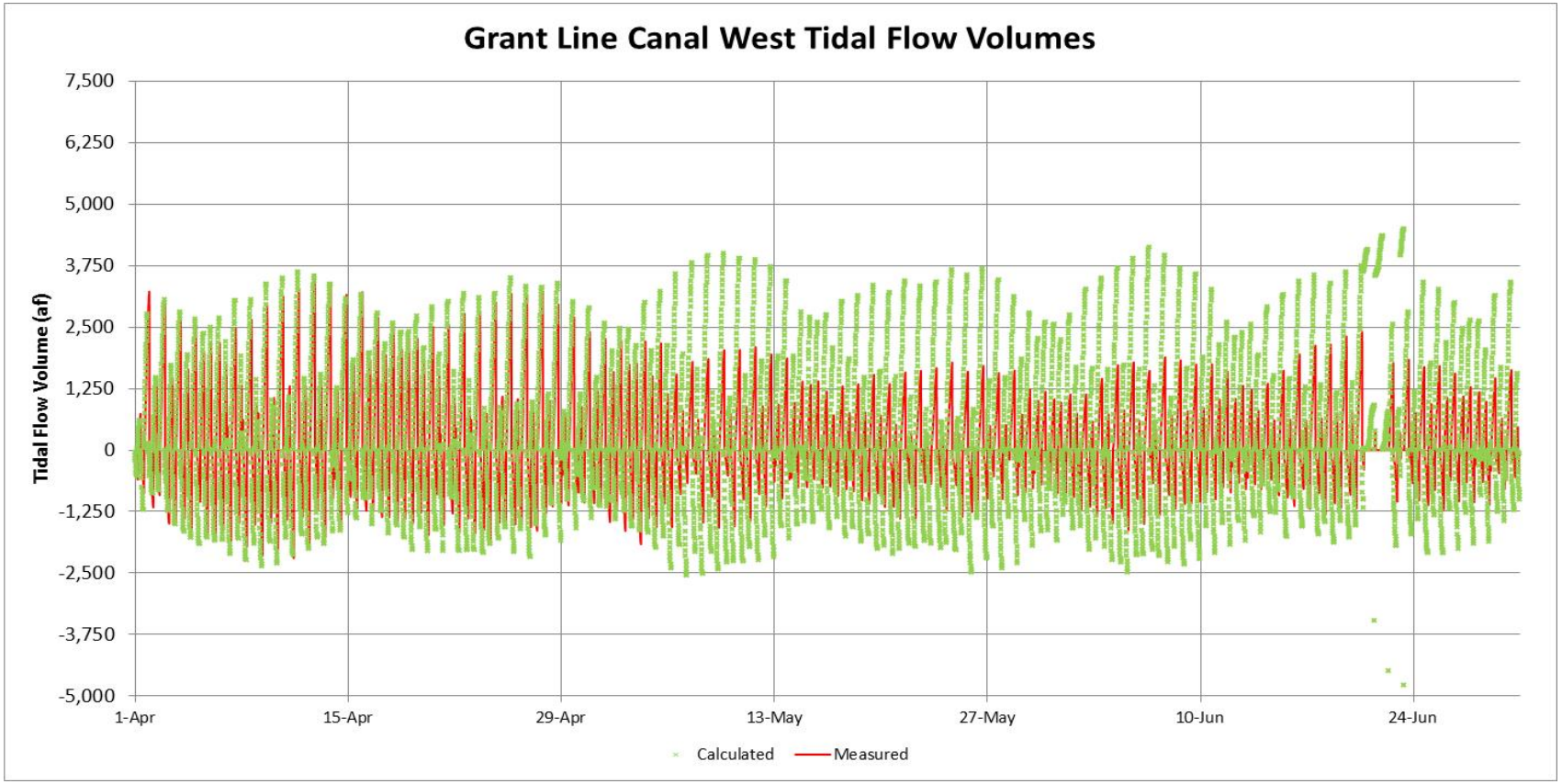
The measured tidal flow volumes in Old River at Tracy Boulevard were all downstream (net flow), but were much higher than the calculated tidal flow volumes. This might have been caused by a difference in the estimated net flow (10% of the head of Old River). The flap gates in the Grant Line Canal barrier were operated during this period, which might have caused a greater net flow in Old River at Tracy Boulevard, to satisfy downstream irrigation diversions.



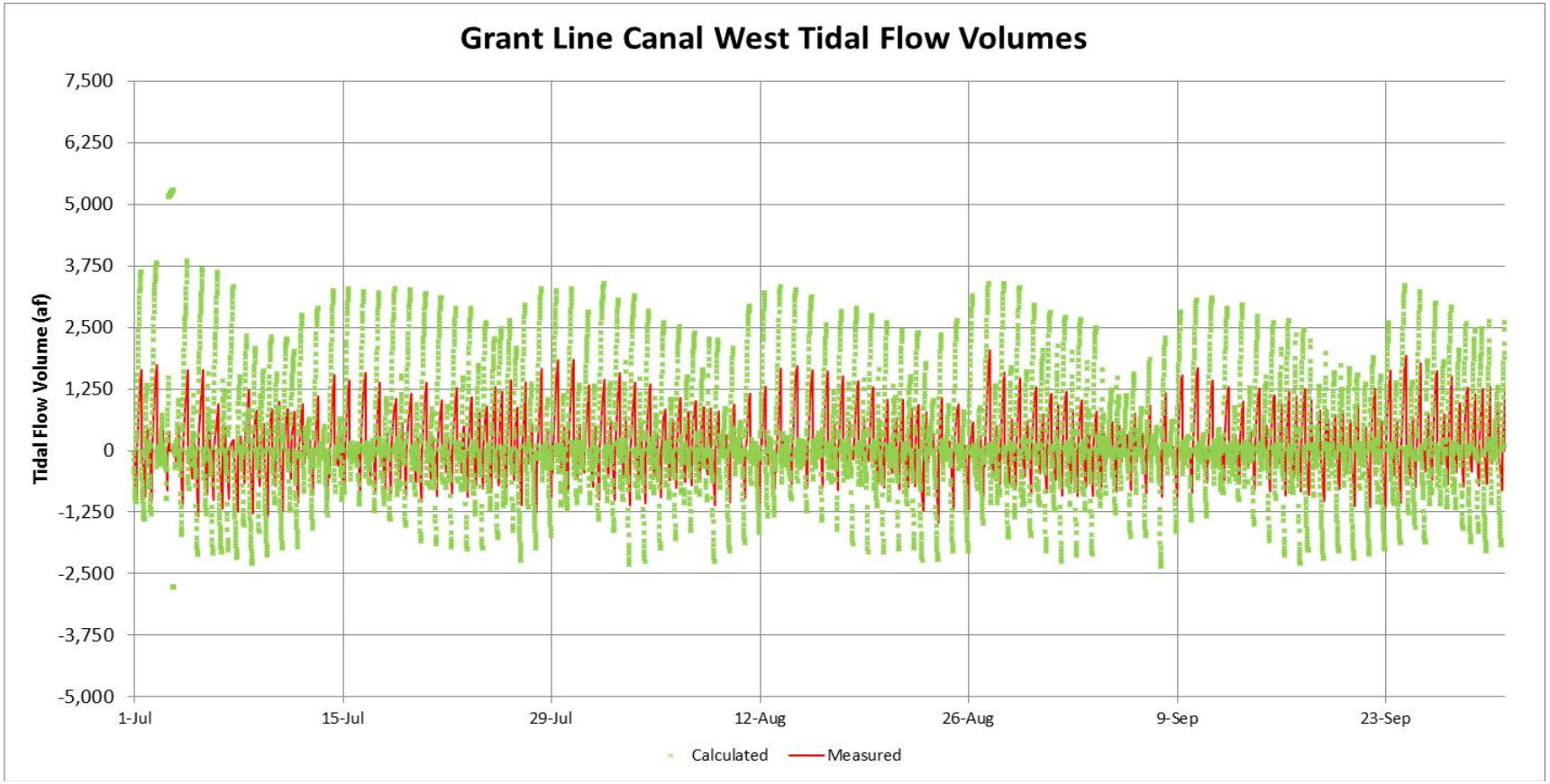
The measured tidal flow volumes in Old River at Tracy Boulevard were all downstream (net flow), and were similar to the calculated tidal flow volumes after the barriers were removed in mid-October. The tidal flows in Old River at Tracy Boulevard were very small; most of the flood-tide flow in the upstream end of Old River (including Sugar Cut and Paradise Cut) comes from Grant Line Canal and Doughty Cut.



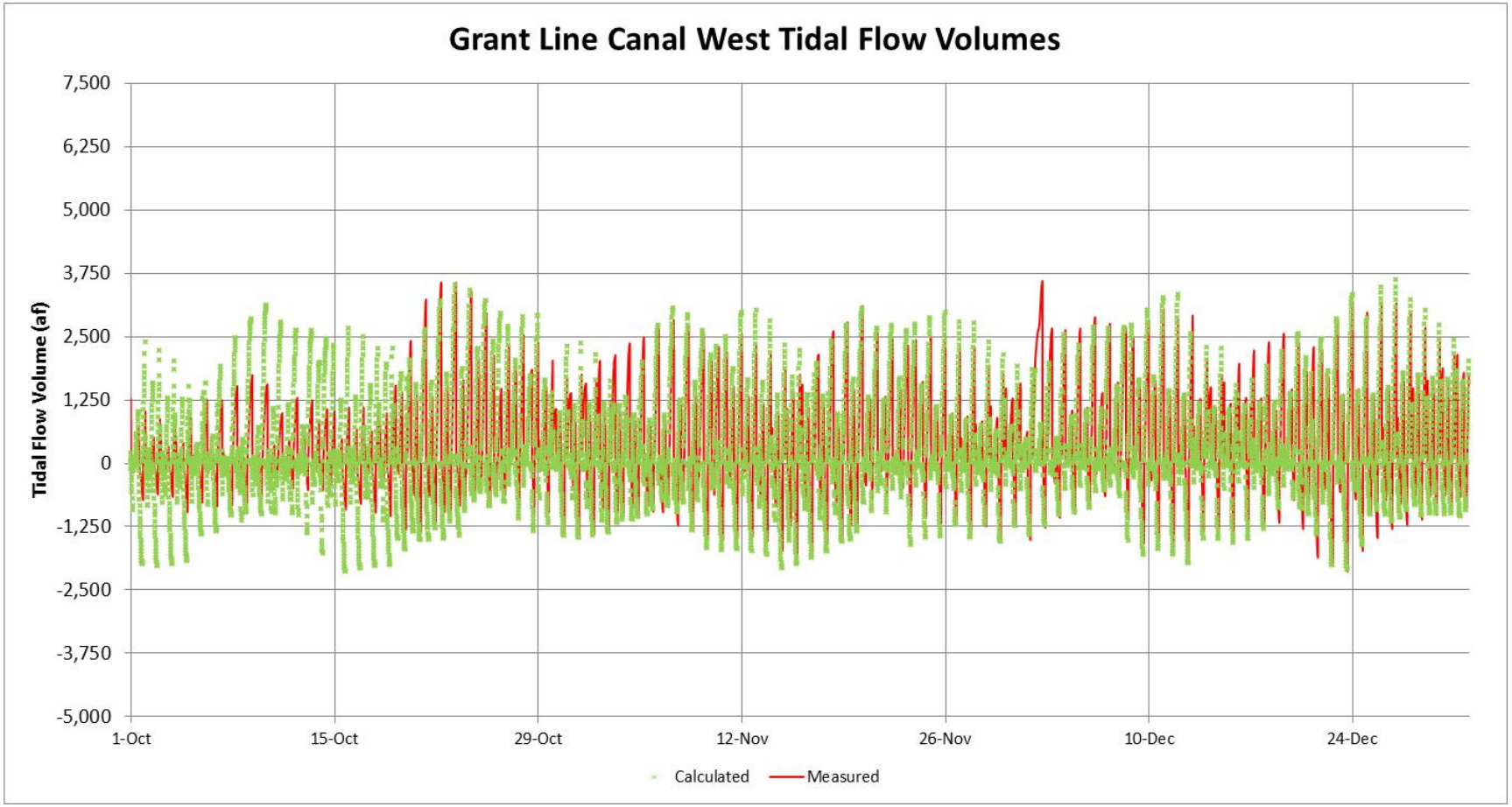
The Grant Line Canal tidal flow volumes (at the western end) were estimated with the measured tidal elevations and an upstream surface area of 750 acres, with a net flow of 85% of the Head of Old River flow. The calculated tidal flow volumes were very similar to the measured tidal flow volumes during the January-March period without any temporary barriers. The ebb-tide flow volumes were higher than the flood-tide flow volumes because the net flow in Grant Line Canal was about 1,000 cfs to 1,500 cfs.



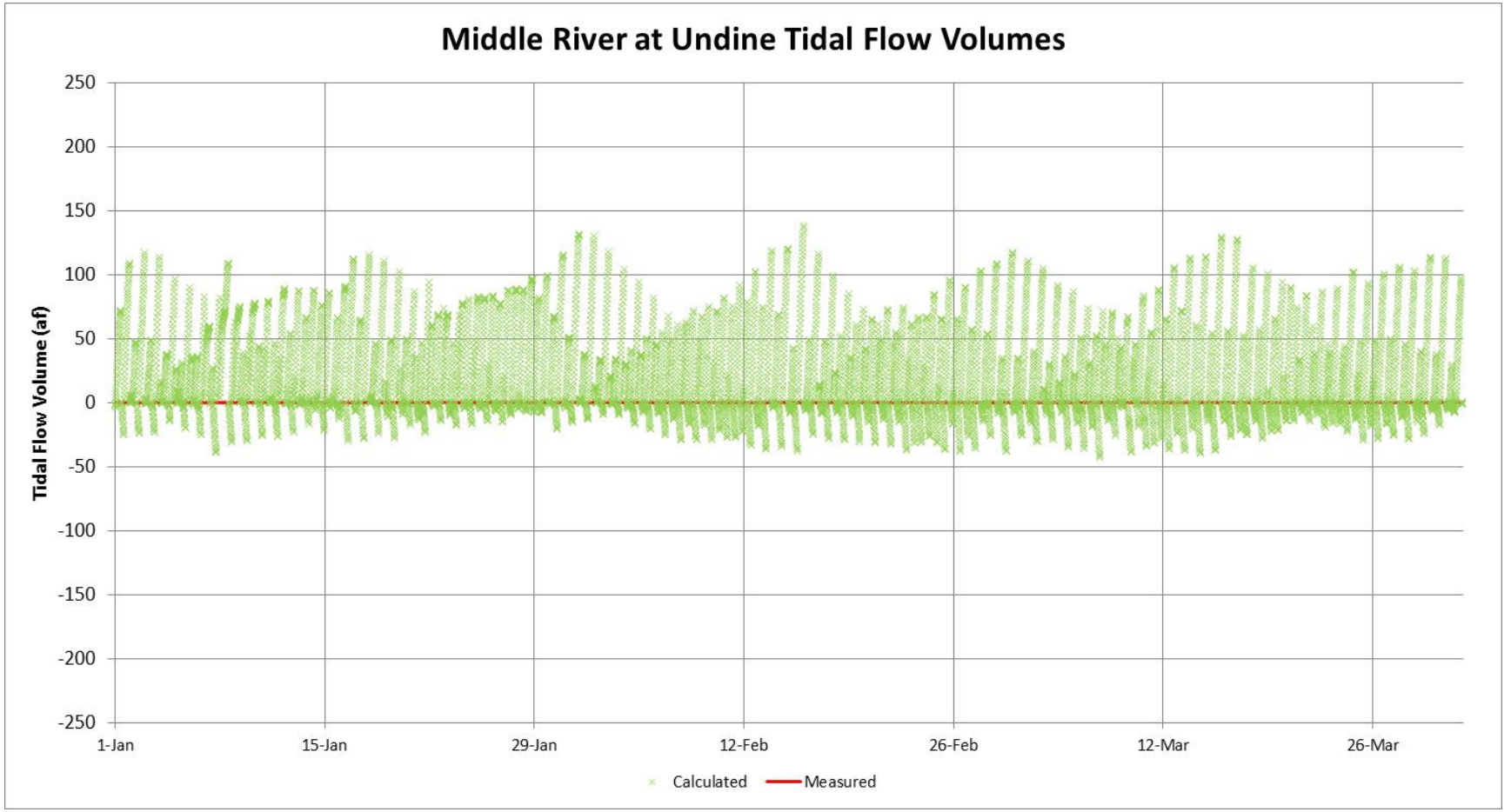
The measured Grant Line Canal tidal flow volumes (red line) were reduced in May when the barrier was installed (with culverts open). The estimated tidal flow volumes (green cross) were not reduced, because the measured tidal elevations were not substantially changed. Apparently the upstream surface area (estimated as 800 acres without temporary barriers) was reduced to about 400 acres by the Grant Line Canal barrier near Tracy Boulevard. The net flow was about 500 cfs during these months, and the average ebb-tide flow volumes (positive, downstream) were about 1,000 af, slightly higher than the average flood-tide flow volumes.



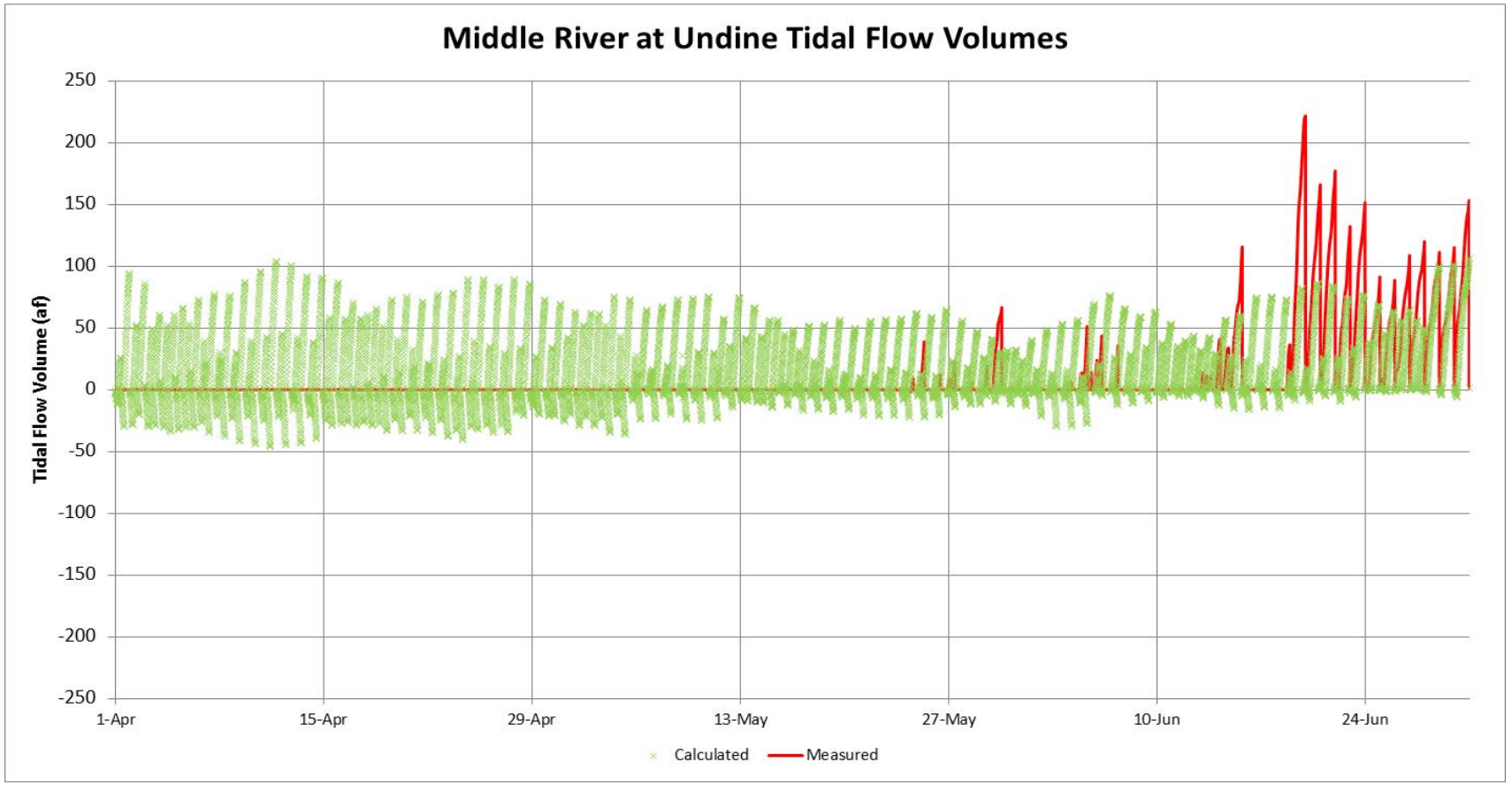
The measured Grant Line Canal tidal flow volumes (red line) were much lower than the calculated tidal flow volumes (based on tidal elevations). Apparently the estimated upstream surface area (800 acres without temporary barriers) was reduced to about 400 acres by the Grant Line Canal barrier near Tracy Boulevard. The net flow was about 500 cfs during these months, and the average ebb-tide flow volumes (positive, downstream) were about 1,000 af, slightly higher than the average flood-tide flow volumes.



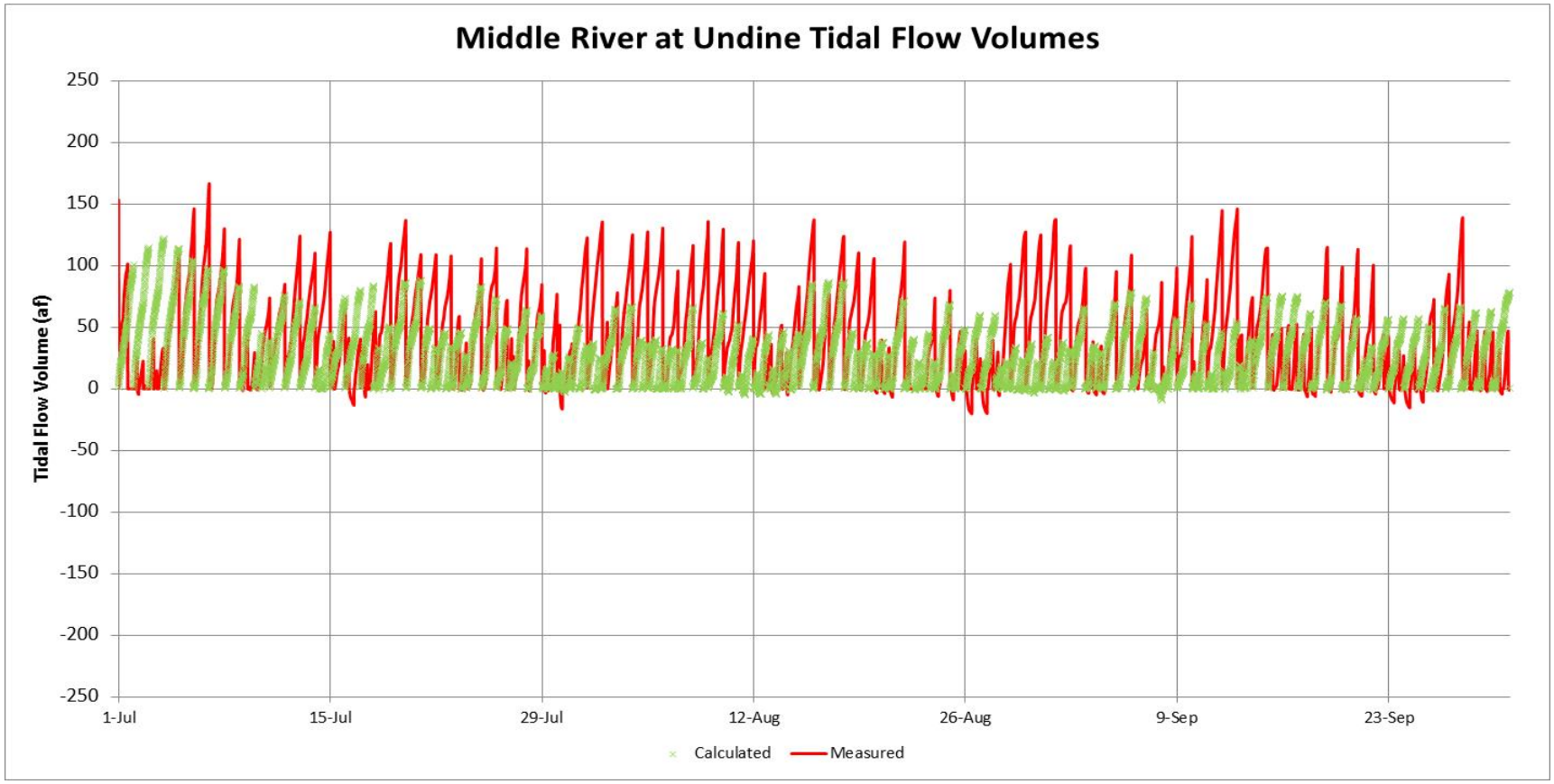
The measured Grant Line Canal tidal flow volumes (red line) were higher after the temporary barriers were removed at the end of October, and the estimated tidal flow volumes, with an upstream surface area of 800 acres, matched the measured tidal flow volumes. The net flow was about 1,000 cfs during these months, and the average ebb-tide flow volumes (positive, downstream) were about 2,000 af, definitely higher than the average flood-tide flow volumes of about 1,000 af.



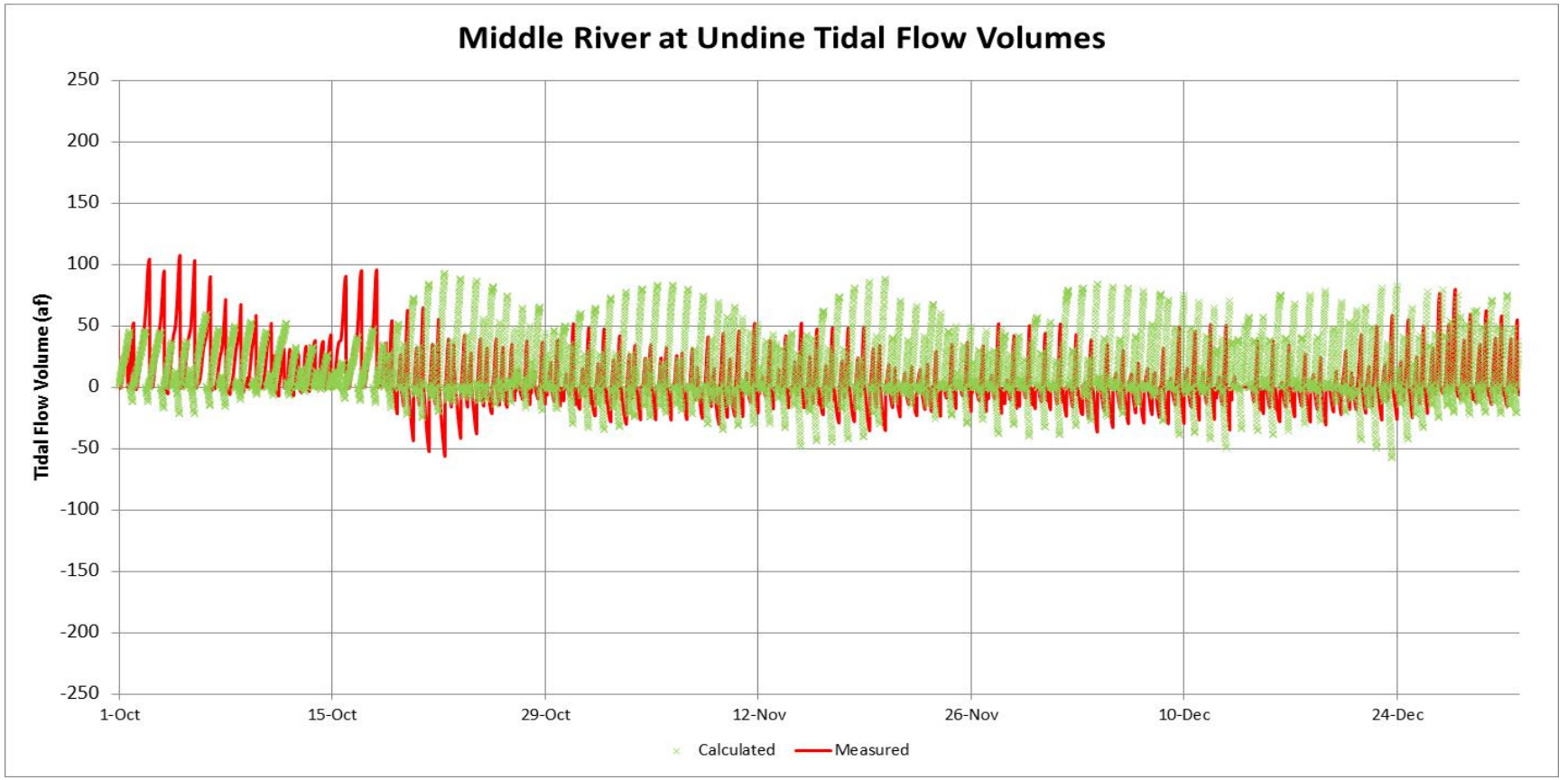
Tidal flow measurements in Middle River at Undine Road (near the upstream end) indicated that the tidal flows were small. The tidal flow volumes were estimated (green cross) from the measured tidal elevations and an assumed upstream area of 25 acres and with an assumed net flow of 5% of the head of Old River flow. There were no tidal flow measurements at Undine Road until June 2012.



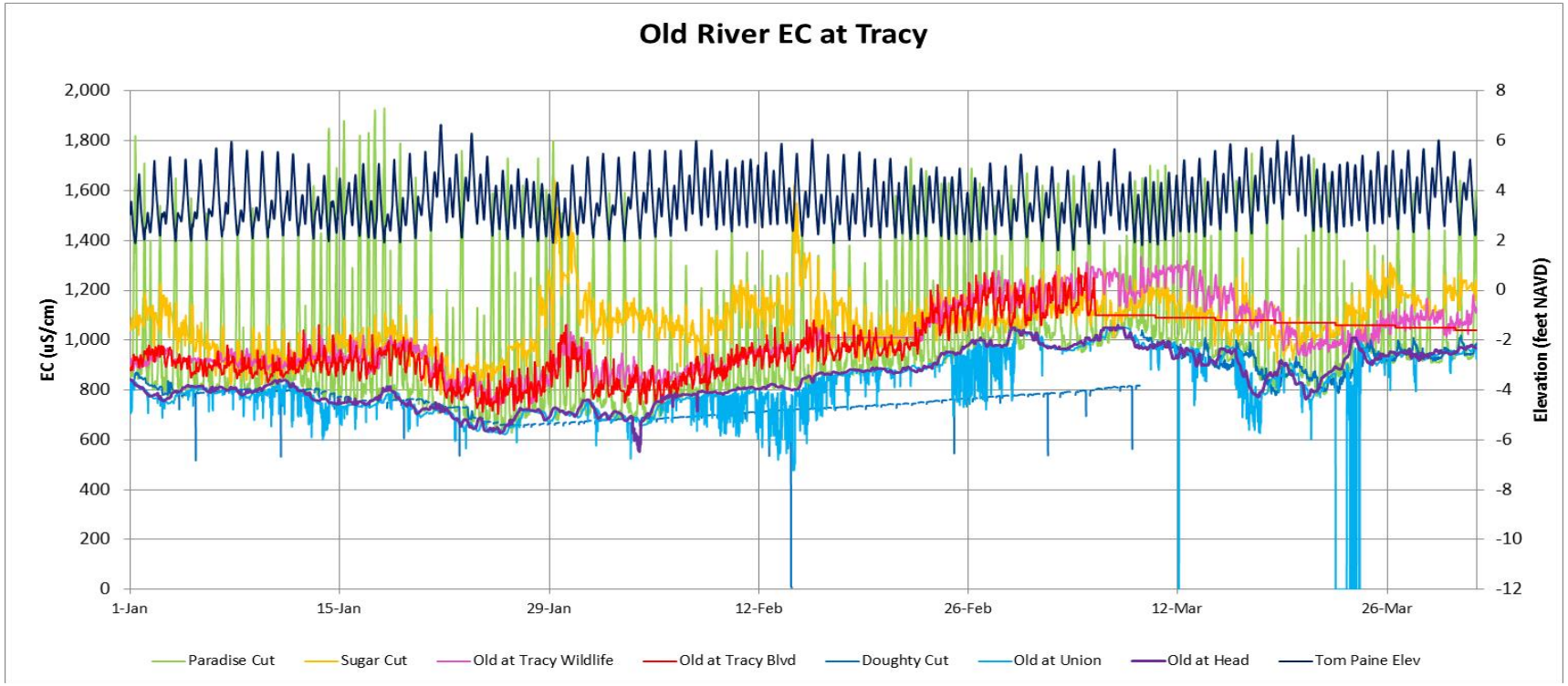
The tidal flow volumes in Middle River at Undine Road were estimated (green cross) from the measured tidal elevations with an assumed upstream area of 25 acres and net flow of 5% of the head of Old River flow. The tidal flow measurements had no flood-tide (negative flow, upstream), so the ebb-tide volumes accumulated through each day, while the calculated tidal flows had small flood-tides with two ebb-tide volumes each day. The tidal flow volumes were very small at this location.



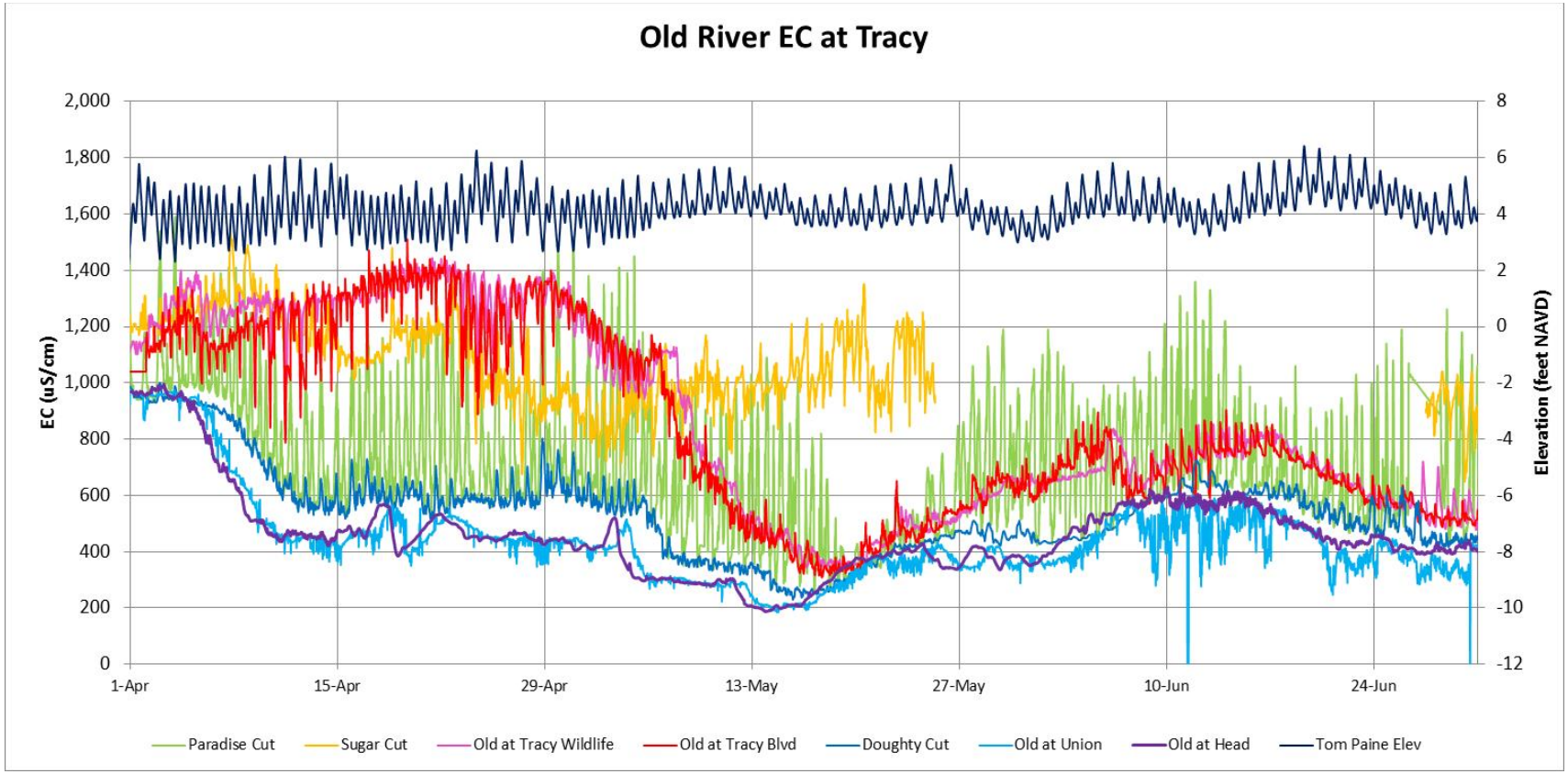
The tidal flow volumes in Middle River at Undine Road were estimated (green cross) from the measured tidal elevations with an assumed upstream area of just 10 acres and net flow of 5% of the head of Old River flow during July-September with the temporary barriers installed. The tidal flow measurements had no flood-tide (negative flow, upstream), so the ebb-tide volumes accumulated through each day, with an average tidal flow volume of about 100 af (50 cfs net flow).



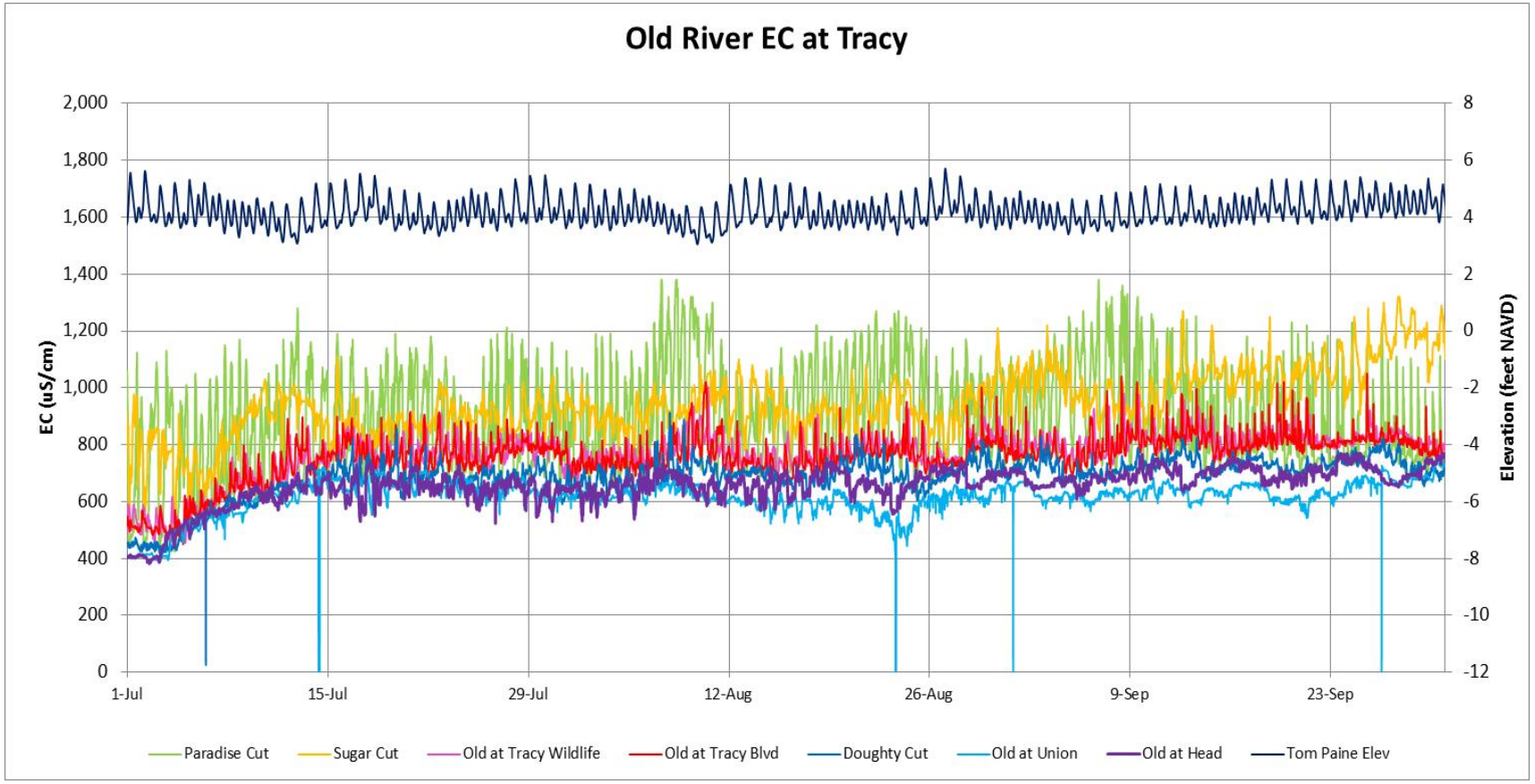
Without temporary barriers (removed in late October) the upstream tidal area was about 25 acres and the measured tidal flows (red line) indicated small flood-tide flows.



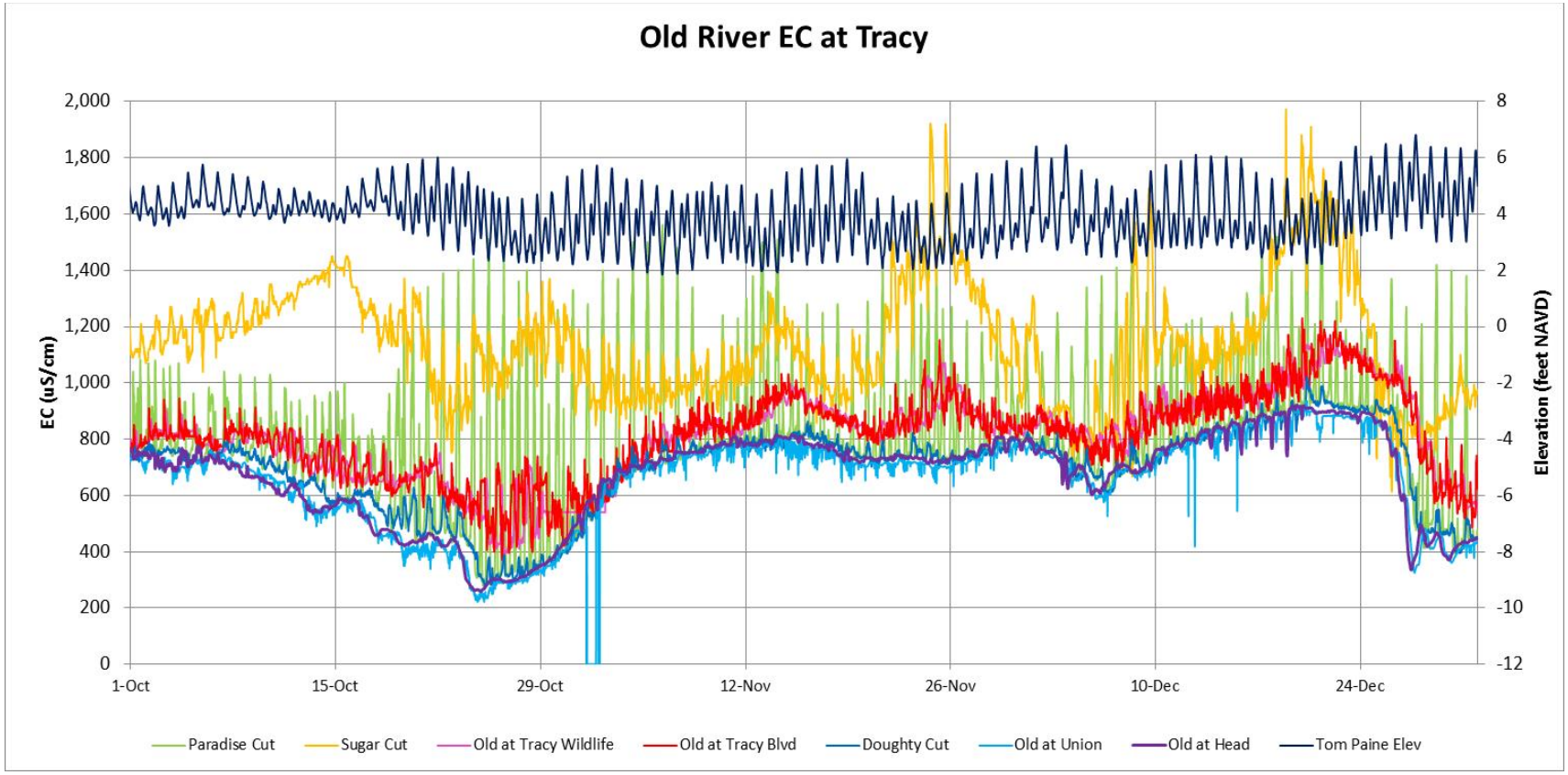
The salinity (EC) in Old River was generally controlled by the SJR EC. The SJR at Mossdale EC (purple line) and the Old at Union EC (dark blue line) and the Doughty Cut EC (light blue line) were similar in the months of January-March, ranging from 800 uS/cm to 1,000 uS/cm (the Vernalis and south Delta EC objective for September-March). The Doughty Cut EC was out of service in February and March, while the SJR at Mossdale and Old at Union EC data show some bad data points. The EC in Old River at Tracy Boulevard (red line) was much higher than the EC at Mossdale, Union, and Doughty Cut, and had a tidal variation of 100 uS/cm. The EC at Tracy Boulevard was confirmed by an independent station at Tracy Wildlife Island (pink line), just downstream of the Tracy Boulevard station. The Old at Tracy Boulevard EC was 200-250 uS/cm greater than the upstream Old River EC. The Paradise Cut EC (green line) had a tidal variation of 600-800 uS/cm, with maximum EC of 1,600-1,800 uS/cm. The Sugar Cut EC was similar (slightly higher) to the Old River at Tracy Boulevard EC, with a tidal variation of 100-150 uS/cm.



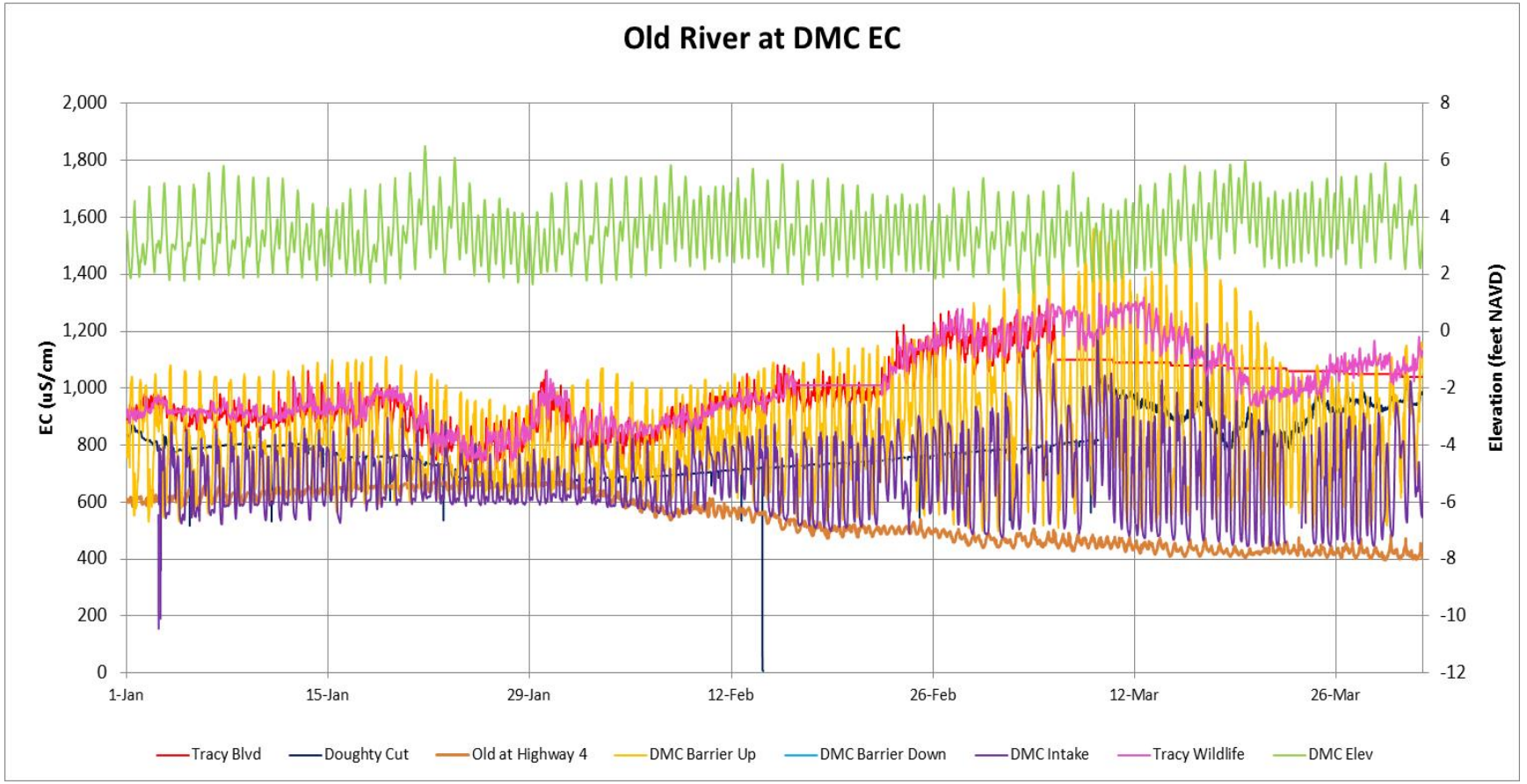
Because of increased SJR flows in April and May, the SJR EC was reduced to about 400 uS/cm in April and to about 200 uS/cm at the peak flow in mid-May. However, the head of Old River barrier was installed in April and May (for fish protection) and the net flow was about 500-750 cfs. The Old River at Union EC was similar to the SJR at Mossdale EC, but the Doughty Cut EC remained 200 uS/cm higher. Because the Old at DMC barrier was also installed at the beginning of April, the tidal flows in Old River at Tracy Boulevard were reduced, and the net flow was reduced. The Old River at Tracy Boulevard (and at Tracy Wildlife) increased dramatically to 1,400 uS/cm. The high EC at Tracy Boulevard was reduced when the Grant Line Canal temporary barrier was installed in early May and the net flow in Old River at Tracy Boulevard was increased (from 0 cfs in April to 125 cfs in May. Installing the Old at DMC barrier without the Grant Line Canal barrier will greatly reduce the Old River at Tracy flow and increase the Tracy Boulevard EC. The Paradise Cut EC tidal variation was increased during April and was reduce in May as the elevations were raised. The Sugar Cut EC tidal variation remained similar to the EC variation in January-March.



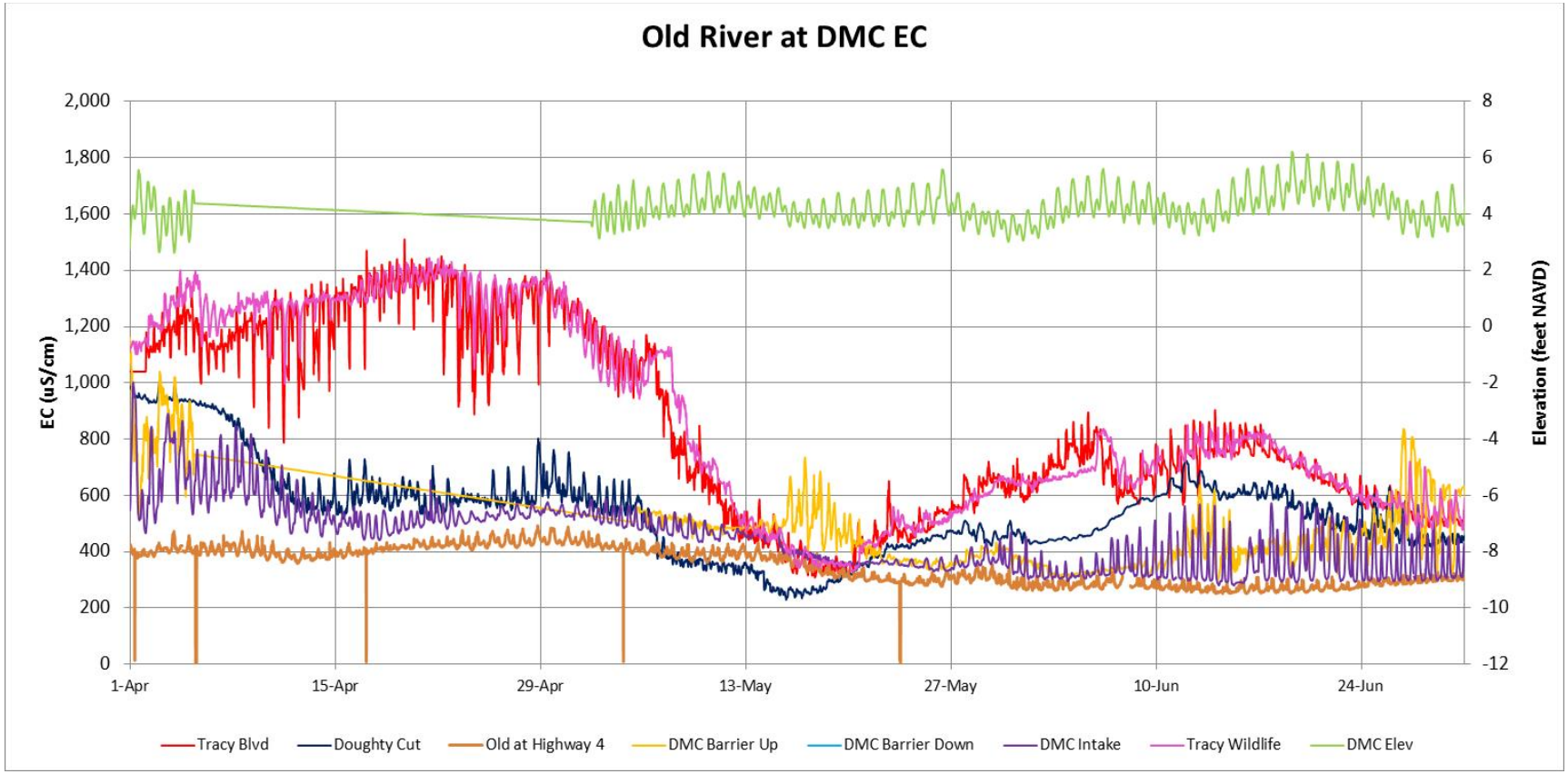
The SJR at Mossdale and Old River at Union EC were quite uniform at 600-800 uS/cm during the summer months. The tidal variations in Paradise Cut EC were 400-500 uS/cm during these summer months, suggesting that the (unidentified) salt source was relatively constant. The tidal variations in the Old River at Tracy Boulevard EC were 50-200 uS/cm, suggesting that the salt source from Paradise Cut was diluted by the Old River tidal flow (during ebb tide). The net flow in Old was about 250 cfs and the tidal flows were reduced by the temporary barriers. 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 EC in Sugar Cut was higher than the EC in Old River and remained higher throughout the tidal cycle.



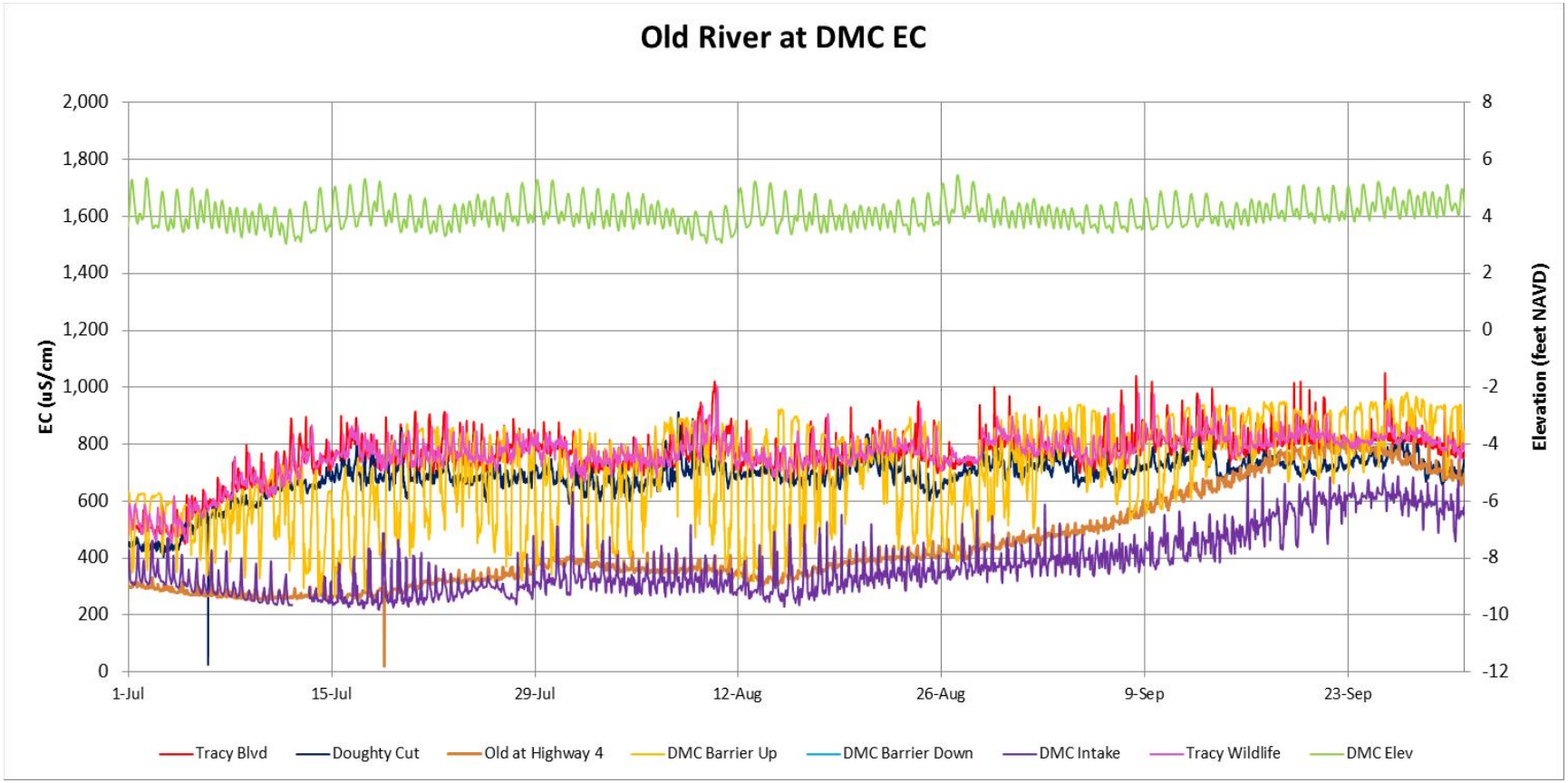
The SJR at Mossdale and Old River at Union and Doughty Cut EC were reduced by the pulse flow at the end of October (for adult Chinook salmon attraction) and by the runoff event at the end of December. The Old River at Tracy Boulevard (and Tracy Wildlife) was 100-200 uS/cm higher than the Old River at Union or Doughty Cut EC. The Old River at DMC and the Grant Line Canal temporary barriers were removed near the end of October, so the combined effects of reduced elevations, increased tidal flows, and increased net flows are difficult to separate. The tidal variations of Paradise Cut EC and of Sugar Cut EC remained similar to the variations seen in previous months, although the periods of increased Sugar Cut EC and some periods of reduced tidal variations of Paradise Cut EC remain unexplained. 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.



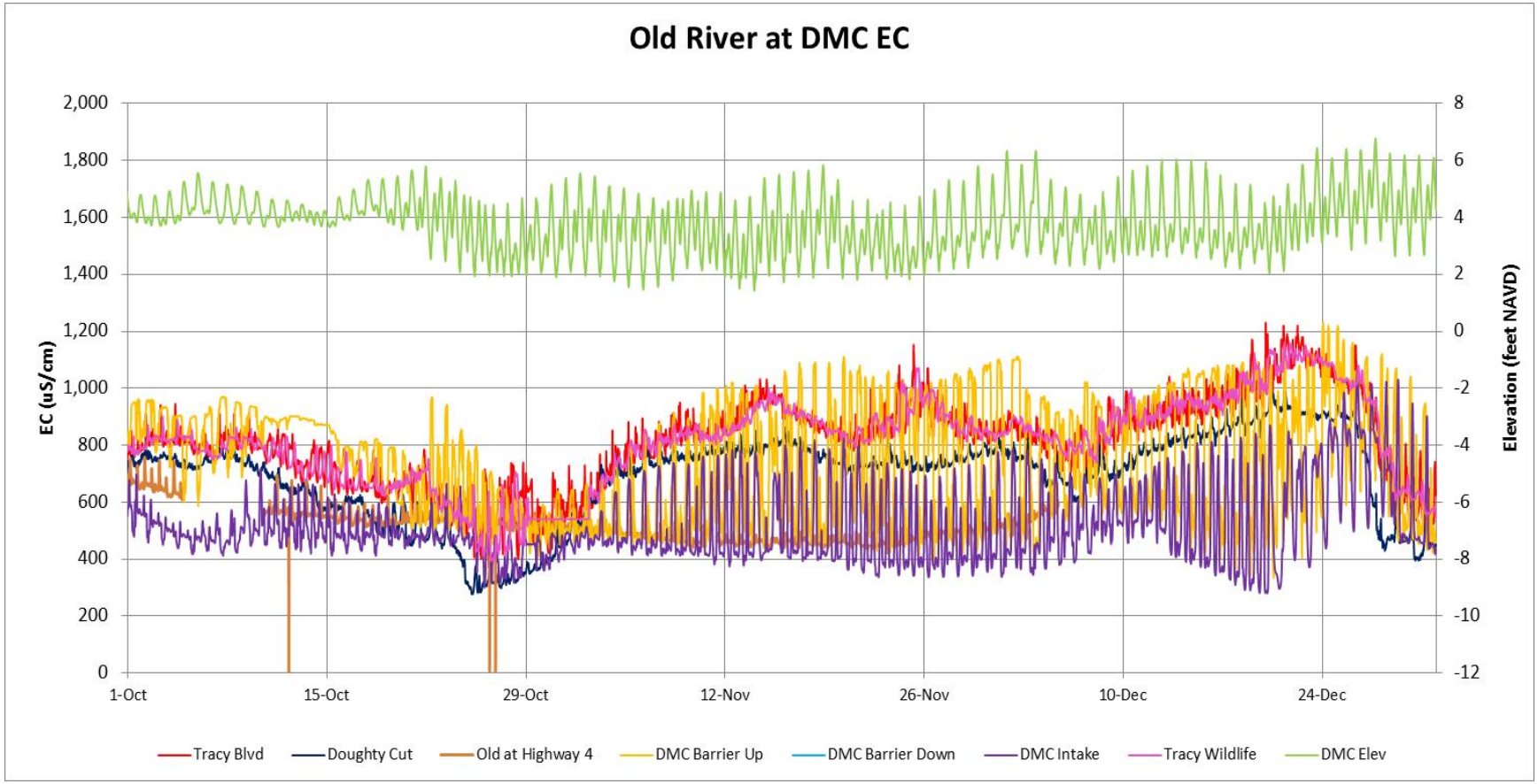
The salinity (EC) in Old River at the DMC was generally controlled by the tidal mixing of water from upstream at Tracy Boulevard (red and pink lines) and water from downstream (Old at Highway 4, brown line). During the January-March period when the downstream EC was 400-600 uS/cm and the upstream EC was 800-1,200 uS/cm, the tidal movement of water in Old River created a tidal fluctuation in the measured EC at the DMC barrier (gold line) and at the DMC intake (purple line). The maximum EC at the DMC barrier was observed at low tides, when higher salinity water from upstream moved about 5 km downstream. The highest EC in the DMC intake occurred about 2-4 hours after low tide, when the higher EC water moved back upstream and into the DMC. The lowest EC generally matched the downstream EC at Highway 4, and the highest EC generally matched the upstream EC at Tracy Boulevard (and Tracy Wildlife).



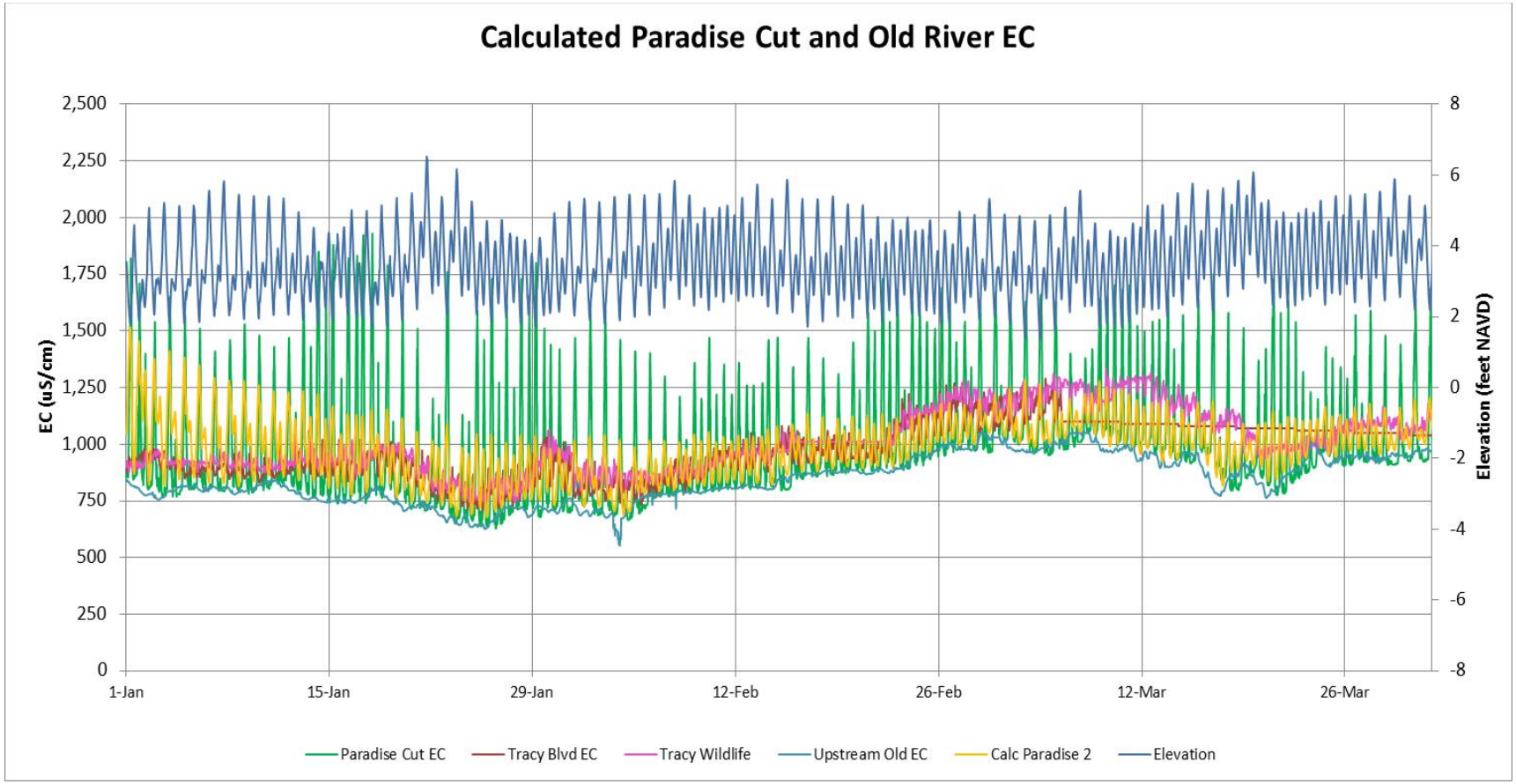
The salinity (EC) in Old River at the DMC barrier during the April-June period was much closer to the downstream EC at Highway 4, because the head of Old River barrier was installed in April and May, and the net flow in Old River at Tracy Boulevard and at the DMC barrier was reduced considerably. There was some tidal fluctuation in the EC at the DMC barrier and DMC intake, but the highest EC at Tracy Boulevard was not transported downstream to the DMC barrier and DMC intake. The higher SJR flow reduced the EC in Old River at Doughty Cut, and this lower EC water moved downstream in Grant Line Canal to Old River, downstream of the DMC intake. The EC at Tracy Boulevard and Tracy Wildlife remained much higher that the EC in Doughty Cut during April and May, and was about 200 uS/cm higher in June.



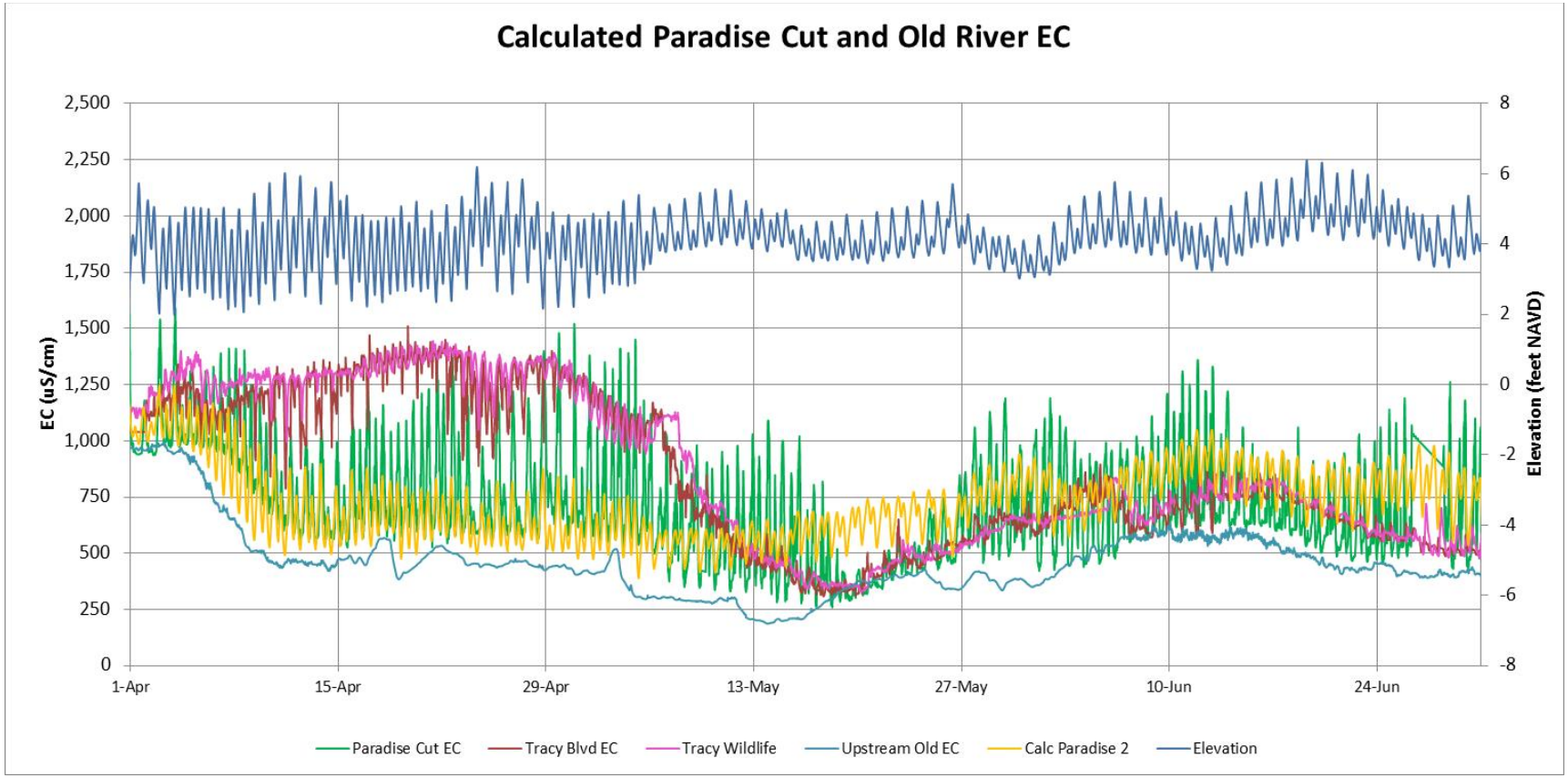
The EC in Old River at the DMC barrier during July-September showed a large tidal fluctuation (200-400 uS/cm), with maximum EC similar to Old River at Tracy Boulevard, and minimum EC similar to Old River at Highway 4. The effects of seawater intrusion, caused by relatively low Delta outflow in August and September, increased the EC at Highway 4 from less than 400 uS/cm in July to a peak of about 800 uS/cm in late September. The EC in the DMC intake increased more slowly in September, because some of the water to supply the CVP and SWP pumping comes down Middle River and Victoria Canal, with a lower EC from the Sacramento River.



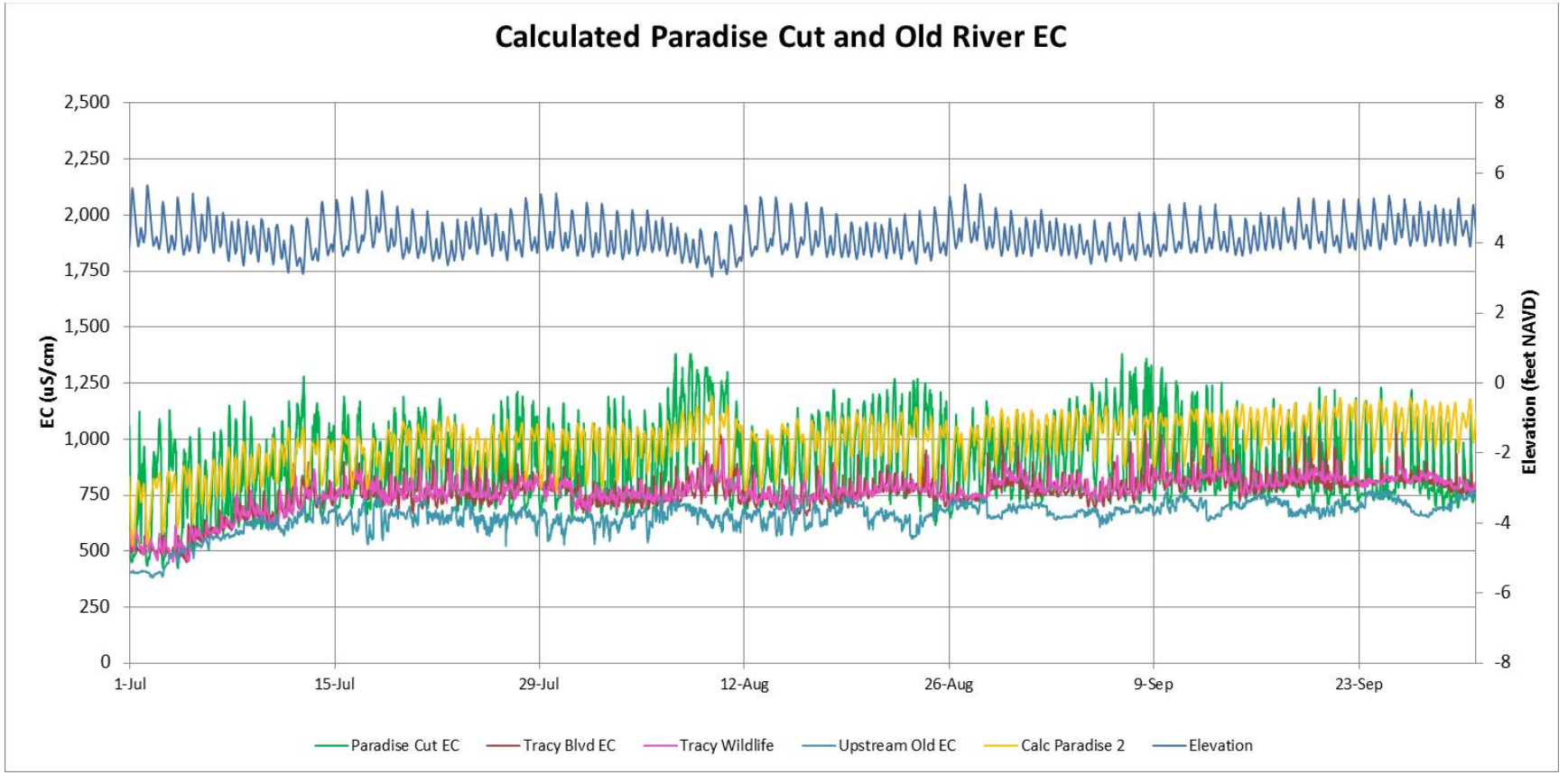
The EC fluctuations in Old River at the DMC barrier and DMC intake were increased in November and December, after the temporary barriers were removed. The maximum EC was similar to the Old at Tracy and Old at Wildlife EC, while the minimum EC was similar to the Middle River EC (not shown) and the Old at Highway 4 EC (brown line). The tidal movement in Old River was increased after the barriers were removed, so the EC fluctuations were also increased.



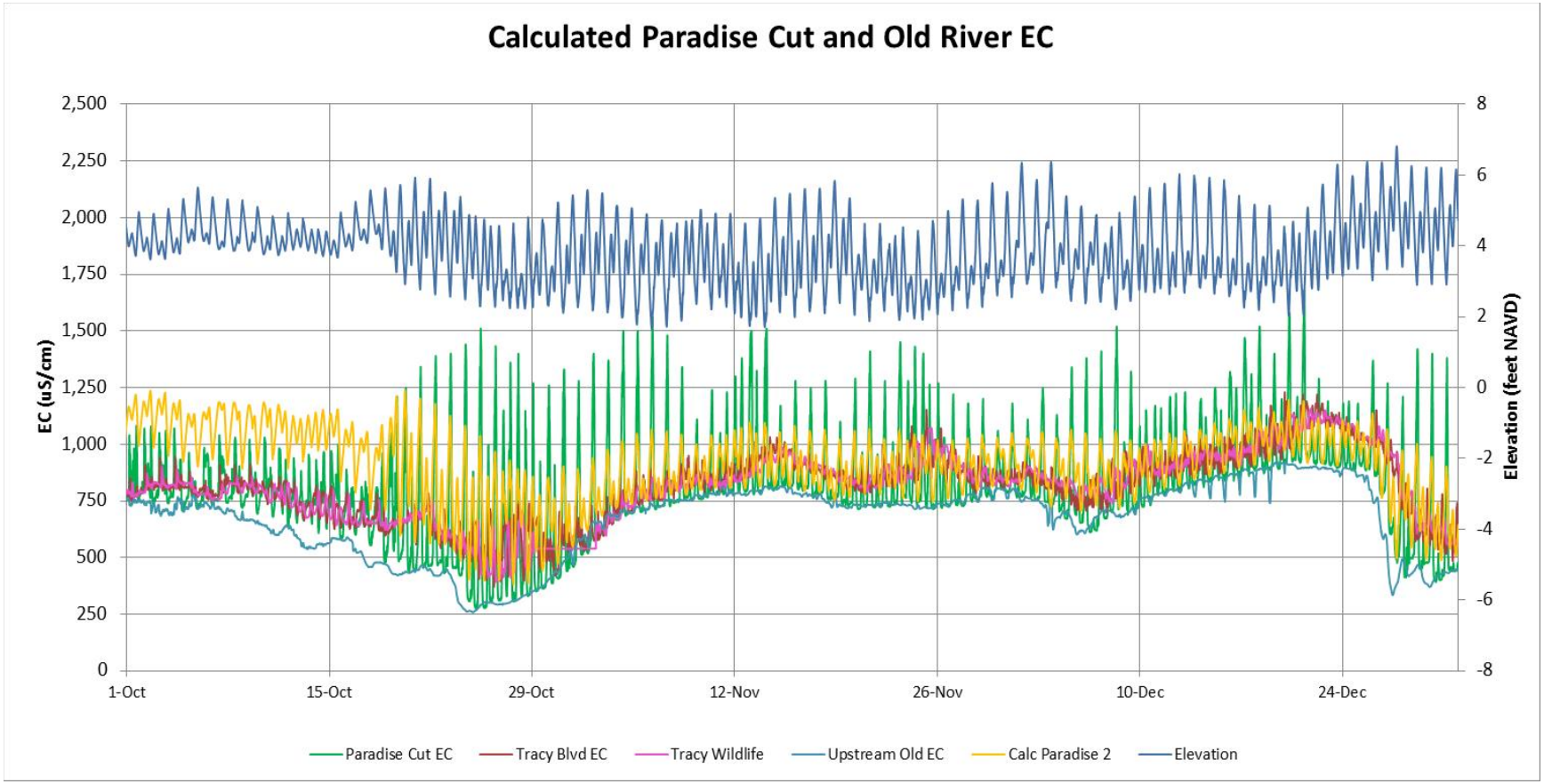
The Paradise Cut EC was calculated from the measured tidal elevations (blue line) and assumed geometry segments of Paradise Cut. The salt source was assumed to enter at the upstream end with an EC of 5,000 cfs and a constant flow of 10 cfs (87.5 tons/day). Paradise Cut discharged to Old River during ebb tides and fills with Old River water 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 is relatively constant.



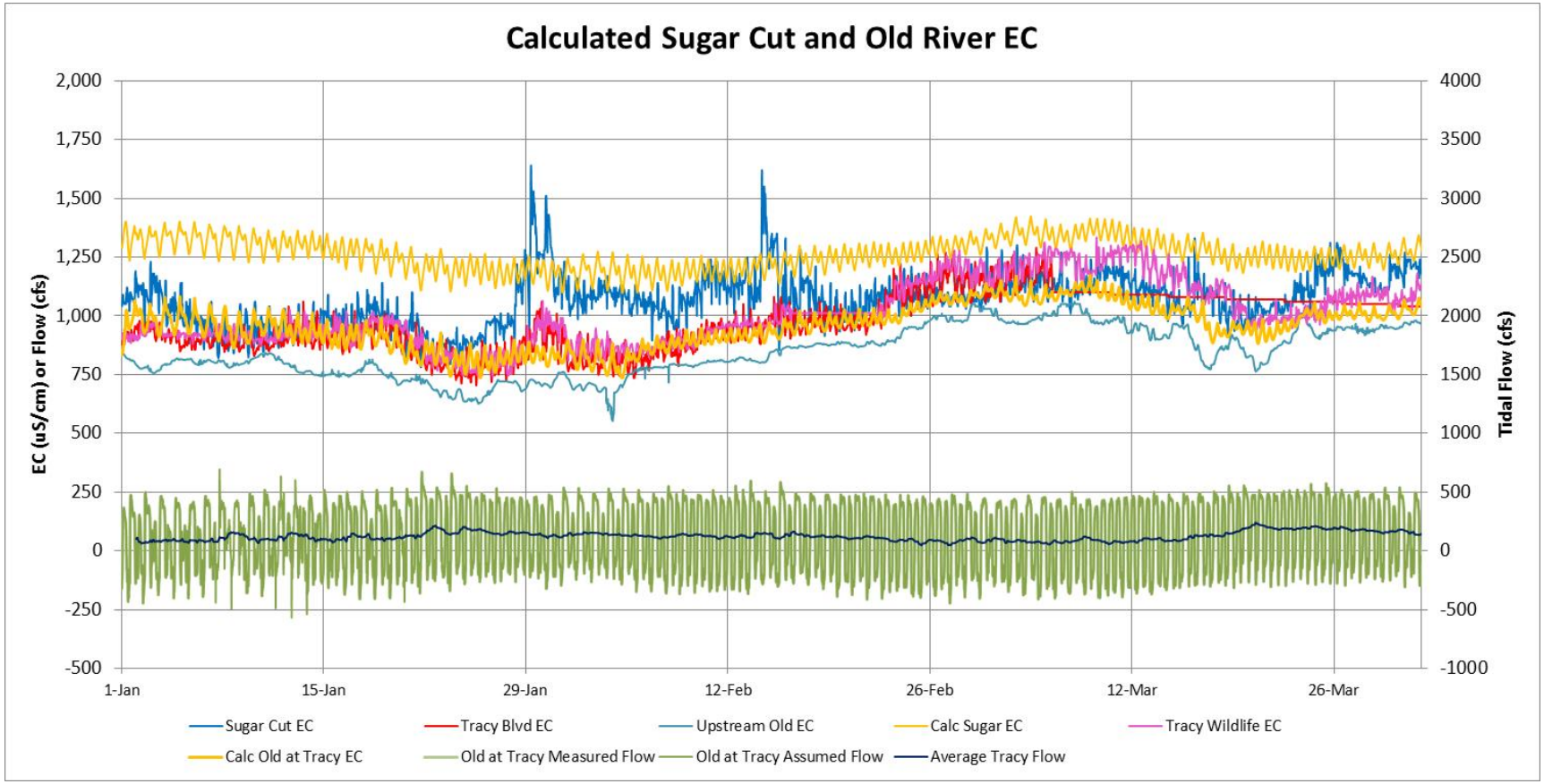
Paradise Cut is filled with Old River water during flood tide periods and the minimum Paradise Cut EC is therefore similar to the Old River EC. The maximum Paradise Cut EC is controlled by the tidal flushing of the assumed salt source; the maximum EC is greatest during neap tide periods when the tidal elevations are reduced. The calculated EC fluctuations were more uniform than the measured EC; for example the maximum measured EC was reduced from May 15-25, while the calculated maximum EC values remained about 500 uS/cm greater than the minimum EC values.



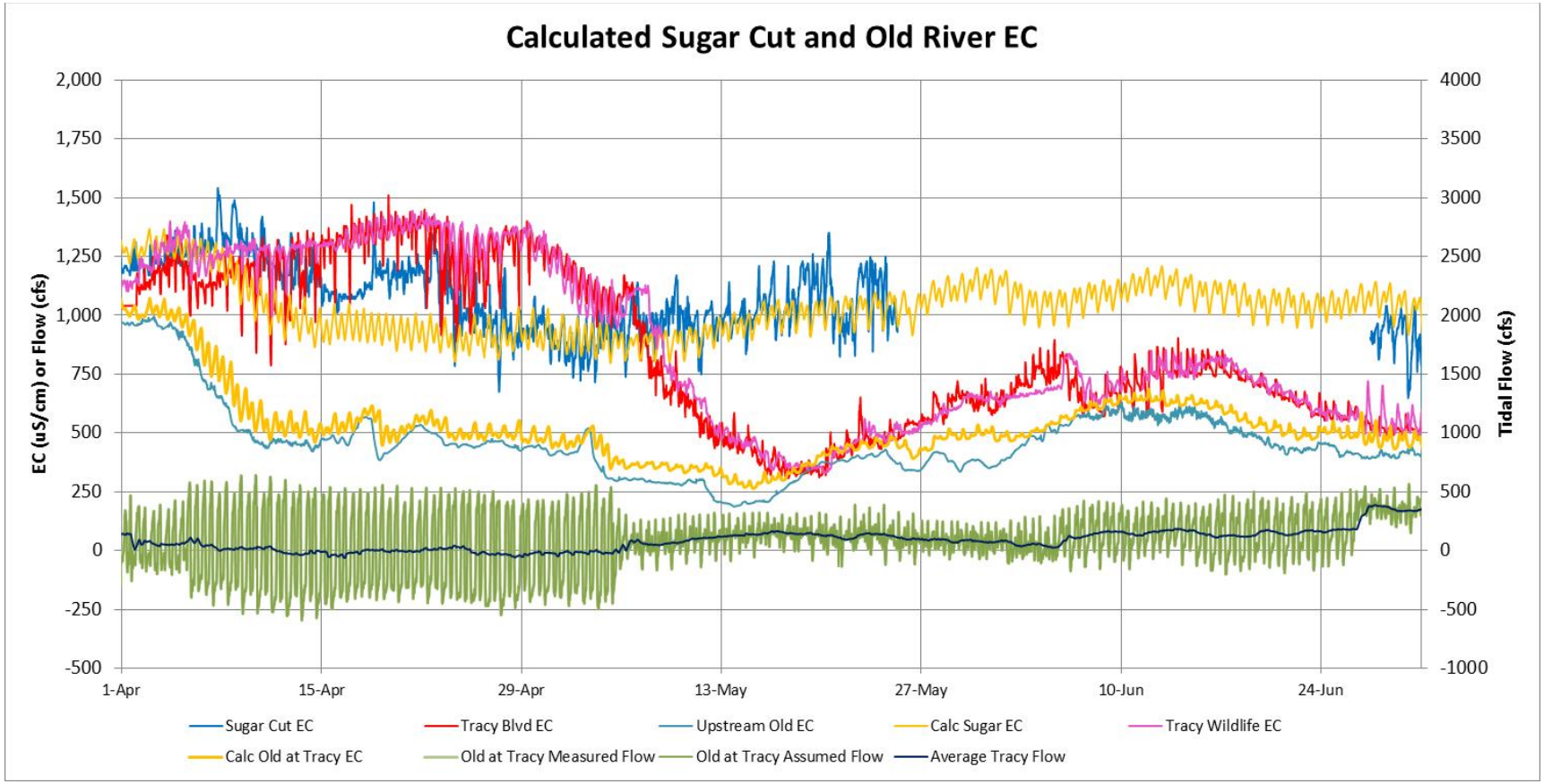
The tidal elevation variations were very small during the summer period when the Old River, Grant Line Canal and Middle River barriers were installed. The tidal variations in measured and calculated EC were about 500 uS/cm, ranging from a minimum EC of 750 uS/cm to a maximum EC of about 1,250 uS/cm.



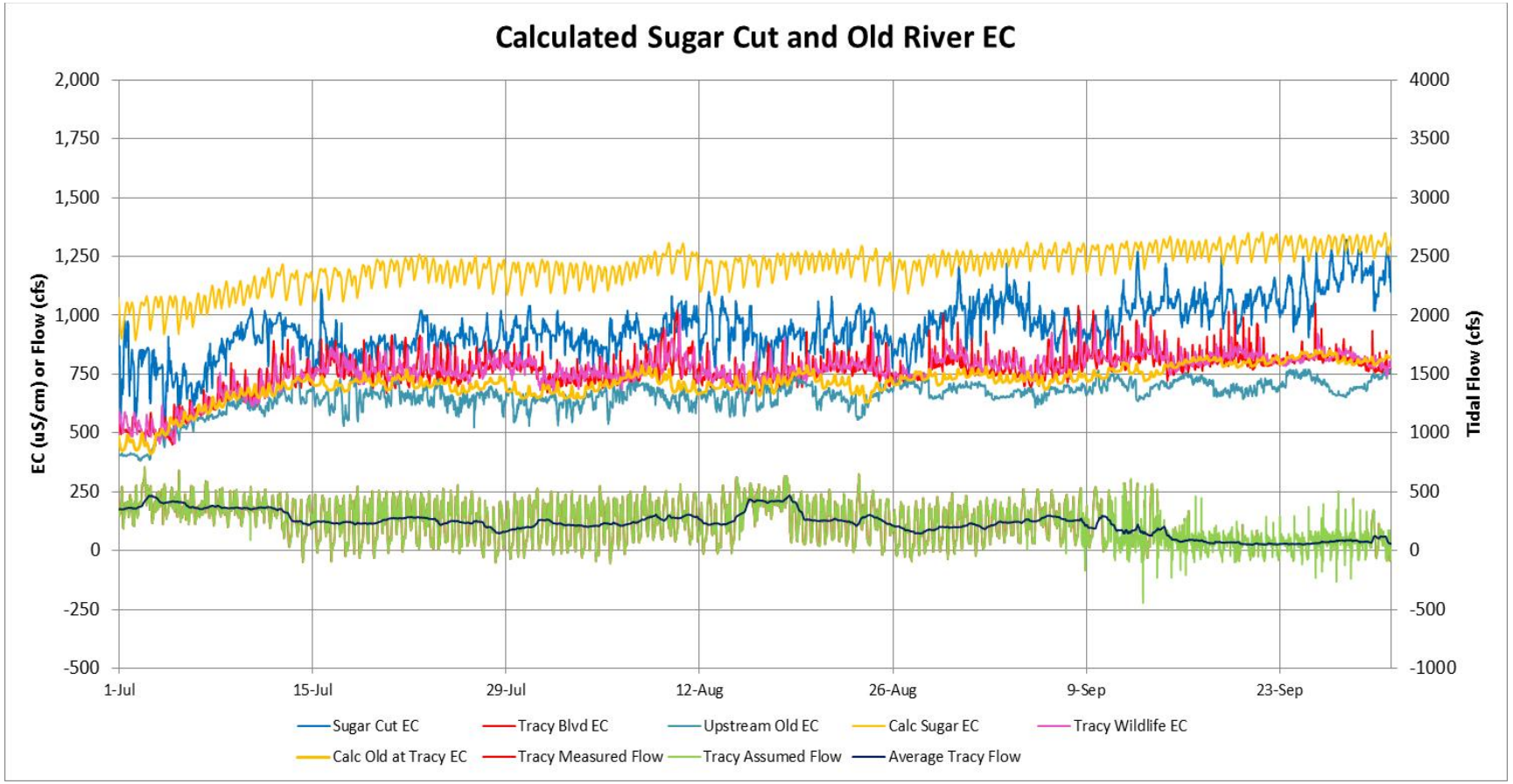
The measured Paradise Cut EC is controlled by several factors that are only partially captured in the calculated Paradise Cut EC. The minimum EC is controlled by the Old River EC during flood tides, and the maximum EC is flushed by ebb tides and during neap-tide periods by reduced tidal elevations. The 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. Amazing- that relatively simple tidal slough flushing calculations provide such a good match with the Paradise Cut EC measurements for the entire year, with full tidal movement (elevations and flows) and with the reduced fluctuations in tidal elevations and flows.



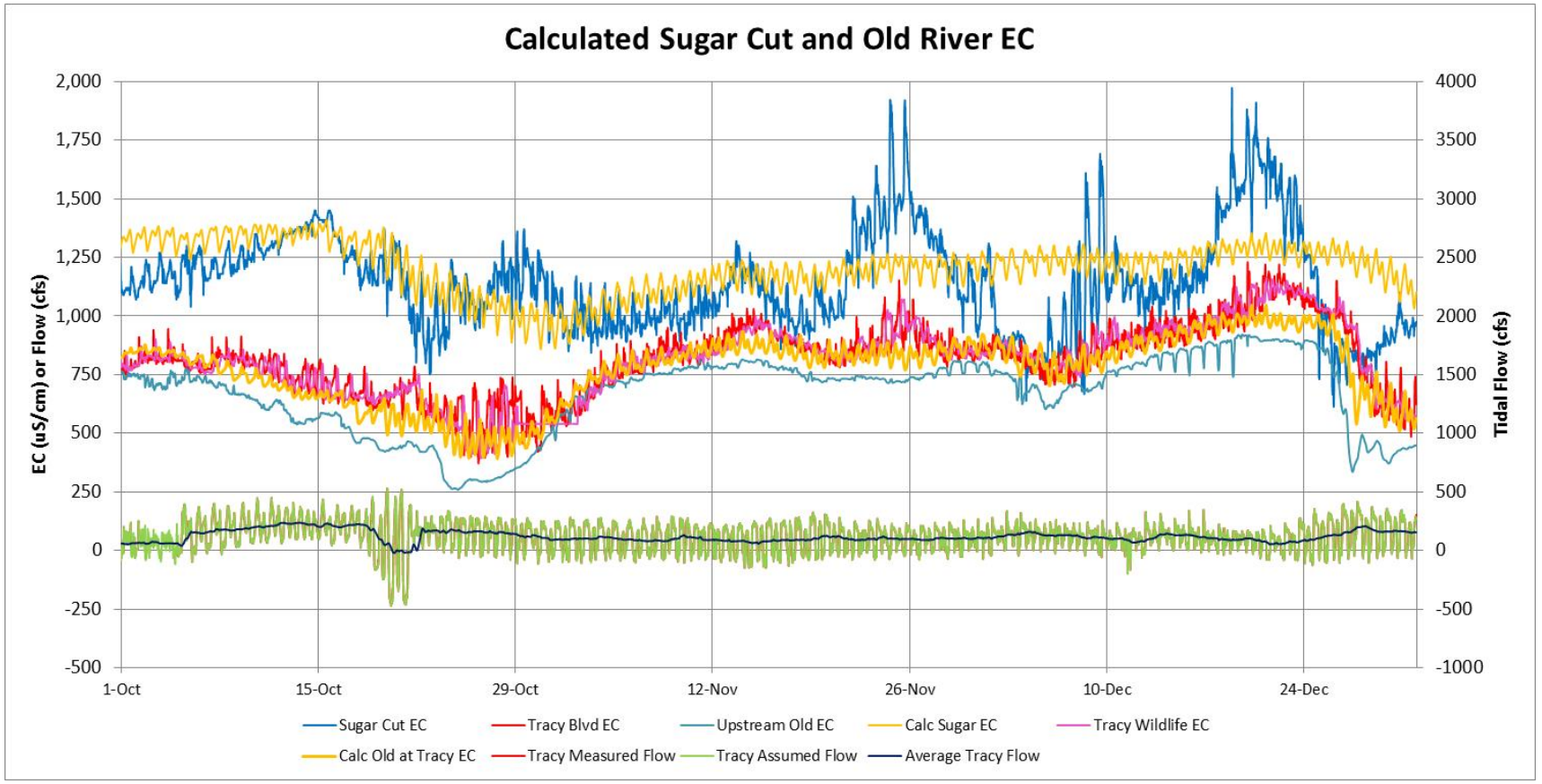
The Sugar Cut EC (dark blue) fluctuations are similar to the Paradise Cut EC fluctuations (previous graphs), but the minimum Sugar Cut EC is usually higher than the upstream Old River EC. This is likely caused by the EC measurements being further upstream (less flood tide flushing) and because during the summer months, the tidal gates on Ton Paine Slough divert the Old River water before it can reach the EC monitoring station. Nevertheless, the tidal flushing calculations for Sugar Cut indicate that the salt load is about 25% of the Paradise Cut salt load. The assumed salt source had an EC of 2,500 uS/cm and a flow of 5 cfs. This graph also shows the measured Old River at Tracy Boulevard tidal flows (green line) that reflects the tidal elevations (shown in previous graphs of Paradise Cut EC). The calculated effects of the ebb tide discharge from Paradise Cut and Sugar Cut on the downstream Old River at Tracy Boulevard EC (red line) are generally very similar to the measured EC at Tracy Boulevard.



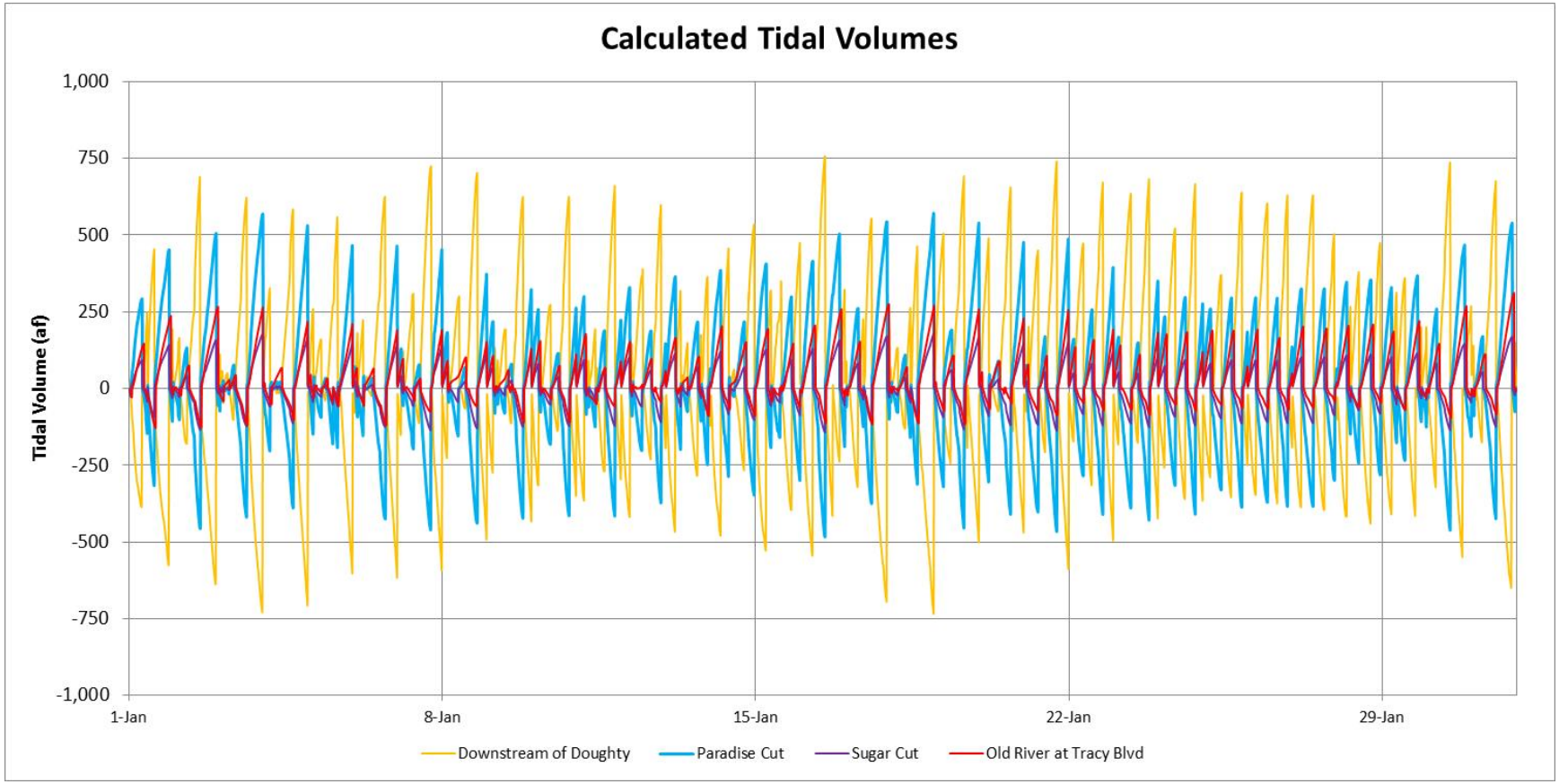
The very high EC at Tracy Boulevard during April (confirmed by Tracy Wildlife EC measurements) cannot be explained by salt loading from Paradise Cut and Sugar Cut. The head of Old River barrier was installed, reducing Old River flow to about 500-750 cfs, but the tidal flows at Tracy Boulevard (green line) remained high (-500 cfs to 500 cfs). However, the net flow at Tracy Boulevard approached 0 cfs during most of April. Because the Old River at DMC barrier was installed (with flap gates closed) at the beginning of April, but the Grant Line Canal barrier was not installed until May 3, there may have been a slight upstream flow between Old River at DMC and Old River at Tracy. There may have been some discharges from fields after salt leaching, and this high EC water may have accumulated in the vicinity of Tracy Boulevard. The EC was reduced when the net flows were increased when the Grant Line Canal barrier was installed in early May.



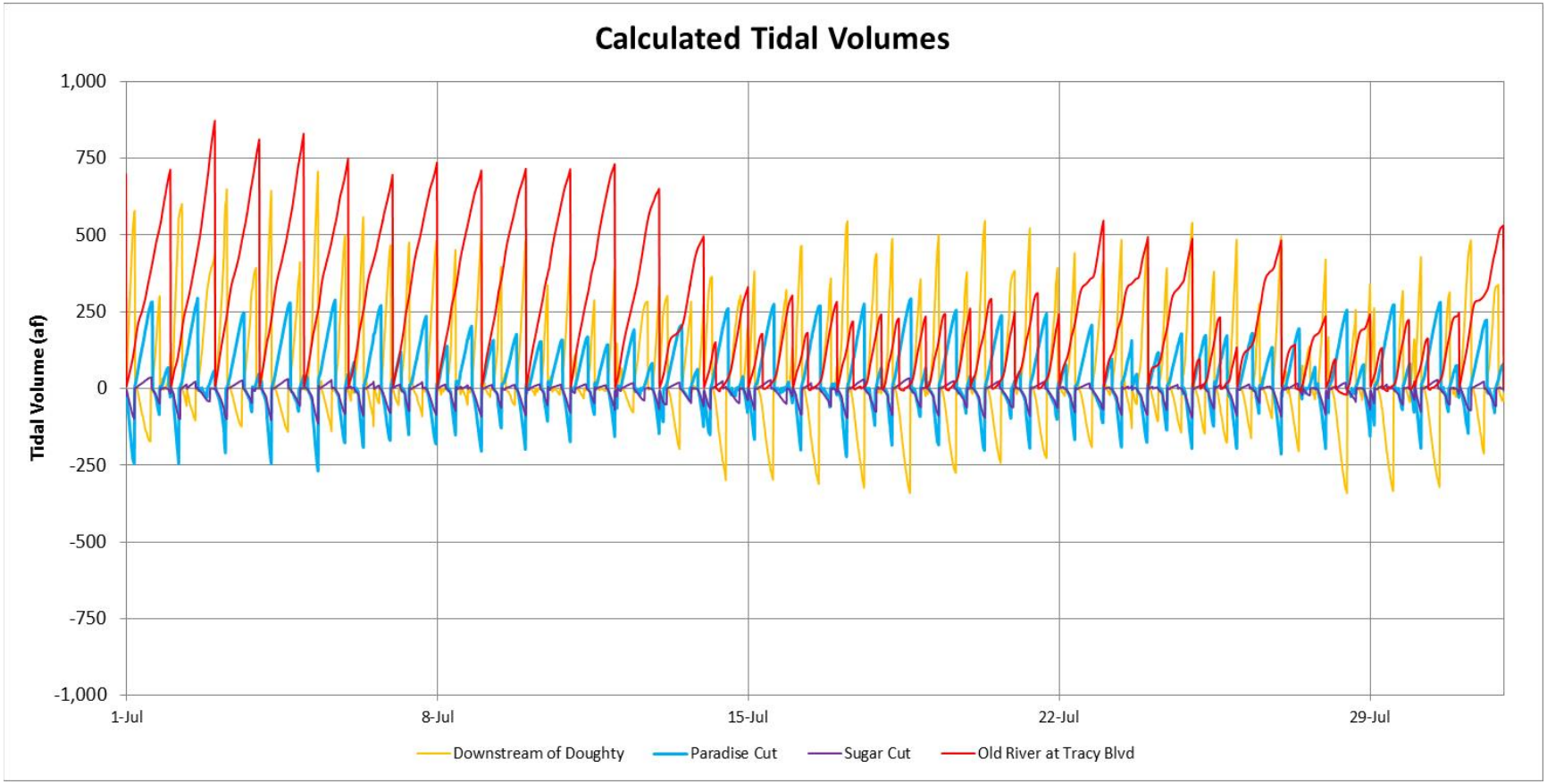
Old River EC increased from about 500 uS/cm in early July to about 750 uS/cm in August and September. The measured Sugar Cut EC and Tracy Boulevard EC increased accordingly. The calculated Sugar Cut EC was about 250 uS/cm greater than the Old River EC and generally matched the measured Sugar Cut EC. The measured flow in the second half of September (may not be accurate) resulted in the calculated Tracy Boulevard EC to become greater than the measured EC at Tracy Boulevard.



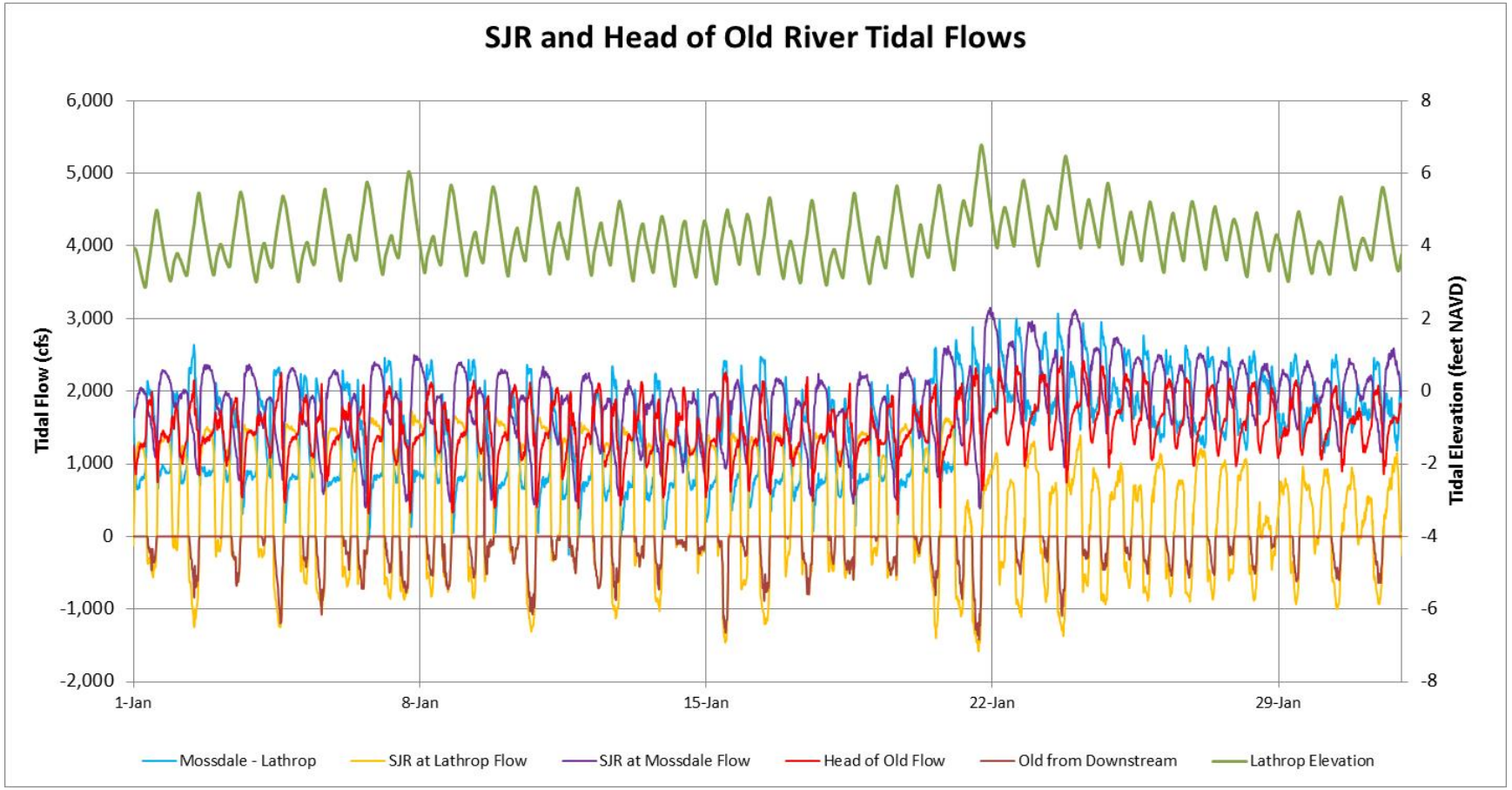
The basic mechanism of tidal flushing of Paradise Cut and Sugar Cut to Old River and the downstream movement of higher salinity water to Tracy Boulevard, located about 2 miles downstream of Sugar Cut, appears to match the measured increase in Old River EC between the Union compliance station (or Doughty Cut) and the Tracy Boulevard compliance station. The EC increments are greatest during periods of low Old River flow, and the EC increments are reduced by higher Old River flow.



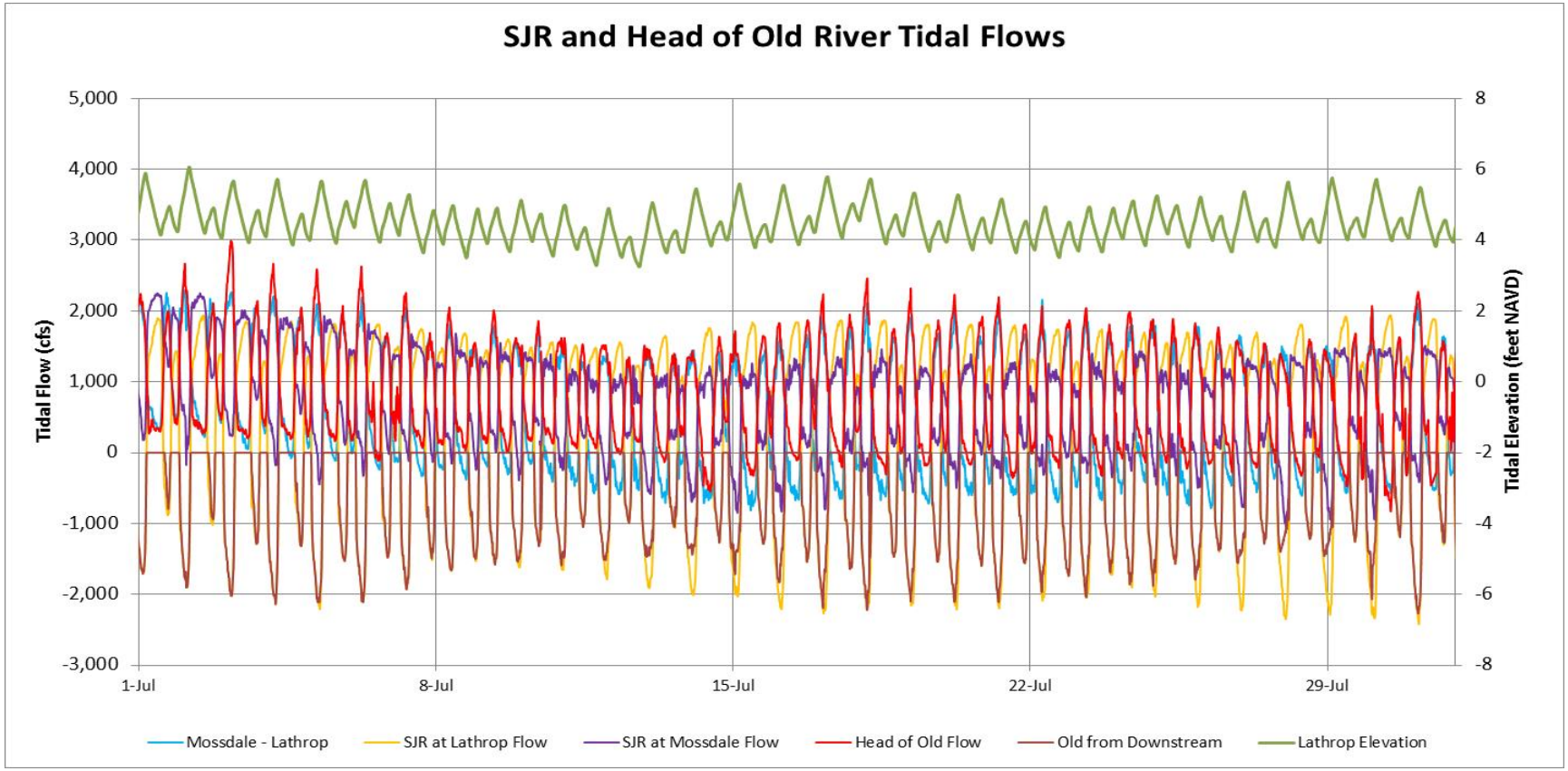
The comparison of the measured tidal flow volumes in Old River at Tracy Boulevard (red line) and the calculated tidal flow volumes downstream of Doughty Cut (gold line) and at the mouth of Sugar Cut (purple line) and Paradise Cut (blue line) in January 2012 illustrates that most of the tidal flows from Paradise Cut and Sugar Cut flow upstream to Doughty Cut (opposite direction) and to Gran Line Canal, rather than flowing past Tracy Boulevard. Measured tidal flow volumes at Tracy Boulevard were about 250 af (maximum ebb) and about -100 af (maximum flood). The measured tidal volumes in Old River at Tracy Boulevard were nearly identical to the calculated tidal volumes in Sugar Cut because the upstream tidal area for both stations was about 50 acres. The maximum calculated tidal volumes in Paradise Cut were about 250 af to 500 af because the assumed upstream tidal area was about 165 acres.



The comparison of the measured tidal flow volumes in Old River at Tracy Boulevard (red line) and the calculated tidal flow volumes downstream of Doughty Cut (gold line) and at the mouth of Sugar Cut (purple line) and Paradise Cut (blue line) in July 2012 illustrates that the tidal flows in Old River at Tracy were almost all ebb-tide (downstream), while the tidal flows in Sugar Cut were almost all flood-tide (upstream) to the Tom Paine Slough diversions for irrigation. Most of the higher salinity water from Paradise Cut would likely move downstream to Tracy Boulevard, but most of the high salinity water from Sugar Cut would likely be diverted to Tom Paine Slough during this period.



The tidal flows at the head of Old River are very sensitive to the tidal elevations in the SJR and the corresponding tidal flows at Mossdale (upstream) and at Lathrop (downstream). The head of Old River tidal flows (red line) are lowest at the beginning of each ebb tide (high tide elevations) and are greatest during flood tide, when the reverse (upstream tidal flow at Lathrop is diverted (squeezed) into Old River, along with the downstream river flow at Mossdale. In January, the net Mossdale flow was about 2,000 cfs and there was reverse flows at Lathrop during most flood tides. The tidal flow records are not always consistent; the Mossdale minus Lathrop flow (bright blue line) is not always the same as the head of Old River flow. The brown line shows the portion of the upstream flow at Lathrop (gold line) that is diverted into Old River during flood tides; most of the upstream flow at Lathrop was diverted into Old River.



The average SJR flow at Mossdale (purple line) was about 1,000 cfs in July of 2012. The flood tide (reverse flow) at Lathrop (gold line) was 1,000 cfs to 2,000 cfs, and nearly all of this reverse flow was diverted (squeezed) into Old River. The Old River flow was quite low during ebb-tide (downstream flow). Most of the SJR flow was tidally transported past the head of Old River in July (barriers installed). Because the flow diversion from the SJR to Old River is entirely controlled by the elevation gradients in the SJR and into Old River, the barriers may cause this shift in the tidal diversions, from a 50% diversion without barriers (e.g., January) to a nearly 100% diversion during flood-tide (upstream flow) and a 0% diversion during ebb-tide (downstream flow) with the temporary barriers installed.