Testimony for the SWRCB Proceeding on Delta Flow Criteria

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Summary

ICF has reviewed the actual Delta operations in WY 2008 and WY 2009 to show the effects of existing D-1641 outflow objectives, and the effects from additional restrictions on reverse Old and Middle River (OMR) flows for fish protection. A daily Delta model was used to estimate the D-1641 exports, outflows, and E/I ratios. The model was then used to calculate the reduced exports, increased outflows, and reduced E/I ratios that resulted from these fish protections in WY 2008 and WY 2009.

ICF suggests that all identified public trust ecosystem benefits and impacts should be evaluated as functions of Delta outflow or the E/I ratio. As an example, the longfin smelt fall mid-water trawl (FMWT) abundance shows a linear increase with higher outflows in the February-May period. This observed biological relationship suggests that 1,000 cfs of additional outflow would result in greater longfin smelt FMWT abundance (increase of 1% of the abundance at 100,000 cfs). The E/I ratio (during the period of biological effects from outflow on a fish species) can be used to track the percentage of the possible abundance in a year that would be lost from reduced outflow caused by exports.

ICF suggests that entrainment impacts from exports are also controlled by the E/I ratio. Entrainment impacts follow a "logistic" curve with E/I. Entrainment impacts are reduced farther away from the exports. Entrainment impacts are also strongly dependent on the distribution of vulnerable fish (larvae and juveniles) in the Delta or the migration pathways through the Delta.

Monthly inflow allocation curves should be based on all available outflow-benefit curves and outflow-salinity impact curves to show the various benefits that would be achieved with any allocated outflow. The minimum outflow and maximum allowed E/I ratio to protect fish abundance and reduce entrainment impacts should then be selected, with the E/I ratio possibly changing with increasing inflow conditions. There may be no biological basis for limiting exports to less than the physical capacity when inflows are large enough to reduce the E/I ratio sufficiently to protect fish.

A daily accounting of Delta inflows, flows within Delta channels, exports, and outflow should be used to begin tracking the fish spawning and migration events in the Delta and to evaluate potential fish impacts from exports and reduced outflow (Kimmerer 2008, Jones & Stokes 2005c). This would allow all identified inflow benefits, outflow benefits, salinity impacts, and export entrainment impacts to be accurately evaluated and considered together in monthly Delta flow allocation curves.

Introduction

The Delta flow criteria that the legislature has asked the SWRCB to develop this year can be considered as a review of the supporting evidence (i.e., scientific basis) for the existing D-1641 Delta flow and salinity objectives. Some changes in the minimum monthly outflows or X2 requirements or E/I limits, which together form the monthly flow allocation rules, might be adopted if compelling biological or ecological evidence for increased benefits at higher outflows are presented at this Proceeding.

Although this Proceeding is focused on Delta outflow criteria, the full public trust (PT) value equation for the Delta ecosystem should be considered:

PT value = PT benefits (Sacramento) + PT benefits (Yolo) + PT benefits (Mokelumne + Cosumnes) + PT benefits (San Joaquin) + PT benefits (outflow) – PT impacts (outflow) – PT losses (exports)

Each of these terms will include multiple benefits at various flows. The benefits from Delta inflows will likely depend on the location of the inflows. Outflow benefits for fish and salinity impacts from low outflow should be separately evaluated. The entrainment losses from exports will likely depend on the location of the exports, because this will change the organisms most vulnerable to entrainment risk. For example, the Bay-Delta Conservation Plan (BDCP) proposes to reduce the PT Losses caused by exports by screening and relocating the export diversions, while maintaining D-1641 outflow and E/I ratios. The Delta Corridors Plan would separate the San Joaquin River inflow from the exports use fish screens at the Delta Cross Channel and Georgiana Slough to separate the water supply diversions from the Sacramento River fish (ICF Jones & Stokes 2009). Additional benefits may be achieved with these future Delta configurations if outflow is increased at times when outflow-benefits are greatest.

This Proceeding is focused on the possibility of increasing the Delta public trust ecological value by raising the required outflows. However, increasing the Delta outflow would require reducing the exports by the same amount. This will reduce the beneficial uses of the exported water. The SWRCB must therefore make careful and reliable choices to properly balance these competing consumptive beneficial uses and public trust ecological beneficial values.

Monthly Delta outflow criteria are needed to provide reliable “water allocation curves” for each month’s inflow among Delta outflow, in-Delta uses (diversions), and exports (CVP + SWP). This discussion assumes that historical in-Delta diversions are allowed, so the monthly allocation curves are simple divisions between required outflow and allowable exports.

Delta Inflow Allocation-Water Year 2008 and 2009 Examples

The existing D-1641 objectives (i.e., allocation rules) and resulting monthly allocation curves will be reviewed using the DeltaOPS (Delta Operations and Protections Simulation) model of daily Delta flows that was developed for the CALFED EWA evaluation in 1999. (A description of this model can be found in Jones & Stokes 2005a). This evaluation of the existing allocation for WY 2008 and WY 2009 is retrospective (looking back over the last two years). However, the actual water allocation process is the combination of seasonal, monthly, weekly, and daily discussions and decisions that occur with limited knowledge about future Delta inflows. The WY 2008 and WY 2009 examples will be shown together to illustrate the existing D-1641 allocation (i.e., water management), and evaluate the public trust ecological benefits achieved with the existing Delta outflow criteria.

Figure 1 shows the daily Delta inflows and channel depletion for water year 2008 and water year 2009 (from DAYFLOW). The remaining inflows that can be allocated between outflow and exports can be estimated by subtracting the channel depletions from the total inflows. Water Year 2008 was classified dry and WY 2009 was classified critical, although the total inflow to the Delta was nearly identical in both years (about 11.5 maf). (Side note: The 40-30-30 year type calculation should be eliminated from ecosystem outflow criteria because Delta habitat conditions are likely independent of upstream hydrology). Most of the Delta inflow was from the Sacramento River, with 9.5 maf in 2008 and about 10 maf in 2009. It is interesting that both years included several weeks with relatively high inflows (more than 25,000 cfs) during January and February of 2008, and during February-March and May of 2009.

Figure 2 shows the D-1641 required outflows (green lines) compared with the available Delta inflow after in-Delta diversions (red lines) for WY 2008 and WY 2009. The outflow in most years is controlled by the required minimum outflow and the maximum export/inflow (E/I) ratio (14-day moving average). The D-1641 minimum outflow requirements range from 3,000 cfs in September to about 11,500 cfs in February, March and April (i.e., X2-outflow requirements). The X2 requirements in May and June were not relaxed (to 4,000 cfs) because the May forecast (90%) for the Sacramento runoff index was not less than 8.1 maf (This low runoff occurred only 2 times since 1967; in 1977 and 1994). Each 1,000 cfs of outflow for a month requires about 60 taf. Each 1,000 cfs of outflow for a year requires about 725 taf. The D-1641 minimum outflows for WY 2008 and WY 2009 each required about 4 maf (about 35% of inflow).

Figure 3 shows the existing D-1641 inflow allocation rules for minimum outflow and maximum export/inflow ratio (14-day moving average) for WY 2008 and WY 2009. Because exports are limited by a specified fraction of the inflow (E/I) and by the permitted capacity (of about 12,000 cfs) the final outflow will often be greater than the minimum required outflow. The combination of these two rules controls the daily allocation of Delta outflow. The potential daily exports are the difference between the available inflow (red line) and the allocated outflow (maximum of green line and purple dots). If the historical outflow was greater than the required (green line) and the maximum E/I limits (purple dots) then some other factor, such as salinity objectives or Old and Middle River (OMR) reverse flow restrictions was limiting the historical exports. Precipitation and runoff in the Delta will also increase the outflow. There was about 600 taf of rainfall-runoff estimated in the Delta for WY 2008 and about 660 taf for WY 2009. (Side note: The estimated rainfall-runoff confuses the inflow allocation, and may not result in much additional outflow in dry years).

For WY 2008, the combination of these water allocation rules (i.e., minimum outflow, X2, E/I limits, and export capacity) required a Delta outflow of about 5.8 maf. For WY 2009 the combination of these water allocation rules required a Delta outflow of about 5.9 maf. February 2009 illustrates the potential problem of fixed monthly rules, when the D-1641 required outflow for X2 (of about 11,400 cfs) was greater than the Delta inflow. Similar problems occurred in May and June of 2008 when X2 requirements were again higher than the inflow. A water allocation curve should always divide the available daily inflow between the Delta outflow, in-Delta diversions, and exports.

Figure 4 shows the D-1641 allowable exports, estimated by the DeltaOPS model, as limited by the objectives for minimum outflow and X2 (dark blue triangles) and maximum E/I and VAMP (light blue circles) for WY 2008 and WY 2009. The DeltaOPS model estimates of the D-1641 allowable exports (with VAMP but without any OMR restrictions) for WY 2008 would have been 3, 939 taf (34% of inflow), and the D-1641 allowable exports for WY 2009 would have been 3,929 taf (34% of inflow). The historical exports in WY 2008 were 3,725 taf, about 213 taf less than the estimated D-1641 allowable exports. The historical exports in WY 2009 were 3,673 taf, about 256 taf less than the estimated D-1641 allowable exports. Some of these differences were caused by the model trying to meet the X2 outflow requirements and reducing exports (to zero) on some days in April-June of 2008 and in June 2009. Some of the differences between the allowable exports (green shaded area) and the historical exports (red line) are variations between the estimated daily limits and the actual (e.g., monthly average) objectives. But the major differences (i.e., large reductions) show the effects of reverse OMR flow restrictions that limited the actual exports in WY 2008 and WY 2009 to less than the D-1641 allowable exports.

Effects of OMR Limits for Fish Protection on Outflow

Beginning in the last week of December 2007, exports were reduced to maintain reverse OMR flows of less than 5,000 cfs in January, February and the first week in March. OMR restrictions were again imposed after VAMP in the last two weeks of May and most of June of WY 2008. Reverse OMR flow restrictions were imposed in December, at the end of February and early March, and after VAMP in May and June of WY 2009.

The DeltaOPS model was used to estimate the effects of the reverse OMR flow restrictions. A second model run used specified weekly reverse OMR flow limits following the Smelt Working Group recommendations. These simulated OMR restrictions may not be completely accurate because there is no official accounting for the mandated OMR restrictions. (Side note: ICF suggests that SWRCB require a daily accounting of Delta operations by CVP and SWP, including the basic D-1641 objectives, water transfers, and the reverse OMR restrictions.)

Figure 5 shows the simulated reductions in exports during these fish protection periods of WY 2008, and the increases in Delta outflow during these same periods. The model results indicate that the OMR restrictions in WY 2008 reduced allowable exports by about 546 taf. The changes in Delta outflow were not large relative to the series of storm events that caused outflow to range between 5,000 cfs and 25,000 cfs in January and February of 2008. The reverse OMR flow reductions represented about 14% of the D-1641 allowable exports in WY 2008. Assuming a moderate water price of $250/af, the increased outflow benefits and reduced entrainment impacts would require about $136 million in reduced export water supply.

Figure 6 shows the reductions in exports during the OMR fish protection periods of WY 2009, and the increases in Delta outflow during these same periods. The estimated export reductions caused by reverse OMR flow restrictions in WY 2009 were about 403 taf. The changes in Delta outflow were not large relative to the major storm runoff in late February and early March that caused outflow to range between 10,000 cfs and 50,000 cfs. The reverse OMR flow reductions represented about 10% of the D-1641 allowable exports in WY 2009. Assuming a moderate water price of $250/af, the increased outflow benefits and reduced entrainment impacts would require about $100 million in reduced export water supply.

Salinity Impacts from Low Delta Outflows

The development of outflow-benefits curves is illustrated with the basic relationships between Delta outflow and salinity distribution in the estuary upstream of Martinez (Contra Cost Water District 2010). The relationship between outflow and X2 is also reviewed and evaluated as a possible link to ecological habitats. These outflow-salinity relationships were introduced by CCWD staff (Denton 1993) using the concept of effective Delta outflow and negative exponential salinity-outflow curves (known as the G-model formulation). Salinity (measured as EC) at Suisun Bay and Delta locations can be well-represented with negative exponential EC-outflow curves. These EC-outflow relationships will be illustrated using historical monthly average outflow and EC values from WY 1976-1991. This 16-year period is often used for Delta salinity modeling of representative Delta conditions because it includes dry-year and wet-year sequences (Jones & Stokes 2005b). The salinity- outflow impact relationships are shown as an example of what is needed for all other outflow-benefit curves. The relationships must be based on measurements from our estuary, and should be applied to the months when the target life-stage or ecological process is present or active in the estuary. Identifying the likely mechanisms for any observed relationships with outflow (i.e., regressions) would strengthen the reliability of the outflow-benefit curve.

The effective Delta outflow is first estimated from the monthly historical outflow (from DAYFLOW). The effective Delta outflow is similar to a moving-average, with a period of about 3 months. Figure 7a shows the monthly outflow and effective monthly outflow for this period. The outflow scale is logarithmic because monthly outflow varied from less than 5,000 cfs to more than 100,000 cfs. Figure 7b shows the historical monthly EC (µS/cm) and the estimated EC using the effective Delta outflow and the negative exponential equation for Martinez (located 56 km from the Golden Gate) and Collinsville (81 km). Considering the uncertainty in the outflow estimates (i.e., estimated depletions and rainfall runoff) the EC estimates from effective outflow match the historical EC during most years, emphasizing the strong relationship between outflow and salinity distribution (i.e., intrusion) in the upper estuary.

Figure 8 shows the negative exponential relationship between effective outflow and EC at Jersey Point and at Rock Slough (CCWD Pumping Plant #1). The historical monthly EC data is generally described with these curves. These EC-outflow relationships can be used directly as outflow-salinity impact curves. Salinity (EC) can be considered an impact for Delta diversions and exports used for drinking water and agricultural purposes. Because salinity intrusion is a physical mechanism caused by tidal mixing, the outflow-impact curve will be the same for any month at a specified location. For any effective Delta outflow, the salinity will be lower at locations farther upstream. The salinity effects on Delta diversions will be greatest at downstream stations. Therefore, there are two basic ways to reduce salinity impacts in Delta diversions and exports; move the location of the diversion upstream, or increase the Delta outflow to reduce the salinity intrusion from the estuary.

Table 1 gives the calculated EC at several Delta locations for effective outflows from 2,500 cfs to 12,500 cfs. Because the salinity-outflow impact curve has a negative exponential shape, the greatest reduction in salinity impacts will be achieved by increasing the lowest monthly outflows. Table 1 can be used to approximate the Delta outflow needed to meet the D-1641 salinity objectives. For example, the EC objective of 450 µS/cm at Jersey Point (April-August) requires an outflow of about 7,000 cfs, similar to the outflow needed to maintain X2 at Collinsville (81 km). The EC objective of

450 μS/cm at Emmaton requires a slightly higher outflow because Emmaton is somewhat closer to the confluence (near Collinsville) than Jersey Point.

The last column of Table 1 gives the estimated EC at the CVP and SWP exports from seawater intrusion. This seawater intrusion effect was simulated with the DSM2 model for the 1976-1991 period, assuming D-1641 objectives. Table 1 indicates that for all Delta locations, a substantial reduction in the salinity impacts could be achieved with a 500 cfs increase in outflow when the outflow is less than 5,000 cfs. More moderate reductions in salinity impacts can be achieved with a 500 cfs increase in outflow when the outflow is between 5,000 cfs and 7,500 cfs. Only small reductions can be achieved with a 500 cfs increase at most Delta locations when the outflow is greater than 7,500 cfs.

Increasing the D-1641 minimum monthly Delta outflows from 3,000 cfs (in September of all years) to 5,000 cfs for all months of all years would provide considerable salinity benefits. The seawater intrusion at the exports would be reduced from about 500 μS/cm with an outflow of 3,000 cfs to about 150 μS/cm with an outflow of 5,000 cfs. The exports would be reduced by the same amount as outflow was increased to provide a minimum outflow of 5,000 cfs. The salinity-outflow curves can be easily quantified with these negative exponential equations. It will be much more difficult to quantify the relative value of the salinity reduction benefits and other ecosystem outflow-benefits.

Figure 9 shows the daily average measured EC at Collinsville and Jersey Point for WY 2008 and 2009 and the calculated EC at Collinsville and Jersey Point using the effective outflow and the negative exponential equations (given in Table 1). The effective outflow pattern is shown for comparison (on right axis). The effective outflow is a running average of the daily outflow and is less variable than the daily outflow. The 14-day tidal cycle (i.e., spring-neap tides) has definite effects on the daily average EC values. The dominant seasonal patterns of EC at both stations was well described with the effective outflow and negative exponential relationships. The salinity changes caused by outflow changes can be accurately tracked and evaluated with the DeltaOPS daily model.

Review of Outflow and X2 Relationship

The X2 objective is the daily average position of the 2 ppt salinity gradient, specified as the distance in kilometers upstream of the Golden Gate Bridge. The D-1641 target X2 positions are the historical EC monitoring stations at Port Chicago (at 64 km), Chipps Island (now Mallard Slough at 75 km), and Collinsville (at 81 km). Using measurements of the salinity (EC) at these stations and the extrapolated position of X2 along the estuary, the X2-outflow auto-regressive equation was identified (Jassby et al 1995). The X2 value depends on the previous X2 position and the current outflow. Separate equations were developed for daily X2 and monthly average X2 position. The daily X2 equation is:

$$\text{Daily X2 (km)} = 10.16 + 0.945 \times \text{previous X2 (km)} - 1.487 \times \text{Log [outflow (cfs)]}$$

This equation can be rearranged slightly to give the steady-state X2 for a given steady outflow. The steady-state X2 equations is:

$$\text{X2 (km)} = 185 - 27 \times \text{Log [Outflow(cfs)]}$$

The outflow required to maintain X2 is therefore:

$$\text{Outflow (cfs)} = 10 \text{ \^{} } [185 - \text{X2(km)}/27]$$

Table 2 gives the outflow required to maintain X2 between 50 km and 90 km. The width and area (acres) of the estuary habitat is given for reference. Because the relationship between outflow and X2 is logarithmic, the X2 position will change by a constant amount for each factor of flow increase. A 10x increase in flow will move the X2 position downstream 27 km. An outflow of 1,000 cfs would correspond to an X2 of 104 km, which is about the location of Rio Vista. An outflow of 10,000 cfs (10x) would correspond to an X2 of 77 km, about 2 km upstream of Chipps Island near Pittsburg. An outflow of 100,000 (10x) would correspond to an X2 of 50 km, about 6 km downstream of Martinez near Crockett (C&H Sugar). Moving X2 downstream 1 km would require the outflow to increase by about 9%, and moving X2 downstream 5 km would require the outflow to increase by about 55%.

Figure 10a shows this relationship between outflow (cfs) and X2 position. On a linear X2 scale the required outflow is exponential with decreasing X2. A larger increment of flow is required for each 1 km downstream movement of X2. The D-1641 X2 objectives require about 7,100 cfs for X2 at Collinsville (81 km), about 11,400 cfs for X2 at Chipps Island (75 km) and about 29,200 cfs for X2 at Port Chicago (64 km). This X2-outflow curve is important because many biological regressions with X2 have been suggested. For example, several of the annual fish abundance index values (e.g., Fall mid-water trawl, summer townet, Bay study trawls) have been evaluated with X2 to determine the importance of the salinity gradient location during some life-stage period on the resulting fish populations (Kimmerer 2002, Kimmerer 2004, Kimmerer 2009).

Figure 10a also shows one of the strongest relationships between X2 and fish abundance, identified for longfin smelt abundance in the Fall mid-water trawl (FMWT). The abundance (number of fish caught in the 400 trawls) varied with X2, increasing exponentially with decreasing X2. The abundance in the FMWT prior to 1987 (before the Corbula clam colonized Suisun Bay) was estimated as:

$$\text{Log [Longfin abundance]} = 7.0 - 0.05 \times [\text{average X2 (km) during February-May}]$$

For an average X2 of 90 km the predicted abundance would be 316 fish. For an average X2 of 80 (Collinsville) the predicted abundance would be 1,000 fish, for an average X2 of 70 km the predicted abundance would be 3,160 fish, and for an average X2 of 60 km (Mothball fleet) the predicted abundance would be 10,000 fish. A log-abundance slope (coefficient) of 0.05 with X2 requires a downstream movement of 20 km to increase the abundance by 10x. A downstream movement of 20 km requires more than 5x the outflow, averaged over this four month period. This is the strongest X2-abundance relationship found in the estuary. Other fish show a smaller increase in abundance with decreasing X2 (or with increasing outflow).

Figure 10b shows X2 and the FMWT abundance of longfin smelt as a function of outflow. Because both the abundance and outflow are exponential with X2, the effects of increased outflow on increased smelt abundance is nearly linear, with about 30,000 longfin smelt estimated at a flow of 100,000 cfs. Therefore, a 1% increase (in the maximum FMWT abundance) would be expected for each 1,000 cfs increase in average February-May outflow. The additional outflow volume would be about 240 taf, representing $60 million (for assumed water value of $250/af) for each 1% increase in the maximum longfin smelt FMWT abundance. Since other fish also show a log-abundance regression with X2, a smaller increase in abundance (of less than 1% maximum abundance) for other estuarine fish might be expected for each 1,000 cfs increase in outflow.

The implications of a linear FMWT abundance with outflow are that: 1) more outflow will increase fish abundance by some relatively constant rate (i.e., fish/outflow), and 2) there is no range of outflows with much higher benefits in proportion to outflow increases. An outflow of 5,000 cfs will provide or protect about 5% of the maximum possible FMWT abundance (i.e., 1,500 longfin smelt), while an outflow of 25,000 cfs will provide or protect about 25% of the maximum possible FMWT abundance (7,500 longfin smelt). The effects of reduced outflow from exports can also be quantified as a linear reduction in the expected abundance. The expected effect from maximum exports of 15,000 cfs would be a reduction of 15% of the maximum possible abundance (i.e., 4,500 longfin smelt).

Because the expected abundance without exports is also a function of outflow, the biological basis for the E/I objective can be described. The percentage reduction in a year's abundance will be that year's E/I (%), because the inflow could have been the outflow if there were no exports. For example, suppose the inflow was 50,000 cfs and the exports were 10,000 cfs (in the months affecting the fish abundance, February-May for longfin smelt). The abundance would have been 50% of maximum abundance (15,000 fish), but was reduced to 40% of maximum abundance (12,000 fish) by the exports. Therefore the impact of the exports on abundance that year would have been equal to E/I (20%) of the fish expected that year without exports (i.e., 3,000/15,000).

Effects of Outflow on Reduced Entrainment Impacts

The generalized Delta ecosystem public trust accounting equation tracks the benefits from inflows and the benefits from outflow, but subtracts the water quality impacts at low outflows and the entrainment impacts from exports. Because fish abundance effects are linear with outflow, the relative effects of outflow reductions from exports on fish abundance can be quantified and regulated with the E/I ratio. The E/I ratio has a second biological basis because export entrainment impacts increase at higher E/I ratios.

The impacts from exports on fish entrainment from the upper estuary (i.e., Delta) will therefore be reduced when outflow is higher because the E/I will be lower. Results from the DSM2 particle tracking model (tracking water movement to the export pumps) indicate that the fraction of water entrained from a specified location during a period (e.g., 30 days) can be described as a function of the E/I ratio. This is simply explained as the probability of water entrainment increasing as the fraction of exported water increases. The curves will have a "logistic" shape, with low entrainment and low rate of increase at low E/I, some transition to higher entrainment with a maximum rate of increase, and maximum entrainment with a lower rate of increase at high E/I. The fraction of water entrained when the E/I ratio is 0.2, 0.4, 0.6 or 0.8 depends on the location within the Delta (See Figure 7 in Kimmerer and Nobriga 2008).

Particle tracking results indicate that the risk of entrainment depends on how far away from the major export pathways the starting location was. For example, water from the Sacramento River at Hood was entrained at nearly the E/I ratio (15% at 0.2 and 35% at 0.4). But water from Rio Vista (downstream of the main diversion from the Sacramento River to the exports was entrained at less than half the E/I ratio (5% at 0.2 and 15% at 0.4). Entrainment from Collinsville (confluence) was very low (less than 5% at 0.4, 10% at 0.6 and 30% at 0.8). Water from the San Joaquin River at Vernalis was entrained at more than the E/I ratio (90% at 0.2), because almost all the SJR water is usually exported. Water from the central Delta (Franks Tract) was also entrained at more than the E/I ratio (20% at 0.2 and 60% at 0.4) because this is one of the main pathways for exports.

Fish entrainment risk will generally be less than the water entrainment risk because fish have other "cues" or behavior that keeps them in preferred habitat or migration corridors. For example, many fish rear in bottom habitat (benthic) or shallow habitat along the channels (littoral) and are not moving with tidal flows. Pelagic fish may have some tidal or nocturnal behavior (i.e., resting) that may reduce their movement with the tidal flows. Various approaches to isolate portions of the Delta from entrainment risk (e.g. Peripheral Canal or the Delta Corridors Plan) should be very effective in reducing the export entrainment impacts for some fish. Improving the CVP and SWP fish collection and salvage facilities or screens to separate water flow from fish (e.g. at the head of Old River, Delta Cross Channel and Georgiana Slough) would also provide substantial reductions in the entrainment impacts.

Figure 11 shows the daily E/I ratios as simulated with the DeltaOPS model for WY 2008 and WY 2009 for 1) D-1641 baseline conditions and 2) the reverse OMR restrictions (adjusted conditions). The E/I ratio will decrease with the reduced exports, but the relative change in the entrainment impacts will be less when the E/I is already low. Because many of the water entrainment to E/I ratio slopes remain low at E/I ratios less than 0.4, the reduction in fish entrainment may be quite small. Reductions in potential entrainment impacts from export reductions are likely to be larger when the baseline E/I is higher than 0.4. The general relationship between export impacts and the E/I ratio is important because a reduction in exports to increase outflow will also reduce the E/I ratio and thereby reduce the entrainment impacts from the remaining exports (i.e., lower fish/export ratio). However, when the outflow is high and the E/I ratio is low, the reduction in entrainment impacts will be smaller. The reduction in fish entrainment impacts will always be smaller at locations that are away from the pathway for the exports and for fish that have stronger habitat preferences.

Monthly Inflow Allocation Curves

Monthly allocation curves, which can be developed based on the outflow benefits achieved in each month, are suggested as the general method for using the information presented at the Delta Flow Criteria Proceeding. The D-1641 objectives provide the existing Delta flow allocations curves for each month. After allowing in-Delta diversions, these monthly curves show how daily inflow is allocated for shared water supply and public trust ecosystem benefits. Because salinity impacts are rapidly reduced with moderate outflows increasing from 2,500 cfs to 7,500 cfs, and because 5,000 cfs would position the estuary salinity gradient within Suisun Bay, Honker Bay and the confluence habitat (X2 of 85 km near Antioch) a minimum Delta outflow of 5,000 cfs should be considered for all monthly allocations curves. The E/I can then be specified for each month to limit the maximum impacts from exports on fish abundance and entrainment. A maximum permitted export limit may be counter-productive for public trust ecosystem benefits, because export impacts will be less when the E/I is lowest. The monthly flow allocation curves should include full physical capacity export pumping.

Figure 12a shows the cumulative distribution of monthly Delta inflows for WY 1968-2007 (e.g., recent 40 years). The monthly allocation curves should be developed for the range of possible Delta inflows from 5,000 cfs to 50,000 cfs. Higher flows will not be as difficult to allocate; full exports could likely be allowed. Biological conditions at flows higher than 50,000 cfs have been observed infrequently. Figure 12b shows the slighlty different cumulative distributions of daily inflows for each month, from WY 1968-2007. Daily inflows show more variations (during storm events) than monthly average inflows, but the monthly range was similar. Evidence for specific public trust ecosystem values should be presented as outflow-benefit relationships for each month or season. This would provide a unifying format for comparing and combining individual outflow-benefit relationships into aggregate public trust ecosystem benefit curves for each month.

Figure 13 shows the existing water allocation curve for February (as an example), based on the D-1641 outflow, X2, and E/I objectives. Because there are several possible D-1641 objectives in February, there is some variation in the allocation curves. Figure 13a shows the February allocation curve with X2 at Collinsville and E/I of 45% (relaxed if January runoff is low) and permitted exports of 11,280 cfs. Figure 13b shows the February allocation curve with X2 at Chipps Island and E/I of 45% and maximum exports of 14,900 cfs. The bottom scale represents the range of possible February inflow, with 5,000 cfs increments to 50,000 cfs. The horizontal blue line represents the flow allocated to in-Delta diversions (assumed to be 750 cfs). The diagonal line also indicates the total inflow available for allocation. The percentiles of historical average February inflows for 1968-2007 are given along the diagonal line for reference. For example, the minimum historical February inflow was 10,000 cfs. About 10% of the February inflows were less than 15,000 cfs, and about 20% o the February inflows were less than 22,000 cfs. Agreeing on the proper allocation curves for these relatively low inflows will likely be the most difficult. About 50% of the February inflows were greater than 43,000 cfs. Outflows would be greater than 25,000 cfs with D-1641 objectives.

The outflow allocation process is relatively simple. The daily total inflow is compared to the outflow allocation curve (dark blue dots) that is based on the applicable D-1641 objectives (for this example). The remaining water can be exported for beneficial water supply uses. For example, if the February inflow was 20,000 cfs and the objectives in the upper graph (Figure 11a) applied, then the outflow would be at least 7,100 cfs, to meet X2 at Collinsville, but the E/I ratio of 45% would limit exports to 9,000 cfs, about 750 cfs would be diverted for in-Delta uses, and the allocated outflow would be 10,250 cfs.

The development of the monthly allocation curves should be based on the outflow-benefit curves that are presented at this Proceeding. Imagine turning all available outflow-benefit and outflow-salinity impact curves so that they are alongside the vertical scale on Figure 13. This would show the various benefits that would be achieved with any allocated outflow (for February). The minimum outflow and maximum allowed E/I ratio to protect fish abundance and reduce entrainment impacts could be selected, with the E/I possibly changing with increasing inflow conditions. There may be no biological basis for limiting maximum exports to less than the physical capacity if the inflows are large enough to reduce the E/I ratio sufficiently. This would allow more exports to be made when inflows are highest.

A daily Delta flow evaluation tool (such as DeltaOPS) can be used to test various monthly allocation curves and evaluate the resulting patterns of outflow and allowable exports, with associated estimates of fish abundance and entrainment impacts. The great advantage of monthly allocation curves, rather than individual objectives (with dependence on previous upstream hydrology), is that monthly allocation curves always divide the actual inflow, and will never require higher outflows than available inflows, nor force exports to zero to meet fixed outflow objectives when there is not sufficient inflow (such as May-June of 2008 and February and June 2009). The development of the reliable monthly allocation curves to protect both beneficial water supply uses and public trust ecosystem values should be the goal for this Proceeding, and should guide all future Delta water management.

Conclusions

The historical Delta inflows and D-1641 objectives for WY 2008 and WY 2009 were used to illustrate the general concept of Delta inflow allocation curves. Although this Proceeding is focused on outflow criteria that will protect public trust ecosystem benefits, the Delta allocation curves must provide a balance between beneficial uses of diversions and exports (with associated impacts) with public trust ecosystem benefits (in-stream uses). Increased outflow during a storm event will likely increase ecosystem benefits and reduce export impacts by reducing the E/I ratio. Increased exports will increase entrainment impacts and reduce outflow benefits, but would not change the inflow benefits. Proper management of exports will require an accurate accounting of all Delta ecosystem benefits and impacts. Therefore, all inflow benefits, outflow benefits, water quality impacts and export impacts must be considered concurrently in a daily accounting framework. The Delta public trust ecosystem benefits can then be properly balanced with allowable exports for water supply benefits. Several more specific conclusions can be made.

1. The daily Delta inflow and outflow patterns are dominated by storm runoff in the winter and spring. Evaluating Delta flow criteria and the effects of managing exports and protecting Delta public trust values should be based on the wise allocation of these unique daily sequences of inflow. This must be a dynamic process open to public review and inter-agency collaboration. This cannot be accomplished by the SWRCB or the new Delta Water master or the Delta Stewardship Council unless everyone with Delta interests and relevant information cooperates.
2. The Delta public trust values are the combination of inflow benefits, outflow benefits, outflow-salinity impacts, and export impacts. Protecting these multiple benefits (beneficial uses, ecological processes, fish abundance) has always been the primary purpose for establishing the Bay-Delta Water Quality Control Plan and objectives. Because these impacts and ecological benefits change rapidly with conditions in the Delta, a daily analysis tool (e.g., DeltaOPS) should be used and shared among all interested agencies and stakeholders. The SWRCB should direct the "OCAP agencies" (i.e., MAs and PAs) to prepare an official accounting of WY 2008 and WY 2009 as a beginning for these reporting and evaluation responsibilities. This would provide a basic level of information about the likely benefits and impacts of outflows and exports for review by the Delta Water master and Stewardship Council.
3. The D-1641 objectives provide the existing Delta flow allocations curves for each month. After allowing in-Delta diversions, these monthly allocation curves describe how daily inflow is allocated for shared water supply and public trust ecosystem benefits. Because salinity impacts are rapidly reduced with moderate outflows increasing from 2,500 cfs to 7,500 cfs, and because 5,000 cfs would position the estuary salinity gradient within Suisun Bay, Honker Bay and the confluence habitat (X2 of 85 km near Antioch) a minimum Delta outflow of 5,000 cfs should be considered for all monthly flow allocation curves.
4. The biological basis for the E/I ratio objectives was described for controlling both fish abundance and entrainment impacts from exports. The E/I ratio controls the reduction in fish abundance caused by the reduction in outflow (during relevant life-stage periods) because fish abundance was found to generally increase at a constant rate with outflow. The E/I ratio also controls the magnitude of entrainment impacts in the Delta. The E/I ratio should therefore be specified for each month, according to the fish life-stages and locations within the Delta, to limit the maximum entrainment impacts and also limit the maximum fish abundance reductions

caused by reduced outflow. A maximum permitted SWP export may be counter-productive for public trust ecosystem benefits, because export impacts will be least when the E/I ratio is low during high inflows. Full pumping at Banks should be permitted whenever inflow is high enough to maintain the specified E/I ratio for protecting fish from export impacts.

5. Because fish benefits appear to increase linearly with outflow, there is no basis for establishing target monthly outflows higher than the minimum flows for reducing salinity impacts (such as the existing D-1641 X2 objectives). Because outflow will always provide higher fish abundance, the major control on fish abundance is upstream hydrologic conditions. Delta water management should focus in properly allocating the sequence of daily inflows to the Delta. The example provided (i.e., longfin smelt FMWT abundance) suggested that 1% of the maximum fish abundance at 100,000 cfs will be lost for each 1,000 cfs exported (during relevant life-stage periods). This outflow-benefit curve approach can be used to provide more detailed evaluation and tracking of outflow benefits and export entrainment impacts so that public trust ecosystem values can be properly accounted for in Delta water management.

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Table 1. Estimated Salinity (EC) at Delta Locations for Various Effective Delta Outflows

Negative Exponential Estimates derived from 1976-1991 Historical EC and Delta outflow
EC (uS/cm) = minimum + constant x exp [factor x outflow(cfs)]

Constant	6000	1500	12500	17500	20000	25000	30000	3000
Factor	-0.0006	-0.0006	-0.0005	-0.0005	-0.00035	-0.0003	-0.0002	-0.0006
Minimum	175	20	175	175	175	175	175	0

Effective Outflow (cfs)	Rock Slough EC (µS/cm)	Rock Slough chloride (mg/l)	Jersey Point EC (µS/cm)	Emmaton EC (µS/cm)	Antioch EC (µS/cm)	Collinsville EC (µS/cm)	Chipps Island EC (µS/cm)	CVP/SWP Exports Bay EC (µS/cm)
2500	1,514	355	3,756	5,189	8,512	11,984	18,371	669
3000	1,167	268	2,964	4,080	7,174	10,339	16,639	496
3500	910	204	2,347	3,216	6,050	8,923	15,073	367
4000	719	156	1,867	2,543	5,107	7,705	13,655	272
4500	578	121	1,492	2,019	4,315	6,656	12,372	202
5000	474	95	1,201	1,611	3,650	5,753	11,211	149
5500	396	75	974	1,294	3,093	4,976	10,161	111
6000	339	61	797	1,046	2,624	4,307	9,211	82
6500	296	50	660	854	2,231	3,732	8,351	61
7000	265	42	552	703	1,901	3,236	7,573	45
7500	242	37	469	587	1,624	2,810	6,869	33
8000	224	32	404	496	1,391	2,443	6,232	25
8500	212	29	353	425	1,196	2,127	5,656	18
9000	202	27	314	369	1,032	1,855	5,134	14
9500	195	25	283	326	894	1,621	4,662	10
10000	190	24	259	293	779	1,420	4,235	7
10500	186	23	241	267	682	1,246	3,849	6
11000	183	22	226	247	601	1,097	3,499	4
11500	181	22	215	231	532	969	3,183	3
12000	179	21	206	218	475	858	2,897	2
12500	178	21	199	209	427	763	2,638	2

Table 2. Required Outflow and Channel Habitat Area for X2 between 50 km and 90 km

X2 (at steady flow) = 185 - 27 x Log [Outflow (cfs)]
Required Outflow = 10 ^ (185-X2)/27

Location of X2 (km)	Required Flow (cfs)	Channel Width (km)	Channel Area (Acres)
50	100,000		
51	91,825		
52	84,319		
53	77,426		
54	71,097		
55	65,285		
56	59,948	1.5	371
57	55,048	2.1	519
58	50,548	2.4	593
59	46,416	3	741
60	42,622	3.6	889
61	39,137	4.2	1,037
62	35,938	5.4	1,334
63	33,000	6.6	1,630
64	30,303	7.2	1,778
65	27,826	7.2	1,778
66	25,551	6.6	1,630
67	23,462	6.6	1,630
68	21,544	3.3	815
69	19,783	3.3	815
70	18,166	3	741
71	16,681	3.3	815
72	15,317	3	741
73	14,065	3.9	963
74	12,915	3.9	963
75	11,860	0.9	222
76	10,890	1.2	296
77	10,000	1.25	309
78	9,183	1.5	371
79	8,432	1.8	445
80	7,743	2.7	667
81	7,110	1.8	445
82	6,529		
83	5,995		
84	5,505		
85	5,055		
86	4,642		
87	4,262		
88	3,914		
89	3,594		
90	3,300		

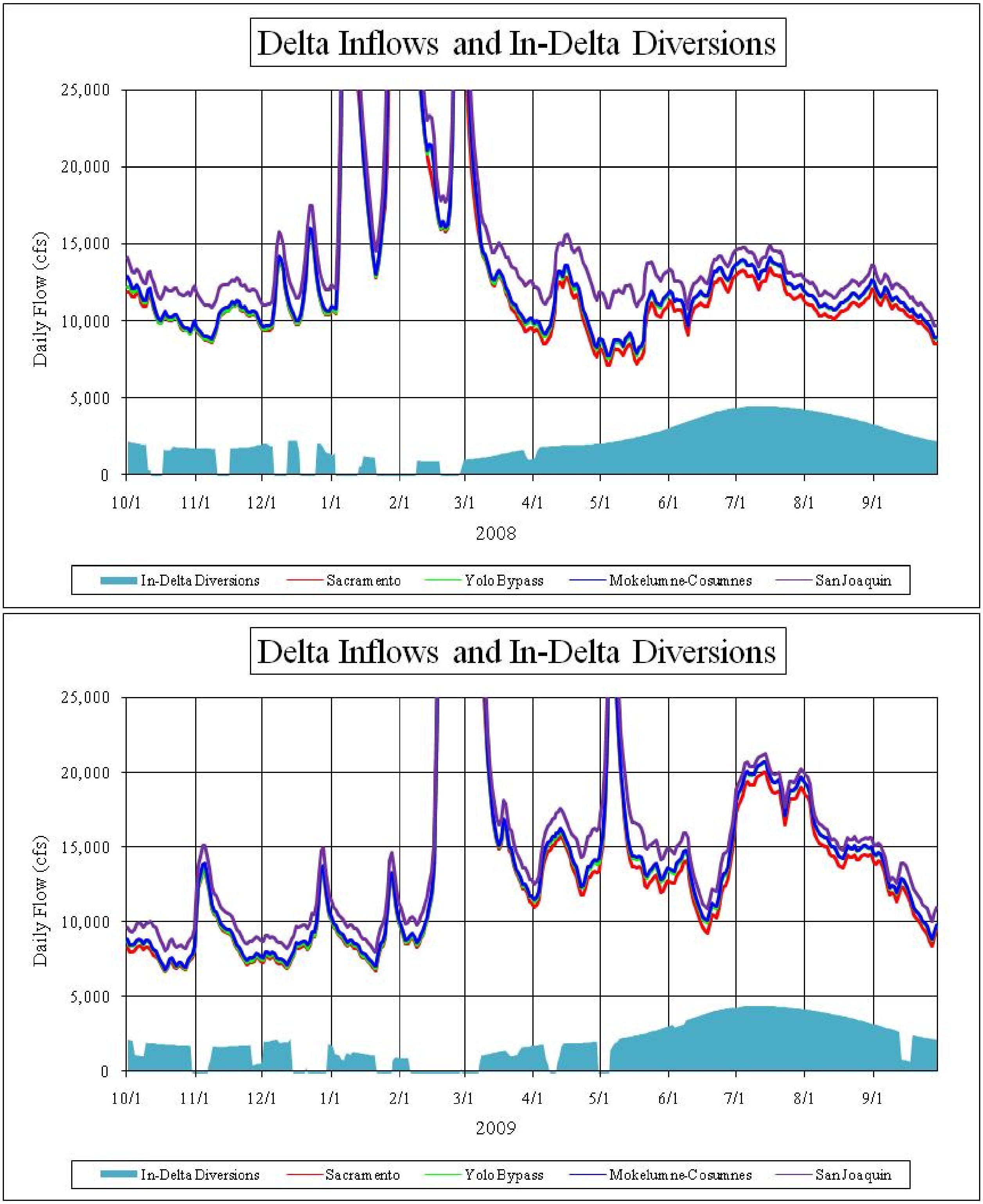


Figure 1. Delta inflows (stacked) and channel depletions for WY 2008 and WY 2009 (from DAYFLOW).

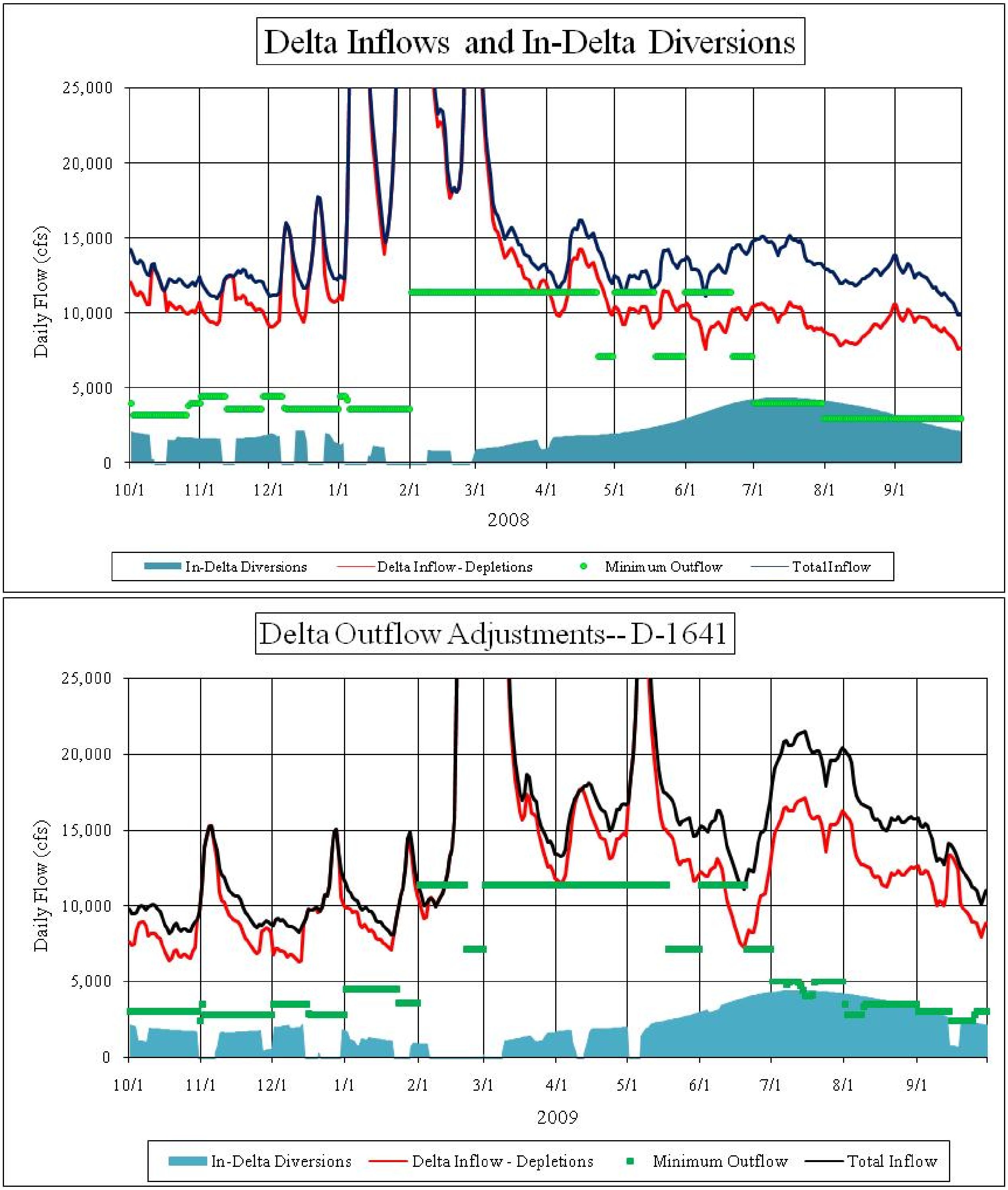


Figure 2. Delta Inflows (minus channel depletions) and D-1641 minimum required outflows for WY 2008 (dry) and WY 2009 (critical). [Channel depletion was about 1 maf and required outflow was 4 maf].

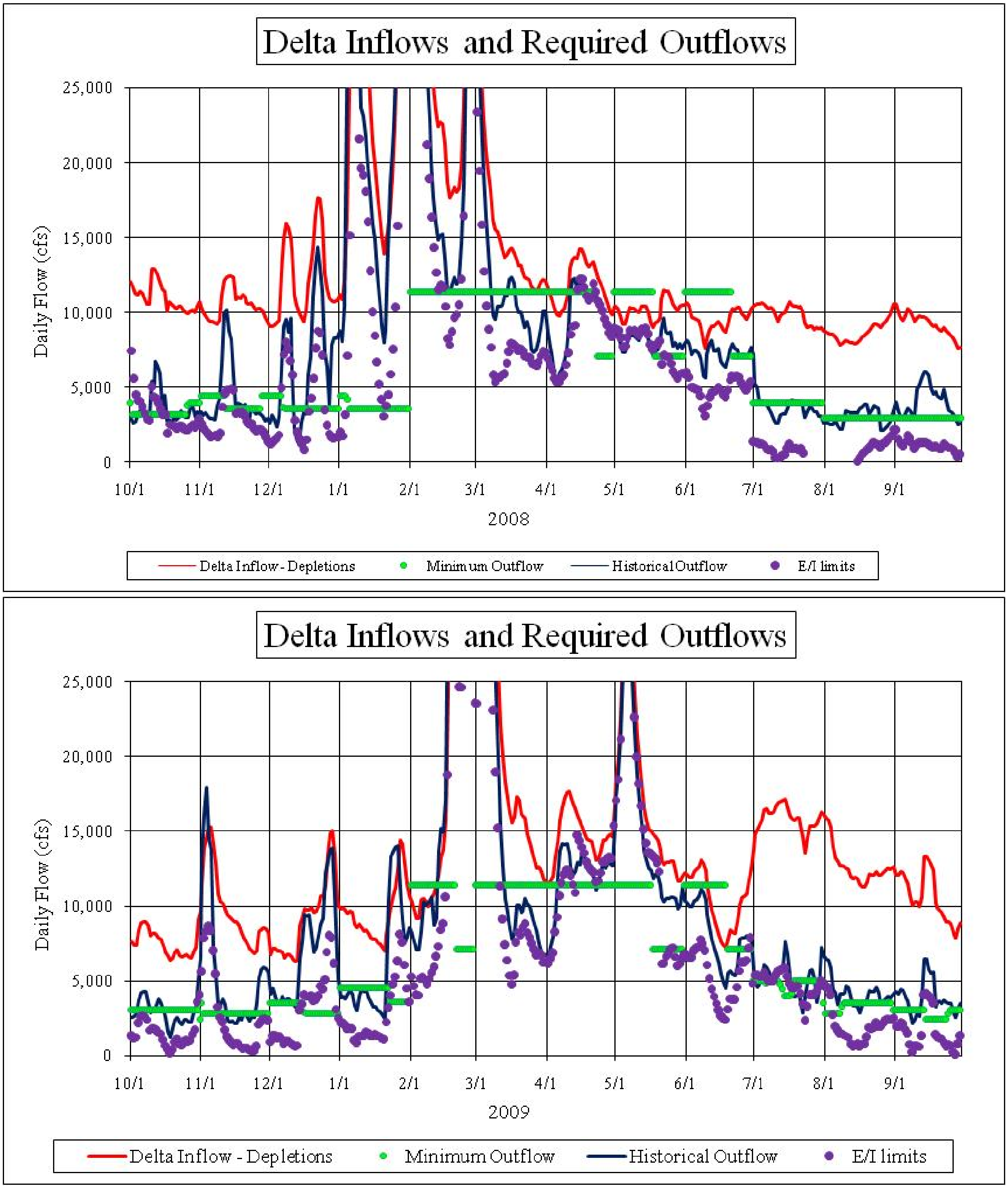


Figure 3. Delta Inflows (minus channel depletions) for WY 2008 and WY 2009 with required outflow and E/I limits (purple dots) estimated with historical outflow shown for comparison.

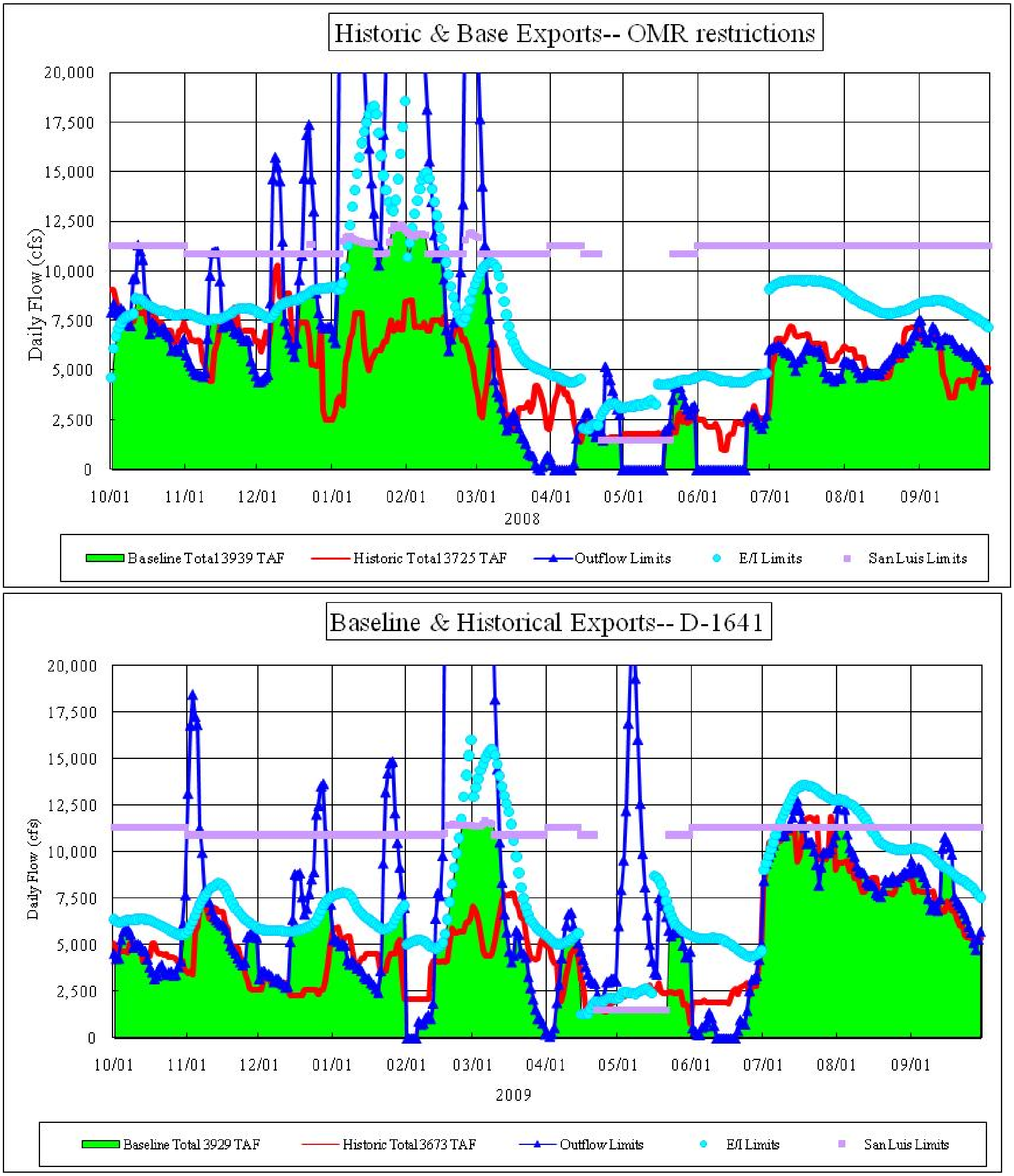
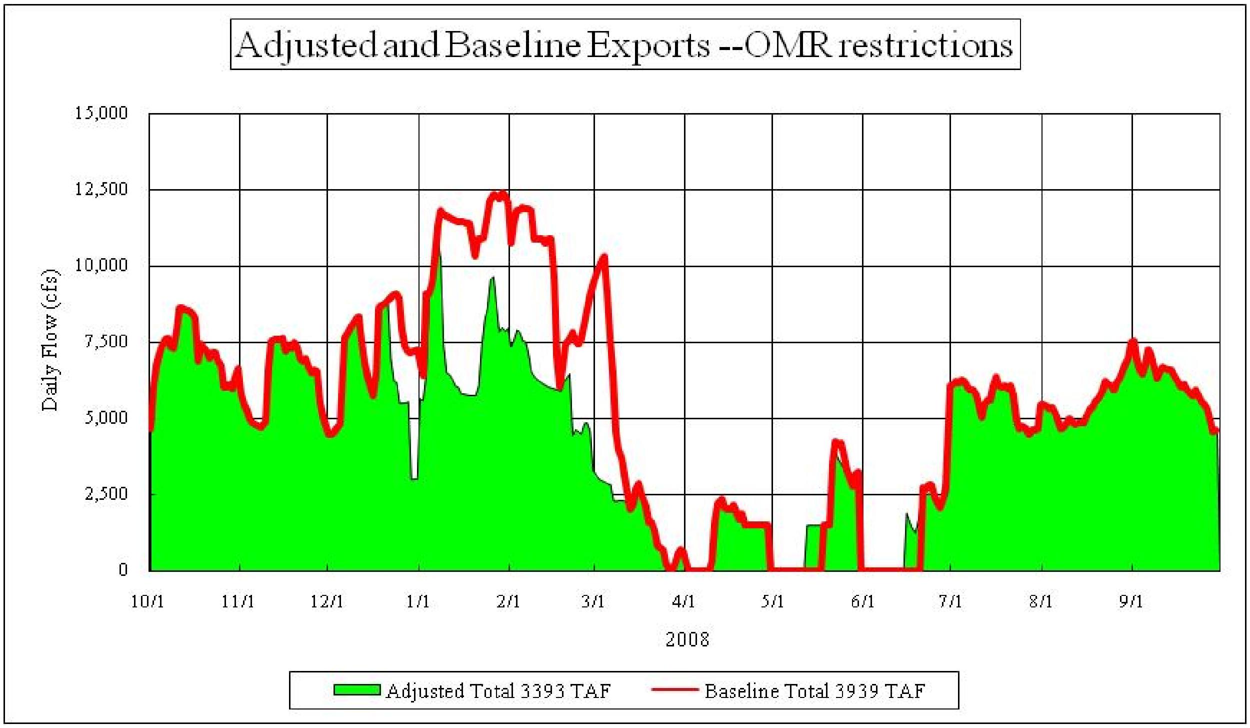


Figure 4. Estimated Baseline D-1641 Exports controlled by required outflow and maximum E/I for WY 2008 and WY 2009. [Historical exports shown for comparison were 213 taf less than the estimates in WY 2008 and 256 taf less than the estimates in WY 2009].



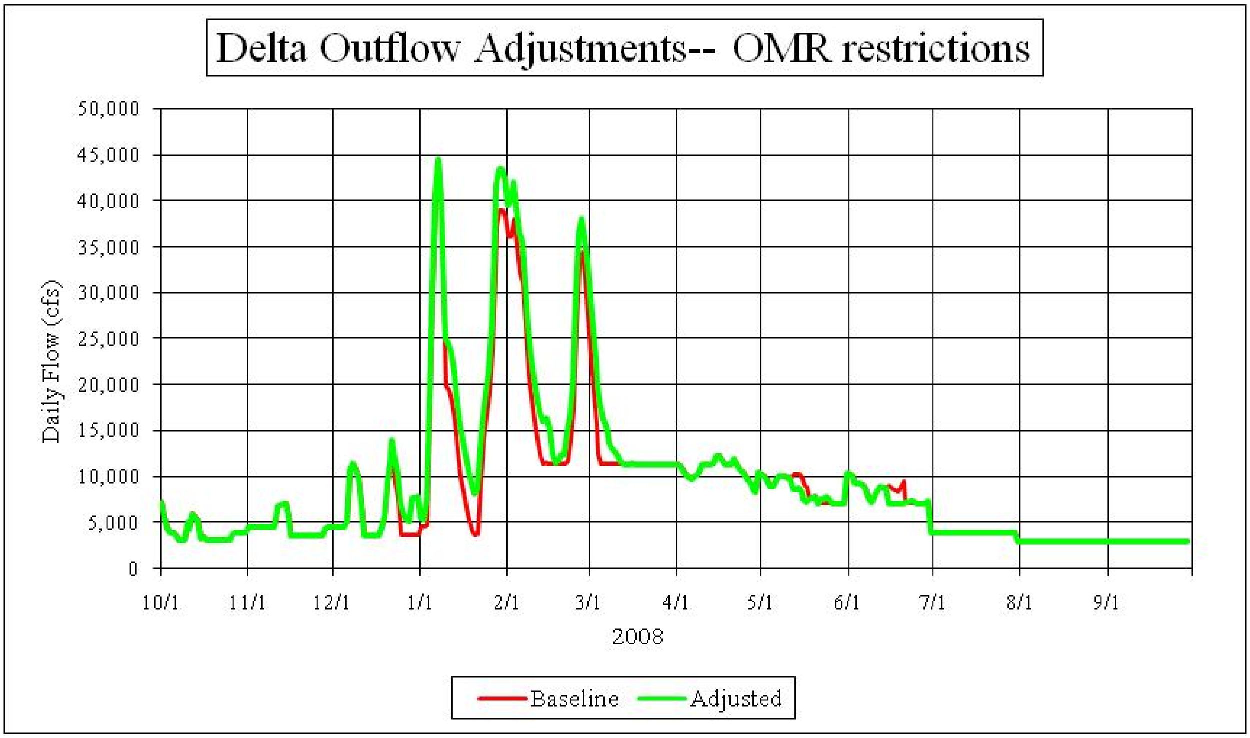


Figure 5. Estimated Reductions in Exports and Increases in Outflow caused by Reverse OMR flow restrictions for delta smelt protections in WY 2008. [DeltaOPS model estimated reductions of 546 taf].

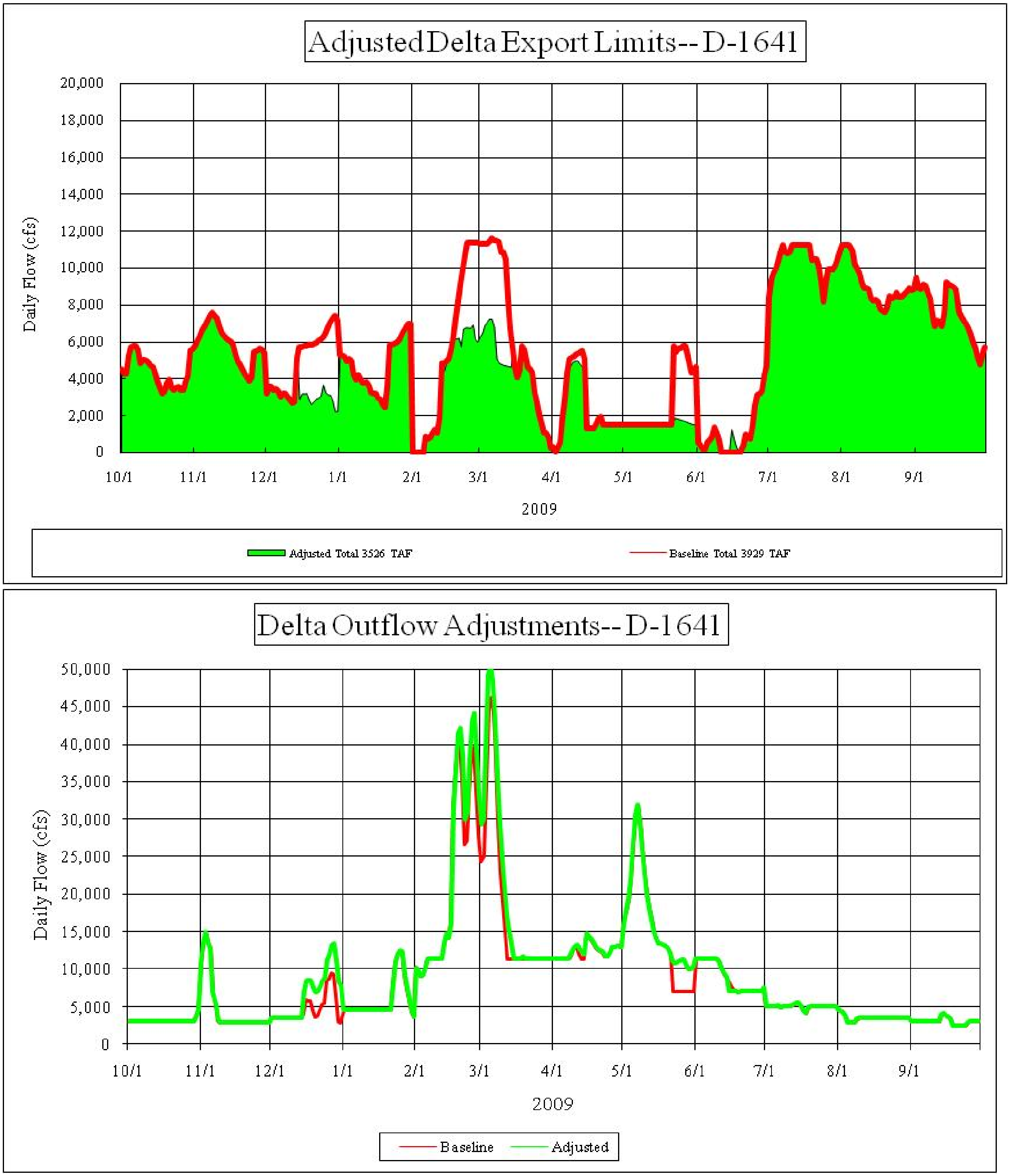


Figure 6. Estimated Reductions in Exports and Increases in Outflow caused by Reverse OMR flow restrictions for delta smelt protections in WY 2009. [DeltaOPS model estimated reductions of 403 taf].

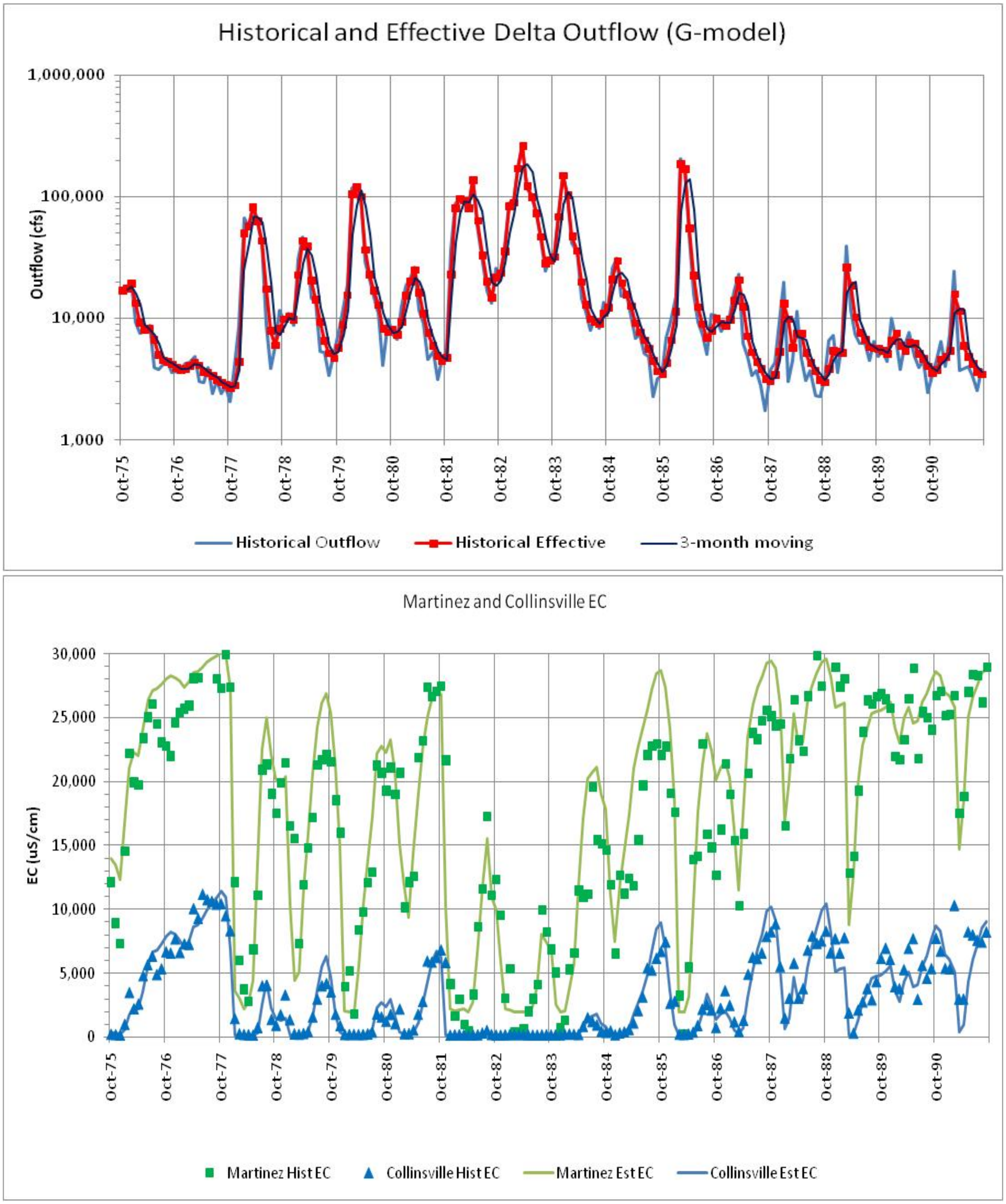
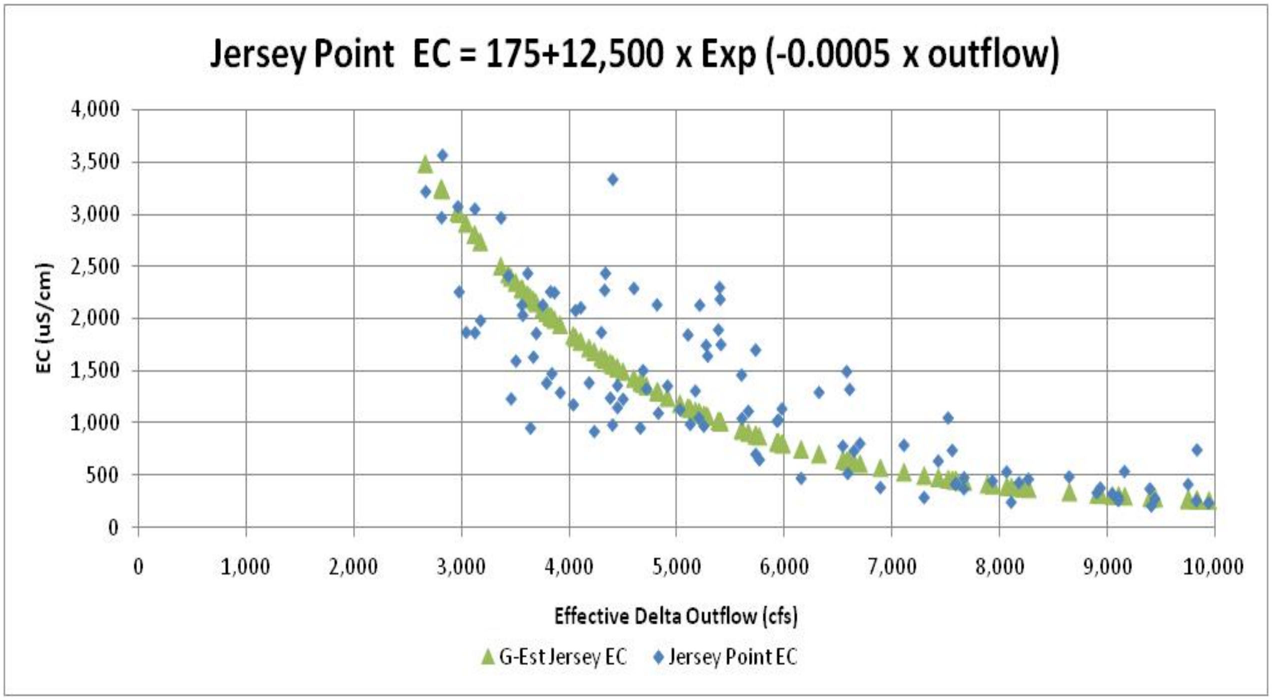


Figure 7a. Historical Monthly Delta outflow and effective Delta outflow for WY 1976-1991 (logarithmic graph). Figure 7b. Historical monthly average EC and estimated EC at Martinez (56 km) and Collinsville (81 km) for WY 1976-1991. [Note: X2 is at the EC station when monthly EC is about 3,000 µS/cm].



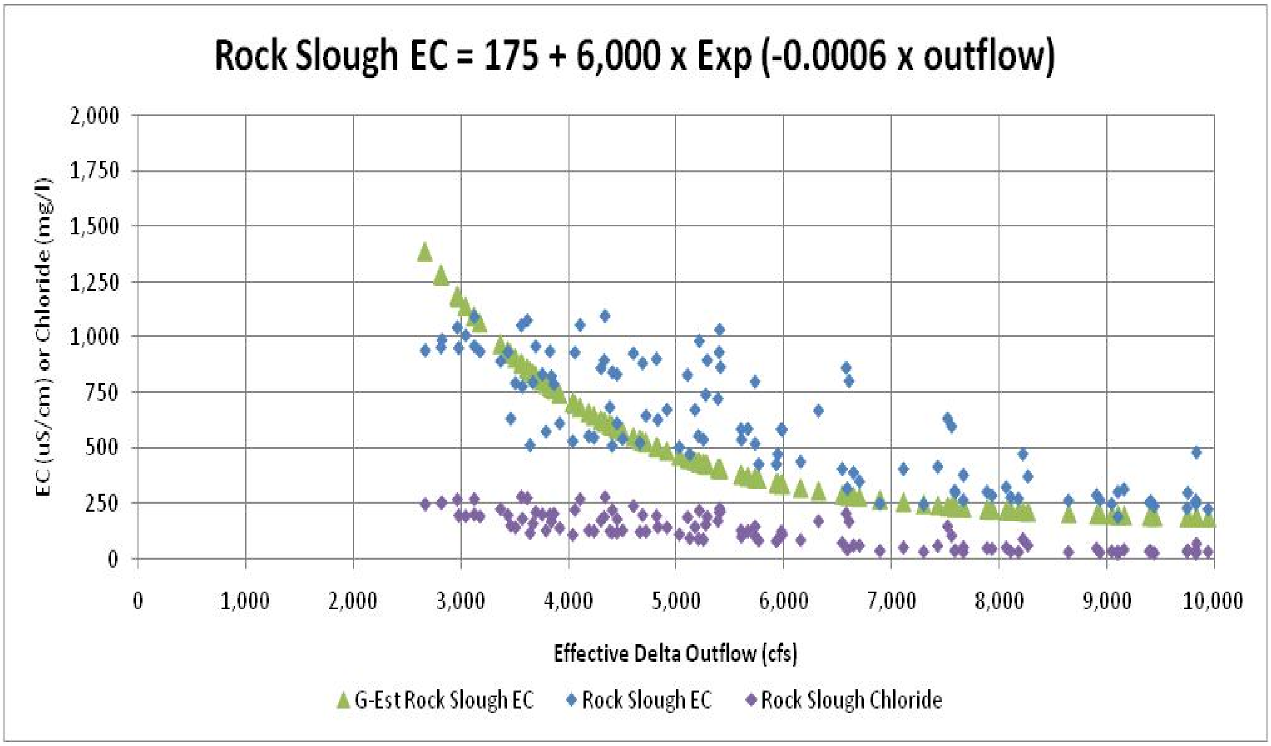


Figure 8a. Outflow-salinity impact curve at Jersey Point estimated from the historical monthly EC and effective outflow for WY 1976-1991. Figure 8b. Outflow-salinity impact curve at Rock Slough estimated from the historical monthly EC and effective outflow for WY 1976-1991. [Note: Chloride concentration (mg/l) is about 25% of the EC (µS/cm) in seawater].

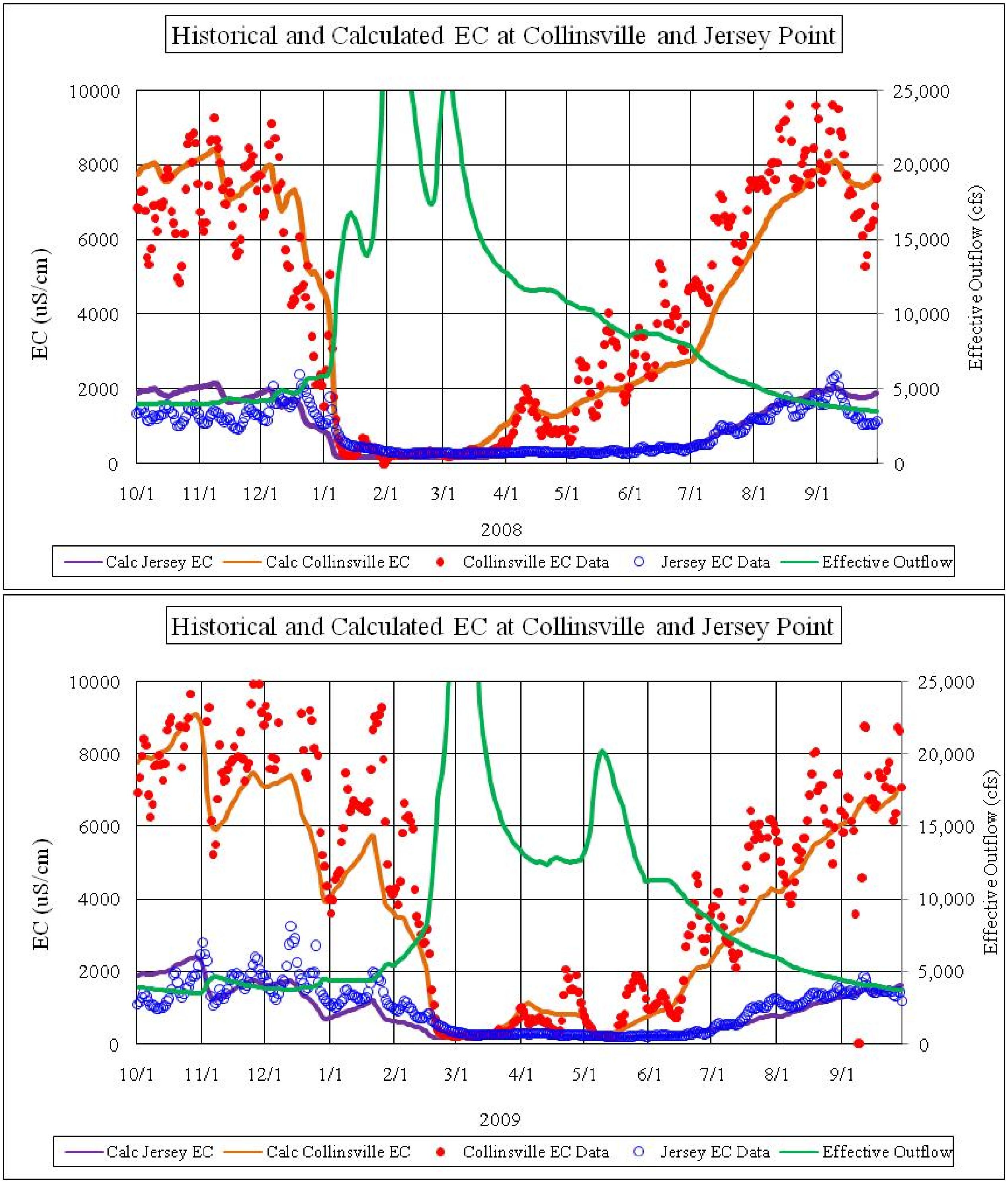


Figure 9. Measured EC at Jersey Point and Collinsville compared with calculated EC using the negative exponential equation with daily effective outflow (G-model formulation) for WY 2008 and WY 2009.

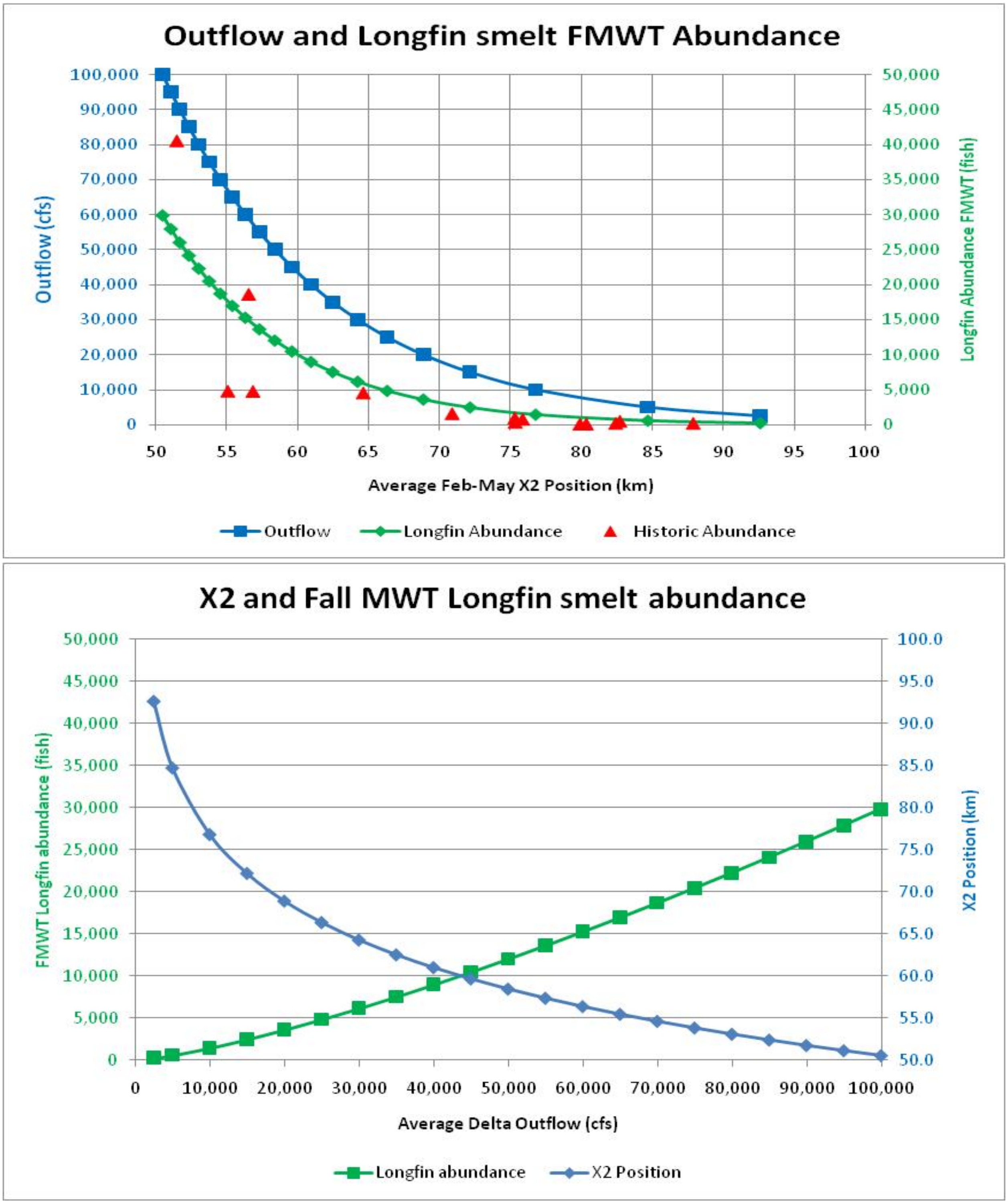


Figure 10a. Relationships between X2 (km) and 1) the estimated FMWT longfin smelt abundance (fish caught) and 2) Delta outflow (cfs). Figure 10b. Relationships between outflow and 1) X2 (km) and 2) FMWT longfin smelt abundance (total fish caught).

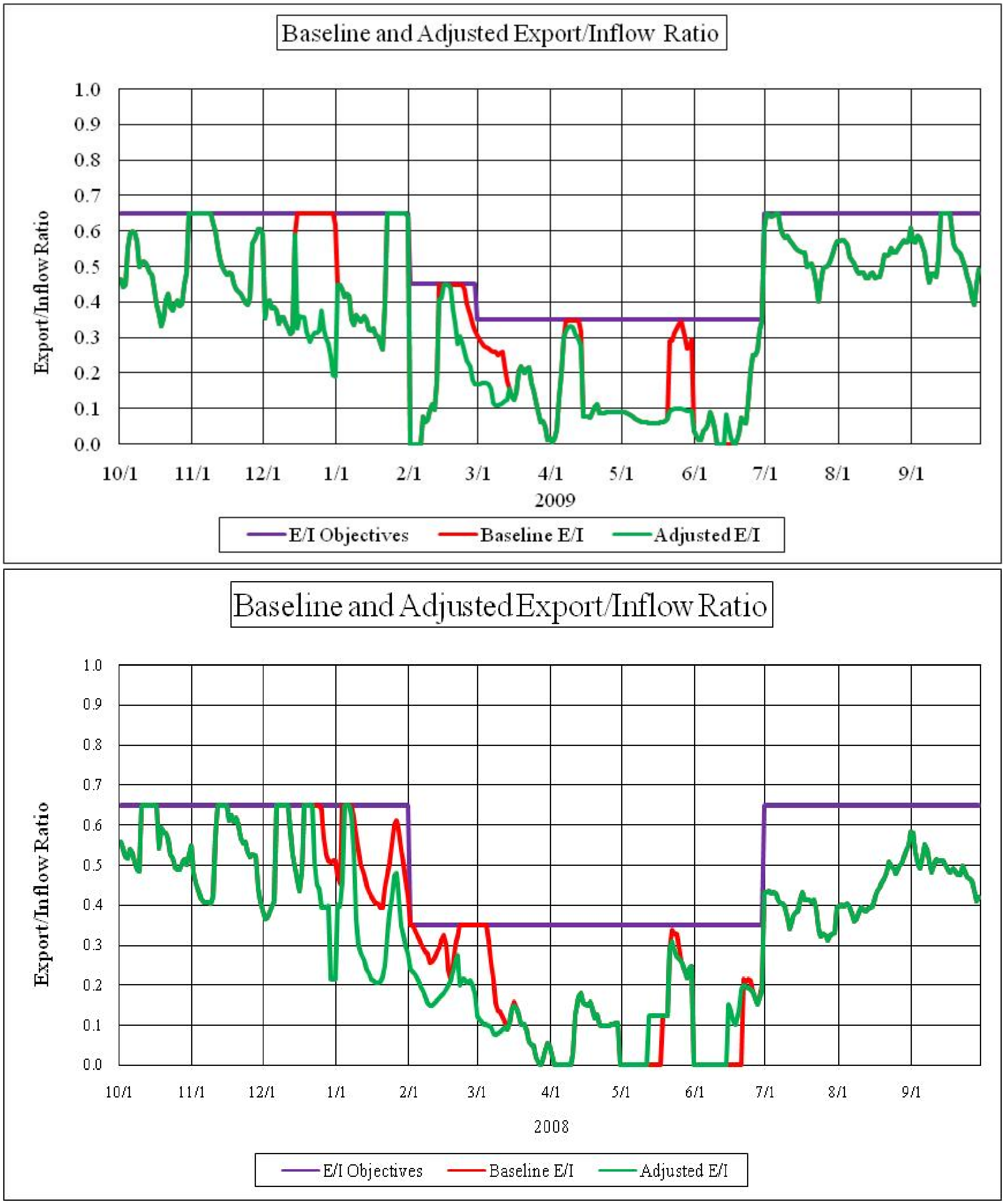


Figure 11. Calculated Baseline (D-1641) E/I ratios and Adjusted E/I ratios with reverse OMR flow Limits in WY 2008 and WY 2009.

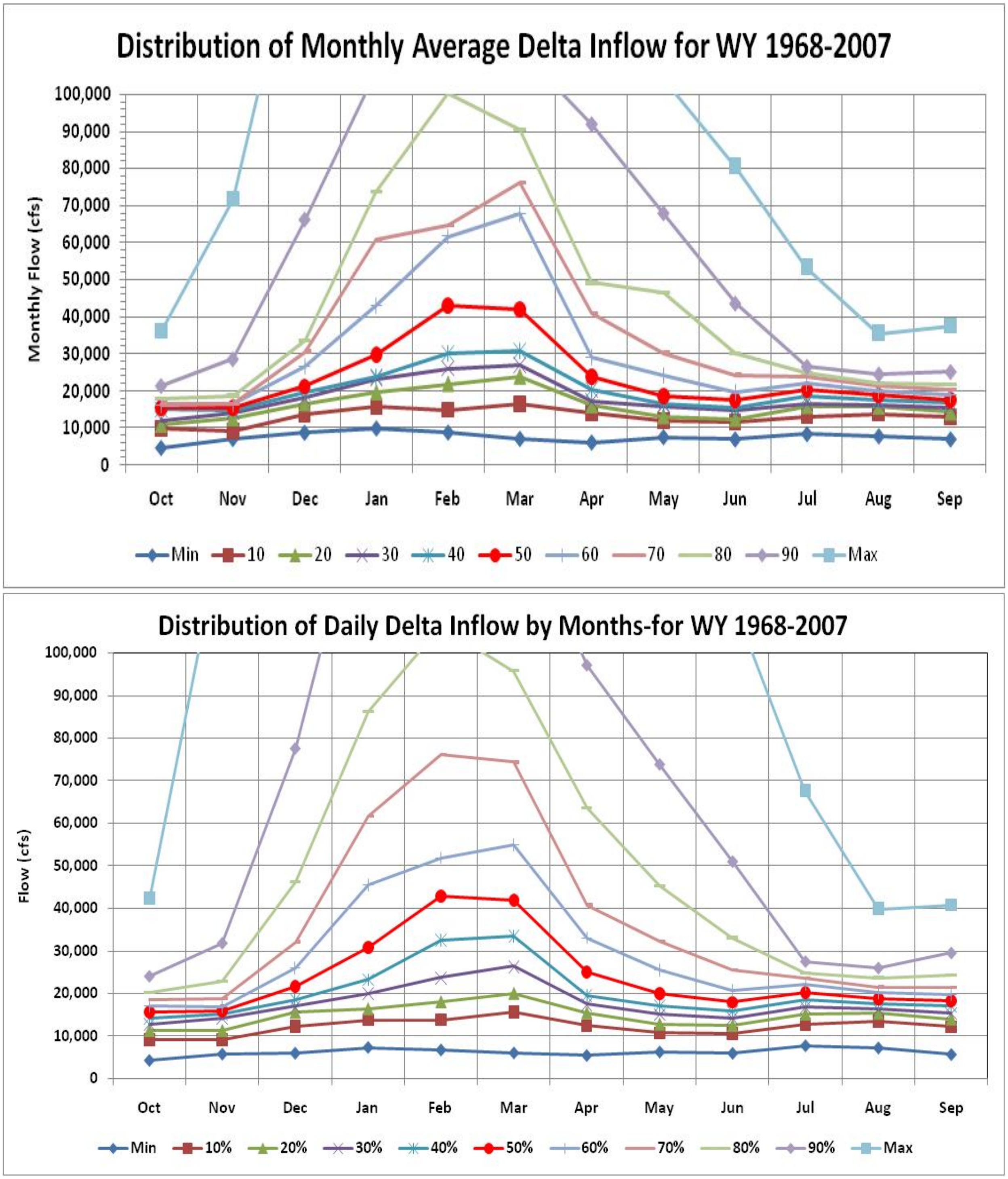


Figure 12a. Cumulative Distribution of Average Monthly Delta Inflows for WY 1968-2007. Figure 12b. Cumulative Distribution of Daily Delta Inflows by Month for WY 1968-2007.

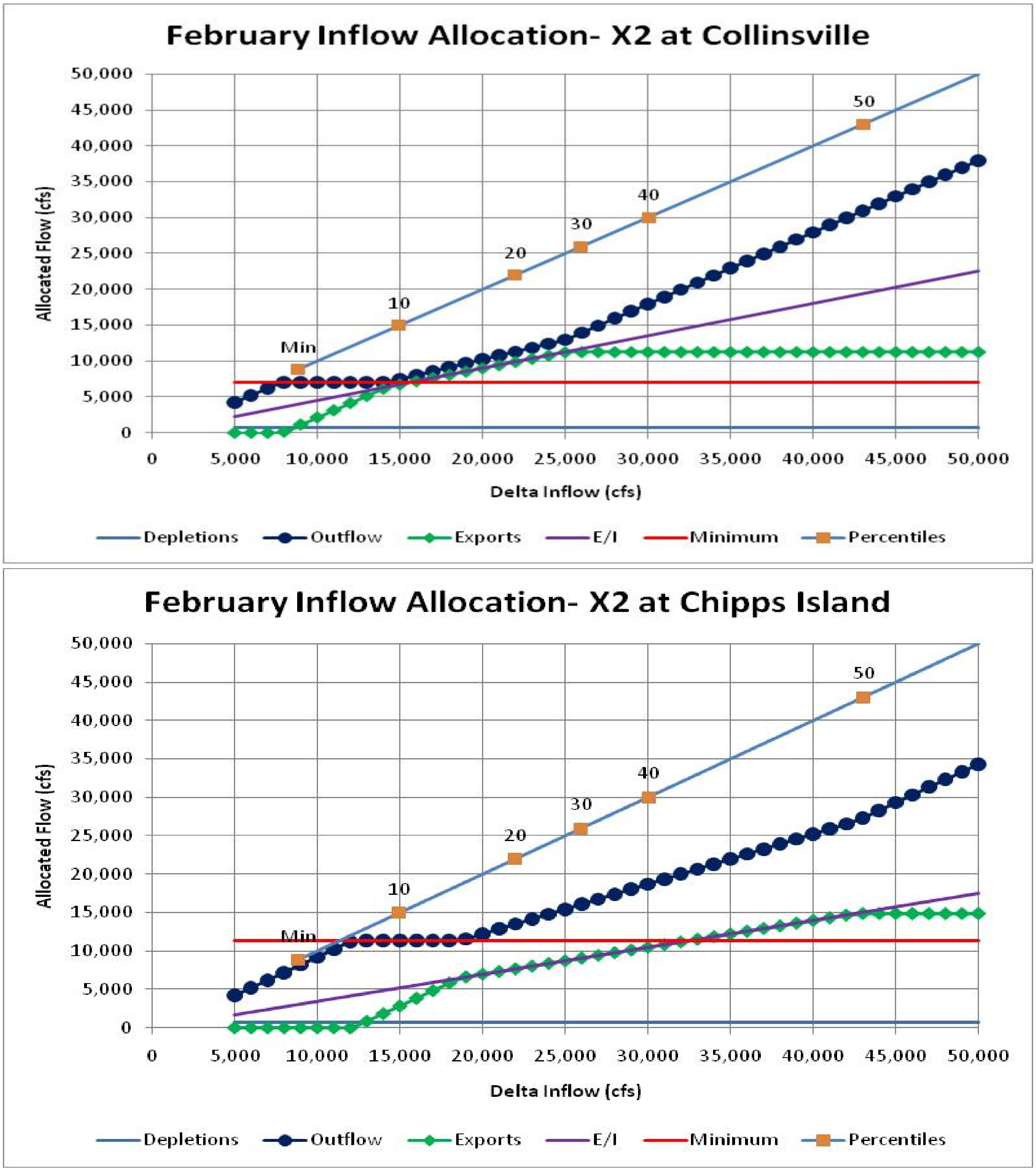


Figure 13a. Delta Inflow Allocation Curve for February, with X2 at Collinsville and E/I of 45% and permitted exports of 11,280 cfs. Figure 13b. Delta Inflow Allocation Curve for February, with X2 at Chipps Island and E/I of 45% and maximum exports of 14,900 cfs.