ICF INTERNATIONAL

LATE COMMENT

October 26, 2012

Dr. Brock Bernstein, Workshop Facilitator
Charles Hoppin, Chair
State Water Resources Control Board
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Submitted electronically to: commentletters@waterboards.ca.gov; brockbernstein@sbcglobal.net

Subject: Bay-Delta Workshop 3 – Analytical Tools

Dear Dr. Bernstein and Mr. Hoppin:

This written comment letter provides information for the State Water Resources Control Board (State Water Board) to consider during the Comprehensive (Phase 2) Review and Update to the Bay-Delta Plan, Workshop 3: Analytical Tools.

The State Water Board should initiate, as part of the Phase 2 Review, a comprehensive framework for compiling, reviewing, and evaluating the historical daily and monthly flow, salinity, temperature, turbidity, and fish data for the Central Valley and the Bay-Delta. This would be a practical way to immediately implement some of the recommendations from several presenters at Workshops 1 and 2 that "someone should organize our available data to integrate the flow and water quality monitoring and fish survey programs." Compiling a daily and monthly "Data Atlas" would be useful for reviewing recent historical conditions and evaluating likely benefits from possible changes in the Delta objectives for the existing Delta configuration. The historical daily data should also be the starting point for evaluating likely fish benefits for modified Delta configurations and expanded aquatic habitats (tidal wetlands, flooded islands, expanded berms, riparian margins, and seasonal floodplains). Some changes in the Delta objectives may be required for new Delta configurations. Alternative Bay-Delta objectives and/or modified Delta configurations and habitats could be evaluated by "adjusting" the daily historical data with water and fish tracking models that include assumed flow-fish relationships and account for changed Delta configurations or modified objectives.

Most water supply modeling in California uses a monthly timescale for calculations (i.e., CALSIM). Many fish analyses in California rely on annual regressions or statistical relationships between flow conditions and fish abundance or adult escapement. However, in-depth analysis of hydrology and reservoir operations, as well as the aquatic habitat conditions and fish tracking below reservoirs and through the Delta, will require daily data to capture storm events, flood control operations, water temperatures, migration patterns, salinity effects, and entrainment episodes. Because many of the Bay-Delta Plan objectives are daily or running-average limits, daily flow and salinity data are also required for determining compliance with the established objectives and for evaluating salinity, fish, and water supply benefits with alternative (modified or new) Bay-Delta objectives.

Fish analyses of population abundance, river flows, ocean conditions, and entrainment effects have often relied on annual data (e. g., Bay-Delta fish survey abundance indices, GrandTab Chinook escapement). There are some monthly fish data sources (Bay Study surveys, beach seines, Suisun Marsh survey) and there are now many daily fish data sources (salvage records; Chipps Island, Sacramento and Mossdale trawls; Red Bluff Diversion Dam (RBDD) ladder and upstream migration weirs; screw-traps for juveniles; coded-wire tag (CWT) recoveries and acoustic tracking). All of the available fish data should be blended with the daily flow and water quality data collected from all the Central Valley Rivers and within the Bay-Delta.

Attached (Attachment 1) is the ICF International Testimony for the 2010 Flow Objective Workshop. It describes the basic features of the daily Delta flow and fish analyses tool called DeltaOPS. The DAYFLOW records for water year 2008 and 2009 are used as examples of how daily flow, salinity, and fish data from the Delta can be reviewed and evaluated; the ability to modify the D-1641 objectives or add operational rules (Old and Middle River [OMR] limits) are presented in this testimony.

Several other examples of applications of daily flow, salinity, temperature, and fish data from the Central Valley and Bay-Delta for evaluating benefits and impacts from alternative reservoir and Delta operations are listed below. Additionally, Attachments 2 through 4 provide information on the use of daily data. These examples are presented as evidence that using daily data provides a more accurate description of the relationships between flows, salinity, temperature, aquatic habitat conditions, and fish tracking (abundance and movement) evaluations.

Daily Hydrology and Fish Tracking Analyses in the Central Valley and the Bay-Delta

Several examples of how daily flow and fish tracking data have been collected and used for the evaluation of conditions in the Central Valley Rivers and within the Bay-Delta are briefly described to provide evidence that daily flow and fish data should be our shared framework for estimating ecological benefits and impacts. These examples illustrate some of the ways that daily data can be used for the review of historical conditions and for the evaluation of potential changes in operations or habitat conditions; many other analyses using daily data are likely in the future.

1. **Daily Data Atlas:** DAYFLOW provides a widely-used official record of the historical daily Delta inflows, outflows, and exports. Estimates of Delta diversions and some channel flows and index flows (i.e., Delta Cross Channel [DCC] and Georgiana Slough, QWEST) are also provided. DAYFLOW should be expanded to include all major channel flows, gate operations, and tidal flow measurements. A similar DAYSALT file should be compiled with all of the Bay-Delta

salinity (electroconductivity [EC], chlorine [Cl], total dissolved solids [TDS], practical salinity unit [psu]) measurements. Similar files for suspended sediment, turbidity, and secchi depth (DAYMUD); for nutrients, chlorophyll, and primary production estimates (DAYPP); for zooplankton (DAYZOO); for fish counts from salvage, trawls, and tracking surveys (DAYFISH); for water temperature (DAYTEMP); and for other water quality parameters (DAYWQ) should be compiled and linked together with graphs and summary tables (DAYALL). This could become our shared compilation (integration) of all measurements and observations related to Delta flows, transport, travel time, fish abundance, and fish movement. Daily data (of all kinds) should be collected and organized in a "Delta Data Atlas" to become a basic analytical tool for reviewing and evaluating what has happened in the Delta; such a Delta Data Atlas would likely lead to increased understanding of the Bay-Delta ecosystem and would likely be the basis for additional concepts and analyses (field measurements, relationships, and models).

2. **Daily Objectives:** The Bay-Delta flow and salinity objectives are all daily values, although they may be listed as monthly numbers. There are some monthly-average objectives, some moving-average objectives (3-day, 7-day, 14-day, and 30-day), some EC objectives that vary with year type and month (or part of the month), and some that require more complex look-up values (e.g., for X2 days based on month and runoff) or days per year of chloride less that 150 milligrams per liter at Antioch or at Rock Slough. The first step in the comprehensive review of the Bay-Delta Plan should be the daily comparison of Delta flows and EC values for the recent 15 years with the D-1641 daily objectives. An "official estimate" of the daily Bay-Delta objectives (outflow, X2, E/I, salinity) should be compiled with the help of the Bureau of Reclamation (Reclamation), Department of Water Resources (DWR), and Contra Costa Water District (CCWD) operations staff and be added to the Delta Data Atlas (DAYOBJECT) to review the compliance with the objectives, and more importantly, evaluate the effectiveness of the objectives for protecting water quality and fish during each year.

3. **In-Delta Storage Operations:** The use of daily flows may enhance understanding of water supply consequences. For example, environmental analyses required for the Delta Wetlands (DW) in-Delta storage project[1] required a daily spreadsheet model, based on DAYFLOW and the D-1485 (or D-1641) objectives, to estimate periods of time when DW would divert water (effects on outflow) and discharge water for export. When DWR evaluated in-Delta storage for CALFED, a similar daily operations model was used (embedded in CALSIM). Using monthly flows, the DW project was simulated to fill almost every year; daily modeling showed the project would fill in about 75% of the years. A similar overestimate (10%-20%) of Central Valley Project (CVP) and State Water Project (SWP) exports results from using monthly flows. Daily modeling thus provides a more realistic representation of water supply potential.

[1] The DW project would divert about 5,000 cfs for a 30-day period to fill about 250 taf of storage on Bacon Island and Webb Tract.

4. **Daily Entrainment Reduction:** CALFED Environmental Water Account (EWA) was planned as an adaptive management strategy to reduce the CVP and SWP fish entrainment impacts. The daily salvage records provided a direct measurement of relative fish abundance; many fish species show very similar patterns at the CVP and SWP facilities and the fish concentration (fish/thousand acre-feet [taf]) was often highest during a few months each year (adult and juvenile migration periods). The EWA strategy was to reduce pumping when fish salvage was high and increase pumping when salvage was lower; fish benefits would be achieved without any reduction in water supply. An actual EWA program was conducted from 2000–2005; about 250–500 taf/year of pumping reductions were specified through a weekly interactive process that responded to the salvage counts, Delta channel flows, water temperatures, turbidity, and recent Kodiak and 20-mm fish surveys.

5. **Daily OMR Flows:** The 2008 U.S. Fish and Wildlife Service (USFWS) Biological Opinions and the 2009 California Department of Fish and Game (DFG) longfin permit have mandated a slightly revised strategy to control negative OMR flows to reduce the entrainment (take) of delta smelt and longfin smelt, based on daily monitoring of temperature and turbidity as well as recent salvage and Kodiak or 20-mm survey data. Daily fish data are routinely used in the management of Delta exports. The evaluation of EWA or OMR protection strategies for delta smelt was described in a report for DWR on tools for evaluating fish protection strategies (Jones and Stokes 2008). The daily Delta flows and the delta smelt salvage data and Chipps Island trawl catch data for 1995–2007 were evaluated using the DailyOPS model with daily exports, OMR, QWEST, and Delta outflow; as well as the daily Chipps Island trawl catch and the CVP and SWP salvage. No simple relationship between daily exports, OMR or QWEST flows, and salvage of delta smelt adults was identified; several other factors (e.g., Sacramento River flow, turbidity, spawning migration, spawning locations) are likely involved in controlling delta smelt salvage. The daily data from these 13 years illustrate that effective management of entrainment losses requires daily data with a weekly adaptive decision-making process; this is now implemented by the smelt working group and the Water Operations Management Team (WOMT).

6. **Vernalis Adaptive Management Program:** The Vernalis Adaptive Management Program (VAMP) provided pulse flows on the San Joaquin River (SJR) at Vernalis for a 30-day period during the peak out-migration period (April and May) for juvenile Chinook salmon. This required scheduling and daily coordination of reservoir releases from the Merced, Tuolumne, and Stanislaus rivers. The pulse flow period was adjusted each year based on fish monitoring, flows, and water temperatures (delayed growth and migration in cooler higher-flow years). Many new and expanded fish monitoring efforts were initiated in Central Valley Rivers for the Anadromous Fish Restoration Program (AFRP) and in the SJR tributaries to support the VAMP analyses; however, these daily fish monitoring data have not often been integrated with fish tracking analyses, which uses the basic approach of following a fish population through its life-cycle and habitat-pathway (movement, migrations) and estimating the mortality (abundance), growth (length and weight), and survival to spawning adults at the end of 3-5 years for Chinook.

It will be more practical to begin Chinook life-cycle modeling with a monthly time step; daily fish data will be needed to understand the monthly "steps" from spawning to emergence, juvenile growth, floodplain rearing, downstream movement, Delta migration, and ocean conditions.

7. **San Joaquin River Daily Salt and DO Management:** SJR real-time salinity management is included as an implementation strategy in the SJR Salt and Boron total maximum daily load (TMDL). The additional flows released by Reclamation from New Melones Reservoir to meet the EC objectives at Vernalis are based on daily measurements of flow and salinity at Maze (upstream of the Stanislaus) as well as at Vernalis. A similar daily modeling of the dissolved oxygen (DO) concentrations in the Stockton Deep Water Ship Channel (DWSC) has been developed for DWR (ICF International 2010, Appendix A) to estimate the effects of SJR flow and City of Stockton treated wastewater discharge (now with nitrification of ammonia to nitrate) on the low-DO episodes and the effectiveness of the dissolved oxygen aeration facility operations to increase the DO to meet the DO objectives. A daily flow and water quality data atlas for the SJR and the Stockton DWSC was compiled for the Ecosystem Restoration Program (ERP) research project supporting the evaluation of low-DO and aeration alternatives.

8. **Daily Hydrology:** Rainfall-runoff in the Central Valley watersheds generally has a timescale of a few days. Most storms have durations of 1–2 days; surface runoff occurs for several days to a week, while the base flow recession (i.e., shallow groundwater discharge) persists for a month or more. Therefore, most flow measurements are recorded as daily average values. Monthly average flows provide a good seasonal summary, but the timing and magnitude of the storm flow patterns are lost with this time step. Reservoirs are operated based on daily inflows, maximum flood-control storage limits, minimum flow requirements, maximum flood control releases, diversion targets, and hydropower capacity and spillway or outlet constraints; monthly reservoir models can only mimic the actual operational decision rules. Because daily models and monthly models can easily simulate relatively long-term sequences (i.e., 25, 50, 75, or 100 years) of historical or climate-adjusted rainfall-runoff, now may be a good time to switch over to daily models, which are closer to actual reservoir operation rules. Monthly and annual summaries of reservoir storage, diversions, flows, and temperatures for upstream reservoirs; and inflows, outflows, salinity, exports, and estuarine habitat conditions for the Delta will remain an appropriate way to compare and contrast seasonal conditions with alternative reservoir and Delta operations.

9. **Daily Temperature Effects on Fish:** Water temperatures are controlled by daily meteorology and daily flows below reservoirs; daily water temperature modeling is already available for many rivers below reservoirs in the Central Valley. Measured daily water temperatures (min, mean, and max) are available at many locations. One example of the possible effects of daily Delta temperatures is the length of time in the spring that delta smelt can spawn. The number of days when spring temperatures are between 14 °C and 18 °C varies each year, and affects the

timing of larvae occurrence relative to the abundance of zooplankton food resources in the Delta. For Chinook, we need better tracking of the biological effects of temperature on holding adults, eggs, larvae, juveniles, smolts, and yearlings. Because egg survival is reduced while fry growth is increased with higher temperatures, there may be tradeoffs involved for different life-stages and for different fish (with different temperature tolerances). Daily temperatures would allow more detailed and accurate assessment of habitat conditions for all fish species and life-stages.

10. **Daily SJR Fish Abundance Tracking:** The effectiveness of the head of Old River rock barrier was reviewed for Reclamation by comparing the daily Mossdale Trawl catch with the daily CVP and SWP salvage records for Chinook and splittail. A simple method for estimating the daily salvage based on the Mossdale trawl catch, SJR flow, CVP and SWP exports, and the barrier was developed to evaluate the effectiveness of the barrier (Jones and Stokes 2007). A surprisingly good correspondence (match) between the daily Mossdale trawl catch (abundance) and the daily CVP and SWP salvage (number) was observed for the years 1996–2005. This comparison of the SJR fish abundance and the CVP and SWP salvage should be included each year in the DAYFISH data file.

11. **Daily Fish Movement Tracking:** CWT studies are generally reported as the overall recovery ratio (number recovered/number released), but there is a daily pattern in the initial recoveries at Chipps Island or in the CVP and SWP salvage. This daily recovery pattern indicates the travel time between the release location and Chipps Island or the exports. The recent increased use of acoustic tags for Chinook and steelhead has a much more obvious daily time element because the fish are tracked to multiple downstream locations and the movement time between locations is a primary result from these studies.

12. **Daily Fish Counts:** The Central Valley hatchery returns, RBDD fish ladder, and escapement weirs and carcass surveys have always been based on daily or weekly counts that indicate the upstream migration patterns. The juvenile screw traps at RBDD and Knights Landing, and with AFRP and ERP funding at many more river locations, gives daily counts of fry and juvenile Chinook, steelhead, and other fish (American shad). The juvenile Chinook trawls at Sacramento, Mossdale, and at Chipps Island have long provided daily records of Chinook (and other fish) movement patterns (abundance and timing). Daily fish data are now commonly collected, and should be more often included in fish-flow analyses and evaluations.

13. **Daily Floodplain Inundation Benefits:** The evaluation of floodplain benefits depends on the daily river flows and the inundated area along the river corridor at each flow; the ecological benefits depend on the timing of the flood and the duration of the inundation. American Rivers has been developing flood-frequency-inundation analyses for the lower San Joaquin river floodplain (existing and expanded). The Bay-Delta Conservation Plan (BDCP) analyses of fish benefits for the Yolo Bypass with a lowered section of the Fremont Weir (notch) to divert some Sacramento River water (and fish) into the Yolo Bypass at a reduced flow (less than the existing

55,000 cubic feet per second [cfs]) requires daily Sacramento River flows at Verona. A daily fish growth and survival calculator has been developed to estimate the improved fish conditions as a function of the daily timing, duration, and area of inundation. In a similar way, daily flows at Freeport are needed for the BDCP evaluation of daily operations of north Delta intakes, which would be operated with daily bypass flow rules that depend on the month and the previous flood events (pulse flows) that are important for the downstream movement of juvenile Chinook.

Sincerely,

Russ Brown, PhD
Hydrology and Water Quality, Technical Director

Attachments:

1) ICF International (February 2010) Testimony for the SWRCB Proceeding on Delta Flow Criteria
2) Jones and Stokes (September 2007) Evaluation of Fish Protection from Installation of the Head of Old River Temporary Barrier. Appendix B: Salvage Evaluation Model for Juvenile San Joaquin Chinook Salmon. Prepared for US Bureau of Reclamation.
3) ICF Jones & Stokes (April 2008) Development of Modeling Tools for Evaluating Delta Smelt Protection Strategies. Appendix B: Evaluation of Delta Smelt Entrainment Events in 1995-2007. Prepared for California DWR.
4) ICF International (December 2010) Stockton Deep Water Ship Channel Demonstration Dissolved Oxygen Aeration Facility Project Final Report. Appendix A: Possible SJR DO TMDL Implementation Procedures. Prepared for California DWR.

ICF Workshop 3 Submission to State Water Board
Attachment 1:
ICF International (February 2010) Testimony for the SWRCB Proceeding on Delta Flow Criteria

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:

Daily X2 (km) = 10.16 + 0.945 x previous X2 (km) – 1.487 x 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:

X2 (km) = 185 – 27 x Log [Outflow(cfs)]

The outflow required to maintain X2 is therefore:

Outflow (cfs) = 10 ^ [185 – 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:

Log [Longfin abundance] = 7.0 – 0.05 x [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

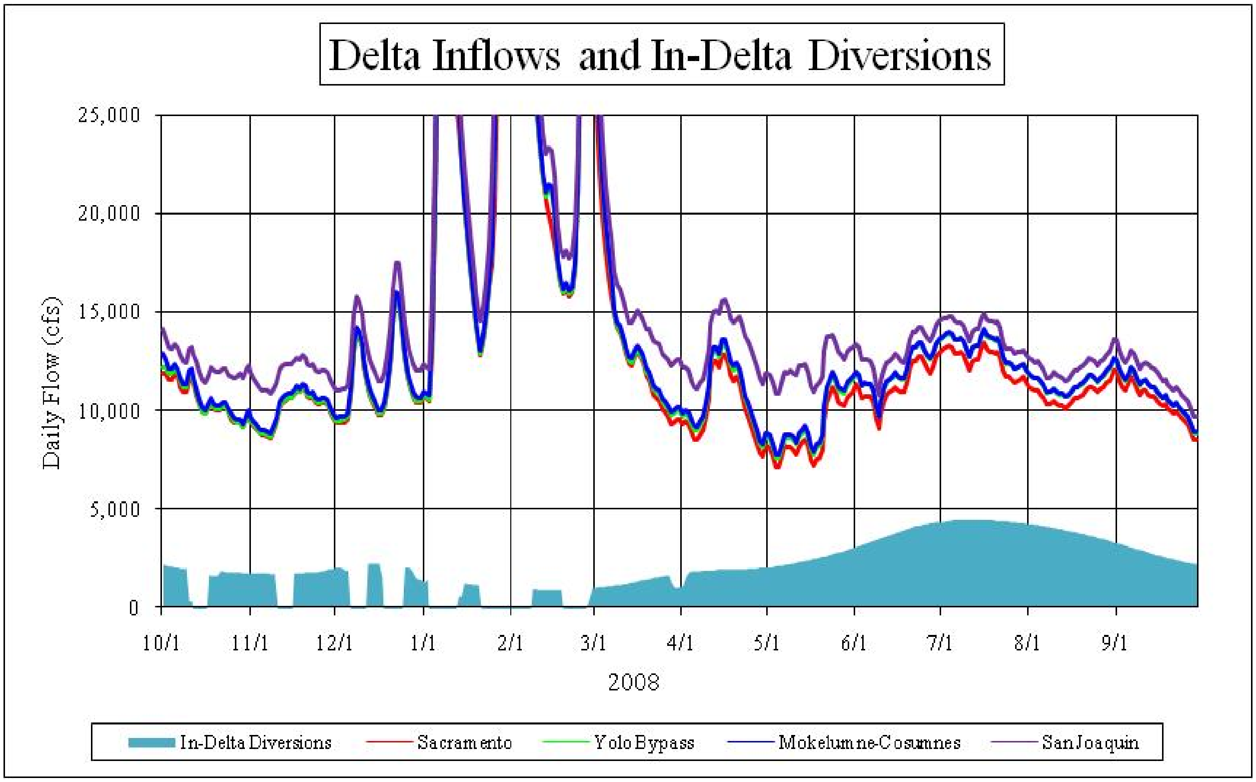
Negative Exponential Estimates derived from 1976-1991 Historical EC and Delta outflow
EC (uS/cm) = minimum + constant x exp [factor x outflow(cfs)]

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		



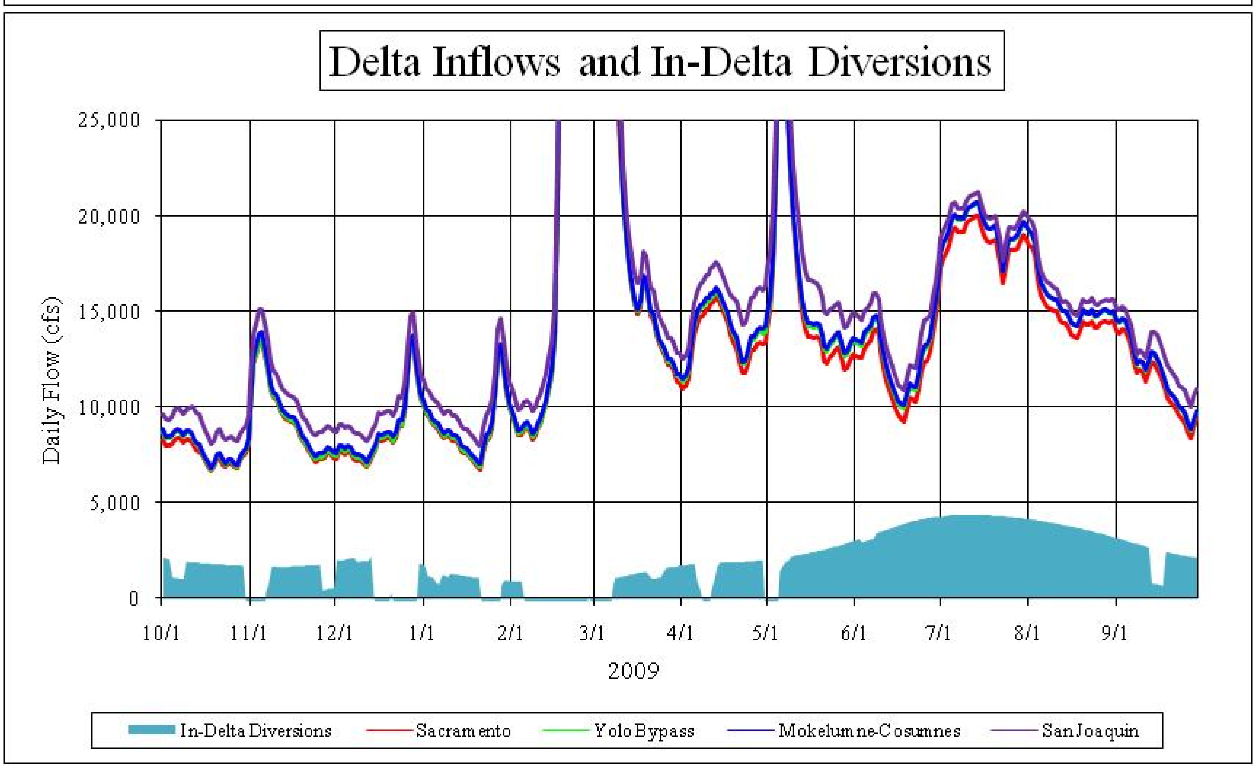
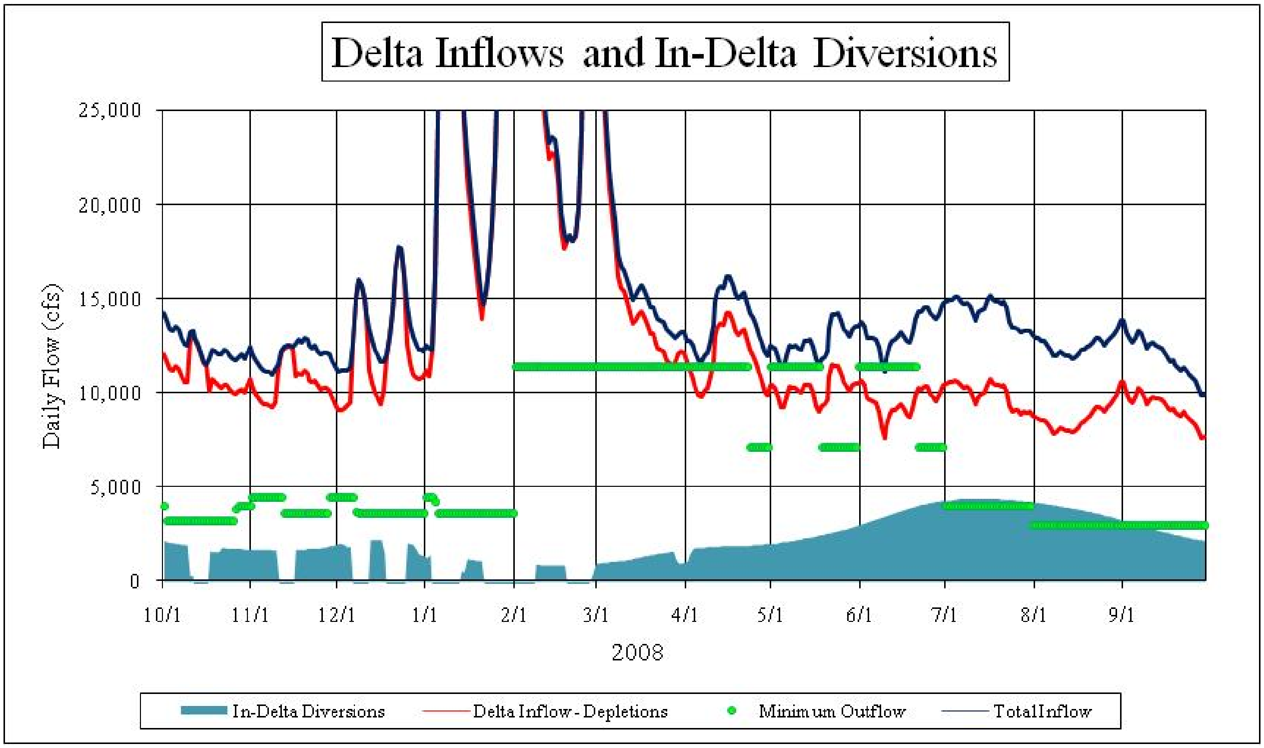


Figure 1. Delta inflows (stacked) and channel depletions for WY 2008 and WY 2009 (from DAYFLOW).



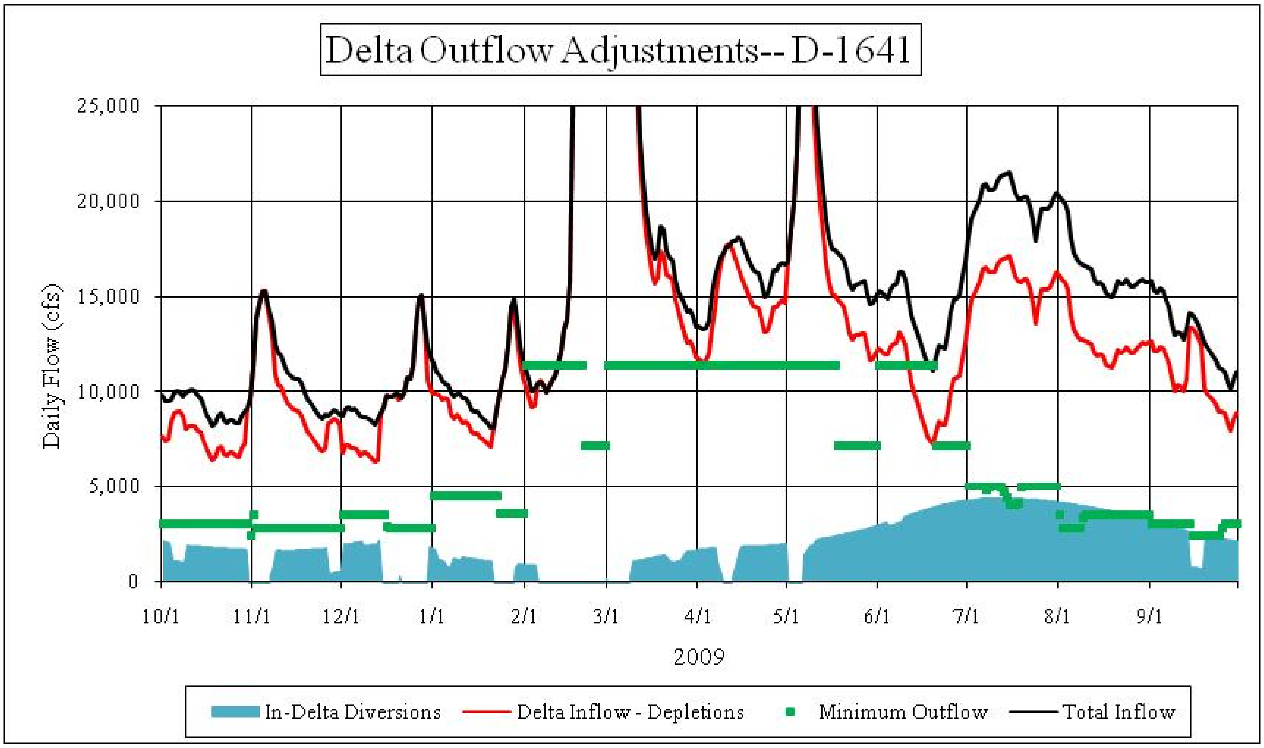


Figure 2. Delta Inflows (minus channel depletions) and D-1641 minimum required outflows for WY 2008 (dry) and WY 2009 (critical). [Channel depletion was about 1 maf and required outflow was 4 maf].

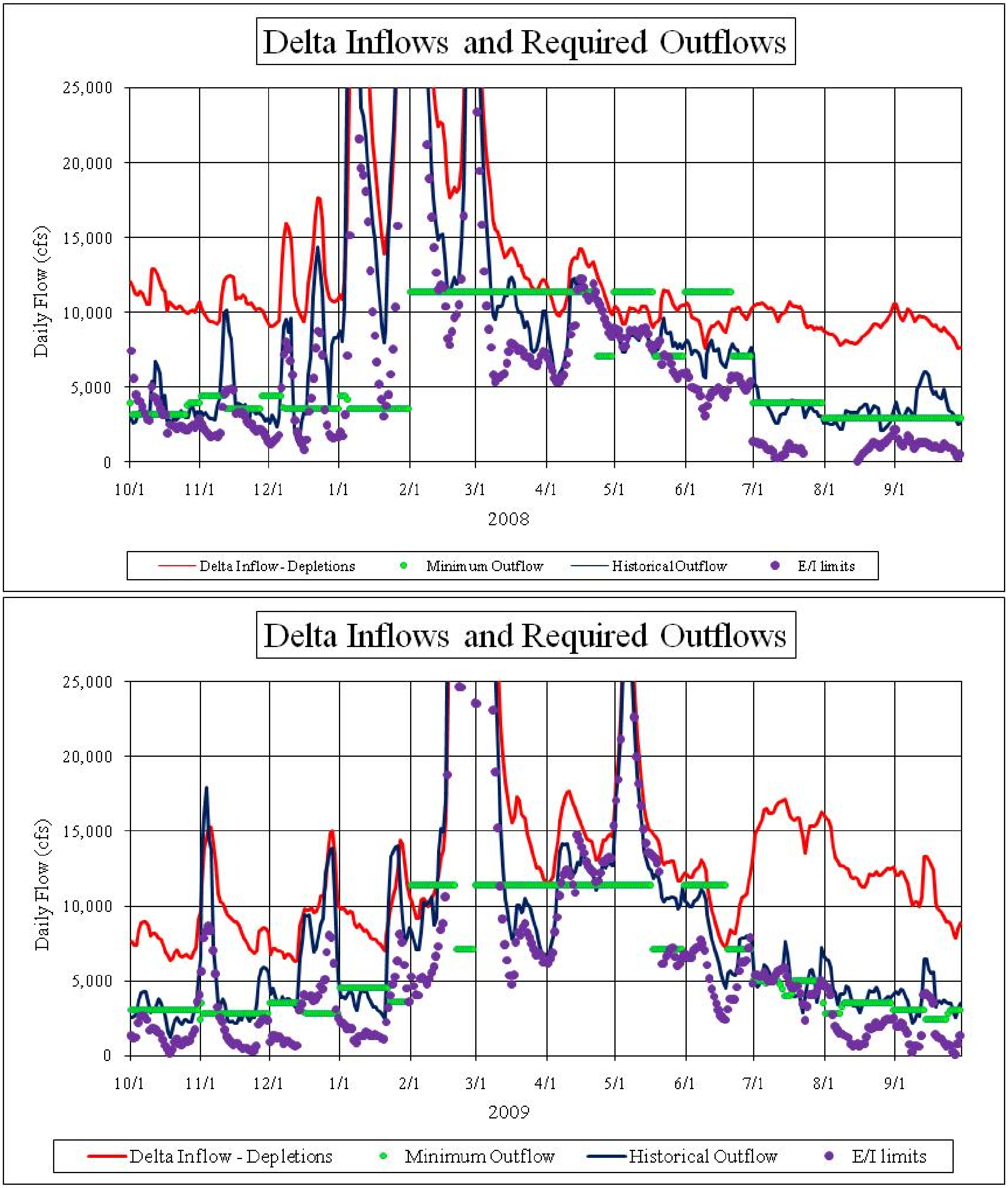
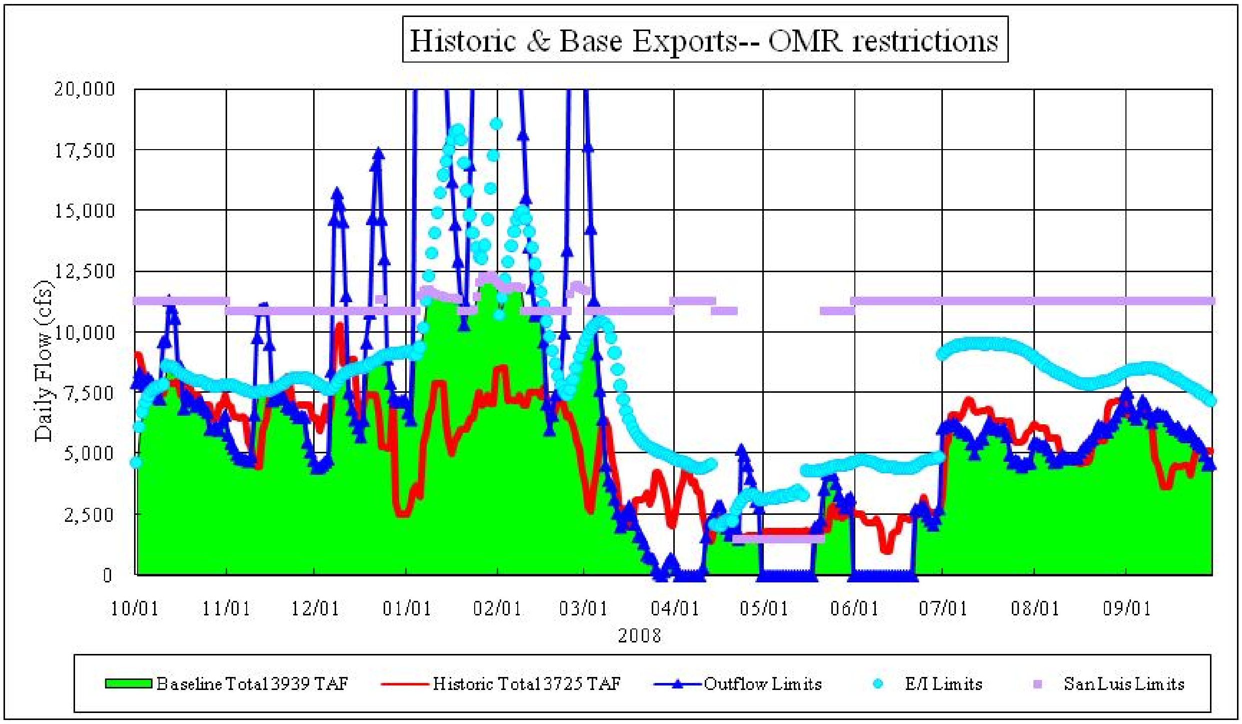


Figure 3. Delta Inflows (minus channel depletions) for WY 2008 and WY 2009 with required outflow and E/I limits (purple dots) estimated with historical outflow shown for comparison.



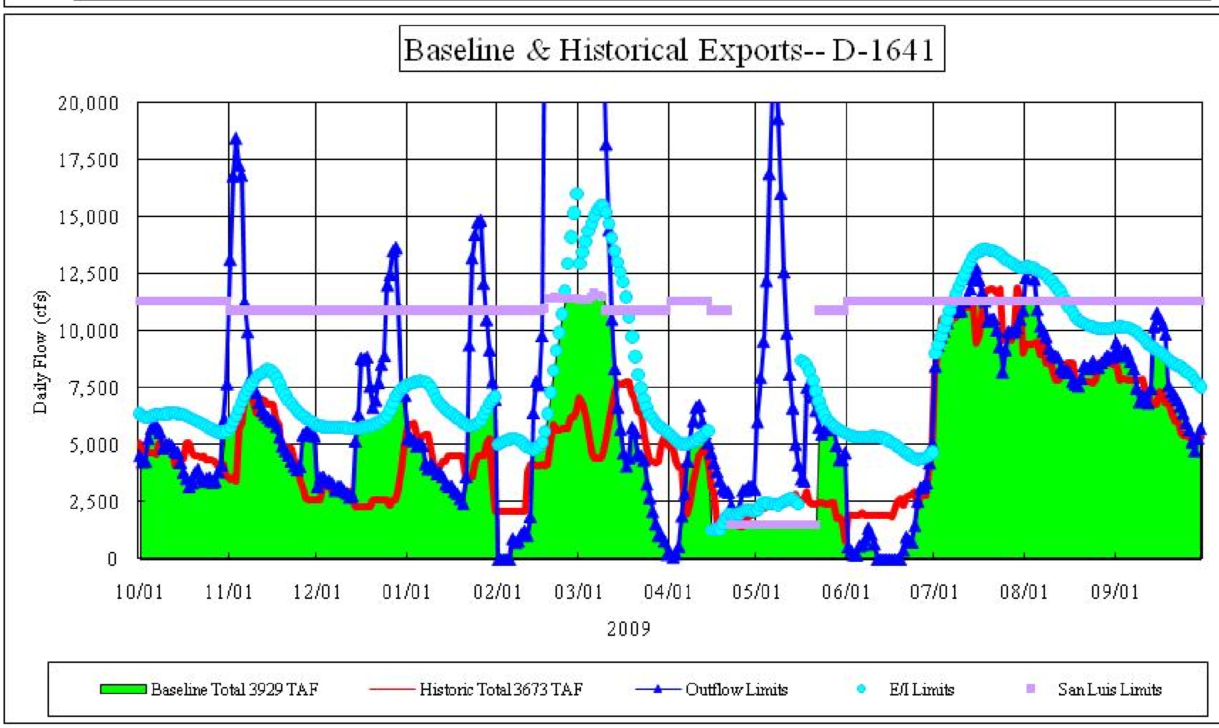


Figure 4. Estimated Baseline D-1641 Exports controlled by required outflow and maximum E/I for WY 2008 and WY 2009. [Historical exports shown for comparison were 213 taf less than the estimates in WY 2008 and 256 taf less than the estimates in WY 2009].

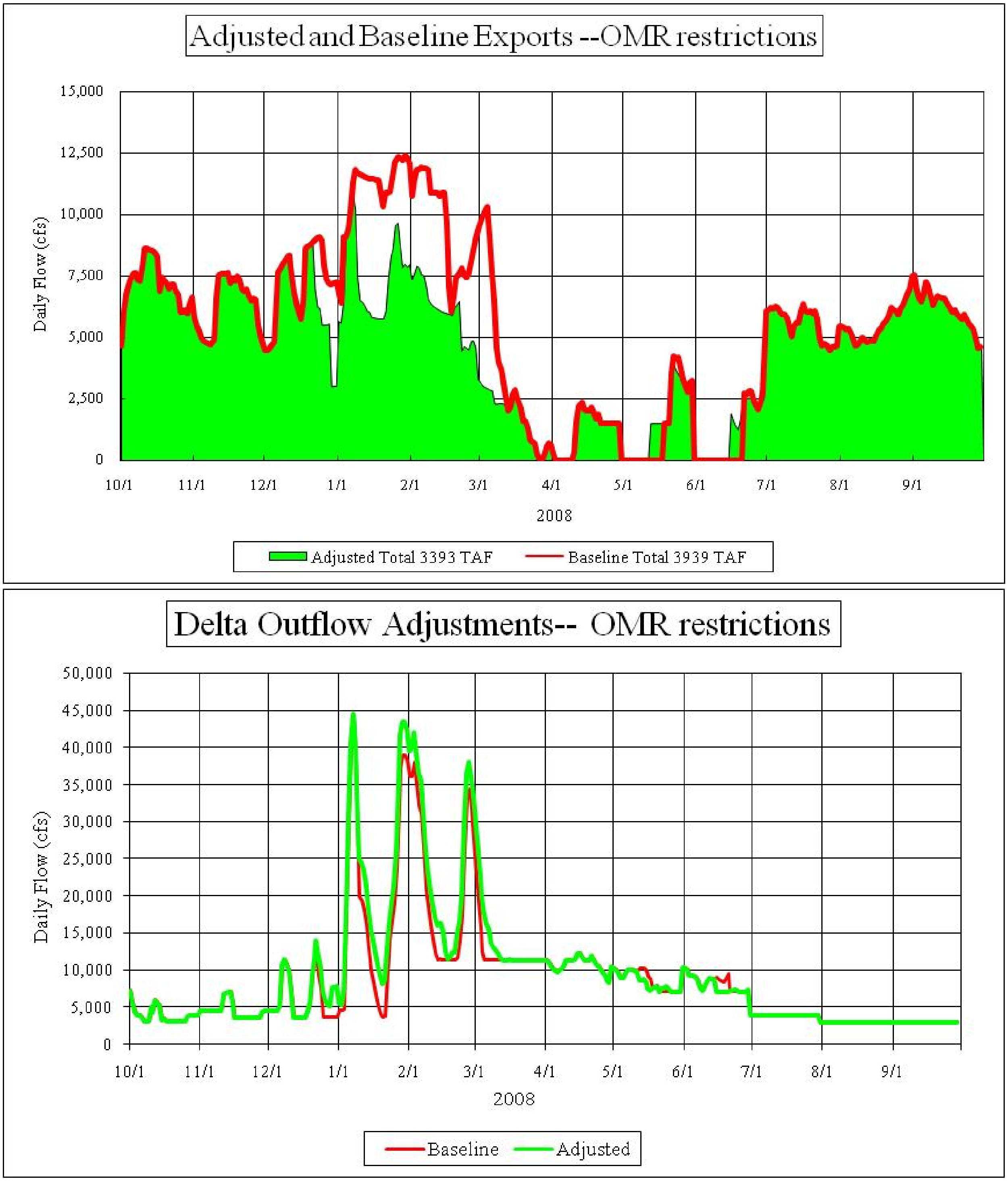
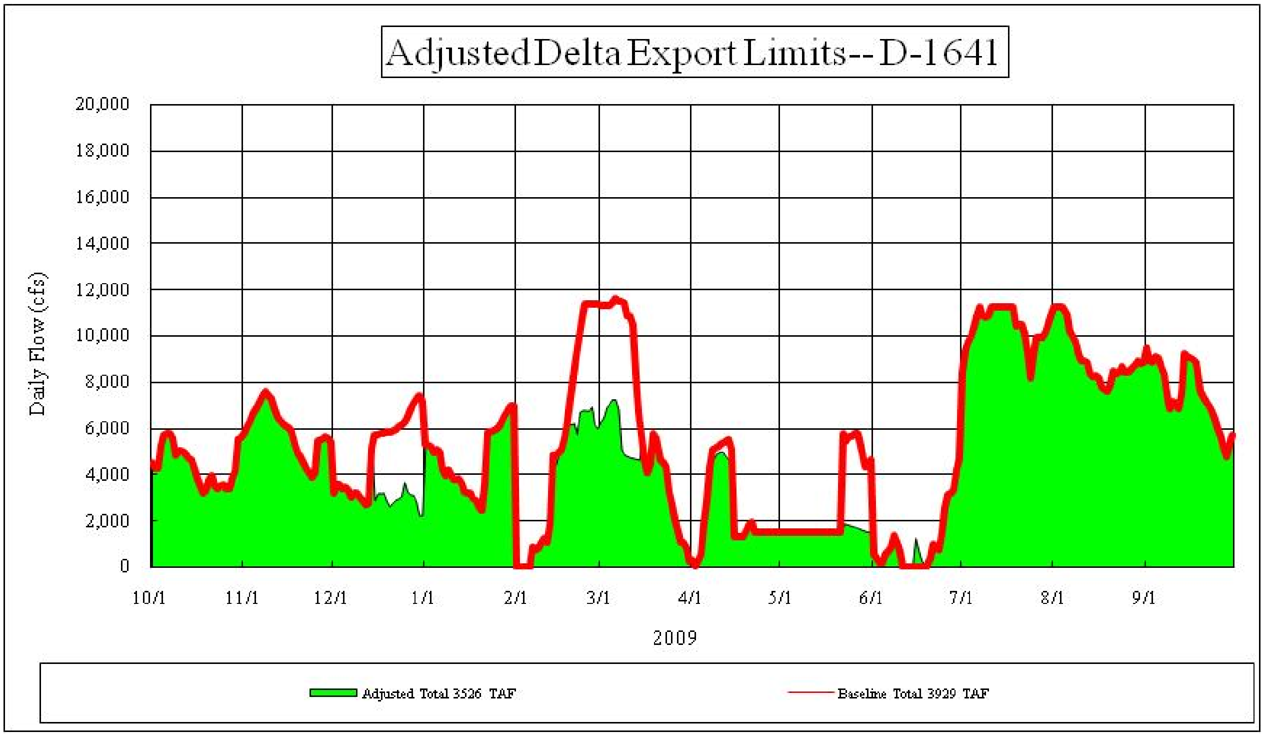


Figure 5. Estimated Reductions in Exports and Increases in Outflow caused by Reverse OMR flow restrictions for delta smelt protections in WY 2008. [DeltaOPS model estimated reductions of 546 taf].



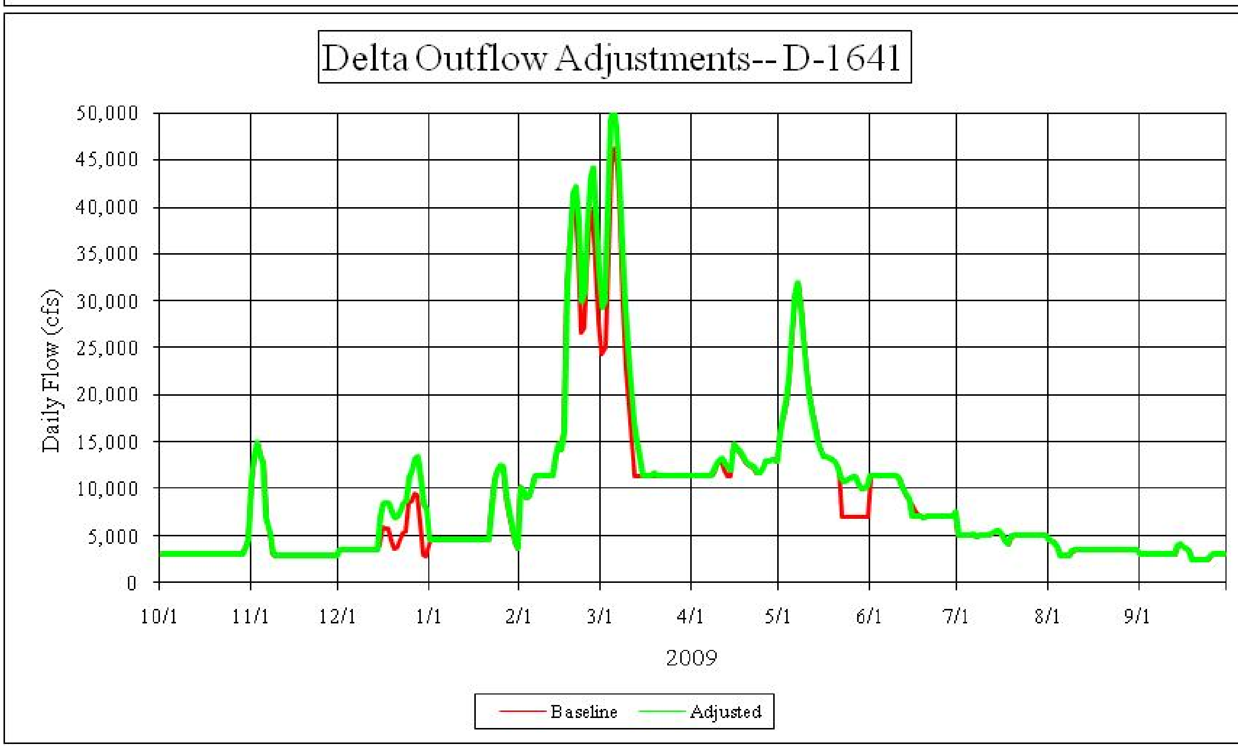
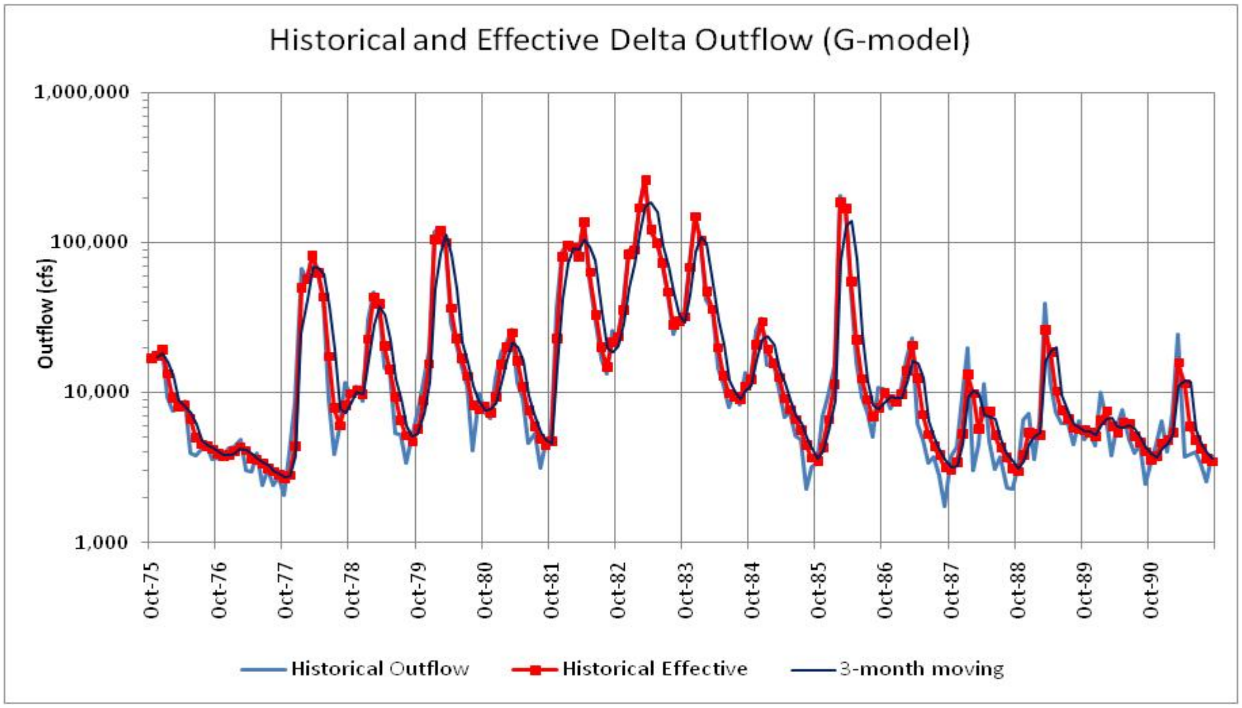


Figure 6. Estimated Reductions in Exports and Increases in Outflow caused by Reverse OMR flow restrictions for delta smelt protections in WY 2009. [DeltaOPS model estimated reductions of 403 taf].



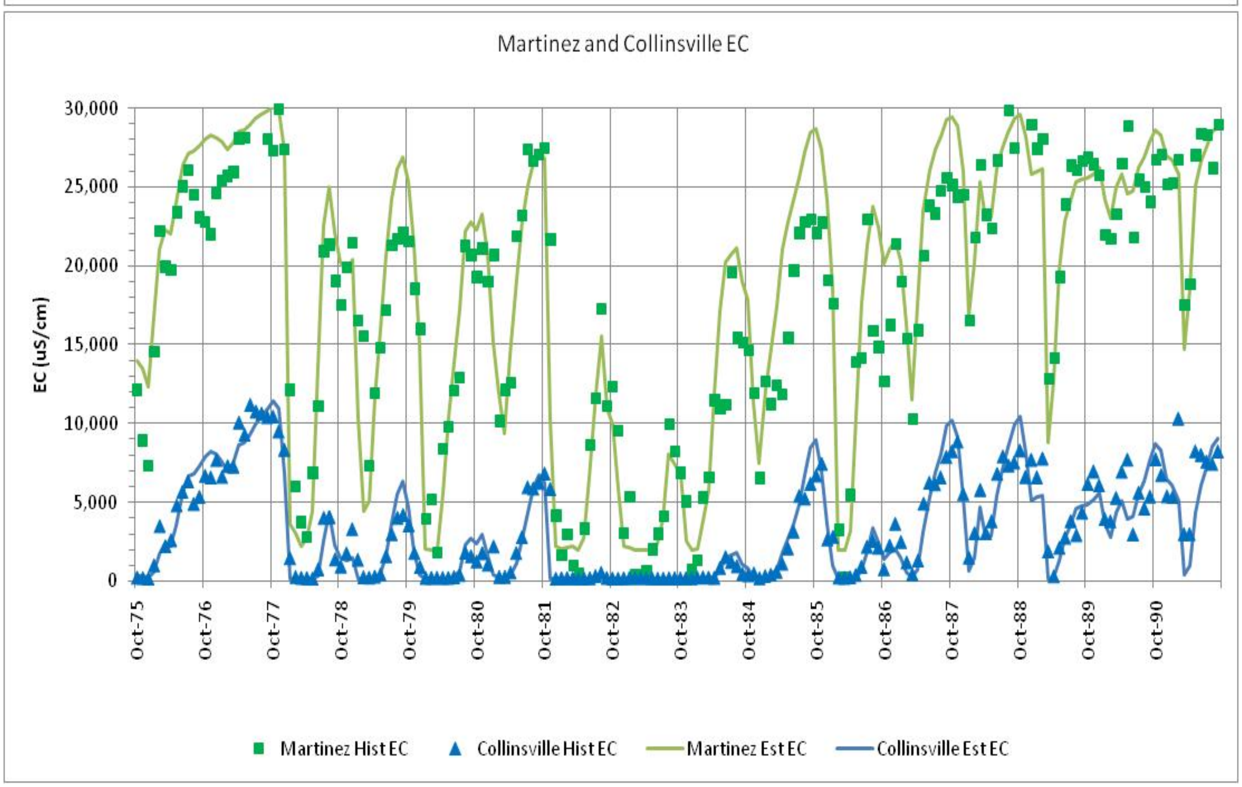
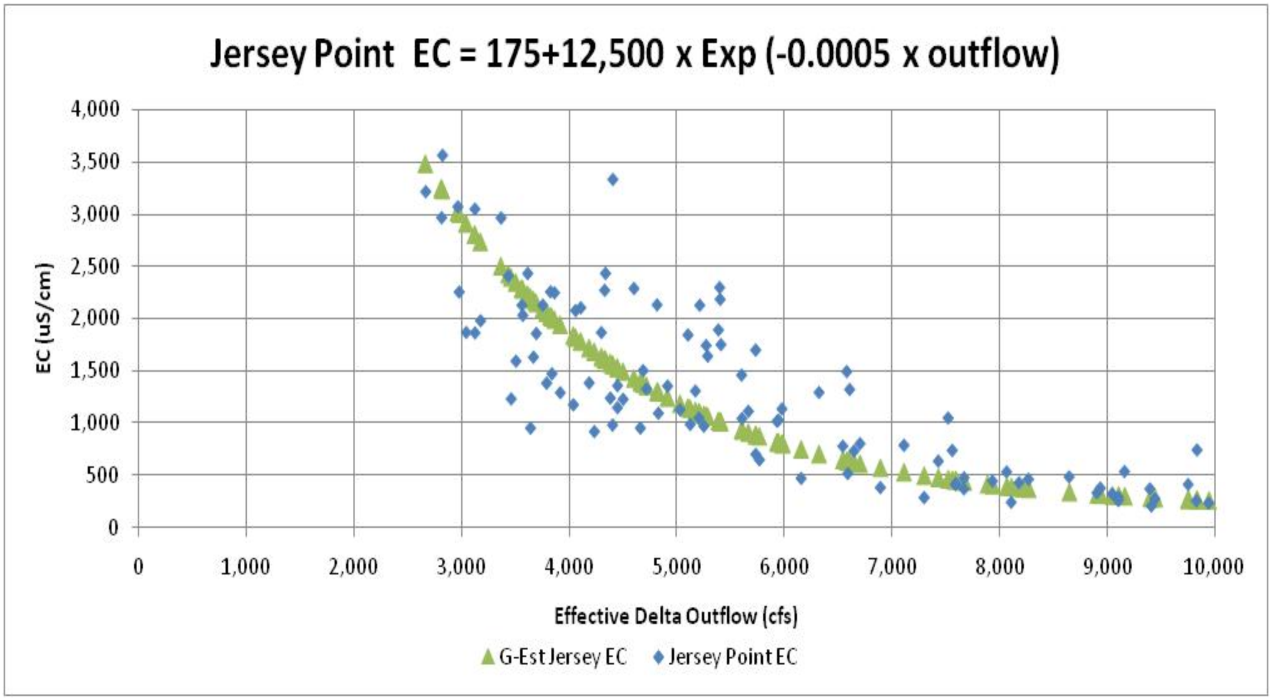


Figure 7a. Historical Monthly Delta outflow and effective Delta outflow for WY 1976-1991 (logarithmic graph). Figure 7b. Historical monthly average EC and estimated EC at Martinez (56 km) and Collinsville (81 km) for WY 1976-1991. [Note: X2 is at the EC station when monthly EC is about 3,000 µS/cm].



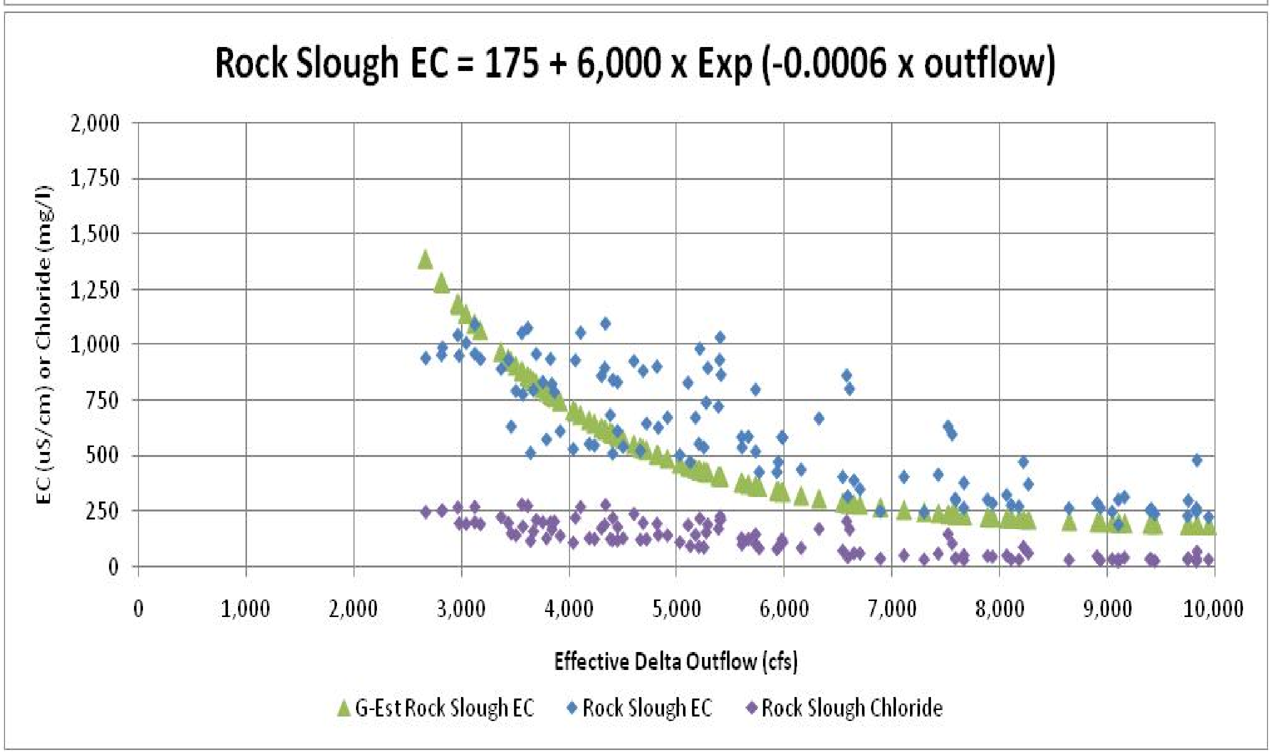


Figure 8a. Outflow-salinity impact curve at Jersey Point estimated from the historical monthly EC and effective outflow for WY 1976-1991. Figure 8b. Outflow-salinity impact curve at Rock Slough estimated from the historical monthly EC and effective outflow for WY 1976-1991. [Note: Chloride concentration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

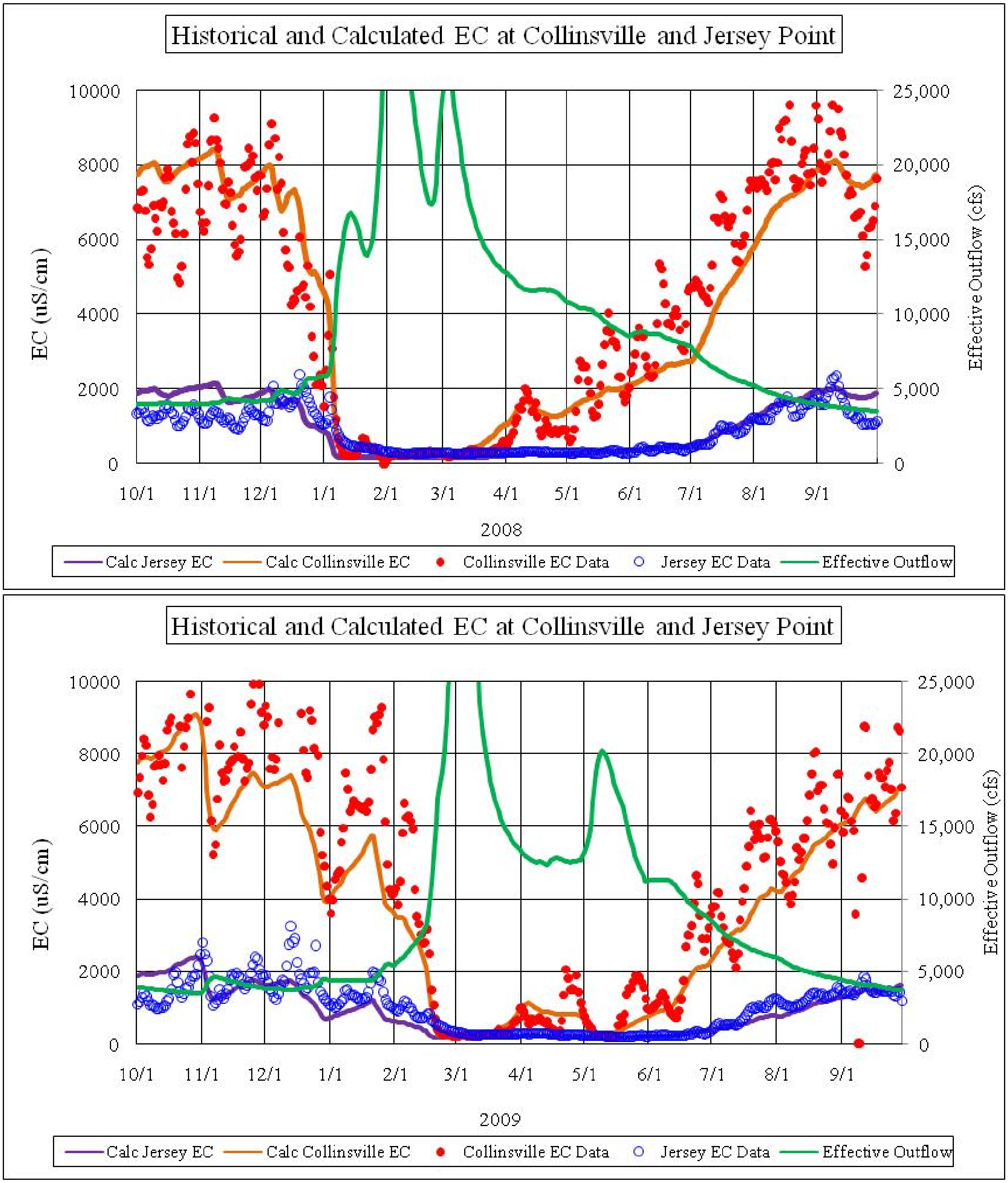
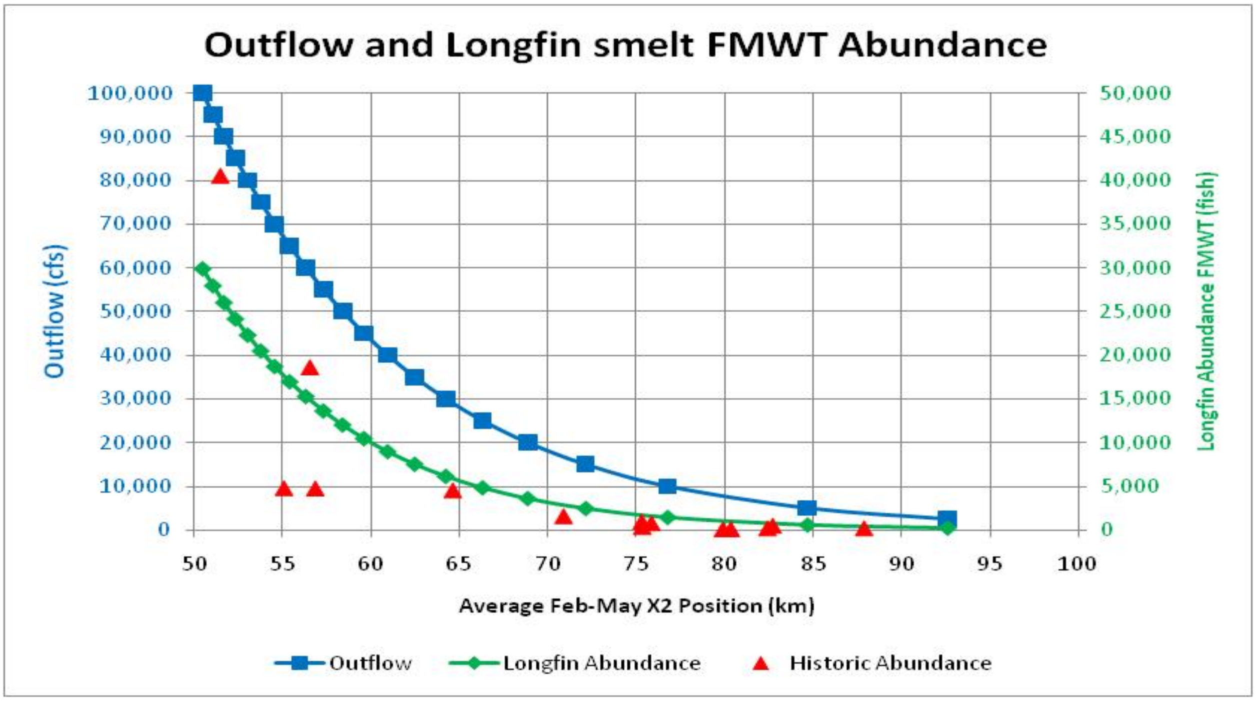


Figure 9. Measured EC at Jersey Point and Collinsville compared with calculated EC using the negative exponential equation with daily effective outflow (G-model formulation) for WY 2008 and WY 2009.



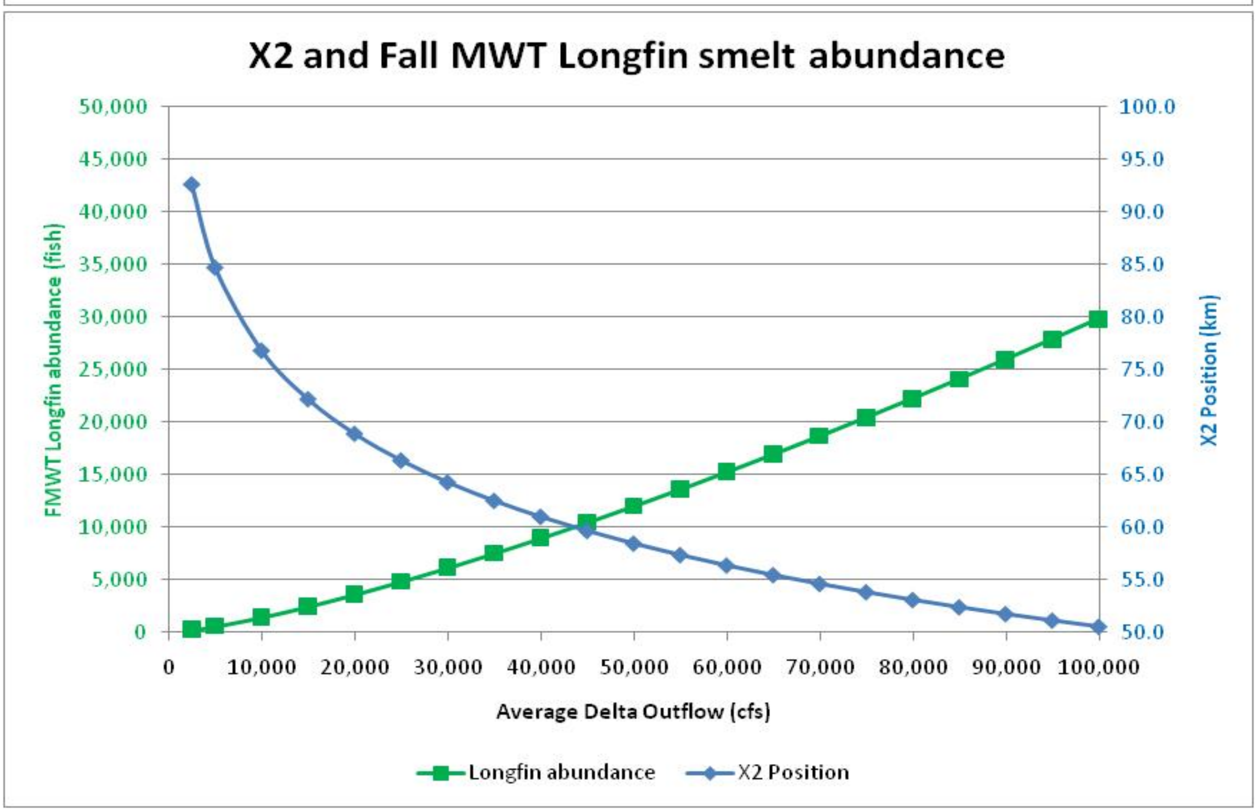
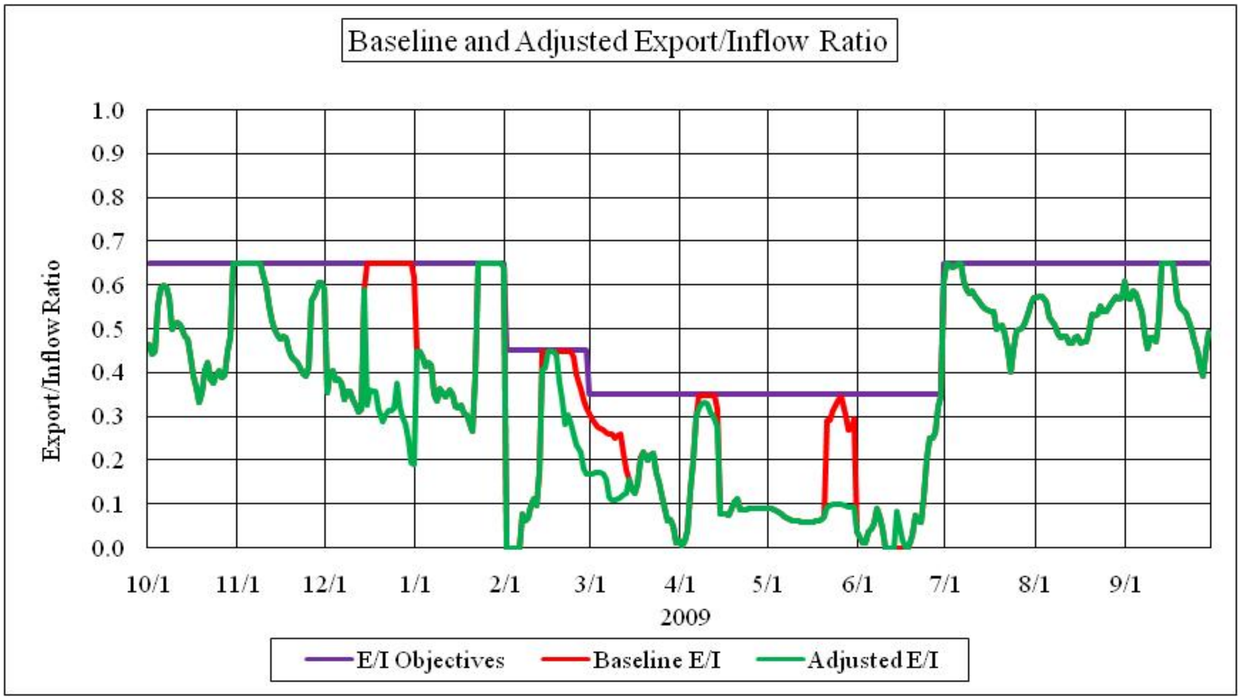


Figure 10a. Relationships between X2 (km) and 1) the estimated FMWT longfin smelt abundance (fish caught) and 2) Delta outflow (cfs). Figure 10b. Relationships between outflow and 1) X2 (km) and 2) FMWT longfin smelt abundance (total fish caught).



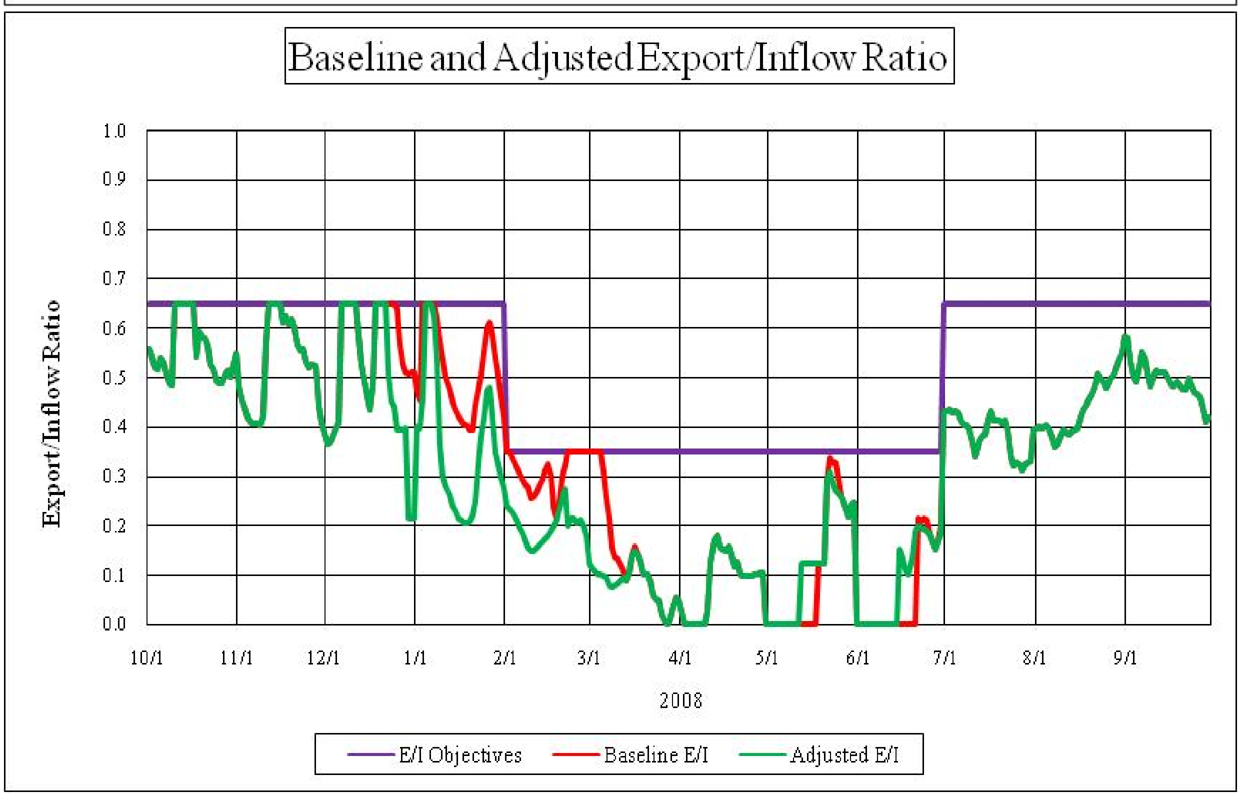
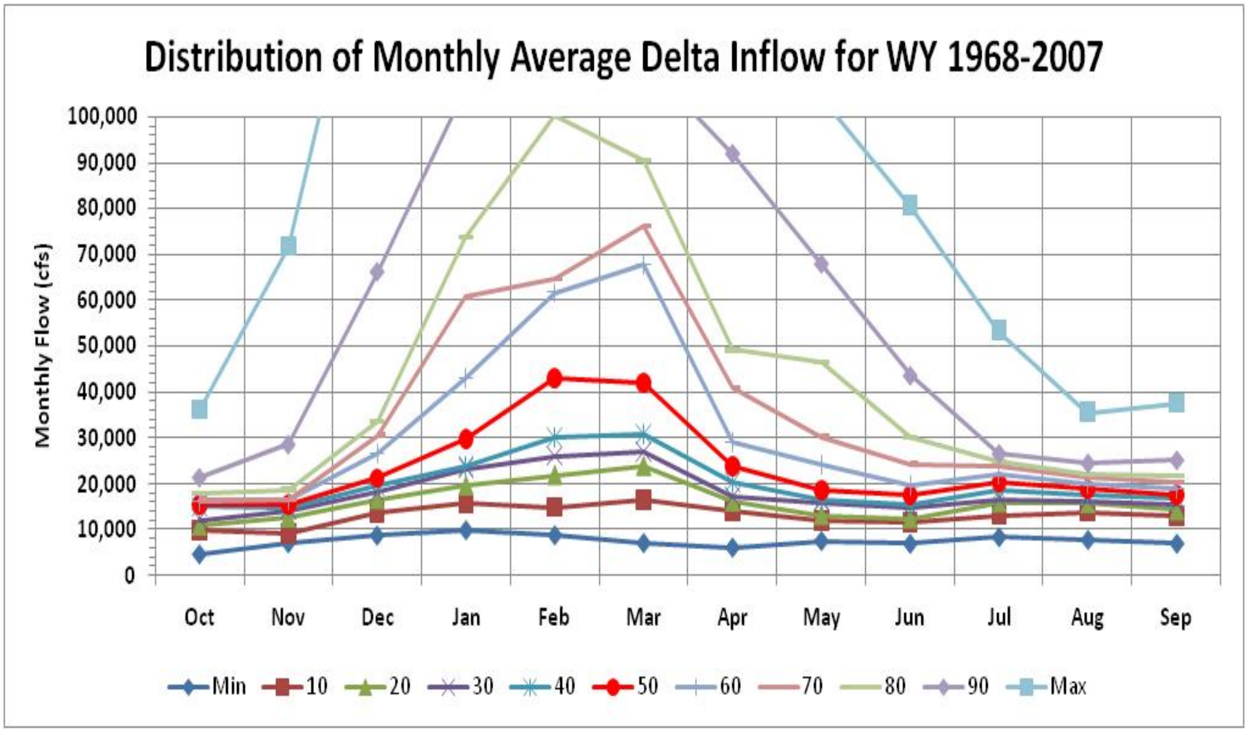


Figure 11. Calculated Baseline (D-1641) E/I ratios and Adjusted E/I ratios with reverse OMR flow Limits in WY 2008 and WY 2009.



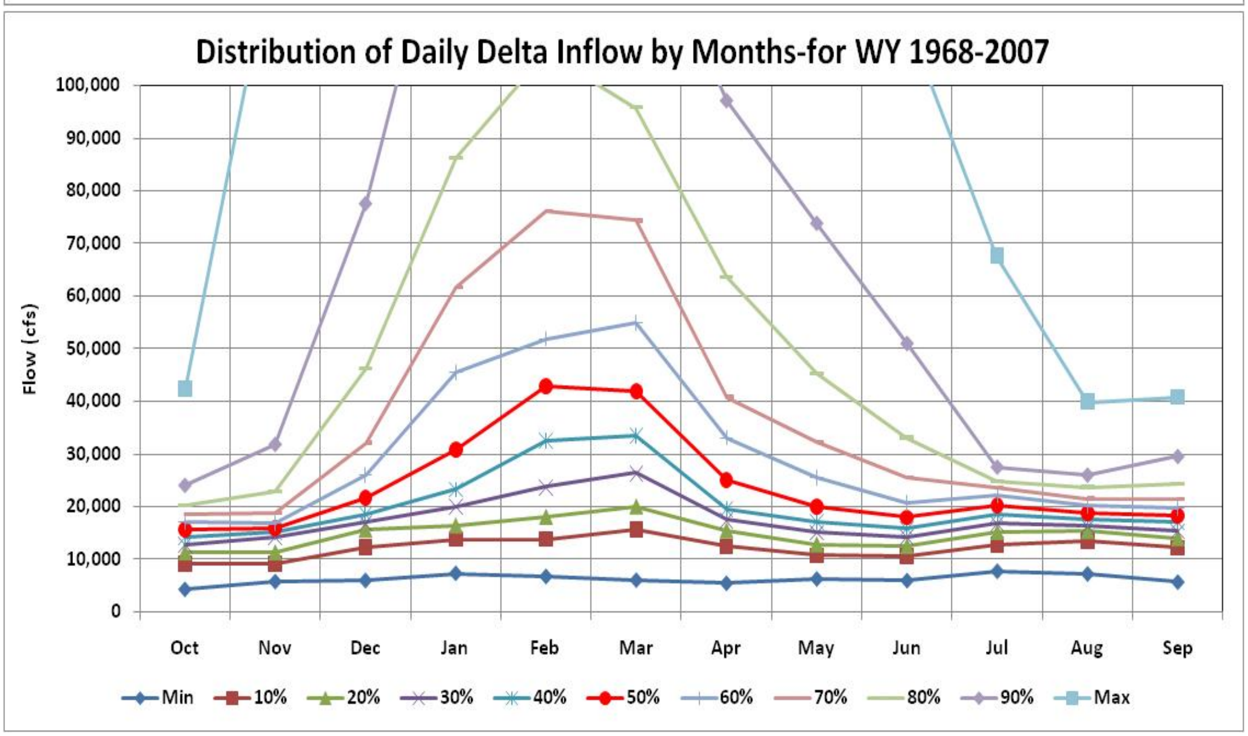
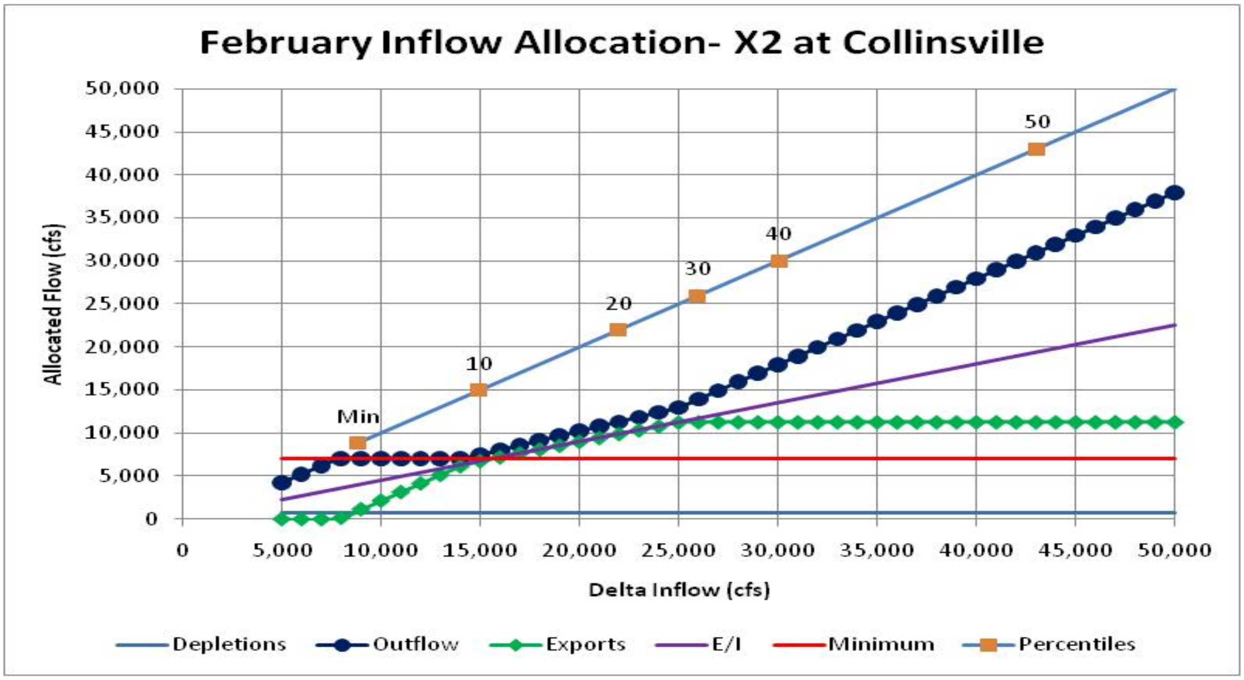


Figure 12a. Cumulative Distribution of Average Monthly Delta Inflows for WY 1968-2007. Figure 12b. Cumulative Distribution of Daily Delta Inflows by Month for WY 1968-2007.



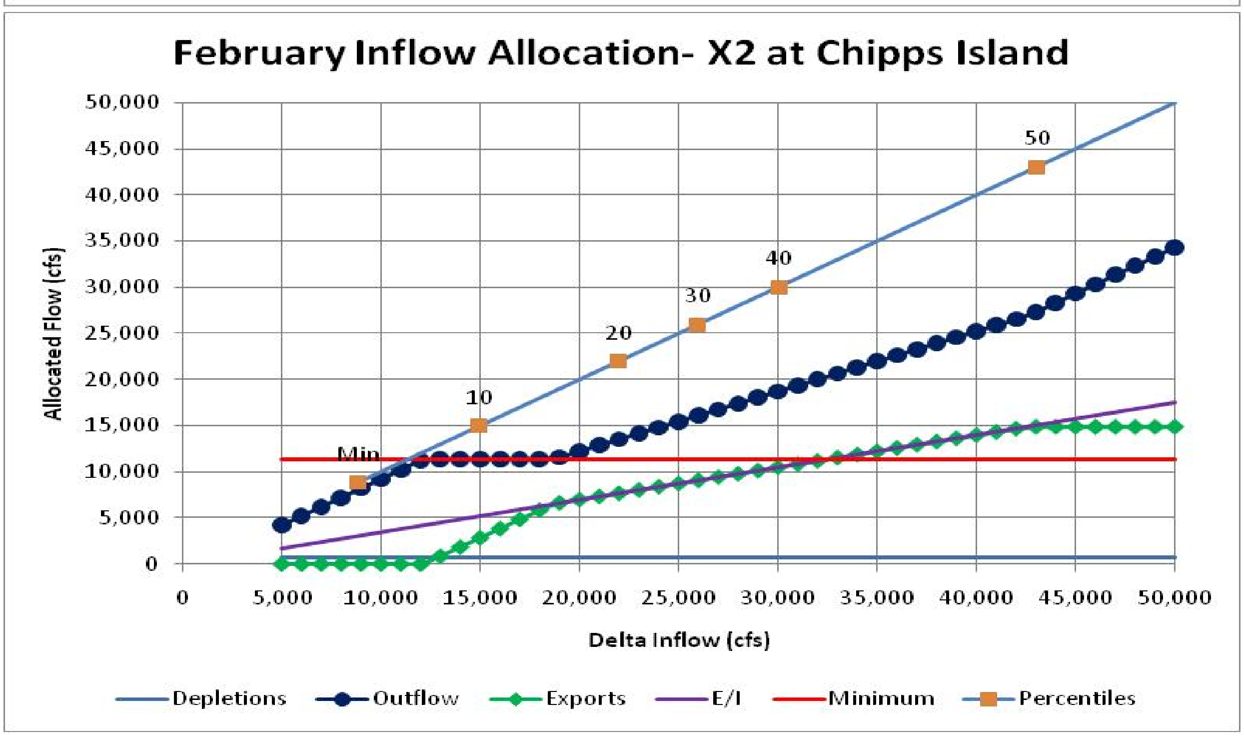


Figure 13a. Delta Inflow Allocation Curve for February, with X2 at Collinsville and E/I of 45% and permitted exports of 11,280 cfs. Figure 13b. Delta Inflow Allocation Curve for February, with X2 at Chipps Island and E/I of 45% and maximum exports of 14,900 cfs.

ICF Workshop 3 Submission to State Water Board
Attachment 2:
Jones and Stokes (September 2007) Evaluation of Fish Protection from Installation of the Head of Old River Temporary Barrier
Appendix B: Salvage Evaluation Model for Juvenile San Joaquin Chinook Salmon
Prepared for US Bureau of Reclamation

Evaluation of Fish Protection from Installation of the Head of Old River Temporary Barrier

Prepared for:

U.S. Department of the Interior, Bureau of Reclamation
2800 Cottage Way MP-700
Sacramento, CA 95825
Contact: Sharon McHale

Prepared by:

Jones & Stokes
2600 V Street
Sacramento, CA 95818-1914
Contact: Jennifer Pierre
916/737-3000

September 2007

Jones & Stokes. 2007. Evaluation of Fish Protection from Installation of the Head of Old River Temporary Barrier. September. (J&S 06757.06.) Sacramento, CA. Prepared for the U.S. Department of the Interior, Bureau of Reclamation.

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Appendix C San Joaquin River Juvenile Chinook Salmon Delta Pathway Survival Model

Appendix D Previous Reports, Salvage Evaluation Files, and Delta Pathway Survival Model Files

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At End of Report

Acronyms and Abbreviations

ADCP	acoustic-doppler current profiler
af/day	acre-feet per day
AFRP	Anadromous Fish Restoration Program
cfs	cubic feet per second
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
CWT	coded-wire-tag
DFG	California Department of Fish and Game
DMC	Delta-Mendota Canal
DO	dissolved oxygen
DWR	California Department of Water Resources
DWSC	Deep Water Ship Channel
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
SWP	State Water Project
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VAMP	Vernalis Adaptive Management Plan

Evaluation of Fish Protection from the Head of Old River Temporary Barrier

1.0 Introduction

Fall-run Chinook salmon migrating past the head of Old River (i.e., Mossdale) may be diverted into Old River and move toward the State Water Project (SWP) and Central Valley Project (CVP) fish salvage facilities and pumping plants. The head of Old River barrier (a rock barrier installed in the San Joaquin River at the head of Old River in the spring) reduces the flow and the Chinook salmon diverted into Old River. Culverts in the barrier allow some flow past the City of Tracy wastewater discharge and provide some agricultural water supply to the south Delta channels. With the barrier in place, the majority of the San Joaquin River flow and migrating fish will move down the San Joaquin River to Stockton and enter the Deep Water Ship Channel (DWSC). Some of the San Joaquin River flow will be diverted into Turner Cut and flow to Middle River and Victoria Canal and be drawn toward the SWP and CVP pumping plants. Some of the San Joaquin River fish may continue migrating down the DWSC past Turner Cut and subsequently move past the Antioch and Chipps Island trawls. A portion of these fish will be captured in these sampling trawls.

The goal of this evaluation is to determine the effectiveness of installing the head of Old River barrier for reducing the entrainment of migrating San Joaquin River fall-run Chinook salmon. The quantitative goal is to determine the fraction of the San Joaquin River Chinook salmon that are protected (i.e., increased survival to Chipps Island trawl) by the head of Old River barrier installation. This is somewhat difficult because the Vernalis Adaptive Management Plan (VAMP) experimental program includes three simultaneous actions implemented each spring:

1. increased San Joaquin River flows at Vernalis (pulse flow),
2. reduced CVP and SWP pumping (export reduction), and
3. head of Old River barrier installation.

Some fish protection is provided by each of these coordinated actions, and identifying the portion of the protection that is achieved by the barrier installation must include a comprehensive evaluation of fish movement and behavior during VAMP conditions. Estimating the fraction of the fish that might be protected by just one of these actions (without the others) is even more difficult, because single-action conditions have seldom been observed. The management goal is to develop a simple model that would estimate the San Joaquin River fall-run Chinook salmon survival for a range of possible conditions to compare survival for management alternatives for a range of pulse flows, different target CVP and SWP pumping rates, and with or without barrier installation.

The evaluation of the head of Old River barrier protection within the VAMP experiment does not consider the historical changes in the San Joaquin River fall-run Chinook salmon population, nor does it evaluate the many upstream efforts to increase fall-run Chinook salmon spawning and rearing survival. These upstream efforts include the Central Valley Project Improvement Act (CVPIA) flows and restoration actions on the Stanislaus River, which is regulated by the New Melones Reservoir operated by the U.S. Department of the Interior, Bureau of Reclamation (Reclamation), as a CVP facility. The possible influences of the Merced River hatchery are not specifically evaluated.

This evaluation includes the daily patterns of San Joaquin River Chinook salmon abundance in the San Joaquin River at the Mossdale trawl in comparison to the observed daily counts of Chinook salmon at the CVP and SWP pumping plants, referred to as *fish salvage numbers*. The evaluation also investigates the results of coded-wire-tag (CWT) recoveries from experimental release groups on the San Joaquin River, as recovered at the CVP and SWP salvage facilities and at the Chipps Island trawl. A descriptive model of the survival of San Joaquin River Chinook salmon migrating down the major pathways from Mossdale to Chipps Island is developed, and the simulated results for various assumed factors (e.g., migrating fish “splits” at the head of Old River and Turner Cut, predation rates, travel times) are presented.

2.0 San Joaquin River Chinook Salmon Population Numbers

Although the evaluation of the benefits of the head of Old River barrier are assumed to be independent of the annual population of San Joaquin River Chinook salmon, a brief review of the historical fluctuations in the adult population (i.e., escapement) is presented as background information. The San Joaquin River fall-run Chinook salmon population has been tracked since 1952 by the California Department of Fish and Game (DFG) using escapement sampling on the three tributary streams. These escapement surveys use a mark-recapture method to estimate the number of adult fish that enter the spawning reaches of the three tributaries. This is the normal method used on Central Valley streams to estimate the annual escapement of returning Chinook salmon numbers. The assumed ocean and sport fishery harvest as well as hatchery returns can then be added to estimate the total population for each year. The size, age, and sex of each fish are recorded. If the adipose fin is clipped (indicating CWT) the head is saved for tag removal and reading. These surveys are made on a regular basis (weekly) during the spawning season (October–November) to better estimate the number of spawned fish along the tributary stream. An adult escapement weir (i.e., Alaskan weir) has been installed for three years (2004–2006) on the Stanislaus River to directly count all adults entering the spawning reach. The results of the escapement survey and the Alaskan weir counts generally have been similar.

The Central Valley Chinook salmon escapement estimates are tabulated by DFG in a spreadsheet called "GrandTab." The San Joaquin River tributary escapement and Merced River hatchery returns (fish taken at the hatchery ladder) are given for the 1952–2005 period in Table 1. Table 1 indicates that the total San Joaquin River Chinook salmon escapement (for 1952–2005) has averaged about 18,000 fish, with an average of about 750 fish returning to the Merced Hatchery (since 1970). The average escapement in the Stanislaus River was about 5,000 fish, the average escapement in the Tuolumne River was about 10,000 fish, and the average escapement in the Merced River was about 3,000 fish.

Table 1. Grand Tab Annual Estimates of San Joaquin River Escapement for 1952–2005

Year	Stanislaus River	Tuolumne River	Merced Hatchery	Merced River	SJR Cohort A	SJR Cohort B	SJR Cohort C	SJR Replace	Stanislaus Replace	Tuolumne Replace	Merced Replace
1950											
1951											
1952	10,000	10,000			20,000			1.35	0.70	2.00	
1953	35,000	45,000				80,000		0.13	0.14	0.12	
1954	22,000	40,000		4,000			66,000	0.19	0.19	0.20	0.10
1955	7,000	20,000			27,000			1.43	0.81	1.63	
1956	5,000	5,500				10,500		4.82	0.86	8.35	
1957	4,090	8,170		380			12,640	4.24	2.03	5.51	0.92
1958	5,700	32,500		500	38,700			0.06	0.33	0.02	0.10
1959	4,300	45,900		400		50,600		0.01	0.07	0.01	0.15
1960	8,300	45,000		350			53,650	0.01	0.02	0.00	0.06
1961	1,900	500		50	2,450			2.38	1.95	4.20	0.70
1962	315	250		60		625		8.83	7.08	12.80	1.50
1963	200	100		20			320	25.05	14.36	51.00	2.25
1964	3,700	2,100		35	5,835			3.31	3.21	3.24	17.14
1965	2,231	3,200		90		5,521		2.81	2.86	2.69	6.11
1966	2,872	5,100		45			8,017	5.63	4.29	6.31	13.33
1967	11,885	6,800		600	19,285			1.68	0.78	2.71	7.83
1968	6,385	8,600		550		15,535		2.51	2.13	2.54	6.27
1969	12,327	32,200		600			45,127	0.26	0.35	0.16	4.21
1970	9,297	18,400	100	4,700	32,397			0.12	0.13	0.11	0.17
1971	13,621	21,885	200	3,451		38,957		0.07	0.06	0.05	0.29
1972	4,298	5,100	120	2,528			11,926	0.38	0.28	0.31	0.67
1973	1,234	1,989	375	797	4,020			0.87	0.49	0.85	1.51
1974	750	1,150	1,000	1,000		2,900		0.28	0.00	0.39	0.35
1975	1,200	1,600	700	1,700			4,500	0.42	0.04	0.81	0.31
1976	600	1,700	700	1,200	3,500			0.92	0.18	0.70	1.60

Year	Stanislaus River	Tuolumne River	Merced Hatchery	Merced River	SJR Cohort A	SJR Cohort B	SJR Cohort C	SJR Replace	Stanislaus Replace	Tuolumne Replace	Merced Replace
1977	0	450	661	350		800		4.39		1.24	8.14
1978	50	1,300	100	525			1,875	13.20	20.00	10.96	18.08
1979	110	1,183	227	1,920	3,213			3.17	0.00	6.02	1.60
1980	100	559	157	2,849		3,508		9.06	5.00	26.54	5.78
1981	1,000	14,253	924	9,491			24,744	2.13	11.44	0.96	2.91
1982		7,126	189	3,074	10,200			6.73		5.66	4.83
1983	500	14,836	1,795	16,453		31,789		0.65	12.99	0.50	0.41
1984	11,439	13,689	2,109	27,640			52,768	0.46	0.55	1.08	0.11
1985	13,473	40,322	1,211	14,841	68,636			0.29	0.76	0.14	0.28
1986	6,497	7,404	650	6,789		20,690		0.15	0.23	0.17	0.05
1987	6,292	14,751	958	3,168			24,211	0.03	0.08	0.01	0.01
1988	10,212	5,779	457	4,135	20,126			0.03	0.04	0.01	0.02
1989	1,510	1,275	82	345		3,130		0.32	0.17	0.10	1.79
1990	480	96	46	36			612	3.95	1.41	4.91	35.25
1991	394	77	41	78	549			7.62	2.62	6.57	33.92
1992	255	132	368	618		1,005		3.75	2.43	6.27	3.75
1993	677	471	409	1,269			2,417	3.24	0.25	9.26	2.59
1994	1,031	506	943	2,646	4,183			3.69	5.42	14.12	1.03
1995	619	827	602	2,320		3,766		4.06	4.99	10.77	1.42
1996	168	4,362	1,141	3,291			7,821	2.01	25.89	1.89	0.95
1997	5,588	7,146	946	2,714	15,448			2.43	1.52	2.50	4.10
1998	3,087	8,910	799	3,292		15,289		1.63	2.28	0.99	2.79
1999	4,349	8,232	1,637	3,129			15,710	1.52	1.79	0.87	2.83
2000	8,498	17,873	1,946	11,130	37,501			0.28	0.69	0.12	0.23
2001	7,033	8,782	1,663	9,181		24,996		0.39	0.71	0.19	0.33
2002	7,787	7,173	1,840	8,866			23,826	0.27	0.45	0.07	0.28
2003	5,902	2,163	549	2,530	10,595						
2004	5,000	1,700	1,050	3,000		9,700					
2005	3,500	500	421	2,500			6,500				

SJR = San Joaquin River.

Reclamation and U.S. Fish and Wildlife Service (USFWS) Anadromous Fish Restoration Program (AFRP) used the 25-year period of 1967–1991 to evaluate the long-term fluctuations and restoration goals for each Central Valley river. The average escapement for this period, which included two relatively high abundance periods and one lower abundance period, was estimated to be about 39,000 fish. The San Joaquin River “doubling” target therefore was set at about 78,000 fish (22,000 for the Stanislaus, 38,000 for the Tuolumne, and 18,000 for the Merced).

The variation in the escapement (i.e., population) from year to year is relatively large. Part of this variation is explained by the basic 3-year life cycle for fall-run Chinook salmon. The juveniles that emerge from the gravel and migrate through the Delta to the ocean in the spring months generally will return to the tributary stream in the fall of the third year after they were spawned. There are therefore three distinct “cohorts” from each tributary (with a few fish returning as 2-year-old fish and a few returning as 4-year-old or 5-year-old fish). The ratio of the escapement in 3 years to the spawning adults that spawn this cohort is a good measure of the overall success of this cohort. This is sometimes called the replacement ratio and indicates whether the cohort population is increasing (ratio greater than 1) or decreasing (ratio less than 1).

The replacement ratio reflects the relative success of the cohort, which is likely controlled by spawning, rearing, and juvenile migration conditions in the spawning water-year, as well as ocean conditions in the second and third year of each cohort. Water years, which begin in October of the previous year, are convenient for identifying San Joaquin River fall-run Chinook salmon cohorts, because spawning in the San Joaquin River tributaries begins in October. Because we are investigating the effects of the head of Old River barrier on the juvenile survival for each cohort, it is most appropriate to calculate the replacement ratios for each cohort as determined by the ratio of escapement 2 years later to the escapement in the previous fall. For example, Table 1 indicates that the fall of 2002 escapement was 23,826 fish and 6,500 fish returned in the fall of 2005. The replacement ratio for the fall 2002 cohort was therefore 0.27. The juveniles from the fall of 2002 cohort would have migrated past the head of Old River barrier in the spring of 2003.

Table 1 gives the replacement ratios for the three cohorts from the San Joaquin River, and for the cohorts from the individual tributaries. Some years the replacement ratio is quite high (10) indicating that the population will be increased by a factor of 10 when they return in 3 years. In other years the replacement ratio is very low (i.e., 0.1) indicating that the population will drop to just 10% in 3 years. A replacement ratio of about 1 indicates relatively stable population. Figure 1 shows the San Joaquin River fall-run Chinook salmon escapement (adult population) and the 3-year replacement ratio for 1952–2006. The population in each tributary has followed similar patterns of increasing to relatively high abundances for several years and then decreasing to lower levels for 5 or more years. The variation in this relative success or failure of each cohort is of great interest for management of the San Joaquin River Chinook salmon population, although the specific causes for high or low replacement ratios may be difficult to identify. The results of this evaluation of the effects of the head of Old River barrier may be used to identify the contribution of the barrier to improved replacement ratios and increased escapement for the San Joaquin River Chinook salmon.

One of the possible causes for relatively high replacement ratios is good survival during the out-migration of the juveniles in the spring months of March, April, and May. High San Joaquin River flows during these months may be associated with relatively high replacement ratios, as shown in Figure 2. However, neither linear nor log-log plots show much of a relationship between flows and escapement, because of the long-term variable population pattern. Annual regressions such as this one (i.e., spring-flow and escapement) are somewhat speculative, because the mechanisms for survival or mortality are likely to occur at much shorter time periods. Nevertheless, these annual regressions may point to environmental variables or conditions that are associated with higher or lower overall survival success.

The regression of annual abundance with a selected environmental factor such as flow will be confounded by the historical fluctuations in abundance (i.e., abundance cycles). Regressions of the cohort replacement ratio might be a better approach for identifying effects of general flow conditions on the Chinook salmon population, because it is the improved survival of a cohort that we are attempting to manage. Figure 3 shows that the replacement ratios are generally higher in years with high spring flows. Years with spring flows of more than 5,000 cubic feet per second (cfs) usually have cohort replacement ratios of greater than 1. However, there does not appear to be a strong relationship for spring flows of less than about 5,000 cfs. The barrier may improve the survival of juveniles and increase the replacement ratio of the Chinook salmon population measured 3 years later.

3.0 Efforts to Protect San Joaquin River Chinook Salmon

There have been many previous efforts to protect the San Joaquin River Chinook salmon population from the effects of low river flows, high export pumping, and other environmental conditions that may have an impact on these fish. Several reports that document these earlier efforts have been scanned as word-searchable PDF files and are provided in Appendix D, on a CD at the end of this report.

The first effort to protect the San Joaquin River juvenile Chinook salmon from the effects of CVP pumping was the design, construction, and initial operation of the Tracy Fish Facility. Three early reports document this innovative research and the subsequent construction and testing of the louver fish-screen design that was selected to reduce the effects (i.e., from clogging) of Delta peat soil clumps and other floating debris on normal wire mesh or perforated sheet fish screens. The louvers were found to separate about 80% of the juvenile striped bass and Chinook salmon from the water in the Delta-Mendota Canal (DMC) intake channel.

Based on the successful operation of the CVP Tracy Fish Facility, the SWP developed and constructed an updated version of the fish facility louvers, with several design improvements. The testing of these louver facilities at the SWP fish protection facility are described in a report prepared jointly by DWR and DFG (1973). A workshop presentation by Skinner (1974) provided a summary of the development and testing program for the SWP fish protection facility, which was subsequently named in honor of his efforts. The louver efficiency for each species was found to depend generally on the water velocity and the fish length. A program for testing fish behavior and screen efficiency and maintenance issues for these intake facilities was conducted jointly by DFG and DWR. Two Interagency Ecological Program (IEP) reports summarize these efforts (Smith 1982; Odenweller and Brown 1982), which are included in Appendix D, on the CD at the end of this report.

A report on the first fall installation of the head of Old River barrier in 1963 was prepared by the California Resources Agency (California Department of Water Resources and Department of Fish and Game 1964). Low-flow conditions and possible effects of the low dissolved oxygen (DO) in the DWSC during adult migration of the San Joaquin River Chinook salmon in the September–November period of both 1961 and 1962 led to a meeting of several government agencies on August 15, 1963, to discuss the situation. The meeting led to the emergency installation of a partial barrier (using a 130-foot barge, filled with rock and sunk) near the head of Old River from October 10 to November 14, 1963. Reclamation conducted DMC recirculation to increase San Joaquin River flow from September 15 to November 1, 1963.

A subsequent study by DFG (Hallock et al. 1970) described the adult migration of the San Joaquin River Chinook salmon and possible impacts from low flows and low DO conditions. Sonic tags were used to track individual Chinook salmon adult migrations in 1964–1967. The possible effects of the head of Old River barrier on flows and DO at Stockton were discussed. The installation of the head of Old River barrier in the fall has continued in most years since 1963 to improve flow and DO conditions in the DWSC. The operation of the head of Old River in the spring period to protect the juvenile San Joaquin River Chinook salmon began in 1992 as part of the DWR South Delta Temporary Barriers Program.

4.0 San Joaquin River Chinook Salmon Juvenile Migration Abundance and Timing

DFG has operated the Mossdale Kodiak trawl for the April–June period since 1989. The USFWS has cooperatively operated the Mossdale Kodiak Trawl from mid-June to April since 1999 as part of its comprehensive Delta juvenile Chinook salmon monitoring program. In 2005 and 2006, DFG also operated a Kodiak trawl in Old River concurrent with the Mossdale trawling to determine the proportion of San Joaquin River fish that entered Old River. High flows in the San Joaquin River in these years precluded the California Department of Water Resources (DWR) from installing the head of Old River barrier. The methods used for conducting the Mossdale Trawl are described in the VAMP annual reports and are generally summarized in Appendix A.

By expanding the daily catch in the trawl volume to the daily flow in the river, a “volumetric” expansion of the trawl catch to daily river abundance (number) is obtained. An annual juvenile population estimate can be calculated for the period of sampling each year. The daily abundance at Mossdale will be compared to the daily CVP and SWP salvage counts to determine the fraction of Chinook salmon that were salvaged. This will allow the effects of the head of Old River barrier to be identified. This evaluation does not include any analysis of the relationship between the adult escapement and the subsequent juvenile abundance patterns. The daily sampling of the Mossdale Kodiak trawl is used to describe each year's juvenile abundance pattern. The Mossdale Trawl data for 1996–2005 are used in the salvage fraction modeling that is described and discussed in Appendix B.

4.1 Mossdale Trawl Abundance Estimates

The 2006 VAMP report contains a table (Table 6-2) with the DFG estimated annual population for 1989 to 2006, using both "vulnerability" and "volumetric" expansions of the trawl data. The annual juvenile Chinook salmon abundance has ranged from less than 25,000 fish (in 1992) to more than 1 million fish (in 1995 and 1998) for the volumetric expansions. Because the sampling vulnerability (i.e., catch/release ratio) is considerably less than the volumetric trawling ratio, the sampling vulnerability (efficiency) expansion generally indicates a higher abundance than the volumetric expansion.

The evaluation of the head of Old River fish protection described in this report includes the 10-year period 1996–2005. The daily data used for estimates of the natural (unmarked) fish are the daily catch, the daily trawl volume (of 75–125 acre-feet per day [af/day]), the daily flow volume (af/day), and the size of the fish (minimum, average, and maximum length). Sampling has been conducted each year during the April–June period, so the "smolt"-sized fish (i.e., longer than 75 mm) can be reliably estimated. A comparison of the larger fish sampled in the April, May, and June period each year may provide the best comparison of migrating smolt abundance.

Because some juveniles are observed in February and March during high-flow events, but these early months have only been sampled since 1999, the fraction of the juvenile population that may enter the Delta channels before April as "fry" (smaller than 75 mm) and successfully rear to smolt size in the Delta is unknown. Although the head of Old River barrier (or future gate) could be closed earlier to protect smaller fish, it is possible that rearing fry could move into the south Delta channels and become vulnerable to salvage even with the barrier installed. The effects of the barrier on fry rearing success cannot be evaluated from the Mossdale Trawl juvenile estimates. The number of fry that may rear in the Delta channels and successfully migrate past Chipps Island as smolts in April, May, or June is unknown.

Most often the peak juvenile Chinook salmon abundance at Mossdale is in late April or early May. The VAMP protection period is targeted to coincide with the peak out-migration period for Chinook salmon juveniles. The VAMP period is often scheduled April 15–May 15. The VAMP experiment generally includes increasing the San Joaquin River flow, reducing CVP and SWP exports, and installing the head of Old River barrier concurrently. The evaluation of the fish protection that is achieved by the head of Old River barrier must be integrated with these other actions that may modify the effects of the barrier.

5.0 Comparison of Mossdale Abundance with Central Valley Project and State Water Project Salvage Patterns

Each year will have a unique pattern of daily San Joaquin River flows, daily Chinook salmon abundance at Mossdale, CVP and SWP export pumping, and corresponding CVP and SWP salvage. The evaluation of the head of Old River barrier will compare the daily observed Mossdale abundance with the observed CVP and SWP salvage, to determine what fraction of the San Joaquin River fish likely were salvaged. The head of Old River barrier is assumed to reduce the number of fish being salvaged and to increase the number of fish migrating down the San Joaquin River to Chipps Island trawl. This should be evident in the reduced fraction of the Mossdale fish that are observed at CVP and SWP salvage. The comparison for 1996 is explained in detail, and the comparison for the other years is described in Appendix B. Periods when the head of Old River provided the most effective protection will be identified from this evaluation of the 10 years of data.

The evaluation of the benefits of the head of Old River barrier depends on being able to accurately estimate the fraction of the San Joaquin River fish that likely would be salvaged at the CVP and SWP pumping plants with and without the barrier. This fraction will depend on the San Joaquin River flow, the Old River flow, and the CVP and SWP pumping rates. These flows will control the flow split at the head of Old River and also will control the fraction of the San Joaquin River flow that is diverted at Turner Cut and flows toward Middle River and the CVP and SWP pumping plants. The two possible pathways for fish moving between Mossdale and the pumping plants were evaluated by considering the water flow splits and then considering the likely movement of fish at these junctions. Fish are assumed to generally follow the water flow, with possible preferences at each flow split (i.e., head of Old River and Turner Cut) as well as at the CVP and SWP export diversions. The fish preference value can be greater than 1 (i.e., preference) or less than 1 (i.e., avoidance). The fish entering a particular flow split will be the flow fraction times the preference value. A preference of 1 indicates the fish split will be equal to the water split. A preference of 1.2, for example, would suggest that the fish split would be 20% higher than the flow split. A preference of 0.2 indicates that the fish split would be only 20% of the flow split. The fish preference is specified for the diversion only. The other fish move downstream with the remaining flow.

5.1 Flow Pathways

San Joaquin River Chinook salmon migrating past Mossdale have several possible pathways to the estuary (i.e., Chipps Island). The water travel time along any pathway can be calculated as the channel volume divided by the daily net flow volume. As the flow volume increases, the water travel time will be reduced. If the fish are actively swimming downstream, however, the fish travel time may be much shorter than the water travel time. Fish travel times are not included in the comparison of the Mossdale abundance and the salvage data. Daily estimates of San Joaquin River fish at Mossdale are used to calculate the expected fish reaching CVP and SWP salvage, without a time delay for channel travel times.

The first pathway is from Mossdale into Old River and downstream to Grant Line Canal and toward the CVP and SWP intakes (and salvage facilities). This is the pathway that the head of Old River barrier is intended to block to reduce San Joaquin River Chinook salmon exposure to the salvage facilities. The length of this pathway is about 30 km. The channel volume between the head of Old River and the CVP Tracy pumping plant intake is about 7,000 af. Because 1 cfs is equivalent to about 2 af/day of flow volume, the travel time along this Old River pathway is:

Old River Pathway Travel Time (days) = 3,500 / Flow (cfs)

For example, an Old River flow of 500 cfs would correspond to a water travel time of about 7 days. An Old River flow of 1,000 cfs would reduce the travel time to 3.5 days. Some of the volume is off-channel and backwater areas that may not contribute to conveyance flows, so the effective volume is smaller and the water travel time may be somewhat shorter.

The second pathway is for fish that move past the head of Old River toward the Stockton DWSC and downstream to Turner Cut. Turner Cut connects with Empire Tract, Middle River, Victoria Canal, and West Canal on its way to the SWP and CVP intakes along Old River. The length of this pathway from Mossdale to Turner Cut is about 30 km. The effective volume from the head of Old River to Turner Cut is about 15,000 af. Therefore, for a San Joaquin River flow of 500 cfs past the head of Old River, the water travel time to Turner Cut would be about 15 days. For a flow of 1,000 cfs, the travel time to Turner Cut would be about 7.5 days.

The length of the pathway from Turner Cut to the SWP and CVP pumps is about 35 km. The daily net flows in these channels are variable and depend on the excess exports (not supplied by Old River flows). The net flow in Turner Cut is about 10% of the combined SWP and CVP excess exports. The net flow in Middle River and Victoria Canal is about 50% of the combined CVP and SWP excess exports. The effective volume in Turner Cut and Empire Cut is about 4,000 af, and the effective volume in Middle River and Victoria Canal and West Canal is about 12,000 af. The travel time in Turner Cut and Empire Cut is about 4 days for excess exports of 5,000 cfs. The travel time in Middle River, Victoria Canal, and West Canal is about 2.5 days for excess exports of 5,000 cfs. The water travel time is therefore about 2–3 weeks for the Turner Cut pathway.

The third pathway is down the San Joaquin River past Turner Cut to Antioch and Chipps Island. The San Joaquin River effective volume downstream of Turner Cut is about 300,000 af. The passive travel time for water therefore would be very long (i.e., 150,000/flow). A flow of 5,000 cfs would have a travel time of 30 days.

5.2 Head of Old River Flow Split and Fish Preference

The diversion of flow from the San Joaquin River into Old River is about 50% of the San Joaquin River flow when there is relatively low CVP and SWP pumping. Tidal flow modeling (i.e., DSM2 results) and tidal flow measurements indicate that the Old River flow will increase by about 5% of the combined CVP and SWP pumping. Each pumping flow of 1,000 cfs therefore will increase the Old River diversion by 50 cfs. A pumping flow of 10,000 cfs would increase the Old River flow by 500 cfs and might divert the entire San Joaquin River flow during low-flow periods. The actual diversion into Old River is calculated as the Vernalis flow minus the net daily flow measured at the U.S. Geological Survey (USGS) tidal flow meter located downstream at Stockton (near Garwood Bridge on State Route 4). This tidal flow meter was installed in 1995.

If the San Joaquin River fish follow the water flow, this same fraction of the San Joaquin River fish will be diverted into Old River. In this case, the fish density (fish/taf) at Mossdale and in Old River would be the same. It is possible that more (or less) of the San Joaquin River fish are diverted into Old River than the flow split would indicate. This might be expected, for example, if the migration pathway for Chinook salmon were along the left bank (or right bank) of this portion of the river channel.

Comparative Kodiak Trawl sampling was conducted at Mossdale and in Old River in two recent years (2005 and 2006). The fish density in Old River was generally similar to the fish density at Mossdale, although there was considerable variability from day to day. Figure 4 shows the ratio of the Old River and Mossdale Kodiak trawl catch for CWT and unmarked Chinook salmon in 2005. During May 2005, the Mossdale flow was about 8,000 cfs, and the flow split into Old River was about 50%. If the fish preference was 1, the density of fish in Old River would be the same as the fish density at Mossdale, and the number of fish caught in the Old River trawl would be about the same as in the Mossdale Trawl (for the same trawl volume). The total unmarked fish caught in Old River was 373, compared to the Mossdale catch of 466. This would indicate a preference of 0.80 (i.e., fish avoiding Old River). For CWT fish, the catch in Old River was 340 and the catch at Mossdale was 812, suggesting a preference (avoidance) of 0.42. However, the trawling volume for Old River was only about 60% of the Mossdale trawl volume, so these ratios need to be adjusted; the adjusted unmarked catch ratio was 1.33 and the adjusted CWT catch ratio was 0.7. These results were generally repeated in 2006, another year with no head of Old River barrier installed because of high flows.

The fraction of fish diverted at the head of Old River was assumed to be the preference factor times the water diversion fraction.

Fraction of Fish Diverted = Preference Factor x Fraction of Flow Diverted

The head of Old River preference was assumed to be 1, so the density of fish in the diverted flow would be the same as in the San Joaquin River at Mossdale.

When the head of Old River barrier is installed, the culverts and leakage through the rock barrier were assumed to provide a minimum flow of about 500 cfs (leakage and six culverts). The comparison of San Joaquin River fish abundance and salvage data (shown in Appendix B) suggests that only a few fish are diverted into Old River when the barrier is installed. This is likely because few fish move through the rock barrier with the leakage flow, and few fish move toward the culverts. The fish preference is assumed to be 0.1 (10%) when the barrier is installed. The spreadsheet salvage fraction evaluation and pathway survival model both allow the head of Old River fish preference to be adjusted to demonstrate the effects of this uncertain fish preference.

5.3 CVP Pumping Flow and Fish Diversion

The CVP export pumping comes from Old River. Most of the head of Old River flow moves down Grant Line Canal, and only about 15% of the diverted flow and fish remain in Old River. Grant Line Canal rejoins Old River just downstream of the CVP pumping plant intake. It is assumed that all of the Old River flow will be diverted into the CVP pumping intake if the CVP pumping flow is greater than the Old River flow. All of the fish diverted into Old River will be diverted into the CVP salvage under these conditions.

However, if the Old River flow is greater than the CVP diversion, the fish preference value is assumed to be equal to this flow ratio. This suggests that the fish will avoid the CVP intake if the CVP diversion is less than the Old River flow. For example, if the Old River flow is about twice the CVP pumping, the expected CVP fish preference would be 0.5 and the CVP fish density would be about half of the Mossdale fish density. This is a consistent result that has been observed during periods when the Old River flow is relatively high compared to the CVP pumping.

This factor can be adjusted in the salvage fraction and pathway survival evaluation models, because the assumed CVP fish preference factor is uncertain. However, the use of the CVP/head of Old River flow ratio as the fish preference provides a reasonable match with the CVP salvage data during most periods when the Old River flow is greater than the CVP exports.

5.4 SWP Pumping Flow and Fish Diversion

The Old River flow was assumed to be first diverted to the CVP pumping, and diverted to SWP pumping only if the Old River flow was greater than the CVP pumping. The fish preference for the SWP diversion was assumed to be 1 if the remaining Old River flow was less than the SWP pumping. If the remaining Old River flow was greater than the SWP pumping, the fish preference was assumed to be the ratio of the SWP pumping to the remaining Old River flow. Only during very high San Joaquin River flows would the remaining Old River flow be greater than the SWP pumping. Therefore this SWP fish preference factor can be evaluated only during these few periods of high Old River flows.

5.5 Turner Cut Flow and Fish Diversion

The Turner Cut diversion from the San Joaquin River depends on the excess CVP and SWP pumping (i.e., pumping not supplied by the head of Old River diversion). Based on tidal hydraulic modeling results (DSM2), the Turner Cut diversion is about 10% of this excess pumping and increases with higher San Joaquin River flow.

Tidal flows in Turner Cut and in the San Joaquin River downstream (north) of Turner Cut were measured by USGS with portable (temporary) ADCP (acoustic-doppler current profiler) equipment from May through July 1997, as part of dye studies and flow evaluations of the head of Old River fish protection barrier and agricultural barriers in the south Delta (Oltmann 1998). Figure 5 shows the measured tidal flows in the San Joaquin River downstream of Turner Cut and in Turner Cut during May 1–10, 1997. The tidal flows in Turner Cut indicated that an average net flow of 800 cfs was moving upstream (i.e., negative) from the DWSC toward Middle River and the CVP and SWP export pumps. The San Joaquin River flow was about 6,000 cfs, the combined pumping was about 3,000 cfs, and the head of Old River barrier was installed until May 15, 1997. The measured Turner Cut flow diversion was about 25% of the combined exports, or about 15% of the San Joaquin River flow at Turner Cut. The relatively high San Joaquin River flow was apparently increasing the expected diversion of 10% of the combined exports.

Figure 5 indicates that the tidal flow on the San Joaquin River leads the tidal flow in Turner Cut by about 2 hours. Downstream (i.e., ebb tide) flows of about 15,000 cfs on the San Joaquin therefore are well established before the Turner Cut flow changes from upstream to downstream flow. This suggests that migrating Chinook salmon might enter Turner Cut during the beginning of each ebb tide (downstream flow) because the velocity would still be moving into Turner Cut. As the ebb tide continues, the Turner Cut tidal flow would reverse and become oriented with the San Joaquin River ebb tide flow, with a maximum tidal flow of about 3,000 to 4,000 cfs.

Because there is a very strong tidal flow in the San Joaquin River at Turner Cut, the evaluation model assumes that the fish preference at the Turner Cut diversion is about 0.25. Therefore, only 25% of the San Joaquin River fish that would have been diverted into Turner Cut with the diverted San Joaquin River flow will move toward the SWP and CVP exports. Most of the San Joaquin River fish migrating to Turner Cut will continue down the San Joaquin River toward the Chipps Island Trawl. This assumed fish preference is most important when the pumping is greater than the San Joaquin River flow. All of the San Joaquin River flow would be diverted toward the pumps, but only 25% of the fish reaching Turner Cut would be diverted toward the salvage. The comparison of the estimated salvage with the observed SWP and CVP salvage during periods with these flow conditions has been used to verify this assumed fish preference. Because the April–May period with high fish abundance generally corresponds to the reduced pumping as part of VAMP, periods of high pumping when the

Turner Cut diversions would be high enough to evaluate the assumed fish preference (i.e., avoidance) are relatively rare.

5.6 Fraction of San Joaquin River Fish at Central Valley Project Salvage and State Water Project Salvage

The daily Mossdale fish abundance and the estimated flow diversions and fish preferences can be combined to calculate the number of fish expected at the CVP and the SWP salvage. The salvage fraction evaluation model does not include a travel time delay between Mossdale and the CVP and SWP salvage. Daily calculations of likely salvage numbers without a time delay are used for this initial evaluation of the head of Old River barrier effects. Daily fish abundance and flow conditions during 1996 will be used to introduce these salvage fraction calculations.

Figure 6 (top graph) shows the flows and exports during the February–June period of 1996. The San Joaquin River flows were generally high (>10,000 cfs) in February and March. The San Joaquin River Flows were about 6,000 cfs in April and early May, but increased to 10,000 cfs in late May and were less than 4,000 cfs in June. The Old River diversions were about half of the San Joaquin River flows. The head of Old River barrier was installed in early May, but was removed when the flow increased in late May. Exports were about 6,000 cfs in early April and were reduced to 1,500 cfs in the second half of April and the first half of May. Exports then were raised to about 10,000 cfs in the second half of May and June.

Figure 6 (bottom graph) shows the daily San Joaquin River fish abundance (blue triangles) and the combined CVP and SWP daily salvage estimates for water splits only and with the assumed fish preferences. The fish abundance scale is logarithmic to allow the fraction of fish reaching CVP and SWP salvage to be more easily compared to the Mossdale abundance for the full period, which has both low and high daily fish numbers. On the logarithmic scale a factor of 2 is about 1/3 of the log scale interval.

The Mossdale trawl sampled fish from early April through most of June in 1996. The maximum abundance of San Joaquin River fish occurred in mid-April, with a peak of more than 25,000 per day for a few days. Many days in late April and mid-May had more than 10,000 fish. Most of the early-April through mid-June period had more than 1,000 fish each day. The San Joaquin River abundance was much lower in early April and late June, with fewer than 100 fish per day.

The combined daily salvage was similar to the San Joaquin River fish abundance in early April and late May, when pumping was slightly more than the San Joaquin River flow. The estimates of salvage indicate that most of the fish diverted into Old River were observed at salvage, so the combined salvage was about half of the San Joaquin River fish. The pumping was greatly reduced during the VAMP period, and the corresponding fraction of the San Joaquin River fish observed at salvage declined to less than 10%. The water splits at the export diversions accounted for part of the reduction (purple squares), but the export diversion preferences provided a better match with the observed salvage during this mid-April to Mid-May period of reduced exports.

Figure 7 shows the separate estimates for CVP and SWP salvage, based on water splits and assumed fish preferences for export diversions and Turner Cut diversions for 1996. The CVP salvage was almost always greater than SWP salvage. This was accurately predicted by assuming that head of Old River flows move past CVP salvage first, and only the remaining flows move to SWP exports. Only in the early April and late May periods when pumping was greater than head of Old River flow was there any simulated diversion at Turner Cut. The estimated and observed SWP salvage was similar to the CVP salvage in late May when the combined exports were higher than the San Joaquin River flow. The estimated SWP salvage was higher than observed during the low export period of mid-April to mid-May. There was a general agreement between the measured and estimated CVP and SWP salvage in 1996, based on the San Joaquin River Mossdale fish abundance and the San Joaquin River flow, head of Old River diversion, and CVP and SWP export diversions.

The fraction of the Mossdale fish abundance expected at the CVP and SWP salvage will be equal to the head of Old River diversion fraction, if the CVP and SWP pumping is greater than the head of Old River diversion flow. The number expected at the CVP and SWP salvage will decrease as the pumping flow is reduced to less than the head of Old River flow. This decrease will be greater as the CVP and SWP diversions are reduced, because the assumed fish avoidance is the ratio of the CVP or SWP diversion to the Old River flow. Therefore, reduced pumping will reduce the expected salvage of fish quite rapidly, even without the head of Old River barrier.

Appendix B provides detailed graphs and evaluations of the calculated CVP and SWP salvage based on the Mossdale abundance and flow and export conditions. The match between the estimated and measured CVP and SWP salvage numbers for the 10-year period (1996–2005) is used to confirm the assumed fish preferences.

5.7 Evaluation of the Head of Old River Barrier Effects on the Central Valley Project and State Water Project Salvage Fraction

The comparison of the Mossdale abundance and the CVP and SWP salvage for the 1996–2005 period has provided a method to estimate the expected salvage fraction for the full range of San Joaquin River flows and CVP and SWP exports, with and without the head of Old River barrier. This conceptual model of CVP and SWP salvage of juvenile San Joaquin River Chinook salmon can be summarized as follows.

1. The head of Old River diversion fraction will be about 50% of the San Joaquin River flow plus 5% of the combined CVP and SWP exports. This also will be the fraction of San Joaquin River fish diverted into Old River, because the fish preference was found to be about 1.
2. The diversion flow at the head of Old River is about 500 cfs (leakage and culverts) when the barrier is installed, and the fish preference is about 0.1 (only 10% of the fish in the diverted flow will be diverted) because most of the fish avoid the rock barrier and culverts.
3. The San Joaquin River flow not diverted at the head of Old River may be diverted at Turner Cut (or downstream junctions) and be pumped at CVP and SWP, if the combined exports are greater than the San Joaquin River flow. The fraction of fish in this San Joaquin River flow that will be diverted at Turner Cut will be about 25% of the flow fraction, because most of the fish are oriented with the tidal flows.
4. The maximum fraction of the San Joaquin River fish that can be salvaged is the ratio of combined exports to the San Joaquin River flow. Reducing the exports will reduce the number salvaged and reduce the fraction of the San Joaquin River fish that are salvaged.

6.0 San Joaquin River Juvenile Chinook Salmon Delta Pathway Survival Model

The remaining task for the overall evaluation of the head of Old River barrier effectiveness is to determine the relative survival for (1) fish that are salvaged and trucked to Chipps Island and (2) fish that move toward Chipps Island in the Delta channels. The likely CVP salvage success is generally thought to be relatively high (e.g., 75% for Chinook salmon). An integrated Delta pathway survival model for San Joaquin River juvenile fall-run Chinook salmon was developed to support the overall evaluation of the head of Old River barrier. The Delta pathway survival model was developed to evaluate future VAMP scenarios and to support planning of head of Old River barrier operations based on either a temporary or permanent barrier system. The pathway survival model uses the data, hypotheses and assumptions already described in this report. The model helps to integrate the assumptions and demonstrates their effects on the estimated survival of juvenile San Joaquin River Chinook salmon to Chipps Island. The Delta pathway survival model includes these elements:

1. Migration pathways
2. Travel time distributions
3. Survival along each pathway (i.e., daily mortality)
4. Head of Old River barrier operations
5. San Joaquin River flow and CVP and SWP exports
6. Delta channel flow splits and fish preferences

7. CVP and SWP salvage losses (i.e., predation, louver efficiency)

These elements each introduce uncertainty in estimating the benefits of the head of Old River barrier installation and the potential fish survival benefits of a future head of Old River gate facility. The flow splits and fish preferences determine the routes of travel for migrating fish. Travel times through these pathways describe the duration of exposure to various sources of mortality. The pathway survival rates may depend on the habitat, predation, and water quality conditions along each pathway. The head of Old River barrier will shift the travel routes and travel times, blocking the pathway to CVP and SWP salvage. Flows, exports, and fish preferences will determine the relative fractions of out-migrants that are exposed to each pathway.

The pathway survival model is an integrated analysis that aims to express the consequences of several linked hypotheses, whereas statistical analysis aims to support or reject individual hypotheses. Many sources of uncertainty in the Delta reduce the utility of a statistical analysis of CWT recoveries to explain the mechanisms controlling San Joaquin juvenile Chinook salmon survival. As discussed in Appendix A, this complexity limits the utility of CWT data for assessing the benefits of the head of Old River barrier. The purpose of the Delta pathway survival model is to present a series of linked hypotheses that describe the mechanisms controlling survival of San Joaquin fall-run Chinook salmon through the south Delta, and to provide an analytical framework for investigating alternative hypotheses through comparisons of model results. The model assumptions and general sensitivity results are described in Appendix C and summarized in this section.

6.1 Delta Pathway Survival Model Assumptions

The Delta pathway survival model was developed to evaluate the effectiveness of the head of Old River barrier for increasing survival from Mossdale to Chipps Island. Fish enter the pathway model above or below the head of Old River barrier near Mossdale, move down Old River or Turner Cut, and then to salvage with subsequent trucking to Chipps Island, or migrate down the San Joaquin River channels to Chipps Island. Under certain conditions when Old River flows are higher than exports, fish may also move down Old River and continue past the salvage facilities to Chipps Island. Mortality is experienced in transit between locations and at the salvage facilities.

The model includes several “switches” for adjusting the coefficients and specifying the assumed flow and export conditions. There are several graphs that display some of the basic model inputs and outputs over time, including the number of fish surviving to different locations. All of the flow split equations and fish preferences described for the salvage evaluation model are also used in the Delta pathway survival model. Each day fish enter the model based on the abundance estimates at Mossdale, or the known number of fish released as a VAMP CWT group. These fish travel down the various pathways based on the estimated travel time distribution. Some fish are diverted at the head of Old

River and travel to CVP or SWP salvage with travel time distributions estimated from CWT releases upstream of Mossdale. These fish experience daily mortality along Old River and Grant Line Canal, and also experience mortality (i.e., predation, louver losses) at the CVP and SWP salvage facilities. Fish that are salvaged are assumed to be trucked and released upstream of Chipps Island without additional mortality. Those fish that reach Chipps Island along these four pathways are added to the cumulative estimate of survival to Chipps Island.

Salvage success at CVP and SWP fish salvage facilities is a function of predation, louver efficiency, and other physical losses. Salvage success at SWP salvage is also affected by the delay in the Clifton Court Forebay. Mortality in the forebay is estimated as a daily mortality rate times the travel time estimated as the Clifton Court Forebay volume/daily export volume ratio.

Fish that are not diverted at the head of Old River move to Turner Cut with a specified travel time and daily mortality. Net flows in Turner Cut are often reversed (moving upstream toward the SWP and CVP pumping plants). Fish diverted at Turner Cut are assumed to move along Empire Cut, Middle River, Victoria Canal, and West Canal to the Clifton Court Forebay intake or the DMC intake along Old River. Because there is a very strong tidal flow in the San Joaquin River at Turner Cut, the salvage evaluation model assumed that the fish preference at the Turner Cut diversion is about 0.25 of the flow diversion fraction. With the head of Old River barrier in place, the Turner Cut diversion of fish toward salvage may be about 25% of the migrating fish. The travel time distribution for this pathway was estimated from CVP and SWP recoveries of below head of Old River CWT release groups. Mortality is set as a daily loss rate for this pathway.

The estimated travel time distribution from Mossdale to Chipps Island is considerably longer with the barrier installed, because the barrier has been installed only when San Joaquin River flows are less than 7,000 cfs. The estimated travel time when there is no barrier was estimated from CWT to be shorter. Therefore, the model results give a lower survival for the Mossdale to Chipps Island pathway whenever the barrier is installed, because the estimated travel time distribution changes.

The assumed daily mortality rates represent another important information gap in evaluating the overall effectiveness of the head of Old River barrier. The fraction of fish that are diverted at Turner Cut (assumed to be 25%) is another very important factor with substantial uncertainty. The sensitivity results described in Appendix C provides more information about the relative survival along these three major pathways, and the effects of assumed travel time, mortality, and salvage efficiency on the overall survival of juvenile San Joaquin Chinook salmon.

6.2 Assumed Pathway Travel Times

Travel times for each Delta pathway have been estimated from CWT recoveries at CVP salvage, SWP salvage, and Chipps Island (see Appendix A for a description of the CWT data). The travel time distributions represent the probability of recapturing a fish some number of days after the CWT release. These travel estimates are important because the longer the fish travel along a pathway, the greater fraction of the fish will die from predation and other habitat conditions (see Appendix C for a description of the estimated travel time distributions). The head of Old River barrier will change the overall survival by affecting the proportion of fish that travel each pathway. The assumed travel time distributions and daily mortality rates (and salvage efficiency) will determine the relative survival simulated for each pathway and the overall survival for the juvenile San Joaquin River Chinook salmon.

7.0 Conclusion: Effectiveness of the Head of Old River Barrier for Reducing Salvage and Potential Actions to Improve Survival

7.1 Effectiveness of the Head of Old River Barrier for Reducing Salvage

7.1.1 Overview of Head of Old River Barrier Analysis

The head of Old River barrier usually has been installed during the VAMP period of reduced exports and higher (i.e., pulsed) San Joaquin River flows. Separating the effects of the reduced exports and increased river flows from the barrier installation during VAMP is difficult. The fraction of the San Joaquin River fish that likely would have been salvaged without the head of Old River barrier in place can be compared with the fraction of San Joaquin River fish that were actually salvaged with the barrier in place. For years without the barrier installed, the fraction that likely would have been salvaged with the barrier can be compared with the fraction actually salvaged without the barrier. In both cases, a reliable model estimate of the fraction that would have been salvaged without and with the barrier is the measure of the effectiveness of the head of Old River for protecting fish from CVP and SWP salvage. The salvage fraction evaluation model could also be used to identify the relative protection provided by the San Joaquin River flow pulse and the CVP and SWP export reductions. This would allow an overall evaluation of the VAMP program for protecting San Joaquin River juvenile Chinook salmon from CVP and SWP salvage. This report provides an evaluation of only the head of Old River barrier effectiveness, and does not provide an evaluation of the likely overall effectiveness of VAMP.

7.1.2 Results of Head of Old River Barrier Effectiveness Analysis

The additional protection provided by the head of Old River barrier depends on the CVP and SWP pumping. If pumping is equal to or greater than the head of Old River diversion, the barrier will have a relatively large effect (protecting most of the fish in the head of Old River diversion flow from salvage). But if the pumping is already reduced to less than 50% of the San Joaquin River flow, the assumed fish preference (avoidance) at the CVP and SWP diversions will reduce the expected salvage to less than the export fraction. The barrier effectiveness for protecting Mossdale fish from salvage therefore is reduced when CVP and SWP pumping is less than the head of Old River diversion. Because the assumed Turner Cut fish preference is 25%, the majority (75%) of the fish that would have been salvaged after being diverted at the head of Old River barrier will be protected from salvage.

The difference between the expected CVP and SWP salvage with and without the barrier can be accurately calculated with these basic rules for any specified pattern of San Joaquin River flows and exports. For example, during the VAMP period, the San Joaquin River flows are increased and the exports are reduced to less than 50% of the San Joaquin River flow. The expected salvage fraction without the barrier would be the fraction of the San Joaquin River flow that is exported. For example, if the San Joaquin River flows were 3,000 cfs with exports of 1,500 cfs, about 1,575 cfs would be diverted at the head of Old River (50% San Joaquin River plus 5% pumping), but just 50% of the fish would be salvaged (1,500/3,000) without the barrier. The other 1,425 cfs of the San Joaquin River flow and about 47.5% of the San Joaquin River fish would move down the San Joaquin River past Stockton toward the estuary. The remaining 75 cfs of Old River flow and 2.5% of the fish would move past the exports toward the estuary.

The installation of the barrier would reduce the flow diverted into Old River to about 500 cfs, and would reduce the fish diverted in this 500 cfs flow by 90% (to the San Joaquin River fish in 50 cfs) because the fish avoid the culverts and leakage flow. A small fraction (<2%) of the San Joaquin River fish (i.e., 50/3,000) would move down the Old River pathway to the CVP or SWP salvage. The remaining exports of 1,000 cfs (with 500 cfs supplied from the head of Old River) would be diverted at Turner Cut (or downstream junctions), but the assumed fish preference of 0.25 would suggest that only the San Joaquin River fish in 250 cfs would be diverted at Turner Cut. The fraction of fish salvaged therefore would be about 10% (i.e., 300 cfs/3,000 cfs) with the head of Old River barrier installed. The fraction of San Joaquin River fish protected from salvage depends on the assumed Turner Cut fish preference, because this is the remaining pathway for fish that are salvaged. The lower the Turner Cut fish preference (i.e., more avoidance) the greater will be the protection from salvage achieved by the head of Old River barrier.

The maximum protection of San Joaquin River fish from salvage that the head of Old River barrier can provide will be about 40%, because as pumping increases to more than the head of Old River diversion (without the barrier), more of the San Joaquin River flow (with 25% of the San Joaquin River fish) would be diverted at Turner Cut to satisfy the exports. Therefore, the head of Old River barrier can be very effective in protecting about 40% of the San Joaquin River fish from salvage, if the combined exports are more than 50% of the San Joaquin River flow.

Because a permanent head of Old River gate facility would provide resource managers with additional control of the south Delta flows, the permanent gate may be useful for increasing out-migrant juvenile Chinook salmon survival under various flow and export conditions. Accurate travel time distributions and daily mortality estimates for each pathway will be needed to effectively operate a permanent head of Old River gate. The pathway survival model (using confirmed travel times and mortality estimates) could be used to support adaptive operations of a permanent head of Old River gate structure to increase the survival for juvenile San Joaquin Chinook salmon out-migrants.

7.2 Potential Actions to Improve Survival

The comparison of the fraction of San Joaquin River fish that would be salvaged (with and without the barrier) does not provide the complete answer for the head of Old River barrier evaluation. The effectiveness of the barrier for improving the survival of the San Joaquin River juvenile Chinook salmon migration to Chipps Island must also include the possible effectiveness of CVP and SWP salvage operations for juvenile Chinook salmon survival.

7.2.1 Overview of Evaluation of Pathway Survival

The survival of fish migrating the 25 km (15.5 miles) down Old River to CVP and SWP salvage must be compared to the likely survival for juveniles migrating the 100 km (62 miles) from Mossdale to Chipps Island through the Delta channels (i.e., San Joaquin River–DWSC, Middle River, Old River). As indicated by the CWT recoveries, the travel time to Chipps Island (15–20 days) is generally longer than the travel time to CVP or SWP salvage (5–10 days). The expected mortality during the additional 10 days of migration to Chipps Island should be compared to the salvage mortality to determine the pathway with the highest overall survival. This was the purpose for developing the Delta pathway survival model for sensitivity analysis of the relative survival of these alternative pathways. This overall comparison of survival for juvenile San Joaquin River Chinook salmon is more uncertain than the calculation of the fraction of juvenile San Joaquin River Chinook salmon reaching salvage.

7.2.2 Pathway Survival Results and Recommendations

Because the survival estimates for CWT fish moving to Chipps Island are generally lower (10% to 25%), it may be that survival for San Joaquin River Chinook salmon smolts would be greater if the salvage fraction were increased. This could be accomplished by not installing the head of Old River barrier and increasing exports to be greater than the San Joaquin River flow. If this potential effect of increased salvage on survival were found to be accurate, this would definitely change the adaptive management approach for San Joaquin River Chinook salmon. If salvage were beneficial for San Joaquin River juvenile Chinook salmon survival to Chipps Island, the future VAMP conditions would likely not include the San Joaquin River pulse flow, would not include the head of Old River barrier, and would not include the reduced export pumping.

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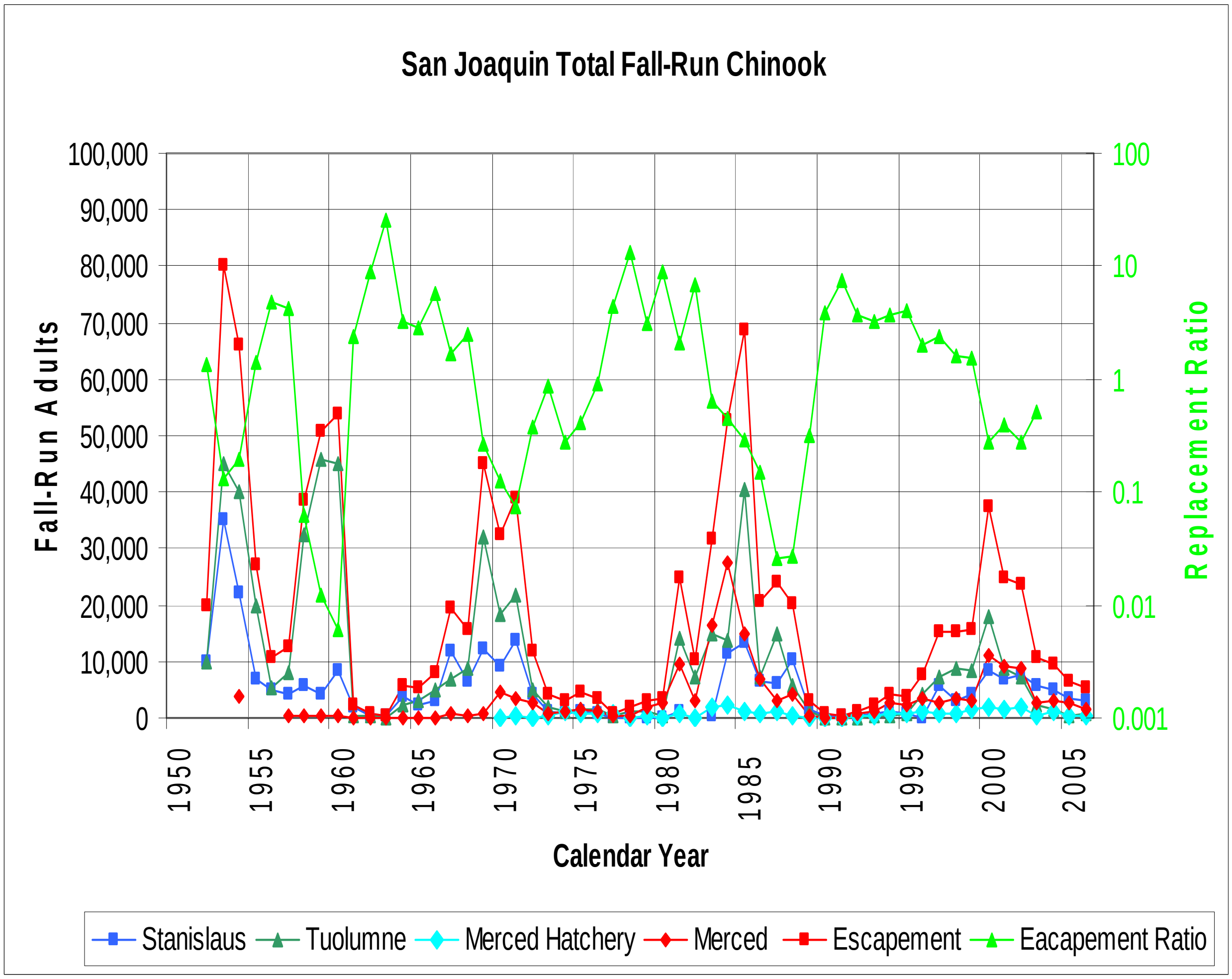

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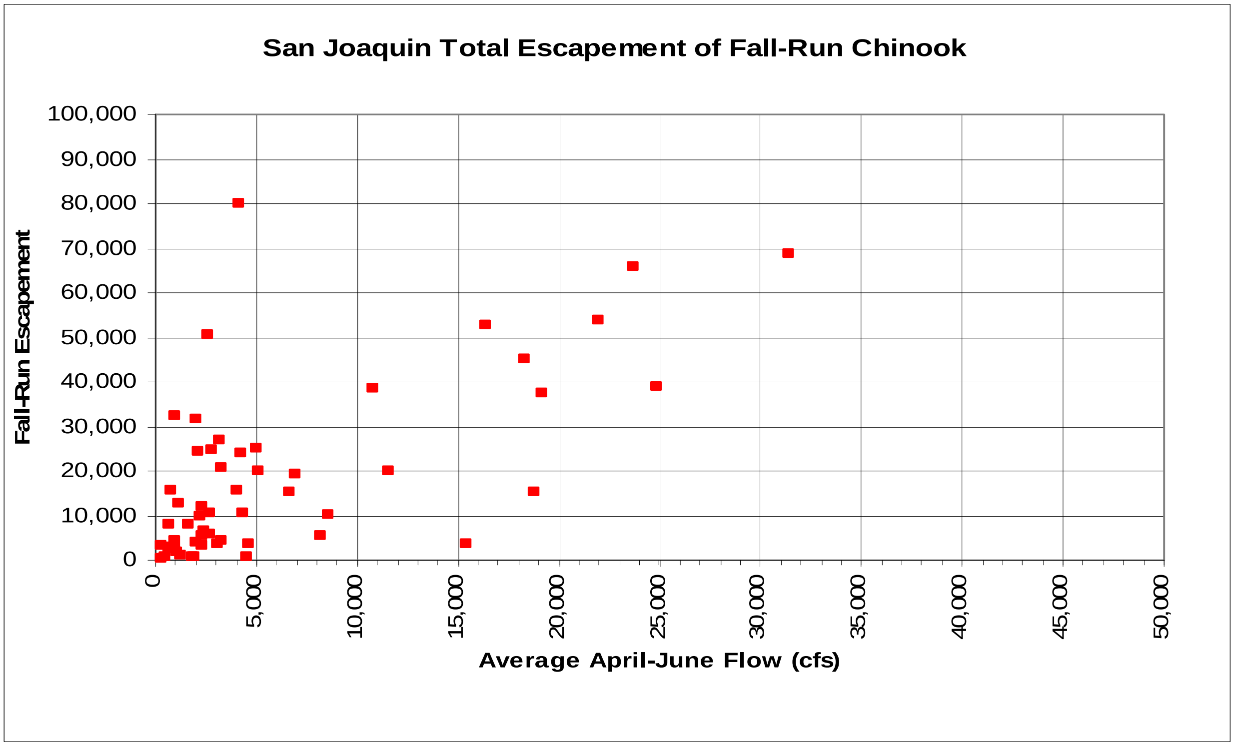
Figure 1

San Joaquin River Fall-Run Chinook Salmon
Escapement and 3-Year Replacement Ratio for 1952–2006



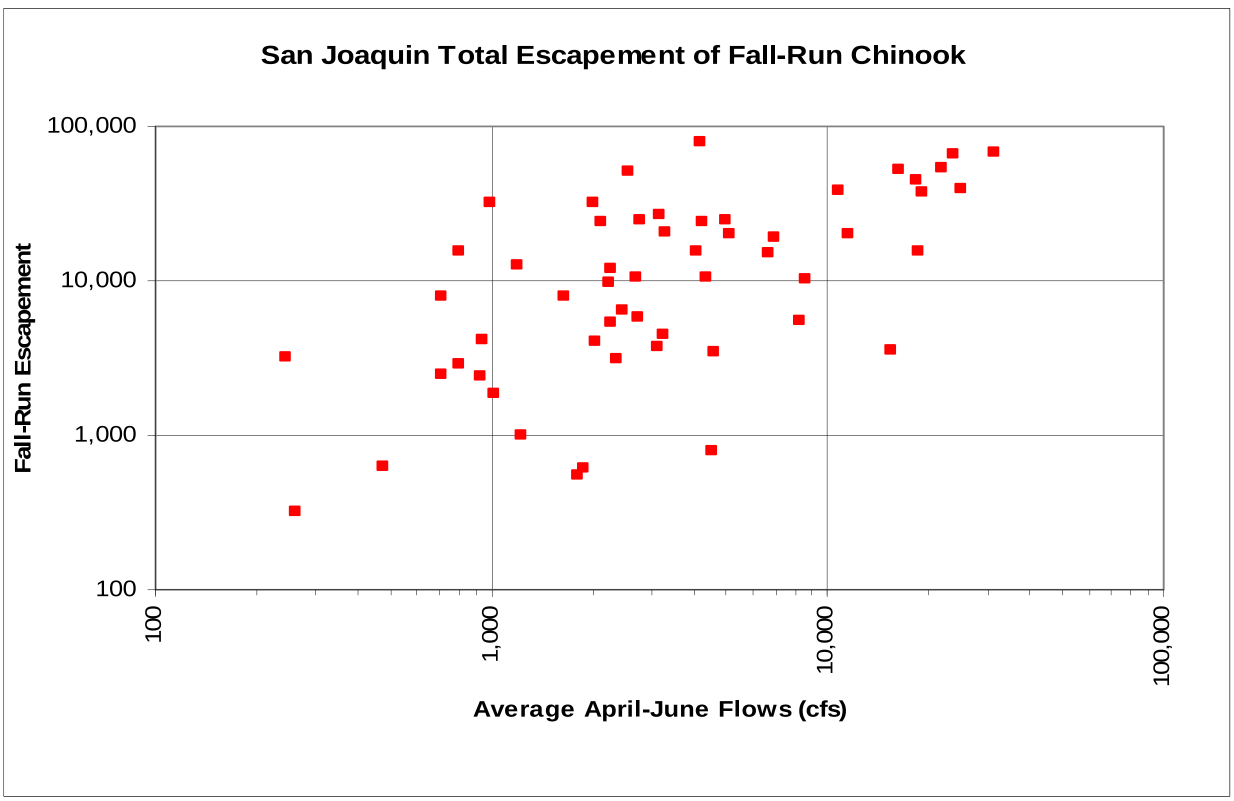


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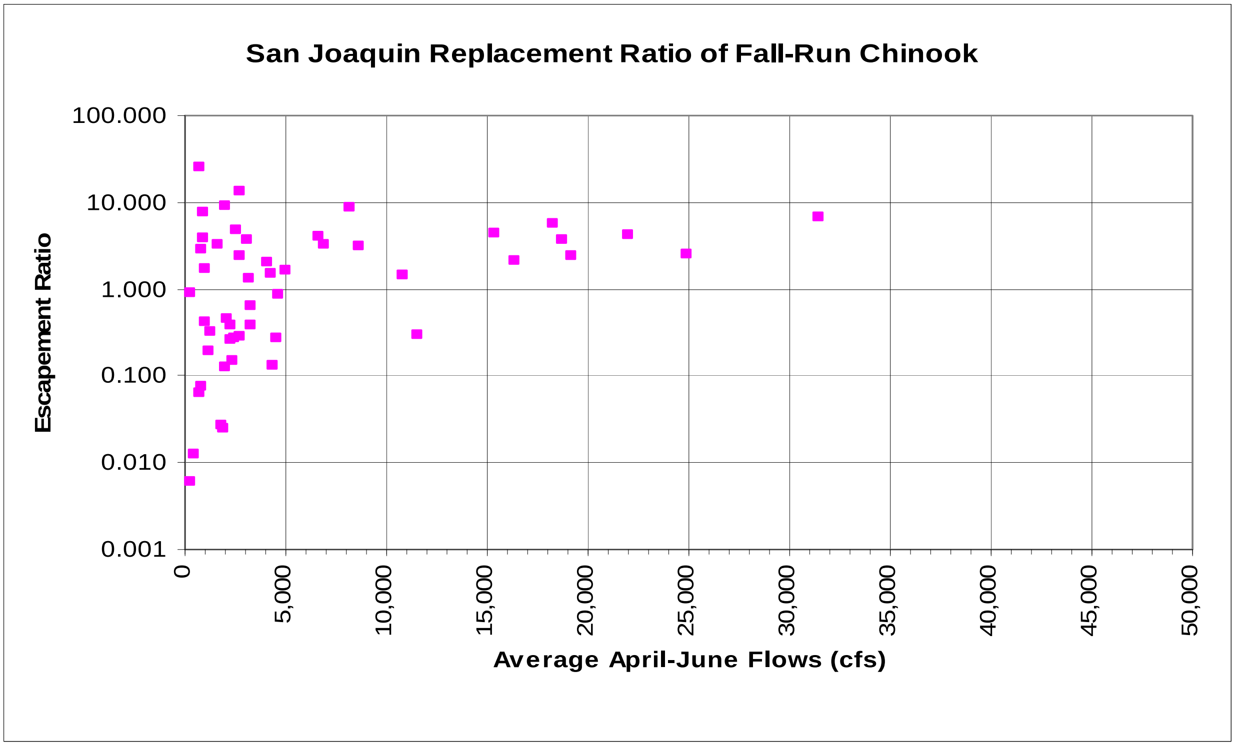
Figure 2

San Joaquin River Escapement in Three Years as a Linear and Logarithmic Function of April–June Flow (cfs) during Juvenile Out-Migration of Cohort for 1952–2003



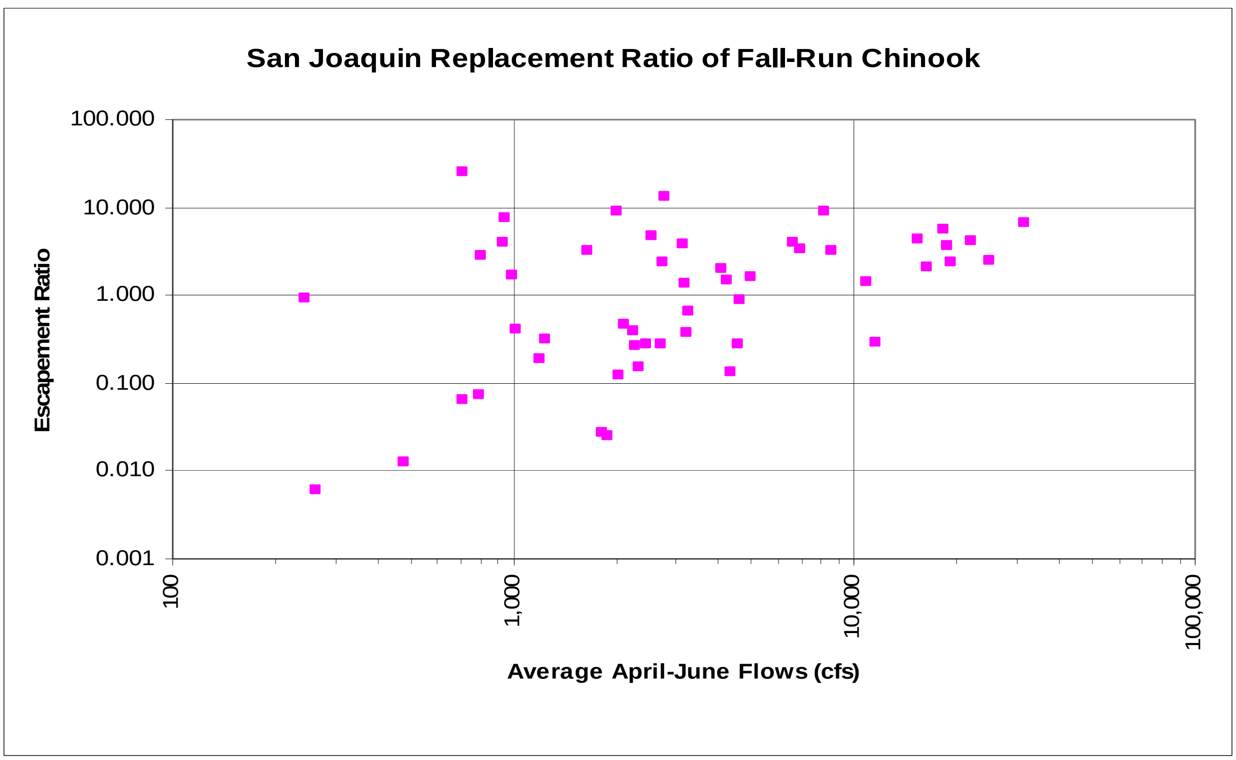


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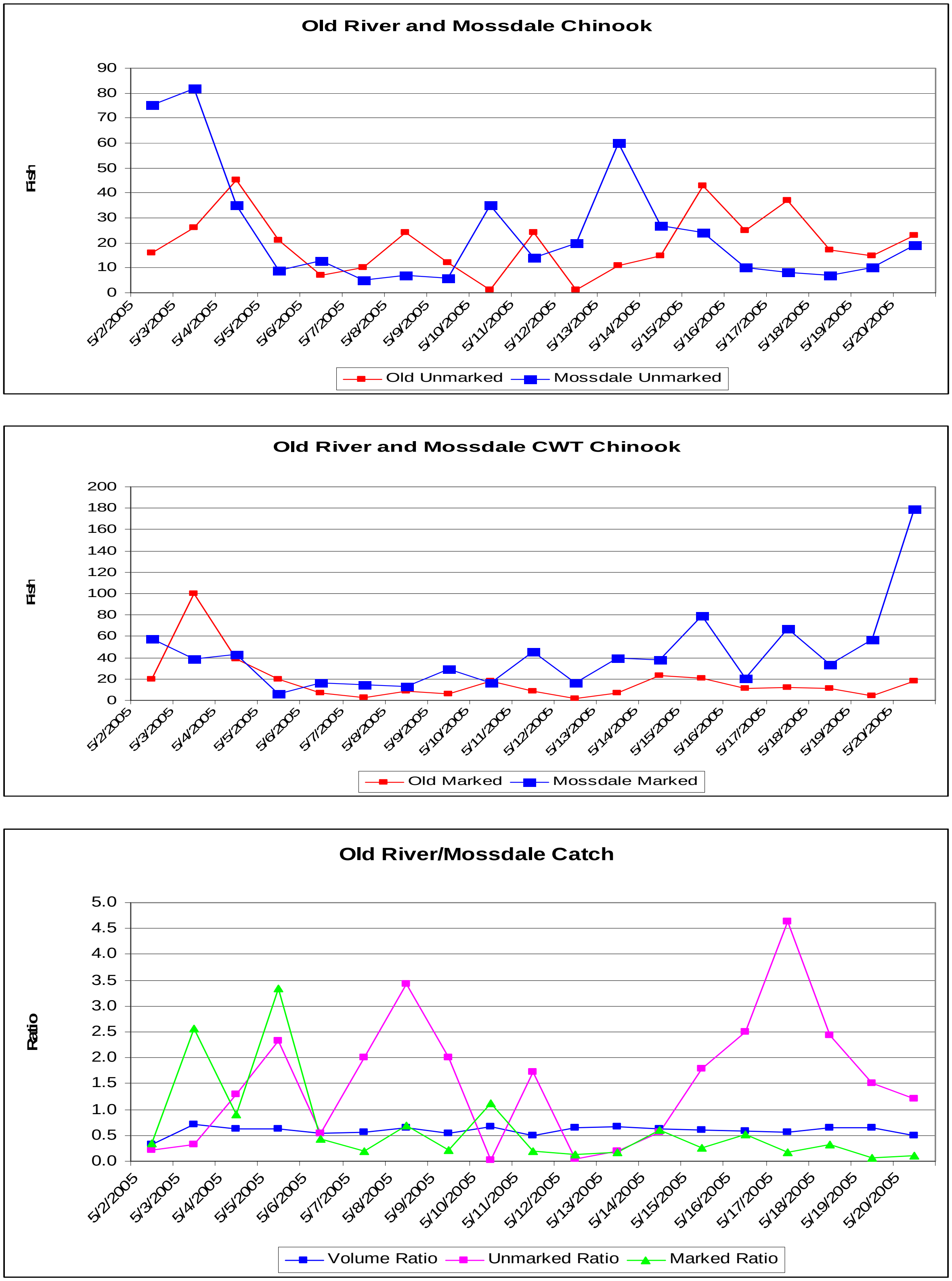
Figure 3

San Joaquin River Chinook Salmon Replacement Ratio (Escapement in 3 Years/Cohort Escapement) as a Logarithmic Function of April–June Flow during Out-Migration of Juveniles for 1952–2003



The Old River daily trawl volume was only about 60% of the Old River trawl volume, so the number of unmarked and CWT fish in Old River should be about half of the Mossdale catch.

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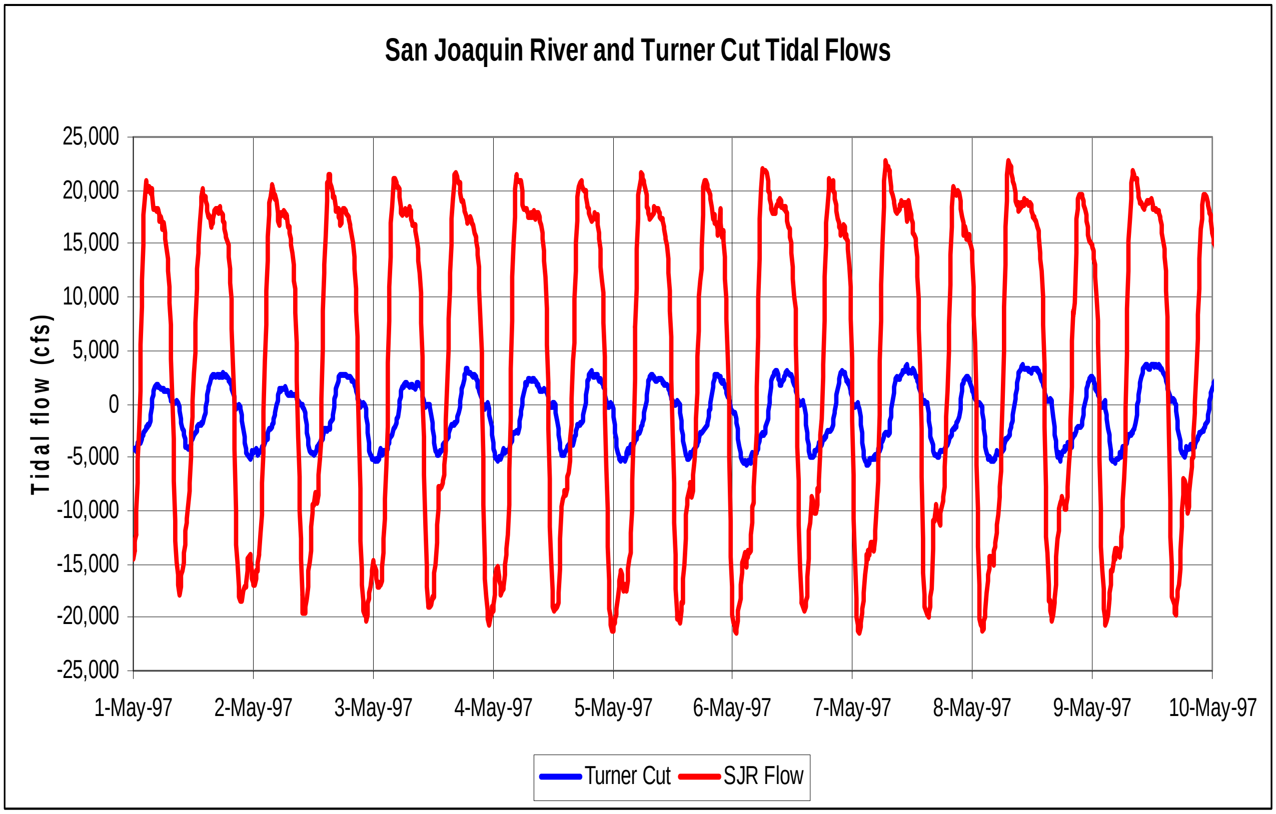
Figure 4

Comparison of CWT and Unmarked Chinook Salmon in Kodiak Trawls at Old River and at Mossdale for 2005



Source: Oltmann 1998.

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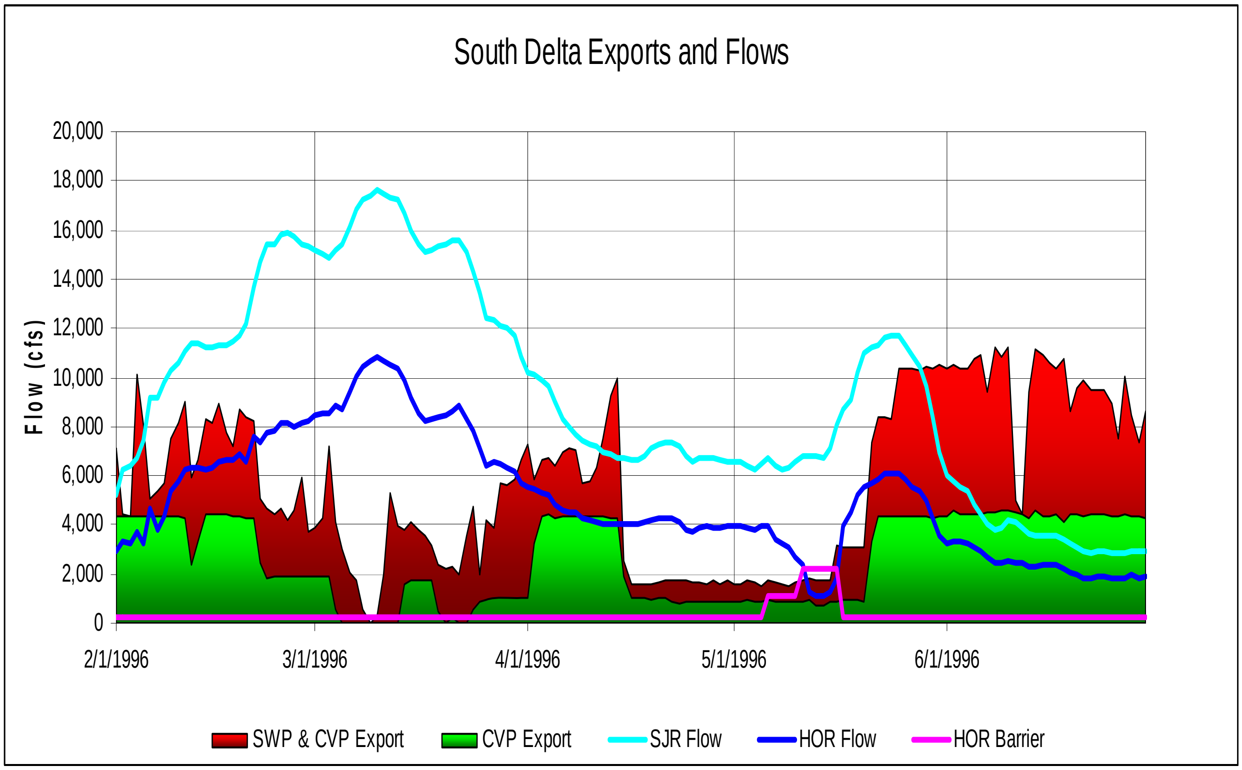
Figure 5

U.S. Geological Survey Tidal Flow Records from the San Joaquin River Downstream of Turner Cut and from Turner Cut during May 1997



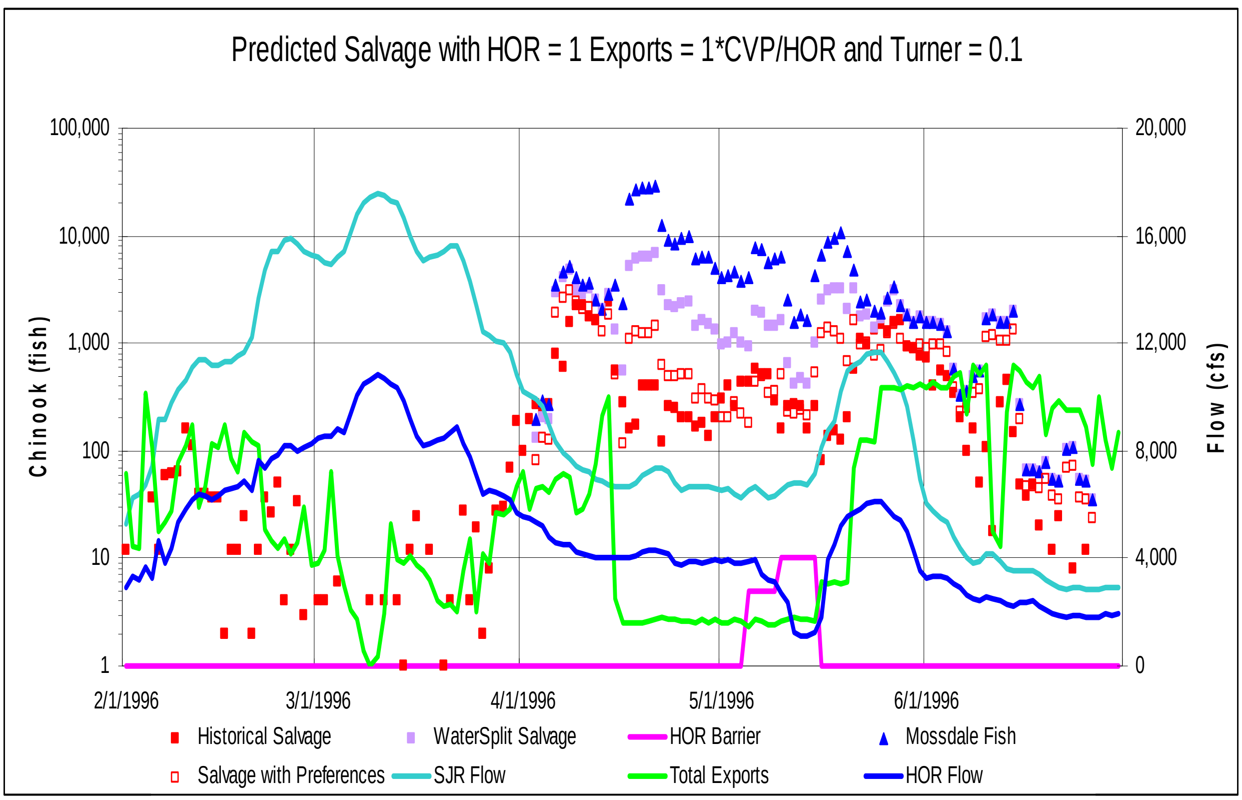


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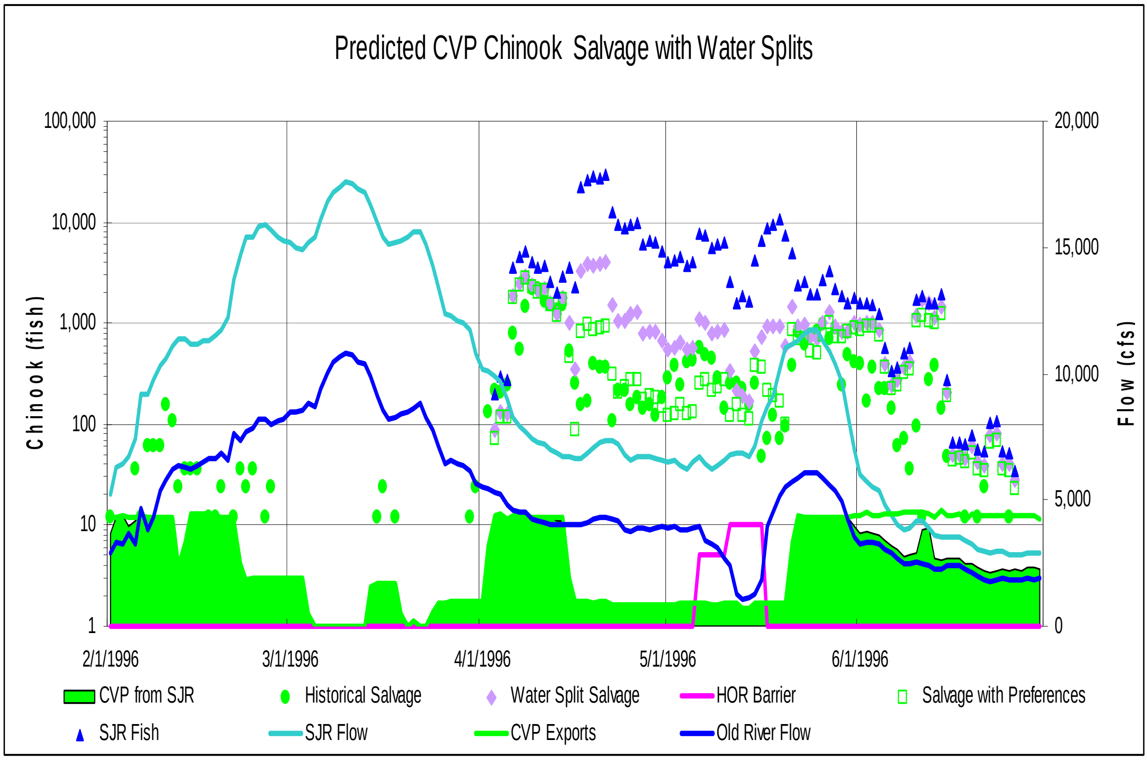
Figure 6

Daily San Joaquin River Flows and Exports Compared with Mossdale Unmarked Chinook Salmon Abundance and Combined CVP and SWP Salvage during February–June 1996



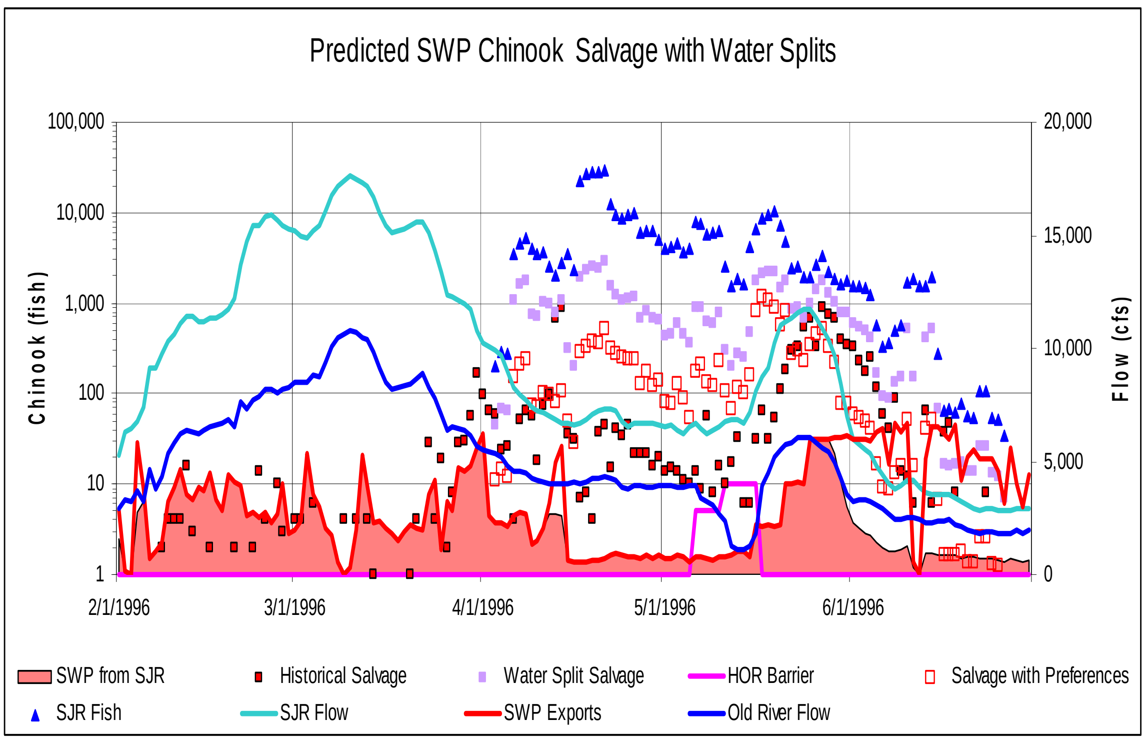


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Figure 7

Daily Estimates of CVP and SWP Salvage Based on San Joaquin River Flows and Exports With Water Splits Only and With Assumed Fish Preferences Compared to Observed CVP and SWP Salvage for February–June 1996

Appendix A

Fish Sampling Methods and Results

Appendix A
Fish Sampling Methods and Results

This Appendix presents fish sampling methods and results that have been used for the evaluation of the Head of Old River barrier and future tidal gate operations. Fish data from three basic fish sampling programs have been used in this evaluation: (1) Mossdale Kodiak trawl for San Joaquin juvenile fall-run Chinook salmon, (2) Coded Wire Tag release and recovery results for San Joaquin River fall-run Chinook salmon, and (3) Central Valley Project (CVP) and State Water Project (SWP) fish facility daily salvage for Chinook salmon. The methods used and general results for the 1996–2005 study period are described and discussed.

Mossdale Trawl Methods

The California Department of Fish and Game (DFG) operates the Mossdale Kodiak trawl to monitor outmigrating juvenile fall-run Chinook salmon in the San Joaquin River. Monitoring is conducted from just upstream of the Old River confluence to approximately 2 miles downstream of the Mossdale Landing County Park (at river mile 56). The trawl net is made of variable mesh and is composed of four panels, each decreasing in mesh size, from 2-inch mesh at the mouth to ¼-inch mesh at the cod end. The cod end of the net is secured with a rope to prevent fish from escaping and to facilitate the collection of the catch at the end of each tow. The overall length of the net is 65 feet, and the mouth opening is 6 feet deep and 25 feet wide (150 square feet). A float line and lead line attached to 6-foot-long spreader bars on each wing enable the net to fish the top 6 feet of the water column. These features work to keep the net mouth open while the trawl is being towed. Based on experience from mid-water trawl studies, the effective opening of the net mouth is estimated to be 135 square feet (12.5 square meters) while it is being towed.

Photograph A-1 shows an aerial view of the Mossdale Kodiak Trawl being towed by two boats. The net is fished 100 feet behind two boats, with each boat pulling one of the wings of the net. All tows are conducted near the center of the channel to avoid contacting the bottom or sides of the channel or entangling the net in debris. Photograph A-2 shows a view of the Mossdale Kodiak Trawl in the San Joaquin River channel during high flow conditions.

Typically, sampling commences near the Old River confluence and continues in an upstream direction toward Mossdale. About 4–5 trawls are completed before resetting at the downstream end of the sampling reach. During periods when San Joaquin River flows are high, such as in 2005 and 2006 when flows exceed about 10,000 cubic feet per second (cfs), river currents (about 2 feet per second [ft/sec]) push the net and boats downstream. Under these conditions, sampling is initiated at the upstream end of the sampling area. Although the net is towed against the current, each successive tow occurs downstream of the previous tow, with the last tow concluding at the Old River confluence. Photograph A-3 shows the Kodiak Trawl net being retrieved to re-position the boats. Typically, 2–3 tows can be completed before the net has to be retrieved and reset at the upstream end of the sampling reach.

Sampling frequency varies from 5 to 7 days per week during the spring sampling season. Trawling is conducted from Monday through Friday (i.e., 5 days per week) when densities of Chinook salmon smolts are low. Trawling is increased to 7 days per week when smolt densities are highest.

All trawling occurs during daylight hours beginning around 8:00 a.m. On a typical sampling day, ten to fifteen, 20-minute tows are conducted, for a total sampling period of 3.3 to 5 hours per day. The normal trawl volume is about 8 acre-feet (af), or about 25 af per hour of trawling. This corresponds to a daily trawl volume of about 75 to 125 af. Individual trawl volumes are estimated by taking the product of trawl velocity (as measured by a flow meter) and the estimated area of the net opening (i.e., 135 square feet). The trawl velocity (tow speed) through the water is about 2 ft/sec, so a river distance of about 2,400 feet is sampled during each 20-minute trawl. The boat movement depends on the river velocity, which depends on river flow, as shown in Figure A-1. At a flow of 2,500 cfs, the velocity is about 0.75 ft/sec, so the boat would move upstream about 1,500 feet during each trawl. At a flow of 5,000 cfs, the river velocity is about 1.25 ft/sec, so the boat would move upstream about 900 feet during each tow. At a flow of 10,000 cfs, the river velocity is about 2.25 ft/sec and the boat would move slowly downstream about 300 feet during each trawl.

All fish captured in trawls are identified to species and enumerated, and all Chinook salmon are measured (fork length) to the nearest millimeter. For species other than salmon, only the first 20–30 individuals of each species per tow are measured. In addition, all captured Chinook salmon are examined for marks. Chinook salmon with an adipose fin clip are measured, individually bagged and labeled, and saved for subsequent coded-wire-tag analysis. Chinook salmon with marks other than adipose fin clips, including fish marked with a colored dye (for net efficiency studies), are noted and enumerated. Environmental parameters, including water temperature, turbidity, weather, beginning tow time, tow duration, and trawl velocity, also are measured and recorded for each tow.

Two different methods are used to expand trawl catches to estimate smolt production in the San Joaquin River basin: volumetric expansion and net efficiency expansion. Daily (24-hour) estimates by volumetric expansion are calculated by dividing the daily sum of unmarked Chinook salmon smolts captured in all trawls by the total daily volume of water sampled by all trawls to calculate the number of smolts capture per acre foot of water (i.e., fish density).

This fish density (fish/af) is then multiplied by the volume of water passing Mossdale during the day (i.e., acre-feet = daily flow (cfs) x 1.98). The volumetric expansion estimates assume that smolts are uniformly distributed, both horizontally and vertically, within the water column. Volumetric expansion will overestimate abundance if fish are more concentrated in the water column sampled by the trawl than other areas of the river. Likewise, abundance will be underestimated if fish are more concentrated along the river margins or below the net. Abundance estimates for days not sampled have been assigned a value by averaging the measured smolt densities for the 2 days preceding and following the day not sampled (i.e., centered 5-day moving average).

Daily estimates by net efficiency expansion rely on periodic releases of marked (color dyed) smolts to estimate the vulnerability of fish to capture in the trawl. On the days that the vulnerability tests are conducted, marked fish are released at the Mossdale Landing County Park boat ramp (upstream of the trawl sample area). Releases are made concurrently with the first tow of the day and extend over a 2-hour period to avoid schooling and ensure that fish are dispersed throughout the reach. Net efficiency is estimated as the ratio of the marked fish captured to the marked fish released. This net efficiency applies to the period of each day when sampling is conducted. DFG calculates an annual population estimate using the logarithmic average of all vulnerability tests for the year. Expansion estimates of smolt production are then calculated by dividing the trawl catch of non-marked salmon by the average net efficiency value and expanding this abundance for fraction of the time period that was sampled (i.e., 5 hours per day is about 20% of the time).

Figure A-2 compares the recapture rates of marked fish with the proportion of the river volume passing Mossdale during the time period that was trawled, for net efficiency tests from 1989–2006. The net efficiency test method assumes that all of the marked fish that are released upstream of the trawl pass through the sampling area. Losses that result from predation, or the lack of downstream movement by the marked fish, can lead to significant errors in abundance estimates, particularly if few marked fish, relative to the total released, are recaptured. The volume fraction sampled is greater on days when the river flow is lower. Because the Mossdale trawl samples about 25 af/hr and the river volume per hour is equal to the daily flow (cfs)/12, the volumetric sampling fraction during periods of trawling is:

Mossdale Trawl Volumetric Sampling Fraction = 300/flow (cfs)

But because sampling occurs for a maximum of 5 hours each day (fifteen 20-minute tows) the daily sample fraction is about 20% of this sampling rate. For example, with a flow of 1,200 cfs the daily sample fraction would be 5%, with a flow of 2,400 cfs the daily sample fraction would be 2.5%, and with a flow of 4,800 cfs the daily sample fraction would be 1.25%.

The net efficiency results appear to increase with lower flow, and indicate an average net efficiency of about 50% of the volumetric sampling fraction. However, the net efficiency estimates are variable at the lowest flows of about 2,500 cfs. This suggests that the daily abundance estimates based on the volumetric expansion (used in this evaluation) might be increased by a factor of about 2 to match the net efficiency results. Because recapture rates of marked fish are typically lower than the percent of the river volume sampled, the net efficiency expansion method results in larger estimates of abundance for a given catch compared to the volumetric expansion method. Both expansion methods will underestimate true smolt abundance if smolts are able to detect and avoid capture by the net.

Example of Mossdale Abundance Estimates

Figure A-3 shows the basic Mossdale Trawl data for the February through June period of 1996. The Mossdale trawl catch has been expanded to estimate the daily river abundance. The abundance is estimated as the catch divided by the sampling volume (i.e., fish/af) times the river volume (af). Because the sampling volume is similar each day, the volumetric expansion is greater on days with more flow. Sampling variability and missed trawling days (weekends) are smoothed using a 5-day centered averaging scheme. The Mossdale trawl sampling began in April and continued through June of 1996. Potential fry migration during the high runoff in February and March were not sampled. The trawl volume was about 80 af per day (8 af for each 20-minute trawl). The daily catch of marked and unmarked fish ranged from 1 to about 100 fish (a few days with more than 100). The average length of the Mossdale fish increased from an average of about 80 mm in early April to more than 100 mm in mid-June. Temperature increased from about 50ºF in early March to almost 75ºF in June. Temperatures of 75ºF may be approaching the upper limit for juvenile Chinook salmon survival.

Figure A-3 (bottom graph) shows that the Mossdale Chinook salmon density was a maximum of about 2,000 fish per thousand acre-feet (fish/taf) in late May, and was less than 200 fish/taf in early April and late May and June. The CVP Chinook salmon salvage density was similar to the Mossdale density in April and May. The SWP Chinook salmon salvage density was considerably less than the CVP salvage density and Mossdale density during this period. The SWP and CVP pumping was generally less than the San Joaquin River flow during April and May of 1996. The reduction of CVP and SWP pumping to 1,500 cfs (combined) in mid-April to mid-May of 1996 was to meet requirements in the 1995 WQCP and delta smelt biological opinion (the Vernalis Adaptive Management Program (VAMP) was not initiated until 2000). The head of Old River barrier was installed (shown as a value of 10) briefly in early May, but high flows on the San Joaquin River required that the barrier be removed (a value of 1 indicates that the barrier was partially installed-under construction or breached).

Evaluation of San Joaquin River Chinook Salmon Coded Wire Tag Recoveries

Introduction

Fall-run Chinook salmon are marked with a coded-wire-tag (CWT) in the Central Valley to evaluate in-stream survival, ocean harvest rates, and adult returns (and strays). Fish are tagged and released at hatcheries and at other locations in the Mokelumne, Sacramento, and San Joaquin River systems. Some CWT fish are released in the Delta (i.e., tidal) sections of these rivers. Table A-1 shows the number of CWT fall-run Chinook salmon released from each location and the number of CWT fish recaptured at Chipps Island, CVP salvage, and SWP salvage for 1994–2006. A total of 37 million fall-run Chinook salmon were tagged and released between 1994 and 2006 (about 2.85 million per year). A total of about 19 million were releases from Sacramento River sites, about 9 million were released from San Joaquin River sites, about 4 million were released from Mokelumne River sites, and about 5 million were released from Delta or San Francisco Bay sites. The methods and results have been thoroughly summarized and evaluated (California Department of Fish and Game 2001).

CWT release experiments utilize a basic mark-recapture design. CWT "tag groups" of 25,000 to 100,000 marked fish are released from a site or pair of sites for comparison of survival to a recovery location. The major recapture location for evaluating out-migration survival is the Chipps Island trawl. The typical recapture rate of about 1 to 10 per 10,000 released fish is relatively low and highly variable. The recapture is a function of the survival to the recovery location and the capture efficiency (i.e., sampling effort). Because the capture efficiency is generally unknown, comparisons are often made between two or more release locations to determine their relative survival rates (assuming the same sampling effort). The basic CWT metrics are the number of released fish, the number of recovered fish, the fraction recovered, and the timing (travel time) of the recaptures.

Table A-1 indicates that only the San Joaquin release groups are consistently recovered at the CVP and SWP salvage facilities, whereas almost all release groups are recovered at the Chipps Island trawl. The recovery rate for CWT fish releases from Sacramento River locations at the CVP and SWP salvage facilities is much lower. A second trawl has been operated at Antioch for the VAMP program, and the recoveries at the Antioch trawl (not shown) are similar to the Chipps Island Trawl for San Joaquin River release groups. The Chipps Island trawl is generally conducted with a standardized effort (i.e., constant trawl volume sampled each day) that results in a sampling efficiency that is inversely correlated with Delta outflow. Both CVP and SWP salvage consistently samples about 1/12 of the exports (5 minutes counted each hour). Sacramento CWT release groups are consistently recovered at the Chipps Island Trawl, with a maximum recovery fraction of about 10 per 10,000 released.

In general, less than 10 fish per 10,000 fish released from any site are recovered at Chipps Island or the salvage facilities, and the variability between CWT groups released from the same locations is relatively high, making interpretation of the comparative survival estimates difficult. San Joaquin River CWT releases have the highest recoveries at CVP and SWP salvage. Fish released from Delta or Mokelumne River locations are recovered at the Chipps Island trawl and fewer are recovered at the SWP and CVP salvage facilities. Very few CWT released from Bay sites (downstream of Chipps Island) are recovered at Chipps Island.

Comparison of the Chipps recovery fractions along with the CVP and SWP salvage recoveries provides the most general assessment of the effects of flows and exports and head of Old River barrier on fall-run Chinook salmon survival. The remainder of this section focuses on the CWT releases made to evaluate the relative survival of San Joaquin River juvenile Chinook salmon in April and May. Although VAMP did not formally begin until 2000, CWT releases in April and May have been made for many years with the goal of better understanding the effects of river flows, export pumping and the head of Old River barrier on San Joaquin River fall-run Chinook salmon survival to Chipps Island.

VAMP CWT Releases

The U.S. Fish and Wildlife Service (USFWS) as part of the Interagency Ecological Program (IEP), and more recently as part of the VAMP studies, has conducted experimental releases of CWT smolts to evaluate survival of San Joaquin River fall-run Chinook salmon associated with flows, exports and the head of Old River barrier. Table A-2 gives a summary of the CWT releases above and below the head of Old River Barrier from 1994–2006. The number of fish released above the head of Old River has been similar for the open and closed head of Old River barrier, however many more releases below the barrier have been made with the barrier open than with the barrier closed.

Table A-2 indicates that San Joaquin River CWT release groups are consistently recovered from the three recovery locations. A smaller fraction is recovered at CVP and SWP salvage during lower flow years when the head of Old River barrier is in place. The fraction recovered at Chipps Island is generally low for groups released below the barrier or released above when the barrier was closed. For release groups from above the barrier when it was open, a higher fraction may be recovered at CVP salvage and at Chipps Island because of trucking from CVP salvage to release stations upstream of Chipps Island (at Antioch or Emmaton).

Table A-2 indicates that recoveries from replicate tag groups (released from the same location on the same date) are quite variable, suggesting that the small recovery fraction is generally not a reliable indication of the survival between the release location and the recovery locations. For example, in 2005 there were four replicate tag groups released from above the head of Old River (no barrier) on April 29. The recoveries from Chipps Island ranged from 1 to 4, the CVP recoveries ranged from 9 to 18, and the SWP recoveries ranged from 9 to 21. For

Table A-1. Coded-Wire Tag Release and Recoveries from Sacramento River and San Joaquin River locations for 1994–2006

Release Location	Total Release	Distance Upstream of Chipps (km)	Chipps Island Recovery	CVP Salvage Recovery	SWP Salvage Recovery	Chipps Island Recovery (per 10,000)	CVP Salvage Recovery (per 10,000)	SWP Salvage Recovery (per 10,000)
Sacramento River Sites	**18,639,338**							
Battle Creek	8,665,427		3,283	4	40	3.79	0.00	0.05
Bow River Resort	27,888		0	0	0	0.00	0.00	0.00
Red Bluff Diversion Dam	912,345		158	3	18	1.73	0.03	0.20
Sac RM 242.5	10,154		1	0	0	0.98	0.00	0.00
Elkhorn	550,193		53	2	36	0.96	0.04	0.65
Elkhorn Park	216,404		21	0	0	0.97	0.00	0.00
Thermolito Bypass	111,350		11	0	0	0.99	0.00	0.00
Downstream Thermolito Bypass	74,695		6	0	0	0.80	0.00	0.00
Feather River	131,258		36	0	0	2.74	0.00	0.00
Feather River FH	203,935		7	0	0	0.34	0.00	0.00
Yuba City Ramp	602,793		397	2	0	6.59	0.03	0.00
Yuba River	50,000		3	0	0	0.60	0.00	0.00
Grayson	66,361		7	31	80	1.05	4.67	12.06
Gridley	188,940		129	0	0	6.83	0.00	0.00
B&W Marina	50,331		1	3	34	0.20	0.60	6.76
Live Oak	1,273,867		394	0	20	3.09	0.00	0.16
Roberts Ferry—Hughson	37,134		5	2	38	1.35	0.54	10.23
Rodeo Minor Port	200,133		0	0	0	0.00	0.00	0.00
Verona	586,488		236	2	20	4.02	0.03	0.34
Fremont Weir	51,543		9	0	0	1.75	0.00	0.00
Yolo Bypass	575,264		34	0	6	0.59	0.00	0.10
Lighthouse Marina	709,529	100	78	5	56	1.10	0.07	0.79
Miller Park	203,113	95	0	1	48	0.00	0.05	2.36
West Sacramento	1,390,934	95	1,073	3	14	7.71	0.02	0.10
Clarksburg	585,321	75	48	5	86	0.82	0.09	1.47
Ryde	439,653	45	209	1	4	4.75	0.02	0.09
Isleton	724,285	35	51	7	28	0.70	0.10	0.39

Release Location	Total Release	Distance Upstream of Chipps (km)	Chipps Island Recovery	CVP Salvage Recovery	SWP Salvage Recovery	Chipps Island Recovery (per 10,000)	CVP Salvage Recovery (per 10,000)	SWP Salvage Recovery (per 10,000)
San Joaquin River Sites	**9,116,096**							
Head of Old River Barrier	24,401		4	33	86	1.64	13.52	35.24
Dos Reis	1,035,431		254	75	134	2.45	0.72	1.29
Mossdale	1,577,377		312	1,273	727	1.98	8.07	4.61
Durham Ferry	909,823		172	219	349	1.89	2.41	3.84
Old Fisherman's Club	238,941		67	177	658	2.80	7.41	27.54
Stanislaus								
Oakdale Rec Area	23,532		0	5	2	0.00	2.12	0.85
Two Rivers	123,234		9	46	252	0.73	3.73	20.45
Knight's Ferry	325,055		12	88	170	0.37	2.71	5.23
Tuolumne								
Mouth of Tuolumne River	47,760		38	36	0	7.96	7.54	0.00
Tuolumne River	13,929		1	17	42	0.72	12.20	30.15
Lower Tuolumne	53,292		12	128	76	2.25	24.02	14.26
Mapes Ranch, Lower Tuolumne	50,055		2	6	4	0.40	1.20	0.80
Upper Tuolumne River	122,999		16	50	26	1.30	4.07	2.11
La Grange	785,149		127	496	862	1.62	6.32	10.98
Merced								
Mouth of Merced River	100,844		11	119	152	1.09	11.80	15.07
Hatfield State Park	1,649,777		251	878	1,368	1.52	5.32	8.29
Upper Merced River	48,889		5	267	268	1.02	54.61	54.82
Shaffer Bridge	25,489		1	0	0	0.39	0.00	0.00
Merced River FF	1,960,119		221	1,077	1,702	1.13	5.49	8.68
Mokelumne River Sites	**3,748,492**							
Mokelumne River	98,003		6	20	0	0.61	2.04	0.00
Mokelumne River (Bean Farm)	204,142		16	37	20	0.78	1.81	0.98
Mokelumne River FH	408,074		93	0	0	2.28	0.00	0.00
Woodbridge Dam	364,727		47	11	8	1.29	0.30	0.22
Thornton	51,757		18	0	0	3.48	0.00	0.00
New Hope Landing-Mokelumne	2,063,218		598	26	84	2.90	0.13	0.41

Release Location	Total Release	Distance Upstream of Chipps (km)	Chipps Island Recovery	CVP Salvage Recovery	SWP Salvage Recovery	Chipps Island Recovery (per 10,000)	CVP Salvage Recovery (per 10,000)	SWP Salvage Recovery (per 10,000)
North Fork Mokelumne	206,022		45	4	12	2.18	0.19	0.58
North Fork Mokelumne (Eagle Tree)	100,965		38	10	6	3.76	0.99	0.59
South Fork Mokelumne	102,839		16	0	0	1.56	0.00	0.00
South Fork Mokelumne (Beaver Slough)	100,142		25	15	0	2.50	1.50	0.00
Mouth of Mokelumne River	48,603		66	0	2	13.58	0.00	0.41
Delta and SF Bay Sites	**5,386,724**							
Georgiana Slough	451,973		92	3	28	2.04	0.07	0.62
Sherman Island	254,651		183	2	2	7.19	0.08	0.08
Lower Old River	100,291		0	13	32	0.00	1.30	3.19
Turner Cut	148,126		9	2	0	0.61	0.14	0.00
Jersey Point	1,770,715		2,233	22	44	12.61	0.12	0.25
Below Chipps								
Port Chicago	430,667		143	0	0	3.32	0.00	0.00
Benicia	205,799		33	0	0	1.60	0.00	0.00
Shore Terminal	237,536		2	0	0	0.08	0.00	0.00
San Pablo Bay	1,733,578		57	0	6	0.33	0.00	0.03
SF Bay - Wickland Oil	53,388		3	0	0	0.56	0.00	0.00
Grand Total	**36,890,650**		**11,497**	**5,226**	**7,650**	**3.12**	**1.42**	**2.07**

Table A-2. Statistics of CWT Recoveries for Individual VAMP CWT tag groups for 1994–2006

Release Date	Release Size	Release Location	Head of Old River Barrier	Recovery Total	Recovery Chipps	Recovery CVP	Recovery SWP	Chipps Recovery rate per 10,000	CVP Recovery rate per 10,000	SWP Recovery rate per 10,000	Average Days to Chipps	Average Days to CVP	Average Days to SWP	Average During Recovery		
														SJR Flow (cfs)	Export Pumpin g (cfs)	Export/ SJR Ratio
1994																
4/11/94	51,084	Above	Open	108		54	54	0.00	10.57	10.57		11	20	2,070	1,799	0.87
4/26/94	50,726	Above	Closed	2	2			0.39	0.00	0.00	17			2,325	1,838	0.79
5/2/94	51,632	Above	Closed	4		1	3	0.00	0.19	0.58		26	19	2,031	2,052	1.01
5/9/94	53,880	Above	Closed	4	1		3	0.19	0.00	0.56	13		18	1,943	2,562	1.32
1995																
4/17/95	50,120	Above	Open	190	10	174	6	2.00	34.72	1.20	20	13	22	20,223	3,931	0.19
4/17/95	50,849	Above	Open	161	10	147	4	1.97	28.91	0.79	21	14	25	20,605	4,012	0.19
4/17/95	50,848	Below	Open	9	8	1		1.57	0.20	0.00	25	10		21,433	4,066	0.19
5/5/95	52,297	Above	Open	84	7	64	13	1.34	12.24	2.49	8	4	4	22,879	4,157	0.18
5/5/95	50,265	Above	Open	9	9			1.79	0.00	0.00	9			22,843	4,637	0.20
5/5/95	52,097	Below	Open	131	10	116	5	1.92	22.27	0.96	12	8	9	22,482	5,612	0.25
5/17/95	52,702	Above	Open	21	21			3.98	0.00	0.00	13			23,013	5,196	0.23
5/17/95	51,422	Above	Open	134	3	117	14	0.58	22.75	2.72	17	9	10	19,934	6,456	0.32
5/17/95	51,670	Below	Open	78	1	60	17	0.19	11.61	3.29	12	4	5	22,900	5,195	0.23
1996																
4/15/96	49,024	Above	Open	66	2	62	2	0.41	12.65	0.41	11	10	22	7,834	3,207	0.41
4/15/96	51,718	Above	Open	62	1	46	15	0.19	8.89	2.90	7	8	18	6,714	1,846	0.27
4/30/96	50,462	Above	Open	73		64	9	0.00	12.68	1.78		9	18	8,205	3,639	0.44
4/30/96	49,194	Above	Open	2	2			0.41	0.00	0.00	8			8,328	3,916	0.47
5/1/96	48,770	Below	Open	57		48	9	0.00	9.84	1.85		12	21	6,770	1,977	0.29
5/1/96	49,868	Below	Open	1	1			0.20	0.00	0.00	10			8,561	3,663	0.43
5/1/96	22,198	Below	Open	1	1			0.45	0.00	0.00	5			6,377	1,849	0.29
5/1/96	25,414	Below	Open	5	5			1.97	0.00	0.00	9			6,547	1,887	0.29
5/1/96	16,050	Below	Open	2			2	0.00	0.00	1.25			14	6,700	1,964	0.29
5/1/96	31,208	Below	Open	13		5	8	0.00	1.60	2.56		14	16	6,546	1,922	0.29

														Average During Recovery		
Release Date	Release Size	Release Location	Head of Old River Barrier	Recovery Total	Recovery Chipps	Recovery CVP	Recovery SWP	Chipps Recovery rate per 10,000	CVP Recovery rate per 10,000	SWP Recovery rate per 10,000	Average Days to Chipps	Average Days to CVP	Average Days to SWP	SJR Flow (cfs)	Export Pumpin g (cfs)	Export/ SJR Ratio
5/9/96	50,168	Below	Partial	2	2			0.40	0.00	0.00	5			11,600	8,638	0.74
5/16/96	50,243	Below	Closed	2	2			0.40	0.00	0.00	15			6,946	10,666	1.54
1997																
4/28/97	23,701	Above	Closed	14	2	8	4	0.84	3.38	1.69	7	12	11	5,614	2,695	0.48
4/28/97	25,073	Above	Closed	20	8	8	4	3.19	3.19	1.60	12	10	14	5,624	2,689	0.48
4/29/97	25,084	Below	Closed	24	7	5	12	2.79	1.99	4.78	9	9	11	5,843	2,662	0.46
4/29/97	24,746	Below	Closed	14	3	3	8	1.21	1.21	3.23	10	11	10	6,048	2,693	0.45
4/29/97	48,973	Below	Closed	38	9	9	20	1.84	1.84	4.08	12	14	16	4,819	2,678	0.56
4/29/97	53,483	Below	Closed	42	7	13	22	1.31	2.43	4.11	14	13	14	5,835	2,667	0.46
5/8/97	46,674	Below	Closed	17	5	2	10	1.07	0.43	2.14	10	14	16	4,111	2,967	0.72
5/27/97	49,078	Below	Open	48	7	21	20	1.43	4.28	4.08	9	7	6	2,956	6,486	2.19
1998																
4/16/98	26,465	Above	Open	15	5	10		1.89	3.78	0.00	14	4		19,642	2,313	0.12
4/16/98	25,264	Above	Open	8	8			3.17	0.00	0.00	14			20,271	2,196	0.11
4/16/98	25,926	Above	Open	9	9			3.47	0.00	0.00	11			20,133	2,235	0.11
4/17/98	26,215	Below	Open	25	25			9.54	0.00	0.00	8			19,800	2,271	0.11
4/17/98	26,366	Below	Open	34	34			12.90	0.00	0.00	6			19,800	2,271	0.11
4/17/98	24,792	Below	Open	8	2	6		0.81	2.42	0.00	16	4		20,510	2,228	0.11
4/23/98	15,537	Above	Open	33	32	1		20.60	0.64	0.00	9	8		17,988	2,324	0.13
4/23/98	18,365	Above	Open	34	34			18.51	0.00	0.00	8			17,765	2,444	0.14
4/24/98	23,927	Below	Open	44	15	29		6.27	12.12	0.00	10	4		17,119	2,595	0.15
4/24/98	24,330	Below	Open	27	6	21		2.47	8.63	0.00	10	6		16,938	2,413	0.14
5/6/98	21,405	Above	Open	26	25	1		11.68	0.47	0.00	9	13		18,040	3,780	0.21
5/6/98	21,180	Above	Open	33	31	2		14.64	0.94	0.00	9	7		17,831	3,819	0.21
1999																
4/19/99	24,765	Above	Open	161	8	50	103	3.23	20.19	41.59	10	9	10	6,330	3,497	0.55
4/19/99	24,773	Above	Open	170	15	52	103	6.05	20.99	41.58	11	7	11	6,842	3,454	0.50

														Average During Recovery		
Release Date	Release Size	Release Location	Head of Old River Barrier	Recovery Total	Recovery Chipps	Recovery CVP	Recovery SWP	Chipps Recovery rate per 10,000	CVP Recovery rate per 10,000	SWP Recovery rate per 10,000	Average Days to Chipps	Average Days to CVP	Average Days to SWP	SJR Flow (cfs)	Export Pumpin g (cfs)	Export/ SJR Ratio
4/19/99	25,279	Above	Open	175	13	56	106	5.14	22.15	41.93	11	9	11	6,657	3,477	0.52
4/19/99	25,014	Below	Open	42	20	8	14	8.00	3.20	5.60	11	15	19	7,092	3,493	0.49
4/19/99	24,841	Below	Open	38	19	7	12	7.65	2.82	4.83	12	15	20	6,577	3,521	0.54
4/20/99	25,005	Above	Open	2			2	0.00	0.00	0.80			15	6,393	3,510	0.55
4/21/99	24,359	Above	Open	162	2	53	107	0.82	21.76	43.93	14	8	11	7,245	3,671	0.51
2000																
4/17/00	23,529	Above	Closed	56	9	1	46	3.83	0.43	19.55	9	23	11	5,838	2,350	0.40
4/17/00	24,177	Above	Closed	61	9	1	51	3.72	0.41	21.09	7	13	12	5,570	2,378	0.43
4/17/00	24,457	Above	Closed	35	10	1	24	4.09	0.41	9.81	13	7	15	5,772	2,334	0.40
4/18/00	23,465	Above	Closed	34	7	1	26	2.98	0.43	11.08	10	14	15	5,816	2,341	0.40
4/18/00	22,784	Above	Closed	36	5	2	29	2.19	0.88	12.73	9	9	15	5,340	2,614	0.49
4/28/00	23,698	Above	Closed	53	7	2	44	2.95	0.84	18.57	8	15	13	5,231	2,447	0.47
4/28/00	26,805	Above	Closed	51	10	2	39	3.73	0.75	14.55	12	16	13	5,190	2,515	0.48
4/28/00	23,889	Above	Closed	58	11	1	46	4.60	0.42	19.26	11	25	14	5,050	2,658	0.53
2001																
4/30/01	23,351	Above	Closed	15	14	1		6.00	0.43	0.00	8	8		4,104	1,852	0.45
4/30/01	22,720	Above	Closed	24	22	2		9.68	0.88	0.00	8	10		4,106	1,849	0.45
4/30/01	22,376	Above	Closed	21	17	4		7.60	1.79	0.00	8	10		4,106	1,849	0.45
5/1/01	23,022	Above	Closed	21	17	2	2	7.38	0.87	0.87	8	10	13	4,201	1,815	0.43
5/1/01	22,191	Above	Closed	15	14	1		6.31	0.45	0.00	8	9		4,106	1,849	0.45
5/7/01	24,029	Above	Closed	4	2	1	1	0.83	0.42	0.42	7	8	11	4,478	1,786	0.40
5/7/01	23,907	Above	Closed	5	5			2.09	0.00	0.00	6			4,312	1,807	0.42
5/7/01	24,054	Above	Closed	4	2	1	1	0.83	0.42	0.42	10	9	7	4,390	1,786	0.41
5/8/01	23,882	Above	Closed	5	4	1		1.67	0.42	0.00	6	4		4,400	1,787	0.41
5/8/01	25,310	Above	Closed	7	4	1	2	1.58	0.40	0.79	8	10	9	4,477	1,788	0.40

Release Date	Release Size	Release Location	Head of Old River Barrier	Recovery Total	Recovery Chipps	Recovery CVP	Recovery SWP	Chipps Recovery rate per 10,000	CVP Recovery rate per 10,000	SWP Recovery rate per 10,000	Average Days to Chipps	Average Days to CVP	Average Days to SWP	Average During Recovery: SJR Flow (cfs)	Average During Recovery: Export Pumpin g (cfs)	Average During Recovery: Export/ SJR Ratio
2002																
4/18/02	23,920	Above	Partial	14	4	2	8	1.67	0.84	3.34	10	13	15	3,443	1,695	0.49
4/18/02	25,176	Above	Partial	23	6	2	15	2.38	0.79	5.96	13	12	15	3,383	1,692	0.50
4/18/02	23,872	Above	Partial	23	7	6	10	2.93	2.51	4.19	10	10	17	3,390	1,666	0.49
4/18/02	24,747	Above	Partial	8	3	3	2	1.21	1.21	0.81	9	10	10	3,452	1,691	0.49
4/19/02	25,515	Above	Closed	7	4	1	2	1.57	0.39	0.78	9	11	16	3,386	1,658	0.49
4/19/02	25,272	Above	Closed	23	9	5	9	3.56	1.98	3.56	12	13	16	3,380	1,688	0.50
4/25/02	24,680	Above	Closed	10	4		6	1.62	0.00	2.43	12		20	3,419	1,695	0.50
4/25/02	24,659	Above	Closed	10	5		5	2.03	0.00	2.03	11		13	3,315	1,644	0.50
4/25/02	24,783	Above	Closed	12	3	2	7	1.21	0.81	2.82	10	8	12	3,352	1,655	0.49
4/25/02	24,381	Above	Closed	10	4	2	4	1.64	0.82	1.64	9	9	10	3,359	1,659	0.49
4/26/02	24,519	Above	Closed	12	2	1	9	0.82	0.41	3.67	10	11	12	3,312	1,642	0.50
4/26/02	24,820	Above	Closed	6	3		3	1.21	0.00	1.21	13		18	3,253	1,637	0.50
2003																
4/21/03	24,453	Above	Partial	2		2		0.00	0.82	0.00		9		3,340	1,752	0.52
4/21/03	25,927	Above	Partial	5	2	1	2	0.77	0.39	0.77	9	10	18	3,324	1,787	0.54
4/21/03	24,069	Above	Partial	5	1	1	3	0.42	0.42	1.25	8	16	18	3,330	1,786	0.54
4/22/03	25,212	Above	Closed	3	3			1.19	0.00	0.00	10			3,357	1,770	0.53
4/22/03	24,471	Above	Closed	1			1	0.00	0.00	0.41			14	3,360	1,786	0.53
4/28/03	24,685	Above	Closed	2	2			0.81	0.00	0.00	11			3,280	1,732	0.53
4/28/03	25,189	Above	Closed	1		1		0.00	0.40	0.00		3		3,290	1,815	0.55
4/28/03	24,628	Above	Closed	2		1	1	0.00	0.41	0.41		9	14	3,360	1,822	0.54
4/29/03	24,180	Above	Closed	3		1	2	0.00	0.41	0.83		8	13	3,290	1,815	0.55
4/29/03	24,346	Above	Closed	1	1			0.41	0.00	0.00	7			3,320	1,724	0.52
2004																
4/22/04	23,440	Above	Closed	3		2	1	0.00	0.85	0.43		12	6	3,297	1,807	0.55
4/22/04	21,714	Above	Closed	4	1	3		0.46	1.38	0.00	11	10		3,300	1,808	0.55

Release Date	Release Size	Release Location	Head of Old River Barrier	Recovery Total	Recovery Chipps	Recovery CVP	Recovery SWP	Chipps Recovery rate per 10,000	CVP Recovery rate per 10,000	SWP Recovery rate per 10,000	Average Days to Chipps	Average Days to CVP	Average Days to SWP	Average During Recovery: SJR Flow (cfs)	Average During Recovery: Export Pumpin g (cfs)	Average During Recovery: Export/ SJR Ratio
4/22/04	23,328	Above	Closed	3	1	2		0.43	0.86	0.00	10	8		3,304	1,809	0.55
4/22/04	23,783	Above	Closed	3	1	1	1	0.42	0.42	0.42	9	13	9	3,312	1,702	0.51
4/23/04	23,586	Above	Closed	3	1	2		0.42	0.85	0.00	13	9		3,303	1,709	0.52
4/23/04	24,803	Above	Closed	3	2		1	0.81	0.00	0.40	11		17	3,291	1,647	0.50
2005																
4/29/05	23,414	Above	Open	41	2	18	21	0.85	7.69	8.97	12	4	7	9,489	2,544	0.27
4/29/05	23,193	Above	Open	26	1	9	16	0.43	3.88	6.90	3	3	7	8,869	2,526	0.28
4/29/05	23,660	Above	Open	40	3	17	20	1.27	7.19	8.45	10	5	8	8,791	2,523	0.29
4/29/05	23,567	Above	Open	18		9	9	0.00	3.82	3.82		4	7	9,003	2,529	0.28
5/3/05	22,675	Below	Open	1	1			0.44	0.00	0.00	9			9,110	2,652	0.29
5/3/05	22,302	Below	Open	7	3		4	1.35	0.00	1.79	5		9	9,140	2,653	0.29
5/3/05	24,149	Below	Open	2	2			0.83	0.00	0.00	8			9,070	2,666	0.29
5/9/05	22,777	Above	Open	49	5	38	6	2.20	16.68	2.63	9	6	18	11,296	3,657	0.32
5/9/05	22,968	Above	Open	30	2	25	3	0.87	10.88	1.31	12	6	20	9,608	2,619	0.27
5/9/05	23,012	Above	Open	48	4	37	7	1.74	16.08	3.04	16	6	17	11,115	3,483	0.31
5/9/05	22,806	Above	Open	25	1	19	5	0.44	8.33	2.19	8	6	18	10,858	3,185	0.29
5/10/05	21,443	Below	Open	1	1			0.47	0.00	0.00	8			9,291	2,606	0.28
5/10/05	23,755	Below	Open	4	1	1	2	0.42	0.42	0.84	8	7	12	8,955	2,569	0.29
5/10/05	23,448	Below	Open	1	1			0.43	0.00	0.00	7			8,970	2,602	0.29
2006																
5/4/06	24,703	Above	Open	9	7		2	2.83	0.00	0.81	8		2	26,446	2,095	0.08
5/4/06	24,315	Above	Open	3	2		1	0.82	0.00	0.41	8		2	27,157	1,758	0.06
5/5/06	25,602	Below	Open	7	7			2.73	0.00	0.00	7			26,250	1,743	0.07
5/19/06	25,105	Above	Open	3	2	1		0.80	0.40	0.00	1	1		24,500	6,265	0.26
5/19/06	24,008	Above	Open	1		1		0.00	0.42	0.00		1		24,500	6,265	0.26
5/19/06	25,148	Above	Open	8	6	2		2.39	0.80	0.00	6	1		24,420	6,233	0.26

the May 9 release of four tag groups, the Chipps Island recoveries ranged from 1 to 5, the CVP recoveries ranged from 19–38, and the SWP recoveries ranged from 3 to 7.

Flows and exports have generally varied from year to year, but are not independent. The VAMP flow agreement increases San Joaquin River flows and reduces the CVP and SWP exports in relatively low flow years. The barrier cannot be installed in years with more than 7,000 cfs flow. Therefore, flows and exports are both lower during periods when the head of Old River barrier is installed. The export/San Joaquin River flow ratio is lower when the head of Old River barrier is open. CWT fish released when the barrier is closed generally experience lower flows that may result in higher in-stream mortality and lower survival to Chipps Island.

High spring flows appears to benefit San Joaquin River fall-run Chinook salmon survival through the Delta to Chipps Island, resulting in improved adult returns (Brandes and McLain 2001). This suggests that in-stream or estuarine mortality significantly impacts the smolt-to-adult return ratio. However, because San Joaquin River flows and head of Old River barrier operations are correlated, the benefits from the barrier based on a statistical analysis of the VAMP CWT release group recoveries at Chipps Island has been difficult to establish and confirm.

Previous USFWS analyses have assessed the benefits of the head of Old River barrier using statistical comparisons between above and below release groups (Brandes and McLain 2001). These USFWS reports have clearly described the multiple factors which confound a statistical analysis, including release size, fish length, flows, exports, and water temperature conditions. Brandes and McLain (2001) attempt to address some of the CWT experimental design issues using ratios of release groups as their performance metric; however several confounding factors remain:

1. CWT recoveries at Chipps Island may result from both the San Joaquin River pathway and the salvage pathway.
2. Both above and below CWT releases may be diverted from the San Joaquin River at Turner Cut where they face mortality or salvage.
3. The above and below CWT releases have not been consistently made over the range of flows, exports and head of Old River barrier conditions.

Because the CWT experimental design associated with the VAMP studies is confounded, the information that can be obtained from a statistical analysis of the Chipps Island recovery data is limited. The VAMP CWT Chipps Island survival estimates, including paired survival ratios, appear to be highly compromised, and should probably not be used for management decisions. Comparison of Chipps Island and CVP and SWP salvage recoveries and the evaluation of the travel times for these recovery groups is most likely to provide useful information about the head of Old River benefits. The recoveries at the Chipps Island trawl and at the CVP and SWP salvage from releases made above and below the barrier are reviewed in the next section. A pathway survival model is presented in

Appendix C that may provide a more integrative framework for management decisions than the statistical analyses that have been previously conducted by USFWS.

VAMP CWT Recoveries

Table A-3 gives the VAMP CWT releases and daily recoveries for 2005, as an example of the general results that have been obtained from CWT VAMP experiments. Two releases were made above the head of Old River at Durham Ferry on April 29, 2005 (about 93,000 fish) and on May 9, 2005 (about 91,000 fish). Two releases were made downstream of the Head of Old River barrier on May 3, 2005 (about 69,000 fish) and May 10, 2005 (about 45,000 fish). The San Joaquin River flows were above 7,000 cfs so the Head of Old River barrier could not be installed. For the downstream release groups, there were only 3 fish recovered from Chipps Island from the May 10 release group, and 3 recovered from Chipps Island, 1 from CVP, and 2 from SWP from the May 3 release group. These releases were made during high flows when survival to Chipps Island was expected to be high. These CWT results do not support this basic hypothesis that survival is higher when flows are higher, and are difficult to explain.

The CVP and SWP recoveries from fish released above the Head of Old River on April 29 and May 9 are more easily understood. For the April 29 release of 93,000 fish, a total of 119 fish were recovered from CVP, with 13 recovered on the fourth day, and 101 recovered within the first week after release. A total of 21 fish from the April 29 release were recovered from SWP salvage, beginning on the 10^{th} day after release and continuing until the 23^{rd} day after release. The SWP pumping was quite low and the CCF gates may not have been opened for several of these days. A total of 12 fish from the April 29 release were recovered at Chipps Island beginning on the 7^{th} day after release and continuing until the 21^{st} day after release. Some of these fish may have entered CVP salvage and been trucked to Chipps Island. For the May 9 release, a total of 53 fish were recovered from the CVP salvage and 66 were recovered from SWP salvage. Some of these fish were recovered at CVP and SWP salvage within 3 days of the release. Some fish released on May 9 were recovered at the end of May, about 3 weeks after the release. This very spread out recovery from the salvage is difficult to explain. There were only 6 fish recovered at Chipps Island from the May 9 release of 91,000 fish. Overall, the survival to Chipps Island appears to have been quite low in May of 2005, with less than 1 fish recovered at Chipps Island per 10,000 released during the VAMP CWT experiments.

The number and fraction of recaptures for VAMP CWT releases have been greatest across all years when the head of Old River barrier is open for releases made above the head of Old River. CWT recoveries in CVP and SWP salvage suggests that some of the release group have survived to salvage, and that some were likely trucked to near Chipps Island, although the CVP and SWP salvage mortality is uncertain. These salvaged fish will then be trucked to the vicinity of Antioch and may survive to the Chipps Island trawl. Recoveries at Chipps Island include the salvaged fish plus those that have migrated directly through the Delta

Table A-3. Example of VAMP CWT Releases and Recoveries for 2005 (high flows, no head of Old River barrier)

Date (2005)	SJR Flow (cfs)	CVP Exports (cfs)	SWP Exports (cfs)	Above Mossdale (Durham Ferry)			Above Mossdale (Durham Ferry)			Below Mossdale (Dos Reis)			Below Mossdale (Dos Reis)		
				Recovery Chipps	Recovery CVP	Recovery SWP	Recovery Chipps	Recovery CVP	Recovery SWP	Recovery Chipps	Recovery CVP	Recovery SWP	Recovery Chipps	Recovery CVP	Recovery SWP
4/29	7,090	1,979	1,549	**Release Number: 93,834**											
4/30	7,200	1,980	1,550												
5/1	7,720	1,760	587												
5/2	8,180	1,663	579												
5/3	8,320	1,664	595		13					**Release Number: 69,126**					
5/4	8,070	1,663	0		44										
5/5	7,890	1,658	633	1	29										
5/6	8,130	1,137	1,130	2	15										
5/7	8,400	926	1,398	1	2										
5/8	8,610	912	1,400		6	1									
5/9	8,820	899	1,395	1	3		**Release Number: 91,563**								
5/10	9,060	910	1,389	1	1			4	0		1		**Release Number: 45,198**		
5/11	9,110	907	1,400	2	2	1		16	10	2					
5/12	9,070	907	1,399	1			1	10	11	1					
5/13	9,130	908	1,392	1	1	2		8	3						
5/14	9,220	905	1,399					7	6						
5/15	9,250	902	1,392		1		2	0	5			2			
5/16	9,120	903	1,381		1	4	1	2	3						
5/17	8,970	916	1,346			3		3	5				2		
5/18	8,940	925	1,306	1		3		0	5				1		
5/19	9,340	928	1,349	1		3		2	1						
5/20	10,200	924	1,335			3		0	8						
5/21	11,400	926	1,342			1		0	2						
5/22	12,100	927	1,348					0	1						

Table A-3. Continued

Date (2005)	SJR Flow (cfs)	CVP Exports (cfs)	SWP Exports (cfs)	Above Mossdale (Durham Ferry)			Above Mossdale (Durham Ferry)			Below Mossdale (Dos Reis)			Below Mossdale (Dos Reis)		
				Recovery Chipps	Recovery CVP	Recovery SWP	Recovery Chipps	Recovery CVP	Recovery SWP	Recovery Chipps	Recovery CVP	Recovery SWP	Recovery Chipps	Recovery CVP	Recovery SWP
5/23	12,600	929	1,344					0	0						
5/24	13,000	929	1,348		1			0	1						
5/25	13,200	930	1,344					0	1						
5/26	13,500	928	3,345				1	0	0						
5/27	13,500	933	5,298				1	0	1						
5/28	13,800	927	5,292					0	1						
5/29	14,200	924	5,287					0	0						
5/30	14,700	922	5,298					1	1						
5/31	15,100	1,619	5,298					0	1						
Total Recovery				**12**	**119**	**21**	**6**	**53**	**66**	**3**	**1**	**2**	**3**	**0**	**0**
Recovery per 10,000				**1.28**	**12.68**	**2.24**	**0.66**	**5.79**	**7.21**	**0.43**	**0.14**	**0.29**	**0.66**		

along the San Joaquin River channels. The example of daily recoveries for May 2005 (Table A-3) suggests that perhaps half of the recoveries at Chipps Island were the result of salvage, because more than twice as many were recovered for the above the head of Old River release groups. Increased recovery fractions at Chipps Island suggests that the overall survival was increased when some fraction (20% or less based on flows and exports) were salvaged and trucked to upstream of Chipps Island.

Previous USFWS analyses showed a decrease in Chipps Island survival indices through the years for pair-wise comparisons. The trend was common to fish released in Old River and those released in the San Joaquin River below the head of Old River (Brandes and McLain 2001). The mechanism causing this decline with time is unknown. Some evidence was presented to support the hypothesis that the head of Old River barrier has improved the survival to Chipps Island, despite the general decline in survival with time. However, other CWT evidence would suggest that the head of Old River barrier installation does not change CWT survival.

To address these statistical sampling variability issues Brandes and McLain (2001) include a relative estimate of mortality based on the ratio between above/below head of Old River barrier recaptures relative to the Jersey Point recaptures. Theoretically the Jersey Point recoveries could be used to standardize survival to Chipps. However, the VAMP CWT releases experience changing conditions during the 30 days when they are generally recovered, whereas Jersey Point releases will be recovered within a few days. Therefore, the ratio of recoveries from Mossdale releases versus Jersey Point releases is also confounded.

An estimate of survival fraction cannot be obtained from the CWT recoveries themselves. Brandes and McLain (2001) identified a positive correlation between survival and flow in the San Joaquin River for multiple release locations. This analysis did not address the possible relationships between survival through salvage, flow, and survival to Chipps. Direct estimates of survival to salvage showed mixed results for paired releases, and could not be used to directly assess the impacts of flow or head of Old River barrier.

Table A-3 indicates that there is variability in the recovery ratios for different head of Old River barrier configurations, despite a constant effort in the fish salvage and Chipps trawl. This suggests that the benefits of the head of Old River barrier will be difficult to analyze using CWT recovery ratios. In general less than 1% of VAMP CWT fish released are recaptured in the system. This recapture fraction may be suitable for mark-recapture survival experiments, but the VAMP experiments also include high variability in conditions and confounding factors that complicate the survival estimates.

CWT Recovery Travel Times

Travel time is important because longer out-migrant travel time results in increased in-stream mortality (Anderson 2003). Juvenile Chinook salmon travel time or swimming speed is difficult to predict, because it is a function of the biology of the fish, and the conditions of its environment. Fish size, fish condition, seasonality, temperature, and flow conditions are all involved (Anderson 2003). Figure A-4 shows that VAMP CWT average travel times were generally correlated with flow in the San Joaquin River. High flows should result in faster out-migration times and higher survival to Chipps Island. Although flow velocity is an element of the migration rate, it is generally a secondary factor. In general, when salmon are ready to smolt they undergo active migration and are only partially sensitive to environmental conditions.

The most straightforward impact of the head of Old River barrier on travel time is the blockage of a direct path to salvage. With the barrier in place, fish may still move to salvage through Turner Cut or other downstream (i.e., longer) pathways. Without the barrier fish can move directly to salvage through the head of Old River. Figure A-5 shows that without the barrier there is often a bi-modal distribution of travel times to CVP and SWP salvage. This might suggest that the first pulse of fish arrive at salvage through the head of Old River, whereas the second portion of fish arrives via Turner Cut. With the barrier in place the travel time distribution to CVP and SWP salvage is delayed, with all fish moving through Turner Cut or similar downstream pathways. It is important to reiterate that the head of Old River barrier does not eliminate the passage of juvenile Chinook salmon to salvage. But the barrier will increase the travel time to salvage for the portion of fish that are diverted at Turner Cut, and may reduce the fraction of fish that are diverted at Turner Cut to salvage. Table A-4 gives the average travel times to CVP and SWP salvage and to Chipps island trawl for the CWT releases. Because mortality can be considered as a daily loss rate, the probability of fish loss in the Delta through predation, disease, entrainment, or starvation increases with longer exposure (i.e., travel) times.

Table A-4. Average travel time and speed (km/day) for Coded Wire Tag Releases above and below the Head of Old River (Note: The four bold-dates represent the only paired releases from above and below that were conducted on the same day.)

Release Year	Release Location	Head of Old River Barrier (0=open, 1= partial, 10=closed)	Release Dates	Average Travel Time (d) to Chipps Island	Average Travel Time (d) to CVP	Average Travel Time (d) to SWP	Average Speed (km/d) to Chipps Island	Average Speed (km/d) to CVP	Average Speed (km/d) to SWP
1994	Above	0	4/11		3.4	1.7		11.2	20.1
		10	4/26, 5/2, 5/9	6.4	1.2	1.8	14.8	26.0	18.8
1995	Above	0	**4/17, 5/5. 5/17**	8.0	7.5	4.6	14.8	8.8	12.4
	Below	0	**4/17, 5/5, 5/17**	7.9	3.0		15.8	10.0	
1996	Above	0	4/15, 4/30	10.9	4.2	1.8	9.0	9.9	19.9
	Below	0	5/1	12.9			8.7		
		1	5/9			2.1			14.0
		10	5/16		2.1	2.1		14.2	15.8
1997	Above	10	4/28	11.6	3.3	2.7	9.3	10.8	12.3
	Below	0	5/27	10.6	5.0	5.7	9.3	6.9	6.1
		10	4/29, 5/8	8.9	2.8	2.6	11.2	11.9	13.2
1998	Above	0	4/16, 4/23, 5/6	11.5	10.6		10.9	6.4	
	Below	0	4/17, 4/24	12.0			9.2		
1999	Above	0	**4/19**, 4/20	10.3	8.2	3.8	11.5	8.0	11.3
	Below	0	**4/19**	8.6	2.2	1.6	11.7	15.1	19.3
2000	Above	10	4/17, 4/18, 4/21	10.9	2.4	2.7	10.0	15.2	13.3
2001	Above	10	4/30, 5/1, 5/7, 5/8	13.3	3.8	3.3	7.7	8.5	9.8
2002	Above	1	4/18	9.1	2.8	1.9	10.8	12.2	16.5
		10	4/19, 4/25, 4/26	9.4	3.3	2.5	10.5	9.8	13.2
2003	Above	1	4/21	11.8	2.8	1.8	8.3	11.7	17.6
		10	4/22, 4/28, 4/29	10.4	5.7	2.2	9.4	6.7	13.7
2004	Above	10	4/22, 4/23	8.8	3.4	3.4	10.8	10.3	10.7
2005	Above	0	4/29, 5/9	12.9	8.3	4.2	9.9	5.1	12.7
	Below	0	5/3, 5/10	12.9	4.3	3.1	7.5	7.0	10.3
2006	Above	0	5/4, 5/19	34.4	30.0	15.0	5.5	1.0	2.0
	Below	0	5/5	13.4			7.4		

Typically most fish reach Chipps from Mossdale (about 100 km) in 20 days or less for both above and below head of Old River releases. In some years most fish traveled this distance in under 10 days. At these rates of travel fish would need to be moving approximately 5–10 km/day. These rates are somewhat faster than general published migration speeds for Chinook salmon, suggesting that salvage (with trucking to Antioch) may be involved. The trip through salvage is only one day, and salvage facilities are much closer (about 30 km) to Mossdale than Chipps.

Travel to CVP salvage from Mossdale can occur in one day, and is often less than five days. Fish released above head of Old River appear to move at speeds similar to those released below. Similar patterns can be seen at the SWP fish salvage. However the average travel time to the SWP salvage facility is generally longer, possibly due to delay in the Clifton Court Forebay, or because more fish are diverted at Turner Cut with a longer travel time to the SWP salvage facility.

In general the fish salvage facilities begin to detect CWT groups well before Chipps Island does. Chipps Island trawl detects some released as early as 2 days post-release. Given that the trawl is about 100 km from the release location, it seems very unlikely that these fish migrated this distance in just a few days. They were most likely salvaged and released upstream of the trawl, saving them a long journey through the Delta channels. Conversely, fish salvage continues to detect release groups long after the Chipps trawl. This longer period of recovery may be caused by the greater sampling effort at CVP and SWP salvage, but it suggests that some juvenile Chinook salmon fish are delayed in south Delta channels. This is important because it exposes some fish to much higher cumulative mortality, in addition to the normal salvage entrainment losses.

There were a large number (~3,000) of CWT recoveries during the 1994–2006 study period that can be used to estimate the probability of travel times. Flows, exports, and the head of Old River barrier status may affect the travel time distribution for San Joaquin River juvenile fall-run Chinook salmon. The individual distributions of specific release groups provide useful templates for estimating general travel time distributions for each Delta pathway under different San Joaquin River flow, head of Old River barrier, and export conditions. Estimated travel time distributions were used in the Delta pathway survival model described in Appendix C. The results from the CWT experiments have therefore been used in the Delta pathway survival model, but do not provide enough information by themselves to allow the benefits of the head of Old River to be evaluated directly.

Salvage Estimates at CVP and SWP Fish Facilities

Estimates of Chinook salmon salvage and loss are based on the measured fish and operational data collected at the John E. Skinner Delta Fish Protective Facility (SWP salvage) and the Tracy Fish Collection Facility (CVP salvage). SWP loss calculations utilize estimates based on DFG studies of screening efficiency, handling and trucking mortality, and pre-screening losses (i.e., predation) occurring in Clifton Court Forebay (CCF) and the intake channel. CVP loss calculations do not include the high estimates of CCF predations losses. The salvage estimates were used in this study to compare the daily abundance of juvenile Chinook salmon at Mossdale with the daily abundance in CVP or SWP salvage. The loss estimates attempt to quantify the number of fish that passed Mossdale but were never observed at CVP or SWP salvage because of in-stream mortality along the migration pathway or predation at the fish facilities, as well as fish that passed the louvers without being separated into the salvage facilities.

Salvage is estimated from samples (counts) of fish collected at least every two hours while water is being pumped. The expanded daily salvage is calculated as the observed number of fish times the total minutes of pumping divided by the minutes of counting. The counting is actually done by isolating the discharge from the secondary louvers for five minutes (each hour) or ten minutes (every two hours) and then screening and counting all fish from this tank. Salvage counting is done at one or two hour intervals around the clock.

This indicates that the daily sampling effort for CVP and SWP salvage is about 1/12 of the daily pumped volume. This is a very high sampling rate. For example, with CVP maximum pumping of about 4,500 cfs, the daily pumping volume is about 9,000 af and the sampled volume is about 750 af per day. The species and length of each fish is recorded. For Chinook salmon the fish are checked for clipped adipose fins, indicating a CWT fish. Any CWT fish found during the counting periods are saved for analysis of the CWT ID.

Loss estimates are based on the expanded salvage counts. There are three assumed salvage loss components: pre-screen loss (predation), screen (louver) efficiency, and handling and trucking loss. Fish may be eaten by predators or they may pass through the louvers and be pumped and exported along with Delta water. Fish loss also occurs when some fish die in the process of being handled or trucked.

Estimating the number of fish encountering the screens depends on fish size because louver efficiency is generally higher for larger fish. The ability of a fish to avoid the louvers and enter the bypass also depends on the water velocity through the louvers. For small fish, higher velocities increase the likelihood that they will pass through the louvers and will be lost. The number of fish encountering the screens is calculated by dividing the expanded salvage by the screen efficiency (generally 50–90%).

The assumed pre-screen loss rate at Tracy is about 15%. The assumed pre-screen loss at the SWP salvage is based on an average of measured pre-screen loss rates in CCF for Chinook salmon of about 75%. The handling and release loss for CVP and SWP is assumed to be less than 5%. This means that the assumed loss at the SWP salvage facility is about 5 times the expanded SWP salvage number, and that the assumed loss at the CVP salvage facility is about the same as the expanded CVP salvage number.

Recommended Future Studies and Adaptive Management Actions

1. The Mossdale Kodiak trawl should definitely be continued during the February–July period (6 months) to allow the daily abundance of the San Joaquin River Chinook salmon fry and smolts, as well as the migration pattern and abundance of San Joaquin River splittail, to be accurately tracked each year. The trawling in August–January (with no likely migration of San Joaquin River fish) possibly should be discontinued in favor of more important monitoring efforts.

2. The Mossdale Trawl abundance estimates and the CVP and SWP salvage estimates appear to match very well for the period of San Joaquin River juvenile out-migration of fry in February and March, and for smolts in April, May, and early June. These intensive sampling efforts should be compared with each other to provide an integrated evaluation of the daily abundance and salvage patterns. The annual escapement and estimates of tributary out-migration obtained from the rotary screw traps (RST) that are operated in each tributary could be integrated with the Mossdale Kodiak trawl abundance estimates and fall escapement and hatchery returns to provide a full population assessment of San Joaquin River Chinook salmon for each year.

4. The historical CWT studies in the San Joaquin River tributaries could be evaluated further to give travel times to Mossdale as well as recovery ratios at Mossdale, CVP salvage, SWP salvage, and Chipps for the range of environmental conditions observed following the CWT releases.

5. There may be only limited additional information that can be obtained from repeating the basic CWT paired release studies in future years. More specific studies of Chinook salmon migration behavior (pathways and travel times) as well as survival as related to predator density and temperature could be pursued. For example, Dave Vogel has demonstrated the possibility of tracking individual juvenile Chinook salmon with acoustic tags and receivers (fixed and mobile). Passive induced transmission (PIT) tags offer another possible technology for tracking fish, although the fish must pass through a magnetic antenna loop to read the PIT tags. It may be possible to place recorders in the CVP and SWP salvage facilities and under the Mossdale Bridge (for example), or PIT antenna could be mounted on trawls of various kinds.

6. Earlier studies of CWT releases into Old River (1985–1989) suggested that the overall survival to Chipps Island was lower than for fish released in the San Joaquin River downstream of the head of Old River. A large release of color-coded CWT fish into the CVP and SWP salvage facilities (i.e., trashracks) could be made to directly test the survival from salvage to Chipps Island. The salvage recoveries (without removing the color-coded fish) could be compared to recoveries at Chipps Island to determine the salvage efficiency and survival fraction.

7. Several CWT releases could be made at Dos Reis (downstream of Old River and upstream of Turner Cut) when the San Joaquin River flow is relatively low (less than 5,000 cfs) and with CVP and SWP pumping at near maximum (10,000 cfs) to allow the fish preference at Turner Cut to be more accurately estimated. The previous downstream CWT releases have been made when exports were generally reduced and the Turner Cut diversions to CVP and SWP salvage have been low. The ability to estimate the fish preference (avoidance) at the Turner Cut diversion from the salvage fraction or the CWT recoveries has been limited by these low pumping conditions.

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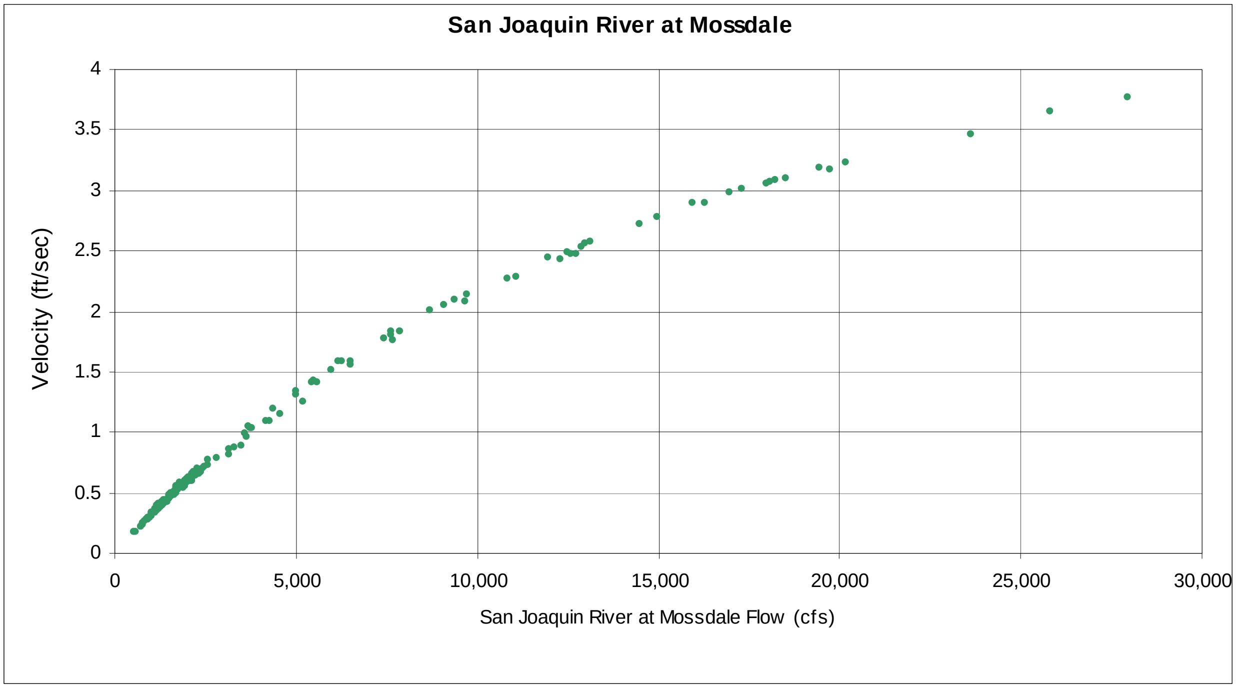
Brandes, P. L., and J. S. McLain. 2001. Juvenile Chinook salmon abundance, distribution, and survival in the Sacramento–San Joaquin Estuary. Fish Bulletin 179 Vol II Pg 39–136

California Department of Fish and Game. 2001. Contributions to the Biology of Central Valley Salmonids. Fish Bulletin 179. Edited by Randall L. Brown.



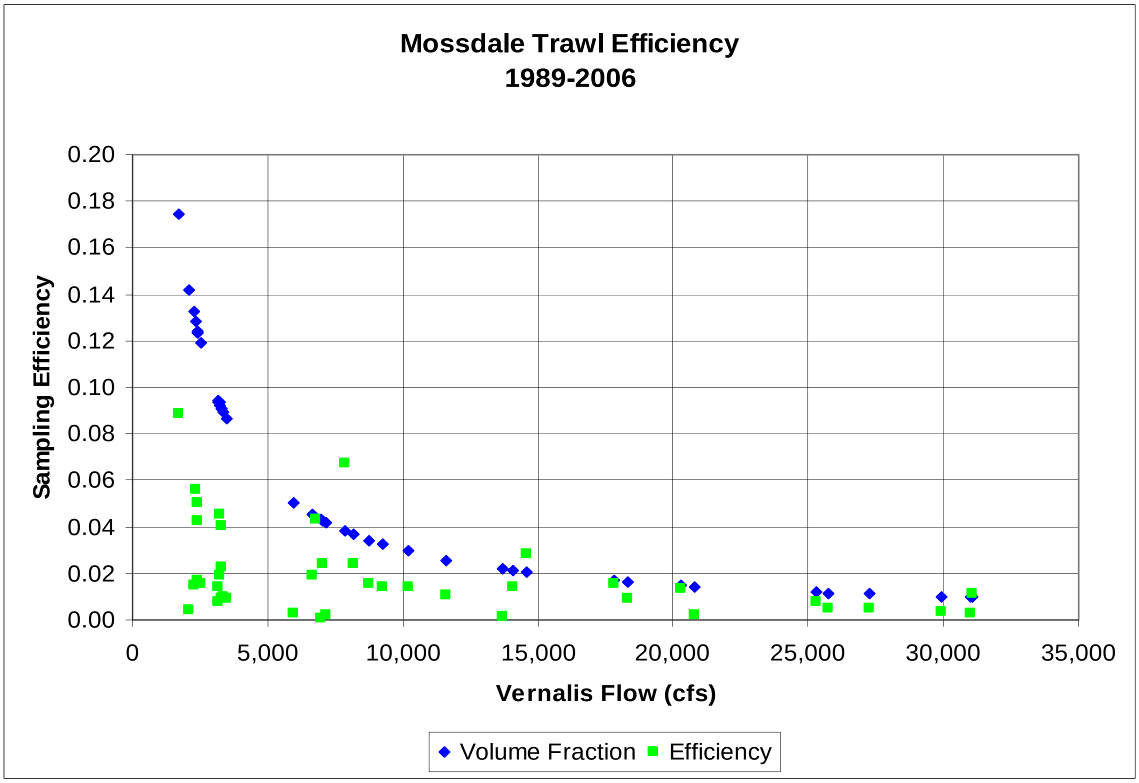
The river velocity exceeds the trawling velocity (2 feet per sec) at a flow of about 8,000 cfs.

06757.06

Jones & Stokes

Figure A-1

San Joaquin River Velocity at Mossdale as Function of River Flow at Vernalis



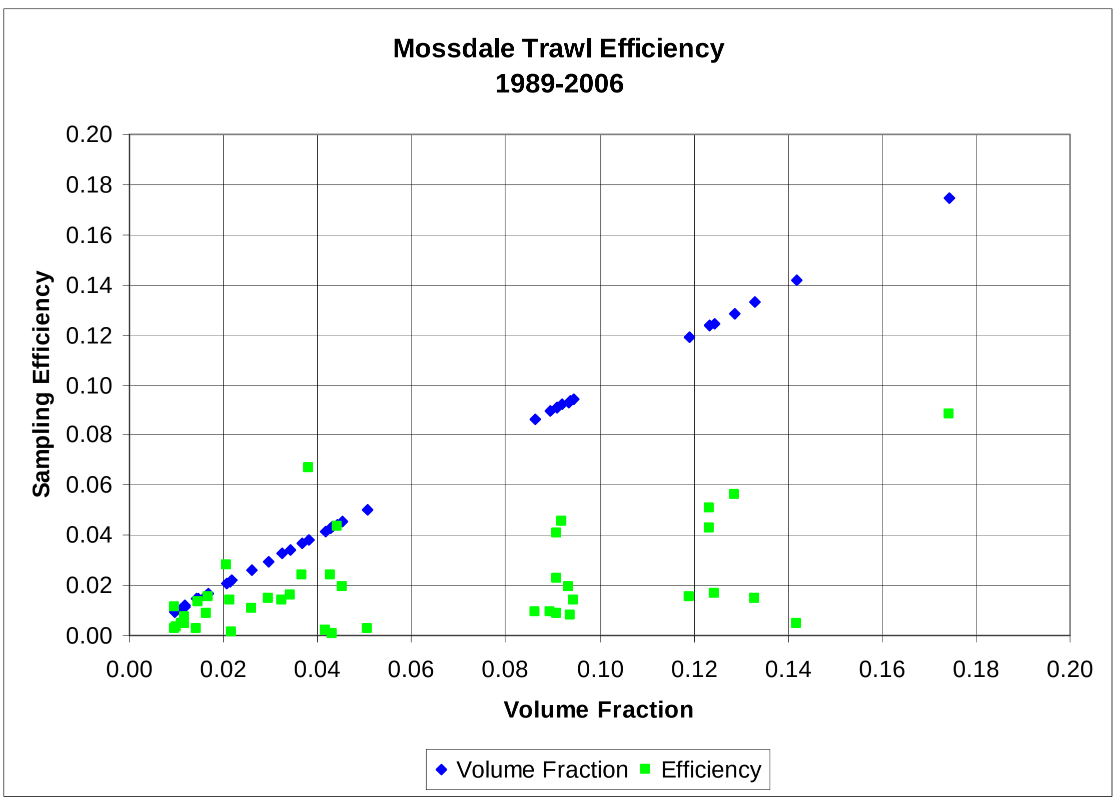


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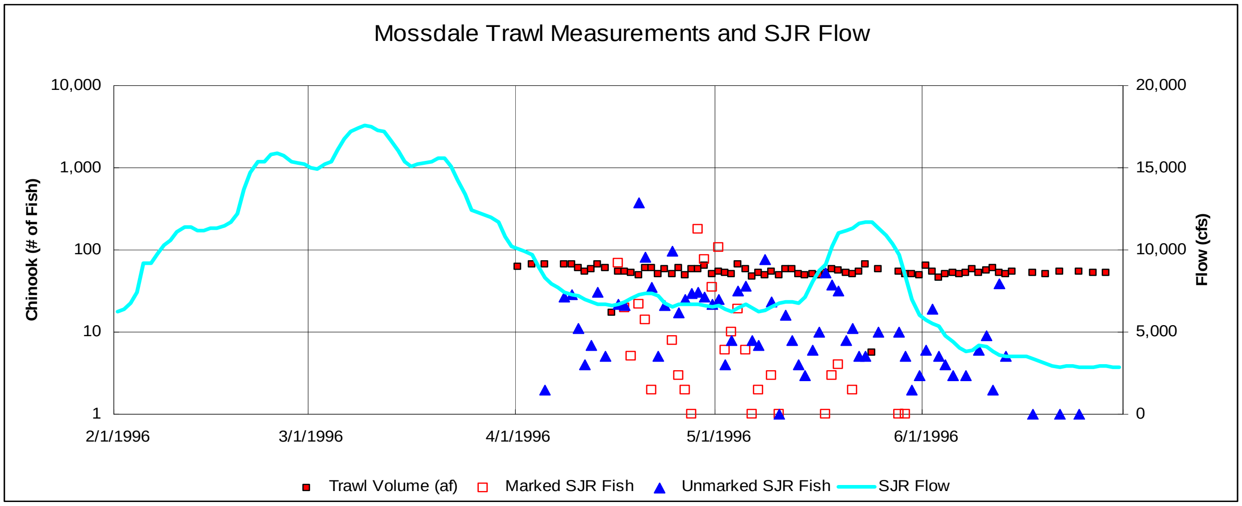
Figure A-2

Comparison of Mossdale Trawl Sampling Volume and Vulnerability of Marked Fish to Capture for 1989–2006 Mark-Recapture Trials



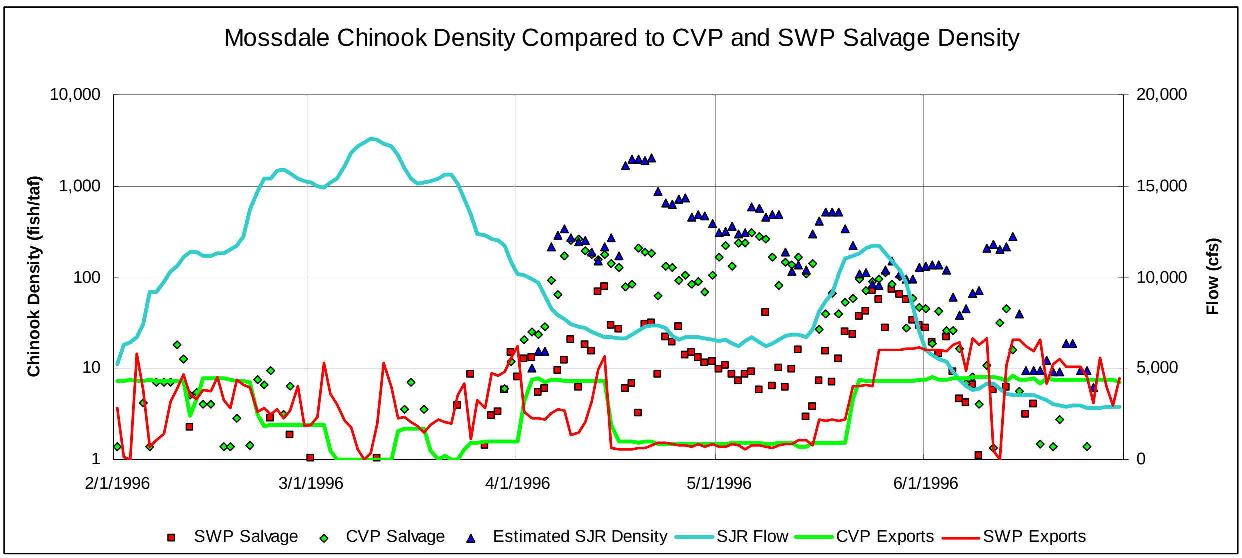


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Figure A-3

Basic Mossdale Trawl Measurements and San Joaquin River Flow Compared to CVP and SWP Pumping and Chinook Salmon Salvage Data for February–June of 1996

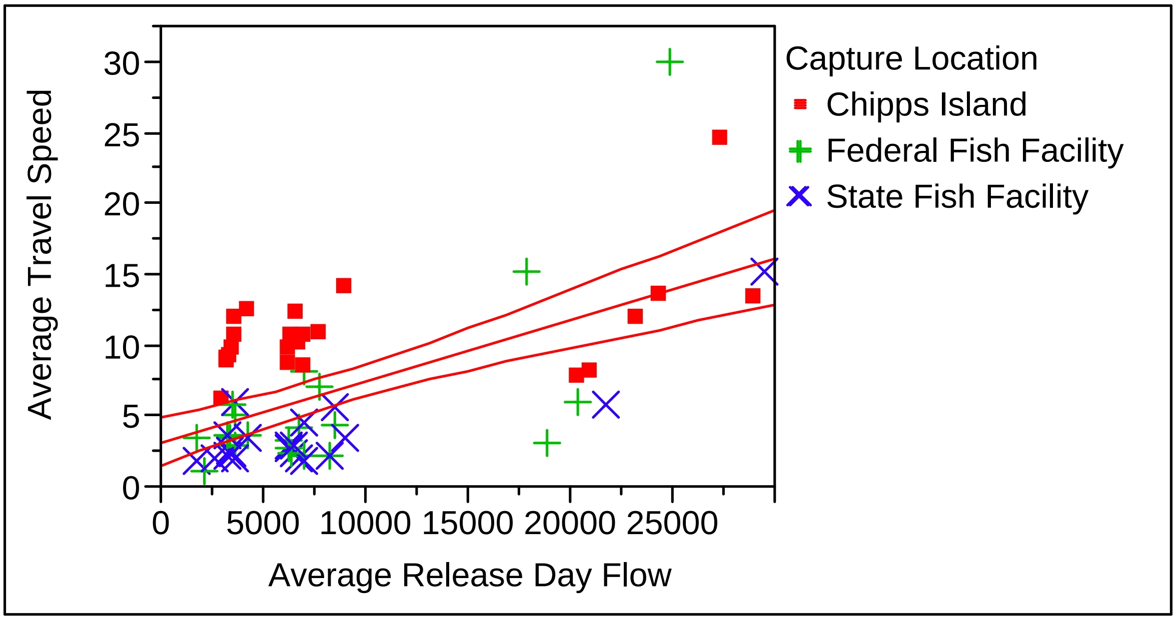

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Figure A-4

Average Release Day San Joaquin River Flows (cfs) Versus Average Travel Time to Recapture (Rsq=0.34, p<0.0001)

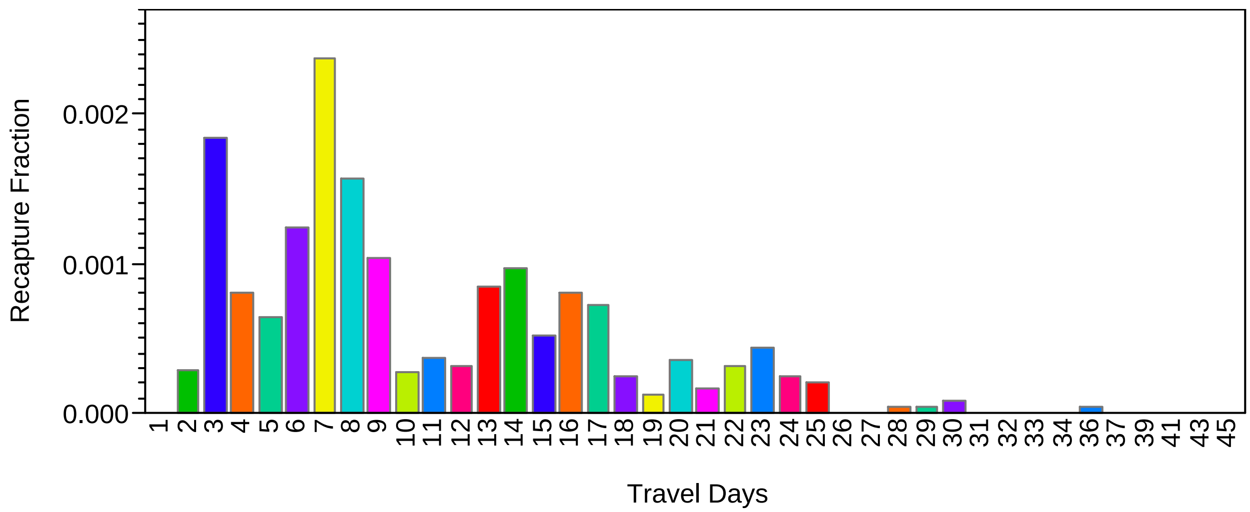

Figure A-5a. Fraction of Recaptures by Days Post Release for VAMP CWT San Joaquin Fall Chinook Salmon Released in 1999 from above the Head of Old River and Recaptured at the State Fish Salvage Facility while the Barrier Was Out

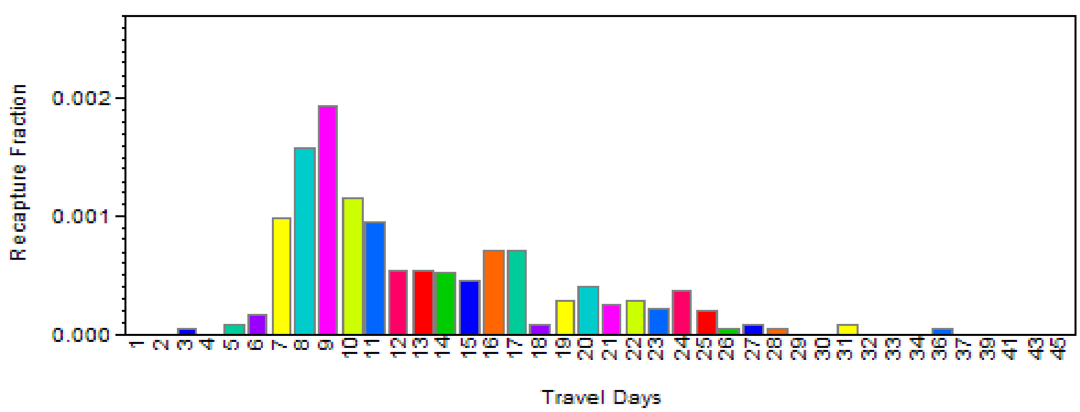

Figure A-5b. Fraction of Recaptures by Days Post Release for VAMP CWT San Joaquin Fall Chinook Salmon Released in 2000 from above the Head of Old River and Recaptured at the State Fish Salvage Facility while the Barrier was in

Photograph A-1. Aerial View of the Mossdale Kodiak Trawl being Towed by Two Boats
The Kodiak trawl samples the near-surface (25-feet wide and 6-feet deep). The Kodiak trawl cannot sample in the near-shore migration zone.

Photograph A-2. View of the Mossdale Kodiak Trawl in the San Joaquin River Channel during High Flow Conditions (Note the Flooded Riparian Vegetation)
The trawl samples about 1% (during high flows of 25,000 cfs) to 10% (during low flows of 3,000 cfs) of the water (and fish?) in the river while trawling, so the daily volumetric fraction is about 0.2% to 2% (trawling for a maximum of 5 hours each day).

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Photograph A-3. Retrieving the Mossdale Kodiak Trawl Net to Reposition Boats on a Rainy Day
This is hard and tedious work to catch and count and identify fish.

06757.06

Appendix B

Salvage Evaluation Model for Juvenile San Joaquin Chinook Salmon

Appendix B
Salvage Evaluation Model for Juvenile San Joaquin Chinook Salmon

Comparison of Measured and Estimated Salvage Patterns for 1996–2005

This appendix describes the calculated Central Valley Project (CVP) and State Water Project (SWP) salvage estimates in comparison with the measured CVP and SWP salvage for the 10 study years (1996–2005). The measured seasonal pattern of San Joaquin River Chinook salmon abundance at Mossdale are used to estimate the CVP and SWP salvage, and these estimates are compared with the observed salvage of Chinook salmon. The results using the water splits only are compared to the results for the assumed fish preferences at the head of Old River and Turner Cut flow splits, as well as at the CVP and SWP export diversion preferences. The overall seasonal matches with the measured CVP and SWP salvage numbers are used to validate the flow split and fish preference assumptions for the 1996–2005 period. Six graphs are shown for each year:

1. comparison of the San Joaquin River and Old River flows and CVP and SWP exports for the February–June period,
2. comparison of the Mossdale abundance and total salvage numbers,
3. comparison of the CVP salvage numbers,
4. comparison of the SWP salvage numbers,
5. comparison of the CVP salvage fraction of Mossdale abundance, and
6. comparison of SWP salvage fraction of Mossdale abundance.

Results for 1996

Figure B-1 (top graph) shows the flows and exports during the February–June period of 1996. The San Joaquin River flows were generally high (>10,000 cubic feet per second [cfs]) in February and March. The San Joaquin River Flows were about 6,000 cfs in April and early May, but increased to 10,000 cfs in late May, but were less than 4,000 cfs in June. The Old River diversions were about half of the San Joaquin River flows. The head of Old River barrier was installed in early May, but was removed when the flow increased in late May. Exports were about 6,000 cfs in early April and were reduced to 1,500 cfs in the second half of April and the first half of May. Exports were than raised to about 10,000 cfs in the second half of May and June. The State Water Resources Control Board (Order 96-6) required that the exports be reduced to just 25% of the San Joaquin River flow, and allowed the projects to make up this reduced pumping in October and November. This was intended as a test of the water quality control plan (WQCP) recommended exports during the Vernalis Adaptive Management Program (VAMP) period.

Figure B-1 (bottom graph) shows the daily San Joaquin River fish abundance (blue triangles) and the combined CVP and SWP daily salvage estimates for water splits only and with the assumed fish preferences. The fish abundance scale is logarithmic to allow the fraction of fish reaching CVP and SWP salvage to be more easily compared to the Mossdale abundance for the full period, which has both low and high daily fish numbers. The Mossdale trawl sampled fish from early April through most of June in 1996. The maximum abundance of San Joaquin River fish occurred in mid April, with a peak of more than 25,000 per day for a few days. Many days in late April and mid-May had more than 10,000 fish. Most of the early-April through mid-June period had more than 1,000 fish each day. The San Joaquin River abundance was much lower in early April and late June, with less than 100 fish per day. The combined daily salvage was similar to the San Joaquin River fish abundance in early April and late May, when pumping was slightly more than the San Joaquin River flow. The estimates of salvage indicate that most of the fish diverted into Old River were observed at salvage, so the combined salvage was about half of the San Joaquin River fish. On the logarithmic scale a factor of 2 is about 1/3 of the log scale interval.

The pumping was greatly reduced during the VAMP period, and the corresponding fraction of the San Joaquin River fish observed at salvage declined to less than 10%. The water splits at the export diversions accounted for part of the reduction (purple squares), but the export diversion preferences (i.e., CVP/head of Old River and SWP/[head of Old River-CVP]) provided a better match with the observed salvage during this mid-April to Mid-May period of reduced exports.

Figure B-2 shows the separate estimates for CVP and SWP salvage, based on water splits and assumed fish preferences for export diversions and Turner Cut diversions. The CVP salvage was almost always greater than SWP salvage. This was accurately predicted by assuming that head of Old River flows move past CVP salvage first, and only the remaining flows move to SWP exports. Only in the early April and late May periods when pumping was greater than head of Old River flow was there any simulated diversion at Turner Cut. The estimated and observed SWP salvage was similar to the CVP salvage in late May when the combined exports were higher than the San Joaquin River flow. The estimated SWP salvage was higher than observed during the low export period of mid-April to mid-May. There was a general agreement between the measured and estimated CVP and SWP salvage in 1996, based on the San Joaquin River Mossdale fish abundance and the San Joaquin River flow, head of Old River diversion, and CVP and SWP export diversions.

Results for 1997

Figure B-3 (top graph) shows the flows and exports during the February–June period of 1997. The San Joaquin River flows were extremely high (>20,000 cfs) in February but declined to 4,000 cfs by the end of March. The San Joaquin River flows were increased to about 6,000 cfs in mid-April through mid-May pulse period, and declined from 4,000 cfs after the pulse flow period to less than 3,000 cfs at the end of June. The head of Old River barrier was installed during the pulse flow period of mid-April to mid-May, reducing the head of Old River flow to about 500 cfs. CVP exports were about 4,000 cfs in March and early April, but were reduced during the pulse flow period and remained low until late May. CVP pumping was again 4,000 cfs during June. The SWP pumping was similar to CVP pumping, with about 4,000 cfs in March and early April, about 750 cfs during the VAMP period, about 2,000 cfs in late May and early June, and was about 4,000 cfs near the end of June.

Figure B-3 (bottom graph) shows the San Joaquin River daily fish abundance and the combined CVP and SWP daily salvage estimates for water splits only and with the assumed fish preferences. The Mossdale trawl sampled fish from mid-March when the flows had declined to 8,000 cfs. Sampling continued through June of 1997. The maximum abundance of San Joaquin River fish occurred in mid-April, with a peak of about 10,000 per day for a few days. The Mossdale fish abundance was greater than 1,000 per day from April 1 to early June. The San Joaquin River abundance declined to less than 100 fish per day by mid-June. The combined salvage was similar to the San Joaquin River fish abundance in late March, early April, late May and June, when pumping was greater than the San Joaquin River flow. The salvage was much less than the San Joaquin River abundance during the VAMP period when export pumping was reduced and the head of Old River barrier was installed. The San Joaquin River pulse flow allowed more of the San Joaquin River fish to escape the reduced pumping. The estimated salvage was similar to the measured salvage for most of the period. The measured salvage was more than the San Joaquin River abundance only in late March, when only a few Mossdale trawls sampled fish (on 3 days). These late-March salvaged fish were 100 mm (smolt-sized) and were recorded at the CVP salvage, suggesting they were of San Joaquin River origin. It is likely that the San Joaquin River abundance was several hundred a day rather than the 100 fish per day estimated from the few trawls.

Figure B-4 shows the separate estimates for CVP and SWP salvage for 1997, based on water splits and the assumed fish preferences for export diversions and Turner Cut diversions. The CVP salvage was almost always greater than SWP salvage. This was accurately predicted by assuming that head of Old River flows move past CVP salvage first, and only the remaining head of Old River flows move to the SWP exports (salvage). There were several periods when the exports were greater than the head of Old River flow, so a portion of the exports were diverted at Turner Cut. The exports were reduced substantially during the period when the head of Old River barrier was installed, so very little Turner Cut diversions were estimated during the VAMP period. The CVP salvage was greater than the San Joaquin River abundance at the end of March, and was similar to the San Joaquin River abundance in early April and late May and early June. This suggests that the CVP salvage was accurately estimated from the head of Old River flow split, with some additional salvage of fish that were diverted at Turner Cut. The assumed fish preference of 10% (avoidance) at Turner Cut more accurately estimated the CVP salvage during these high export periods than the flow splits only (i.e., CVP/San Joaquin River).

Figure B-4 (bottom graph) shows the measured SWP salvage was less than the CVP salvage and was greatest in early April and late May (1,000 fish/day). The measured SWP salvage was less than 100 fish/day during the VAMP period, equivalent to about 10% of the San Joaquin River abundance. The estimated SWP salvage with flow splits only was higher than observed, but the Turner Cut preference of 10% reduced the estimated SWP salvage to less than observed. There was a general agreement between the measured and estimated CVP and SWP salvage in 1997, based on the San Joaquin River Mossdale fish abundance and the San Joaquin River flow, head of Old River diversion, and CVP and SWP export diversions.

Results for 1998

Figure B-5 (top graph) shows the flows and exports during the February-June period of 1998. The San Joaquin River flows were extremely high (>25,000 cfs) in February and remained greater than 15,000 cfs through June. No head of Old River barrier was installed because of the high flows. CVP exports were between 2,000 cfs and 4,000 cfs for the entire period. There was no SWP pumping until late May, and SWP pumping was about 4,000 cfs at the end of June.

Figure B-5 (bottom graph) shows the San Joaquin River daily fish abundance and the combined CVP and SWP salvage estimates for water splits only and with the assumed fish preferences. The Mossdale trawl sampled fish from April through June of 1998. The maximum abundance of San Joaquin River fish occurred in early and mid May, with a peak of about 25,000 per day for a few days. The Mossdale abundance was greater than 10,000 per day from early April to early June. The San Joaquin River abundance declined to less than 1,000 fish per day in late June. This was a very abundant year for Mossdale Chinook salmon smolts. The measured combined salvage was about 1,000 fish per day in late March, and declined in mid-May to less than 100 fish per day because of reduced CVP pumping. Combined salvage was about 1,000 fish per day in May, and declined to less than 100 per day at the end of June. The estimated salvage was similar to the measured salvage for most of the period. The estimated salvage with flow splits only was more than measured salvage, but the estimates with the fish preferences were less than the measured salvage. The measured salvage was less than 5% of the San Joaquin River abundance in April, about 10% of the San Joaquin River abundance in May, and increased to a maximum of 20% of the San Joaquin River abundance at the end of June with increased exports and reduced river flow.

Figure B-6 shows the separate estimates for CVP and SWP daily salvage for 1998, based on water splits and the assumed fish preferences for export diversions and Turner Cut diversions. There was only a small SWP salvage of between 10 and 200 fish per day in late May and June. The measured CVP salvage was generally between the flow split and fish preference estimated CVP salvage. There were no periods when the exports were greater than the head of Old River flow, so all of the exported water was diverted into the head of Old River. The fish preferences at CVP and SWP were perhaps underestimated, although the measured salvage was less than the water diversions would suggest. There was some avoidance of these diversions when the Old River flow was higher than the diversions. A preference of two or three times the diversion fraction might be indicated from the 1998 data. Because less than 10% of the San Joaquin River fish were estimated to be diverted into CVP and SWP exports in 1998, the effectiveness of the head of Old River barrier would have been small had it been installed. However, CVP and SWP pumping might have been much higher during this high flow period. With higher pumping, the salvage of San Joaquin River fish would have been higher, and the head of Old River barrier (or future gate) would provide protection of up to half of the San Joaquin River fish (if exports were greater than the head of Old River diversions of 50% of the San Joaquin River flow).

Results for 1999

Figure B-7 (top graph) shows the flows and exports during the February-June period of 1999. The San Joaquin River flows increased to about 15,000 cfs in the second half of February and declined to about 8,000 cfs by mid-March and were just 5,000 in early April. The San Joaquin River flows increased to about 7,000 cfs during the VAMP period, and then declined from about 4,000 cfs after the pulse flow period to about 3,000 cfs at the end of June. The head of Old River barrier was not installed during the pulse flow period because the flows were just above the target for installation. CVP exports were about 4,000 cfs in February and March, but were reduced to less than 2,000 cfs during April and May. CVP pumping was again 4,000 cfs during June. There was no SWP pumping in February, and SWP exports were about 4,000 cfs in March and early April, were reduced to about 2,000 cfs during the VAMP period and in late May, but then declined to about 1,000 cfs in June.

Figure B-7 (bottom graph) shows the San Joaquin River daily fish abundance and the combined CVP and SWP salvage estimates for water splits only and with the assumed fish preferences. The Mossdale trawl began sampling in early February and continued through June of 1999. This extended sampling measured many smaller juvenile (fry) during February and March. The peak abundance of San Joaquin River fish occurred in mid-February (>25,000 per day) when a major storm event transported a large number of fry (35–40 mm length) past Mossdale. The Mossdale fish abundance was greater than 1,000 fish per day from February 1 to mid- June. The combined daily salvage was similar to the daily San Joaquin River fish abundance throughout most of the February-June period. The salvage was considerably less than the San Joaquin River abundance during February and

March when the small fry were transported past Mossdale. The fry may have been rearing in the Delta channels or may have been salvaged with a lower efficiency because of their smaller size (<50 mm). The combined daily salvage was sometimes greater than the Mossdale daily abundance in April and May. The measured salvage was similar to the Mossdale abundance during the VAMP period when the pulse flow was about twice the exports, and the expected salvage was less than half of the Mossdale abundance.

The estimated salvage was higher than the measured salvage in February and March, suggesting that a large fraction of these smaller fish were avoiding the salvage (i.e., rearing in the Delta channels or not being counted because of a lower louver efficiency). The estimated salvage in April and May was lower than measured. Some of the early April exports were diverted at Turner Cut, and the assumed salvage of these fish was just 10% of the water diverted. During the VAMP period of increased San Joaquin River flows and reduced exports, only about half of the Mossdale fish were expected at salvage. The measured salvage was about the same as the Mossdale abundance. The estimated salvage in June was similar to the measured salvage and was declining because the Mossdale abundance was declining.

Figure B-8 shows the separate estimates for CVP and SWP daily salvage for 1999, based on water splits and assumed fish preferences for export diversions and Turner Cut diversions. The CVP salvage was almost always greater than SWP salvage. This was accurately predicted by assuming that head of Old River flows move past CVP salvage first, and only the remaining head of Old River flows move to the SWP exports. There were many periods when the exports were greater than the head of Old River flow, so a portion of the exports were assumed to be diverted at Turner Cut. The estimated CVP salvage was greater than measured CVP salvage in March. CVP salvage was less than measured in April and early May, but was similar to measured salvage in late May and June. It is difficult to determine if the fish preferences (i.e., CVP/head of Old River and 10% at Turner Cut) were confirmed by the daily salvage patterns measured in 1999, because several factors might explain the periods of matching salvage, periods of over-estimated salvage, and periods of under-estimated salvage.

Figure B-8 (bottom graph) shows that the measured SWP salvage was greater than the estimated SWP salvage in April and May. The measured SWP salvage was about 500–1,000 fish/day during the VAMP period, equivalent to about 50% of the San Joaquin River abundance. The estimated salvage was less because the head of Old River flow supplied all of the CVP and SWP exports, and so only about half of the San Joaquin River Mossdale fish should have been salvaged. The reason for this discrepancy cannot be resolved; the Mossdale abundance may have been higher than measured, more fish than assumed may have been diverted into Old River, or more fish than assumed may have been diverted at Turner Cut.

Results for 2000

Figure B-9 (top graph) shows the flows and exports during the February-June period of 2000. The San Joaquin River flows were about 2,000 cfs in early February, but increased to 12,000 cfs in mid-February and reached 15,000 cfs in early March. Flows declined to about 6,000 cfs at the end of March and were about 3,000 cfs in mid-April, when the VAMP pulse flow increased flows to about 6,000 cfs. Flows were about 4,000 cfs at the end of May, and declined to about 2,000 cfs at the end of June. The head of Old River barrier was installed to protect juvenile Chinook salmon during the pulse flow period. Combined exports were 12,000 cfs in February and early March, were reduced slightly to 8,000 from mid-March until VAMP, and were about 2,500 cfs during VAMP. Exports remained less than 4,000 cfs until the last week in May when exports increased to about 7,000 cfs and remained constant through June.

Figure B-9 (bottom graph) shows the San Joaquin River daily fish abundance and the combined CVP and SWP daily salvage estimates for water splits only and with the assumed fish preferences. The Mossdale trawl began sampling in early February and continued through June of 2000. This extended sampling again measured many smaller juvenile (fry) during February and March. The peak abundance of San Joaquin River fish occurred in mid-February (>25,000 per day) when a major storm event transported a large number of fry (35–40 mm length) past Mossdale. A second peak in abundance (5,000 fish per day) occurred in mid-March. The Mossdale juvenile fish (>75 mm) abundance was greater than 1,000 fish per day from early April to mid- June.

The combined daily salvage was similar to the San Joaquin River daily fish abundance prior to the VAMP period and after the VAMP period, when exports were greater than the San Joaquin River flows. The measured salvage was less than the San Joaquin River abundance during the VAMP period because of the reduced exports and the head of Old River barrier. Separating the benefits of these two simultaneous actions is difficult. The salvage was about half the San Joaquin River Chinook salmon abundance during February and March when the small fry (<50 mm) were transported past Mossdale. Some of the fry should have escaped salvage because the exports were less than the San Joaquin River flow. In addition, some fry may have reared in the Delta channels or may have been salvaged with a lower efficiency because of their smaller size. The combined salvage was reduced considerably (10% of the San Joaquin River abundance) during the VAMP and late May period.

Figure B-10 shows the separate estimates for CVP and SWP daily salvage for 2000, based on water splits and the assumed fish preferences for export diversions and Turner Cut diversions. The CVP salvage was much greater than SWP salvage in February and March. Because the head of Old River diversions were greater than CVP exports for most of the period, the estimated CVP salvage matched the measured CVP salvage without any fish preferences. The measured SWP salvage was higher than the estimated SWP salvage during the VAMP period. The water splits only provided a better match, suggesting that the assumed fish preference (i.e., avoidance) at Turner Cut was too low, and more of the fish were diverted with the water at Turner Cut. The general match of the estimated salvage with the measured CVP and SWP salvage suggests that most of the San Joaquin River Chinook salmon will be salvaged whenever the exports are greater than the San Joaquin River flow. The relative benefits from export reductions and the head of Old River barrier are difficult to determine because both factors are changed at the same time under the VAMP program. The higher than expected SWP salvage during the VAMP period in 2000 may indicate that more fish than assumed were diverted at Turner Cut when exports remained higher than the reduced head of Old River diversion flow.

Results for 2001

Figure B-11 (top graph) shows the flows and exports during the February-June period of 2001. The San Joaquin River flows were about 2,000 cfs in early February, and increased to about 6,000 cfs in late-February and again in early March. Flows declined to about 2,000 cfs at the end of March and were about 2,000 cfs in mid-April, when the VAMP pulse increased flows to about 4,000 cfs. Flows were about 2,000 cfs at the end of May, and remained at about 2,000 cfs through June. The head of Old River barrier was installed to protect juvenile Chinook salmon during the pulse flow period. Combined exports were greater than 6,000 cfs in February and March, were reduced slightly to 5,000 in early April, and were about 1,500 cfs during VAMP. Exports remained at 1,500 until the end of May when exports increased to about 3,000 cfs through June. Exports were higher than the San Joaquin River flows except during the mid-April through May period.

Figure B-11 (bottom graph) shows the San Joaquin River daily fish abundance and the combined CVP and SWP daily salvage estimates for water splits only and with the assumed fish preferences. The Mossdale trawl began in early February and continued through June of 2001. Because the late February and early storms were relatively small, the extended sampling did not measure many fry during February and March. The peak abundance of San Joaquin River fry was during the early March runoff, with less than 1,000 fish per day. The juvenile abundance was greater than 1,000 per day from early April to the end of May. A peak of more than 10,000 fish per day was observed in late April and again in mid-May.

The combined daily salvage was similar to the San Joaquin River daily fish abundance prior to the VAMP period, when exports were greater than the San Joaquin River flow. The measured salvage was much less than the San Joaquin River abundance during the VAMP period because of the increased San Joaquin River flows, reduced exports and the installation of the head of Old River barrier. The salvage was about 10% of the San Joaquin River Chinook salmon abundance during VAMP, and continued to decline as a fraction of the San Joaquin River abundance in late May and June. Water temperatures reached 75ºF in mid-May, and the high temperatures may have contributed to the lower than expected salvage during the second half of May and early June.

Figure B-12 shows the separate estimates for CVP and SWP daily salvage for 2001, based on water splits and assumed fish preferences. The estimated CVP salvage matched the measured CVP salvage in March and April, when the exports were greater than the San Joaquin River flows, with almost all the San Joaquin River fish ending up in the CVP salvage. But the measured CVP salvage was less than expected in May and June, perhaps the result of higher mortality because of warm water temperatures (>75ºF). The estimated SWP salvage matched the measured SWP salvage in March and April, but was lower than measured in May and June. The water splits only provided a better match, suggesting that the assumed fish preference (i.e., avoidance) at Turner Cut was too low.

The general match of the estimated salvage with the measured CVP and SWP salvage suggests that most of the San Joaquin River Chinook salmon will be salvaged whenever the exports are greater than the San Joaquin River flow. The relative benefits from export reductions and the installation of the head of Old River barrier are difficult to determine because both factors are changed at the same time under the VAMP program. The lower than expected SWP salvage during May and early June of 2001 may indicate that a considerable number of fish measured at Mossdale did not survive because of the warm temperatures.

Results for 2002

Figure B-13 (top graph) shows the flows and exports during the February–June period of 2002. The San Joaquin River flows were about 2,000 cfs from February through mid-April when the VAMP pulse increased the river flow to 3,000 cfs. Flows declined after the VAMP pulse to 2,000 cfs through June. These are very low flows without any storm events. The head of Old River barrier was installed to protect juvenile Chinook salmon during the pulse flow period. Combined exports were about 8,000 cfs in February, March and early April. Exports were reduced to about 1,500 cfs during VAMP and continuing to the end of May (Environmental Water Account [EWA] actions). Exports were increased to about 4,000 cfs in June.

Figure B-13 (bottom graph) shows the San Joaquin River daily fish abundance and the combined daily CVP and SWP salvage estimates for water splits only and with the assumed fish preferences. The Mossdale trawl began sampling in early March and continued through June of 2002. There were no Chinook salmon fry observed in March. The San Joaquin River juvenile abundance was about 500 fish per day in early April, and increased to about 1,000 fish per day for most of April. The peak abundance of 25,000 fish per day was observed in early May. The abundance declined to about 2,500 fish/day by mid-May, and was less than 1,000 fish/day in the last week of May and less than 100 fish/day after the first week of June. Temperatures were greater than 75ºF in the last week of May and early June.

The combined salvage was similar to the San Joaquin River fish abundance in the first week of April and the first week of June. The measured salvage was much less than the San Joaquin River abundance during the VAMP period because of the increased San Joaquin River flows, reduced exports and the head of Old River barrier. The salvage was about 10% of the San Joaquin River abundance during VAMP.

Figure B-14a shows the separate estimates for CVP and SWP salvage for 2002, based on water splits (i.e., flow ratios) and assumed fish preferences. The estimated CVP salvage matched the measured CVP salvage in early April and late May, when the exports were greater than the San Joaquin River flow, with almost all the San Joaquin River fish ending up in the CVP salvage. But the measured CVP salvage was less than estimated during the VAMP period. The observed CVP salvage did not increase during the peak San Joaquin River abundance observed in early May.

There was a measured (Vernalis minus Stockton) flow through the barrier of about 500 cfs in 2002. This flow (culverts and leakage) does not appear to divert the assumed San Joaquin River Chinook salmon density when the barrier is installed. A change in the model calculations was made to assume a fish preference (avoidance) of 0.1 when the barrier was installed. This reduced the estimated salvage to match the measured CVP salvage during the VAMP period. Figure B-14b shows the improved match with measured CVP and SWP salvage during the barrier period, assuming a fish preference (avoidance) of 0.1. This assumed fish avoidance when the head of Old River barrier is installed should also improve the estimates for other years with the barrier installed (i.e., for 1996, 1997, 2000, 2001, 2003, 2004).

The measured SWP salvage was less than the measured CVP salvage in early April and late May and June. The SWP salvage was similar to the CVP salvage during the VAMP period when the barrier was installed. This suggests that the barrier excludes most of the fish from the reduced head of Old River diversion when the barrier is installed, and the assumed fish preference (avoidance) of 0.1 for the Turner Cut diversion was generally confirmed for 2002. For 2002, most of the observed reduction in salvage was the likely the result of reducing the exports.

Results for 2003

Figure B-15 (top graph) shows the San Joaquin River flows and exports during the February-June period of 2003. The San Joaquin River flows were a repeat of 2002 conditions, with about 2,000 cfs from February through mid-April when the VAMP pulse increased the river flow to 3,000 cfs. Flows declined after the VAMP pulse to about 2,000 cfs through June. The head of Old River barrier was installed to protect juvenile Chinook salmon during the pulse flow period. Combined exports were greater than 10,000 cfs in February and March and about 8,000 cfs in early April. Exports were reduced to about 1,500 cfs during VAMP and were increased to about 2,000 cfs to the end of May. Exports were increased to about 10,000 cfs in June.

Figure B-15 (bottom graph) shows the San Joaquin River daily fish abundance and the combined CVP and SWP daily salvage estimates for water splits only and with assumed fish preferences for 2003. The Mossdale trawl began sampling in early February and continued through June of 2002. There were no Chinook salmon fry until mid-March, when about 100 fish/day were observed. The San Joaquin River juvenile abundance increased to about 1,000 fish per day by mid-April, and showed three peaks of 5,000/day in mid-April, late April, and early May. These peaks occurred during the VAMP pulse flows of about 3,000 cfs. The abundance declined to less than 1,000 fish/day by mid-May and were less than 100 fish/day at the end of May. Temperatures were greater than 75ºF at the end of May and early June, which may have influenced the San Joaquin River abundance.

The combined salvage was similar to the San Joaquin River fish abundance in the first half of April and the second half of May and June. The measured salvage was much less than the San Joaquin River abundance during the VAMP period because of the increased San Joaquin River flows, reduced exports and the head of Old River barrier. The combined daily salvage was less than 10% of the San Joaquin River daily abundance during VAMP.

Figure B-16 shows the separate estimates for CVP and SWP salvage for 2003, based on water splits (i.e., flow ratios) and assumed fish preferences. The estimated CVP salvage matched the measured CVP salvage in early April and late May, when the exports were greater than the San Joaquin River flow, with almost all the San Joaquin River fish ending up in the CVP salvage. Estimated CVP salvage also matched the measured CVP salvage during the VAMP period, with the head of Old River preference of 0.1 when the barrier was installed.

The measured SWP salvage was about the same as the measured CVP salvage throughout 2003. The estimated SWP salvage was much less than the measured salvage in late March and early April, when exports were much higher than the San Joaquin River flow, and a majority of the SWP salvage would have come through Turner Cut. This again suggests that the Turner Cut fish preference was greater than 0.1. The Turner Cut diversion and fish preference primarily affects the SWP salvage, and it is difficult to isolate the influence of the Turner Cut fish preference assumption.

Results for 2004

Figure B-17 (top graph) shows the San Joaquin River flows and exports during the February–June period of 2004. The San Joaquin River flows were again very low, like 2002 and 2003. San Joaquin River flows were less than 2,000 cfs in early February, with a small storm of 4,000 cfs in late February, and again in late March with a peak flow of 4,500 cfs. Flows decreased to about 2,000 cfs in mid-April, when the VAMP pulse flow of 3,000 cfs began. Flows were again about 2,000 cfs by the end of May, and declined to about 1,500 cfs in June. The head of Old River barrier was installed to protect juvenile Chinook salmon during the pulse flow period. Combined exports were 8,000 cfs to 12,000 cfs in February and were greater than 10,000 cfs in March, and were about 8,000 cfs in early April. Exports were reduced to about 1,500 cfs during VAMP and were increased to about 2,000 cfs to the end of May. Exports were increased to about 6,000 cfs in June. The SWP and CVP pumping switched back and forth during VAMP. Exports were greater than the San Joaquin River flows except during VAMP.

Figure B-17 (bottom graph) shows the San Joaquin River daily fish abundance and the combined CVP and SWP daily salvage estimates for water splits only and with assumed fish preferences for 2004. The Mossdale trawl began sampling in early January and continued through June of 2004. There were Chinook salmon fry (<50 mm) observed beginning in mid-February when a very small storm increased the flows. A peak abundance of 10,000 fish/day was observed in early February when a storm flow of 4,000 cfs was measured. The fry abundance declined to about 100/day by mid-March and increased to 1,000/day at the end of March (second small storm). The smolt abundance was less than 1,000/day in early April, and increased to more than 1,000/day during the VAMP pulse flow. Peak abundance of about 5,000/day was observed during the middle two-weeks of the VAMP period. The abundance declined to less than 1,000/day by mid-May and was less than 100/day at the end of May. No fish were observed at Mossdale in June, perhaps because water temperatures were warmer than 75ºF.

The combined salvage was similar to the San Joaquin River fish abundance in March and the first half of April and during the second half of May. The measured salvage was much less than the San Joaquin River abundance during the VAMP period because of the increased San Joaquin River flows, reduced exports and the head of Old River barrier. The salvage was less than 10% of the San Joaquin River abundance during VAMP.

Figure B-18 shows the separate estimates for CVP and SWP salvage for 2004, based on water splits and assumed fish preferences for head of Old River diversions, export diversions and Turner Cut diversions. The estimated CVP salvage matched the measured CVP salvage in March, early April and late May, when the exports were much greater than the San Joaquin River flow, with almost all the San Joaquin River fish ending up in the CVP salvage. Estimated CVP salvage also matched the measured CVP salvage during the VAMP period, with the head of Old River fish preference of 0.1.

The measured SWP salvage was much lower than the measured CVP salvage in March. This suggests that fewer fish were diverted at Turner Cut than the water fraction would suggest. However, it is difficult to determine the fish preference for the Turner Cut diversion flow. The modeled value of 0.1 appears to underestimate the SWP salvage (similar to 2003 results). This may suggest that the Turner Cut fish preference may be greater than 0.1. The estimated CVP salvage was similar to the measured CVP salvage throughout the March-May period. Some CVP salvage was observed in June, although there were no Mossdale fish sampled.

Results for 2005

Figure B-19 (top graph) shows the San Joaquin River flows and exports during the February–June period of 2005. The San Joaquin River flows were about 4,000 cfs in early February, and increased to 8,000 cfs with a major storm at the end of February. Flows decreased to about 6,000 cfs by mid-March, and increased to about 15,000 cfs in early April. The flow decreased to about 8,000 cfs by mid-April, but the head of Old River barrier was not installed. Flows remained at about 8,000 cfs during the VAMP period and then increased to 15,000 cfs with a late storm in early June. Flows decreased to about 6,000 cfs by the end of June. Combined exports were 8,000 cfs in February and varied between 6,000 cfs and 8,000 cfs in March. Exports were about 8,000 cfs in early April. During the VAMP period, exports were 4,000 cfs for the first two weeks and then reduced to 2,000 cfs for two weeks in May. Exports increased to about 6,000 cfs at the end of May and were greater than 10,000 cfs in June. Exports were less than the San Joaquin River flows from late-March until early June.

Figure B-19 (bottom graph) shows the San Joaquin River daily fish abundance and the combined CVP and SWP daily salvage estimates for water splits only and with assumed fish preferences for 2005. The Mossdale trawl began sampling in early January and continued through June of 2005. There were Chinook salmon fry (<50 mm) observed beginning in early January, with peaks of greater than 1,000 fish/day in early and late February, and early and late March, corresponding to periods of increased river flows. A pulse of fry was associated with the initial flow increase of each storm event. The late March peak was about 5,000 fish/day. Juvenile (>75 mm) abundance was greater than 1,000 fish/day from mid-April through mid-June. A peak abundance of 10,000 fish/day was observed in early May and a peak of 20,000 fish/day was observed in late May. The abundance was less than 10,000 fish/day by June, and was less than 1,000 fish/day by mid-June. The high flows apparently maintained water temperatures of less than 65ºF by the end of May and less than 70ºF by the end of June. This allowed smolt migration at Mossdale to continue into June.

The combined salvage was less than the Mossdale abundance in February and March, although the exports were greater than the San Joaquin River flow. This may suggest that many of the fry (<50 mm) reared in Delta channels. Salvage was similar to the San Joaquin River abundance in early April and was about half of the Mossdale abundance at the end of April. Salvage was less than the water split only estimates, suggesting that the CVP and SWP fish preferences were properly estimated as the ratio of CVP/Old River flow, when the exports were less than the Old River flow. The measured salvage was less than estimated in late May and June. The exports were less than the Old River flow, and there was a greater avoidance (lower preference) than estimated for the CVP and SWP diversions.

Figure B-20 shows the separate estimates for CVP and SWP salvage for 2005, based on water splits and assumed fish preferences. The estimated CVP salvage was greater than measured in February and March. The estimated CVP salvage was lower than observed in early April when the San Joaquin River flows were greater than exports. The estimated CVP salvage matched the measured CVP salvage during the VAMP period and most of May, but the measured CVP salvage was lower than estimated in June.

The measured SWP salvage was much lower than the measured CVP salvage in February and March. The measured SWP salvage was generally lower than the estimated SWP salvage in April and May. The fish preference for the SWP diversions was lower than the assumed ratio of the SWP exports/Old River flow. The pattern of measured SWP salvage was well matched by the estimated SWP salvage, reflecting the San Joaquin River daily abundance, the flow splits, and the assumed fish avoidance ratios. The effectiveness of the barrier cannot be directly evaluated for 2005 because it was not installed. However, less than 10% of the San Joaquin River fish were salvaged because of the reduced exports during the VAMP period and the observed fish avoidance of the CVP and SWP export diversions when the Old River flow was relatively high. Therefore, the head of Old River barrier could have protected only 10% of the San Joaquin River Chinook salmon abundance during the VAMP period.

Comparison of Splittail Mossdale Abundance and Splittail Salvage

Splittail Results for 1996

Splittail are the second most abundance fish observed in the Mossdale trawl. The peak abundance of splittail is generally observed in May and June, about a month later than the peak abundance of fall-run Chinook salmon. The measured daily abundance at Mossdale for May and June of 1996 are shown as an example of the migration of these juvenile splittail from upstream spawning along the San Joaquin River and tributary streams. Splittail spawning is generally observed in submerged wetlands and in flooded floodplain vegetation areas. There may be considerably more spawning and early rearing habitat during high flow springs (like 1996) with flooded areas adjacent to the San Joaquin River and its tributaries.

Figure B-21 (top graph) shows the measured Mossdale splittail abundance, based on a volumetric expansion of the trawl catch, which peaked at about 100 per day in mid-May and early June of 1996. A five-day centered moving average was used to smooth the Mossdale daily splittail abundance pattern. The Mossdale splittail abundance increased rapidly in early May, and was greater than 10,000 per day from mid-May through mid-June. The trawl catch declined during the peak flow event in late-May, perhaps because the splittail responded to the flooding conditions by delaying their migration out of the newly flooded habitat. Figure B-21 (bottom graph) shows the splittail length data for May and June of 1996. The splittail began migrating (or were first caught by the Trawl) in early May at an average length of about 30 mm, and were 50 mm in early June. Migration may have continued into July (Mossdale Trawl did not sample in

July), although the CVP and SWP salvage was lower than in June, with combined salvage of about 100–300 per day in July.

The CVP salvage of splittail increased in early May to about 500/day and reached about 1,000/day in late May. The peak CVP splittail salvage of more than 2,000/day was observed in late May and mid-June. The SWP splittail salvage was generally lower than at CVP, although the SWP and CVP daily salvage was similar in late May when pumping was increased to greater than the San Joaquin River flow. During June, with combined pumping much greater than the San Joaquin River flows, the combined splittail salvage was only about 10% of the Mossdale splittail abundance. The combined salvage was about 2,000/day in early June and declined to about 500/day at the end of June.

Possible reasons for the lower splittail salvage (compared to the Mossdale splittail abundance) may include lower salvage efficiency for these relatively small fish (<50 mm). Another explanation would be the possibility that many of the splittail find suitable rearing habitat in the submerged tidal vegetation along the south Delta channels, and do not continue migrating past the CVP and SWP facilities. The head of Old River barrier may not be as effective for reducing splittail salvage as for reducing Chinook salmon salvage, if more of the splittail rear in the south Delta channels and do not move past the salvage facilities.

The head of Old River evaluation methods were used to estimate the number of splittail expected in CVP and SWP salvage. Figure B-22 shows the estimated CVP and SWP salvage of splittail for 1996 with the same water splits and fish preferences as used for Chinook salmon. The flow-split estimates of salvage were much higher than the measured salvage. The estimated CVP salvage in early May was lower than the observed CVP salvage. The lower fraction of Mossdale splittail reaching the salvage facilities during the mid-April to mid-May VAMP period was reasonably matched. The estimated SWP splittail salvage was lower in late May and June because less of the San Joaquin River water reached the SWP exports. The assumed fish preference of 0.1 at Turner Cut reduced the estimated SWP salvage in June. However, the reduced salvage might also be attributed to the hypothesis that most of the splittail were finding suitable rearing habitat along the Delta channels, rather than migrating past the Turner Cut diversion. The estimated CVP salvage was much higher than observed in late May and June. Nevertheless, the seasonal Mossdale abundance pattern and the CVP and SWP salvage records appear to match reasonably well.

Splittail Results for 2005

Figure B-23 (top graph) shows the measured Mossdale splittail abundance, based on a volumetric expansion of the trawl catch, which peaked at about 1,000 per day in mid-May and mid-June of 2005. The Mossdale splittail abundance increased rapidly in early May, and was greater than 10,000 per day from mid-May until the end of May and again from early June through mid-June. The peak splittail abundance was more than 50,000 per day in late May and more than 100,000 per day in mid-June. The trawl catch declined during the peak flow event in late-May (just like in 1996), perhaps because the splittail responded to the flooding conditions by delaying their migration out of the re-flooded habitat. Figure B-23 (bottom graph) shows the splittail length data for May and June of 2005. The splittail began migrating (or were first caught by the Trawl) in early May at an average length of about 30 mm, and were 60 mm by mid-June.

The CVP salvage of splittail increased in early May to about 100/day and reached about 1,000/day in mid-May. The CVP splittail salvage was more than 3,000/day in late May and was more than 50,000 per day in mid-June. The SWP splittail salvage was generally similar to the CVP splittail salvage, although the SWP splittail salvage was about 3,000 per day in mid-June. The combined splittail salvage was about 10% of the Mossdale abundance in May, because the pumping was only about 10% of the San Joaquin River flows. During June, as the combined pumping increased and the San Joaquin River flows decreased, the combined splittail salvage was more than 50% of the Mossdale abundance.

Figure B-24 shows the estimated CVP and SWP salvage of splittail for 2005 with the same water splits and fish preferences as used for Chinook salmon. The flow-split estimates of CVP and SWP salvage were slightly higher than the measured salvage, but the estimated salvage with the fish preferences matched the measured CVP and SWP splittail salvage very well. The lower fraction of Mossdale splittail reaching the salvage facilities during the mid-April to mid-May VAMP period was reasonably matched. The Mossdale splittail abundance declined during late May as the San Joaquin River flow increased. The decline in estimated CVP and SWP salvage from mid-May to the end of May matched the measured CVP and SWP splittail salvage. The estimated SWP splittail salvage peak in mid-June was not observed in the SWP salvage. The assumed fish preference of 0.1 at Turner Cut reduced the estimated SWP salvage in June. However, the reason reduced salvage might also be attributed to the hypothesis that most of the splittail were finding suitable rearing habitat along the Delta channels, rather than migrating past the Turner Cut diversion. The seasonal Mossdale splittail abundance pattern and the CVP and SWP splittail salvage records appear to match reasonably well for 2005 (better than 1996). These splittail data from the Mossdale trawl and from the CVP and SWP salvage records for 1996 and 2005 provide additional confirmation of the methods used to expand and compare the Mossdale trawl abundance with the salvage records for juvenile Chinook salmon.

Comparison of Estimated and Measured Salvage Fraction

Perhaps the most important result from the salvage fraction estimates are the daily fractions of the San Joaquin River fish that are expected at CVP and SWP salvage. These daily estimates are provided for the 1996–2005 conditions in the following section.

Results for 1996

Figure B-25 shows the estimated and measured fraction of the San Joaquin River fish in the CVP and SWP salvage for 1996 conditions. The daily San Joaquin River flow at Vernalis and Old River flow as well as the daily CVP and SWP pumping are shown for reference. There were two periods in 1996 when the CVP salvage fraction were greater than 0.1 (10% of the San Joaquin River fish). In early April the CVP pumping was increased to about 4,000 cfs and the estimated CVP salvage fraction increased from about 0.4 to 0.6 as the Old River flow decreased (because the CVP preference is assumed to be CVP/Old River flow). The measured CVP salvage fraction was about 0.4 at the beginning of this period, but declined to 0.1 by mid-April. During the period of reduced exports, the estimated and measured CVP salvage fractions were less than 0.1.

The estimated CVP salvage fraction increased in late-May when CVP pumping increased to about 4,000 cfs. The estimated CVP salvage fraction was 0.3 when the Old River flow was 5,000 cfs (greater than CVP exports) and increased to greater than 0.6 as the Old River flow declined to about 2,000 cfs in June. The measured daily CVP salvage fraction was variable, ranging from about 0.2 to 0.8 throughout the period of high pumping. The estimated and measured SWP salvage fractions were highest in these same two periods, but the estimated SWP salvage fraction was only about 0.2 at the end of May. The measured SWP salvage fraction was less than 0.1 at the end of May. The CVP salvage fraction was much higher than the SWP salvage fraction, because most of the Old River flow was exported at the CVP pumps. There was some Old River flow exported at SWP in late May, corresponding to the maximum estimated SWP salvage fraction of about 0.2.

Results for 1997

Figure B-26 shows the estimated and measured fraction of the San Joaquin River fish in the CVP and SWP salvage for 1997 conditions. There were two periods in 1997 when the CVP salvage fraction were greater than 0.1 (10% of the San Joaquin River fish). In early late March and early April the CVP pumping about 4,000 cfs and the estimated CVP salvage fraction was about 0.6 because the Old River flow carried about 50% of the San Joaquin River fish to the CVP pumps. These same conditions (CVP exports greater than Old River flow) were observed at the end of May and in June. The estimated CVP salvage fraction was about 0.6. The measured CVP salvage fraction was variable, from about 0.2 to 0.6 during June. During the period of reduced exports in April and May, the estimated and measured CVP salvage fractions were less than 0.1.

The estimated and measured SWP salvage fractions were highest in early April, but the estimated SWP salvage fraction was only about 0.1. The measured SWP salvage fraction was less than 0.2 in early April and was generally less than 0.1 throughout 1997. The CVP salvage fraction was higher than the SWP salvage fraction because most of the Old River flow was exported at the CVP pumps.

Results for 1998

Figure B-27 shows the estimated and measured fraction of the San Joaquin River fish in the CVP and SWP salvage for 1998 high flow and low export conditions. The estimated and measured CVP salvage fractions were less than 0.1 in May and June when Old River flows were about 8,000 cfs and CVP pumping was about 2,000 cfs. The estimated and measured SWP salvage fractions were greater than 0.1 only at the end of June when SWP pumping increased to 5,000 cfs. The CVP and SWP salvage fractions remained much less than the exports/San Joaquin River flow ratio because of the assumed fish preference (avoidance) when Old River flows are greater than exports.

Results for 1999

Figure B-28 shows the estimated and measured fraction of the San Joaquin River fish in the CVP and SWP salvage for 1999 conditions. CVP pumping was about 4,000 cfs in February and March, and the estimated CVP salvage fraction varied inversely with flow from about 0.2 at a San Joaquin River flow of about 15,000 cfs to 0.6 at a San Joaquin River flow of 6,000 cfs. The CVP salvage fraction was generally less than 0.2 during the VAMP period and increased to more than 0.5 in late May and June as CVP pumping increased and San Joaquin River flow declined. The measured CVP salvage fraction was only about 0.2 in February and March, considerably lower than the estimated CVP salvage fraction. The measured CVP salvage fraction was variable in April, May, and June, with some periods when CVP salvage was greater than the estimated Mossdale abundance.

The SWP pumping was generally low in 1999, with highest pumping of about 4,000 in March and early April. The maximum SWP salvage fraction was about 0.2 in March and 0.4 in early April. The estimated SWP salvage fraction was less than 0.2 in May and less than 0.1 in June. The measured SWP salvage fractions were generally similar to the estimated SWP salvage fractions, but were higher than estimated during the VAMP period. The CVP salvage fractions were generally higher than the SWP salvage fraction, because most of the Old River flow was exported at the CVP pumps, and SWP pumping was less than CVP pumping.

Results for 2000

Figure B-29 shows the estimated and measured fraction of the San Joaquin River fish in the CVP and SWP salvage for 2000 conditions. CVP pumping was about 4,000 cfs in February, March and early April, and the estimated CVP salvage fraction varied inversely with flow from about 0.2 at a San Joaquin River flow of about 15,000 cfs to 0.8 at a San Joaquin River flow of 2,000 cfs. The CVP salvage fraction was generally less than 0.1 during the VAMP period and increased to more than 0.4 in late May and June as CVP pumping increased and San Joaquin River flow declined. The measured CVP salvage fraction was quite variable in February and March, generally ranging from 0.2 to 0.6. The measured CVP salvage fraction was less than 0.1 during VAMP and increased to 0.6 in late May and was variable between 0.2 and 0.6 in June.

The SWP pumping was variable between 4,000 cfs and 8,000 cfs in February and March. The estimated SWP salvage fraction ranged from about 0.1 to 0.4 in February and March. The measured SWP salvage fraction remained less than 0.1 during this period of Chinook salmon fry migration. In early April, the estimated SWP salvage fraction was about 0.1 because the San Joaquin River flow was not sufficient to supply the CVP and the SWP exports. However, the measured SWP salvage fraction ranged from 0.2 to 0.4 during this period. The SWP salvage fraction was less than 0.1 during VAMP, and increased to about 0.2 to 0.4 after VAMP. The measured SWP salvage fractions were more variable but similar in magnitude to the estimated SWP salvage fractions in April, May and June.

Results for 2001

Figure B-30 shows the estimated and measured fraction of the San Joaquin River fish in the CVP and SWP salvage for 2001 conditions. The San Joaquin River flows were low (peak of 6,000 cfs in early March declining to 2,000 cfs in March) during the juvenile out-migration period of February through June. CVP pumping was low in March and the estimated and measured CVP salvage fraction was less than 0.1. The SWP pumping was about 6,000 cfs and the estimated SWP salvage fraction was about 0.4. The measured SWP salvage fraction was similar. The SWP salvage fraction was higher than the CVP fraction because the CVP pumping was less. The estimated CVP salvage fraction was about 0.8 in late March and early April as CVP exports increased. The measured CVP salvage fraction was somewhat less, ranging from about 0.4 to 0.6. Both CVP and SWP salvage fractions were less than 0.1 during VAMP. The estimated CVP salvage fraction increased to 0.6 as pumping was increased in early June, but the measured CVP salvage increased only to 0.2. The estimated and measured SWP salvage fraction remained less than 0.1 because of low pumping in May and June. The three periods of relatively high estimated SWP or CVP salvage fractions were confirmed by measured salvage during 2001.

Results for 2002

Figure B-31 shows the estimated and measured fraction of the San Joaquin River fish in the CVP and SWP salvage for 2002 conditions. The San Joaquin River flows were even lower than 2001, with flows of about 2,000 cfs during the entire juvenile out-migration period of February through June. There were no juvenile fish caught until early April. The estimated CVP salvage fraction was between 0.4 and 0.8 in early April and early June, because CVP exports were higher than the San Joaquin River flow. The estimated SWP salvage fraction remained less than 0.1 during these periods. The measured CVP salvage fractions were similar to the estimated values in early April and early June, confirming the estimation method. The VAMP actions of increased flow, reduced exports, and the head of Old River barrier were very effective in reducing the CVP salvage fraction in 2002.

Results for 2003

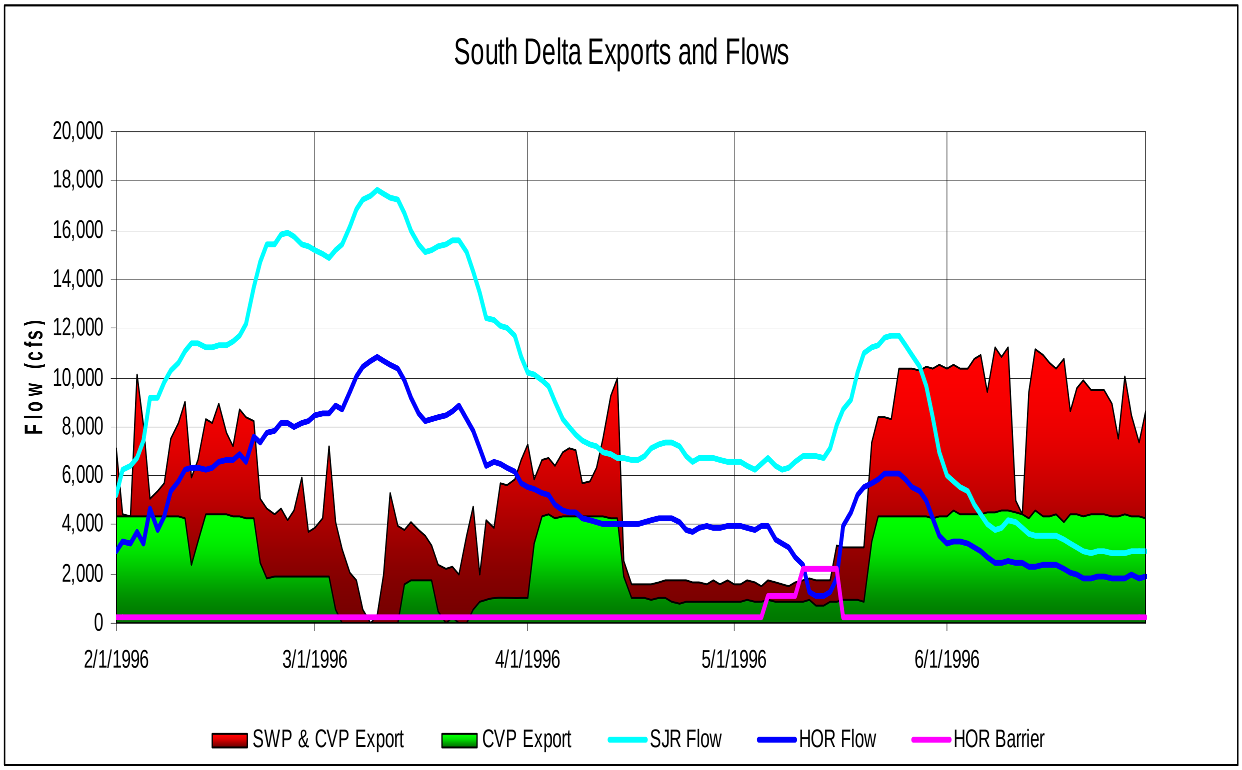
Figure B-32 shows the estimated and measured fraction of the San Joaquin River fish in the CVP and SWP salvage for 2003 conditions. The San Joaquin River flows were almost identical to 2002, with flows of about 2,000 cfs except during VAMP when flows were increased to about 3,000 cfs. CVP pumping was about 4,000 cfs except during the VAMP period, and SWP pumping was about 6,000 cfs except during VAMP. Juvenile fish were first caught in mid-March. The estimated CVP salvage fraction was about 0.8 in late March and about 0.4 in early April. The measured CVP salvage fractions were similar. The CVP salvage fraction was less than 0.1 during VAMP and about 0.4 in late May and June. The measured CVP salvage fraction was similar, although there were very few juvenile Chinook salmon in June. The estimated SWP salvage fraction was less than 0.2 in late March and was less than 0.1 in April and May. The measured SWP salvage fraction was variable between 0.5 and 1.5 in late March, suggesting that the San Joaquin River abundance estimates were somewhat low in late March. The VAMP actions of increased flow, reduced exports, and barrier installation were effective in reducing the CVP salvage fraction in 2003. Additional salvage may have been avoided if the barrier would have been installed earlier and left in until the end of May to protect the entire out-migration period.

Results for 2004

Figure B-33 shows the estimated and measured fraction of the San Joaquin River fish in the CVP and SWP salvage for 2004 conditions. The San Joaquin River flows were again quite low in 2004, with flows of about 2,000 cfs in February, 3,000 cfs in early March, 2,000 cfs in early April, with VAMP flows of 3,000 cfs, and June flows only about 1,500 cfs. CVP pumping was about 4,000 except during the VAMP period and late May. SWP pumping was about 6,000 cfs in February, March, and early April, but was less than 1.000 cfs during VAMP through June. Juvenile fish were first caught at Mossdale in early March. The estimated CVP salvage fraction was about 0.6 to 0.8 during March and about 0.4 in early April. The measured CVP salvage fractions were similar, averaging about 0.5 but with more variability in March. The CVP salvage fraction was less than 0.1 during VAMP and about 0.2 in late May. No juvenile fish were caught in the Mossdale trawl and few were salvaged in June. The estimated SWP salvage fraction was less than 0.1 in March and was less than 0.2 in early April. The measured SWP salvage fraction was more variable but averaged about 0.1 in March and early April.

Results for 2005

Figure B-34 shows the estimated and measured fraction of the San Joaquin River fish in the CVP and SWP salvage for 2004 conditions. The San Joaquin River flows were high, with peak flows of 8,000 cfs at the end of February, 15,000 cfs at the end of March, 7,000 cfs at the end of April and 15,000 cfs at the end of June. CVP pumping was about 4,000 cfs in February and March, about 2,000 cfs in April, less than 1,000 cfs during VAMP (which was in May), and about 4,000 cfs in June. SWP pumping was variable between 2,000 cfs and about 6,000 cfs in February, March, and April, was less than 1.000 cfs during VAMP (in May) and about 6,000 cfs in June. Juvenile fish (fry) were first caught at Mossdale in early February. There was no head of Old River barrier installed in 2005 because of the high flow. The estimated CVP salvage fraction was about 0.5 in late February and early March and decreased to about 0.1 in April and May. The estimated CVP salvage fraction was 0.6 in mid-June as CVP pumping increased to 4,000 cfs following VAMP. The measured CVP salvage fraction ranged from 0.1 to 1.0 during the late February to early April period. The SWP estimated salvage fraction was highest in April, ranging from 0.2 to 0.4. The measured SWP salvage fraction was similar in April. The estimated SWP salvage fraction was less than 0.2 in June, and the measured SWP salvage fraction was less than 0.1 in June. The high San Joaquin River flows and reduced CVP and SWP pumping were effective for reducing the CVP and SWP salvage fractions to less than 0.1 during the VAMP period (in May). If the barrier (or a permanent gate) were in place, it might have been effective for protecting the San Joaquin River juvenile Chinook salmon in April and May.



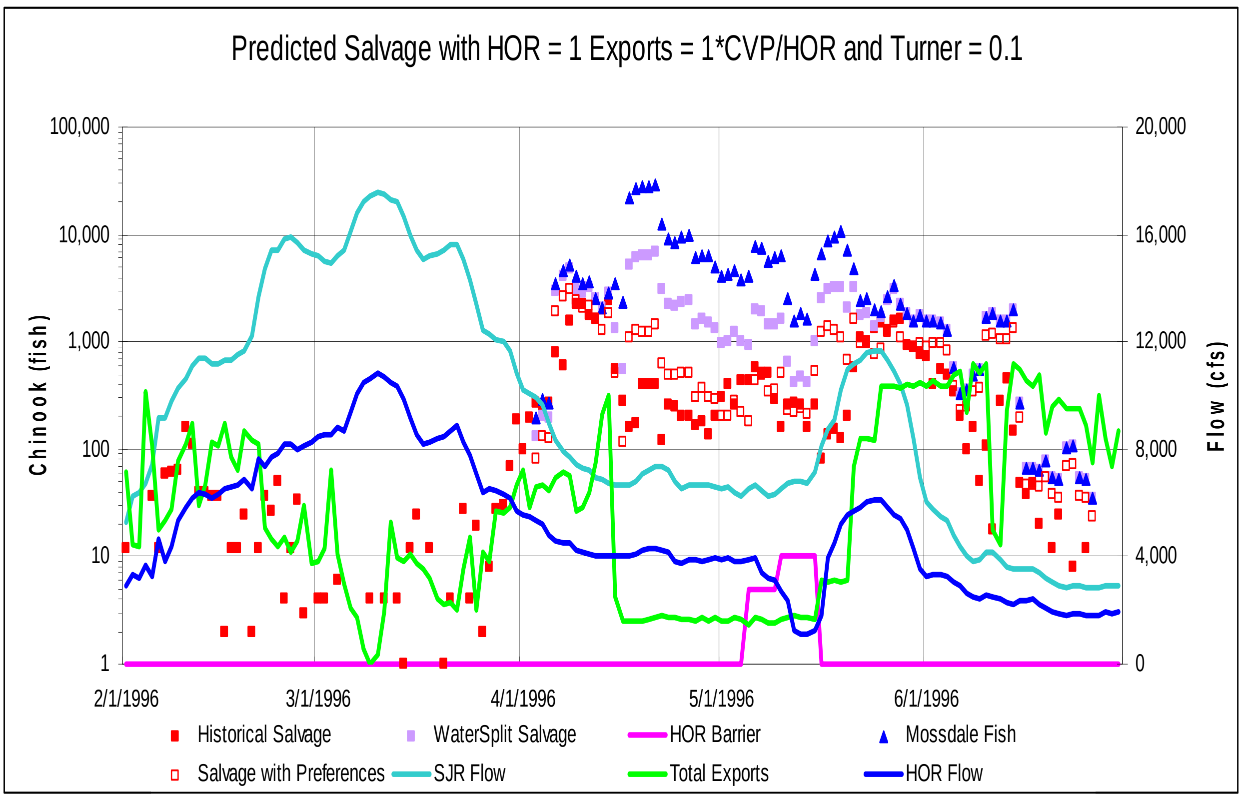


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Figure B-1

Daily San Joaquin River Flows and Exports Compared with Mossdale Unmarked Chinook Salmon Abundance and Combined CVP and SWP Salvage during February–June 1996

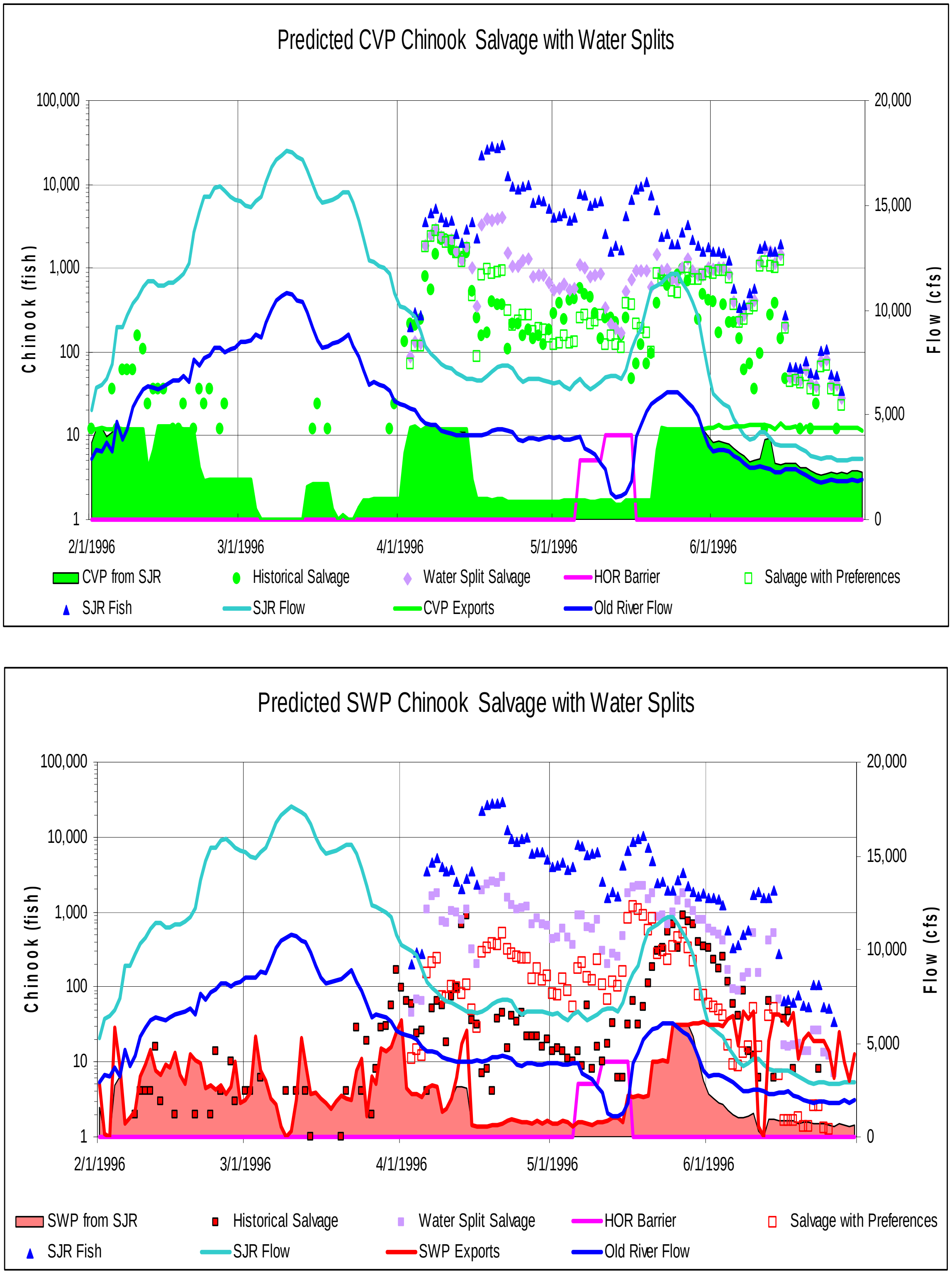

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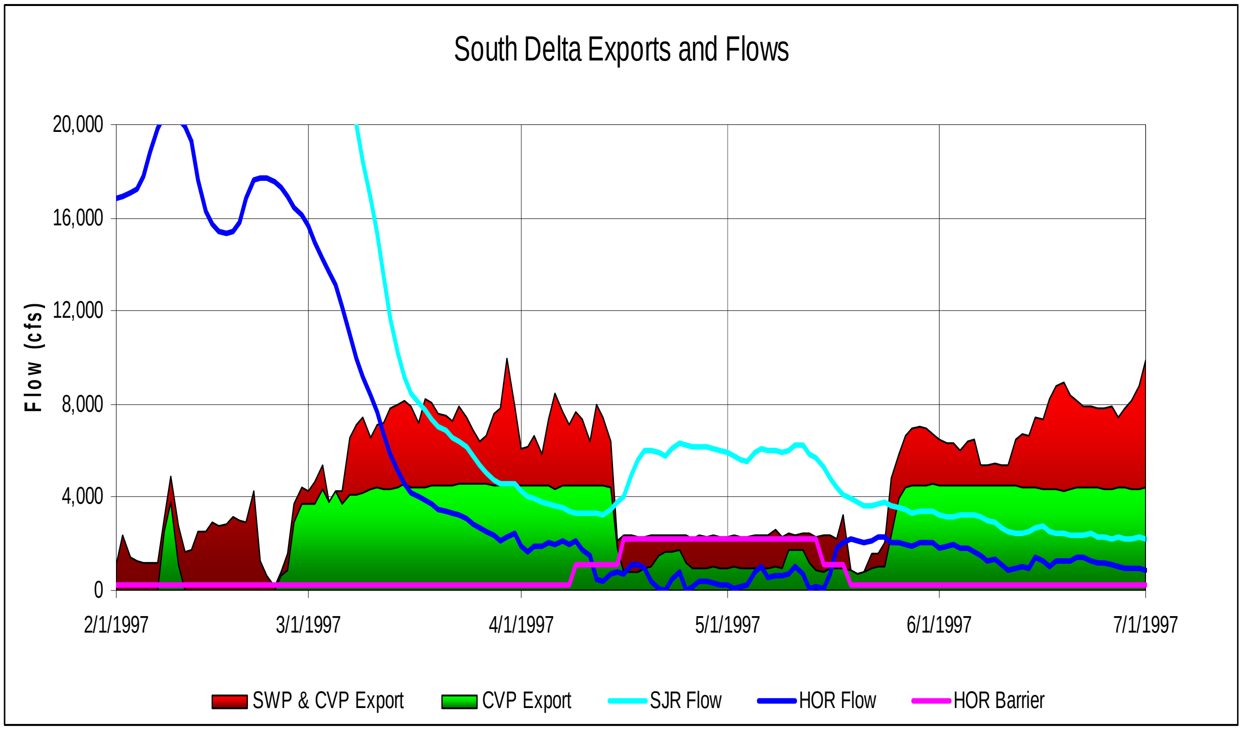
Figure B-2

Daily Estimates of CVP and SWP Salvage Based on San Joaquin River Flows and Exports With Water Splits Only and With Assumed Fish Preferences Compared to Observed CVP and SWP Salvage for February–June 1996



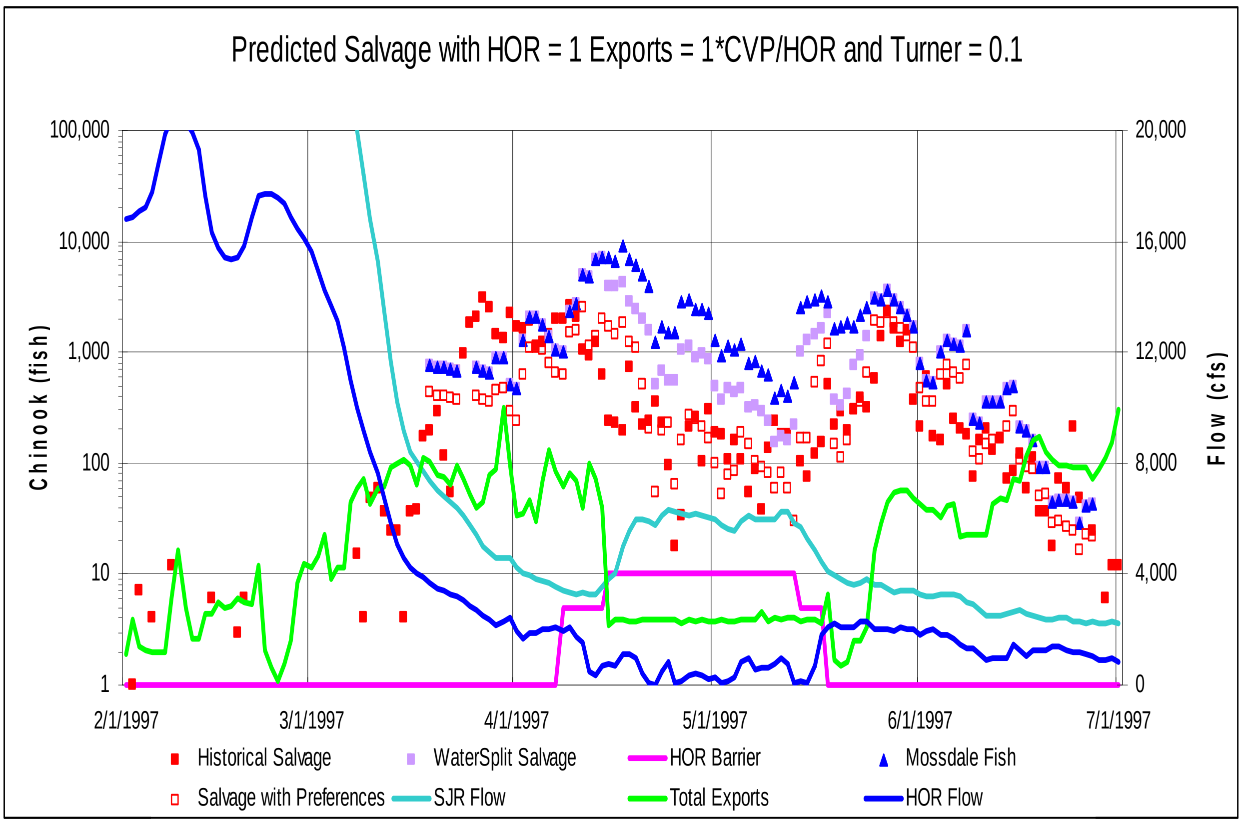


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Figure B-3

Daily San Joaquin River Flows and Exports Compared With Mossdale Unmarked Chinook Abundance and Combined CVP and SWP Salvage during February–June 1997

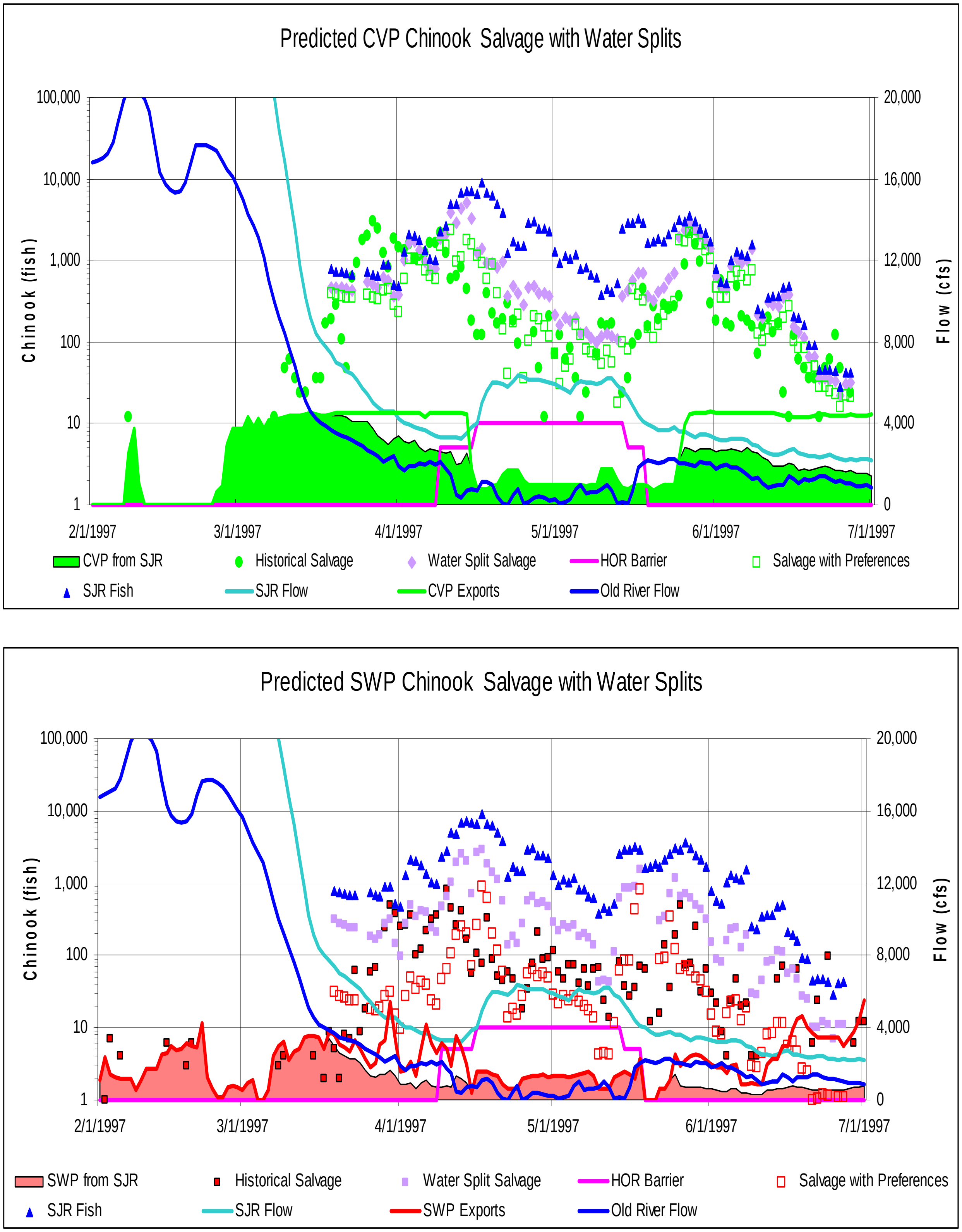

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Figure B-4

Daily Estimates of CVP and SWP Salvage Based on San Joaquin River Flows and Exports With Water Splits Only and With Assumed Fish Preferences Compared to Observed CVP and SWP Salvage for February–June 1997

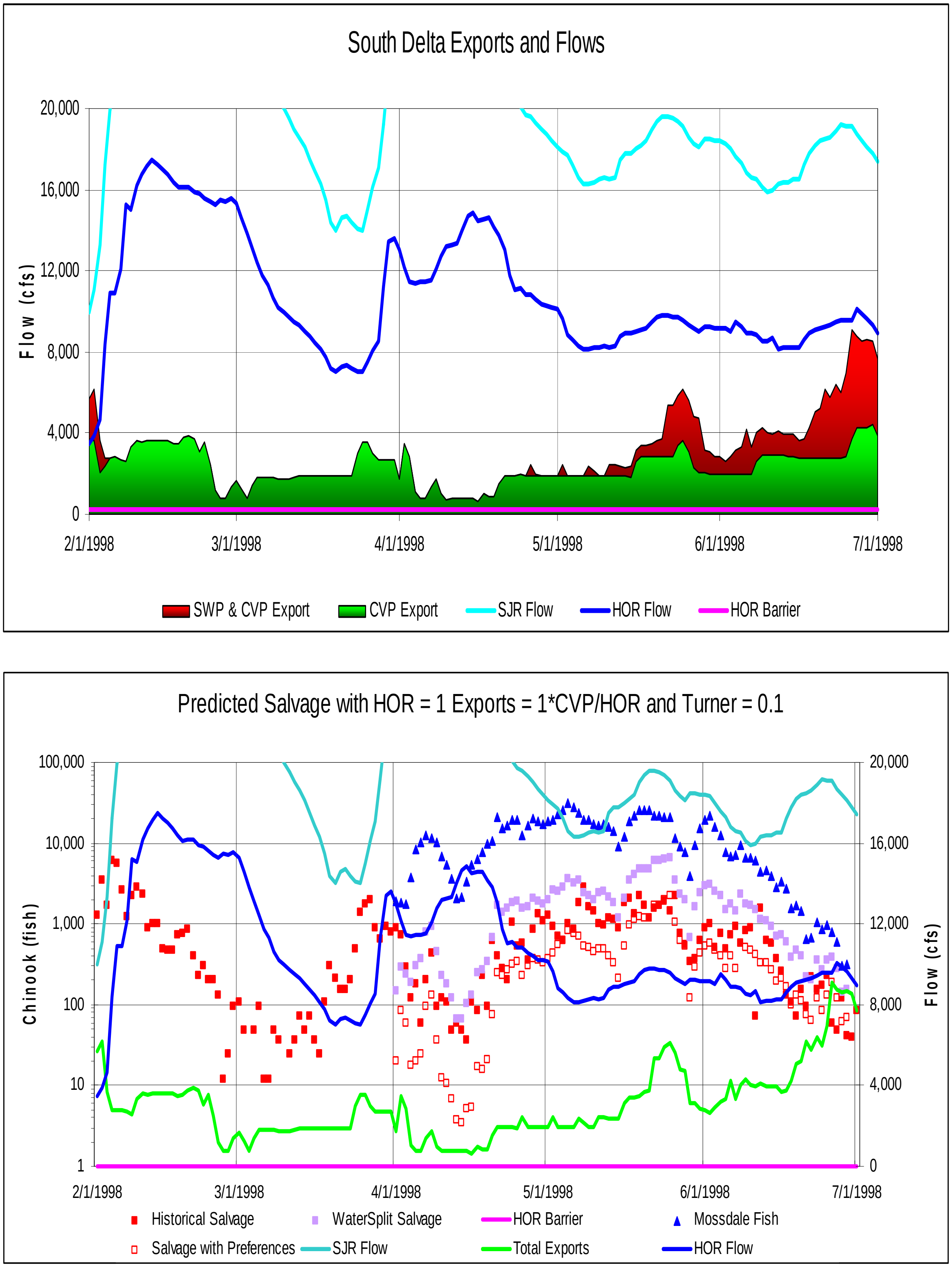

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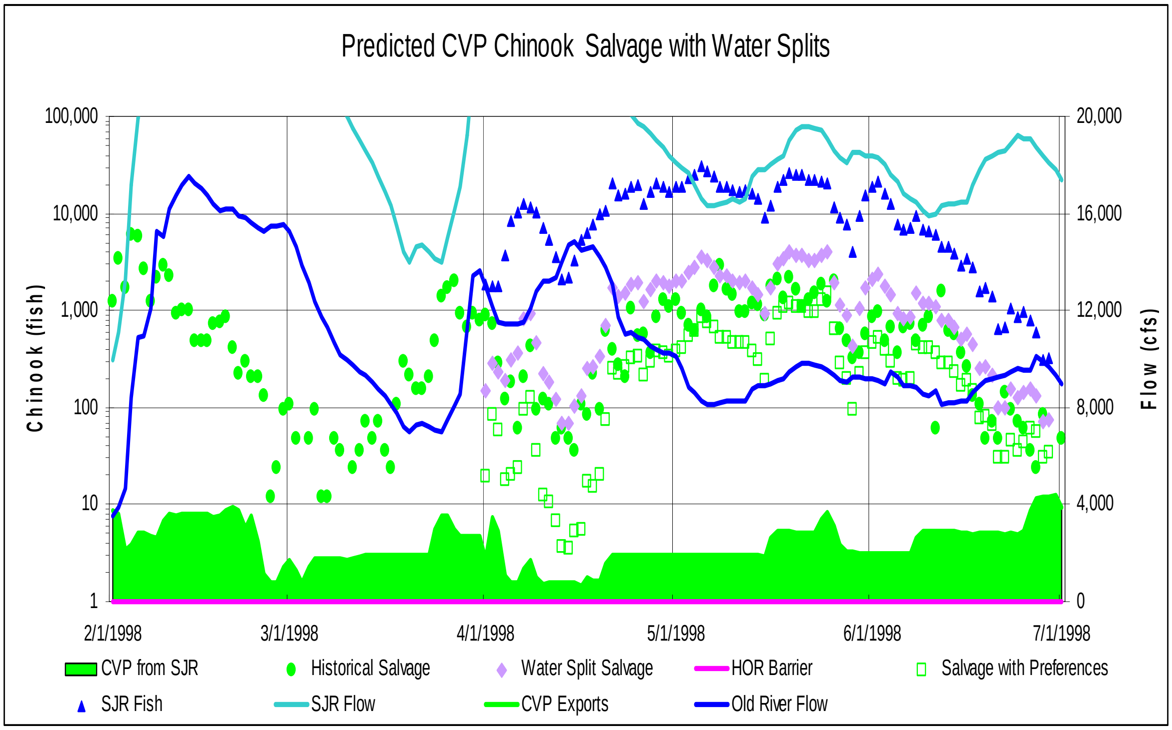
Figure B-5

Daily San Joaquin River Flows and Exports Compared With Mossdale Unmarked Chinook Salmon Abundance and Combined CVP and SWP Salvage during February–June 1998



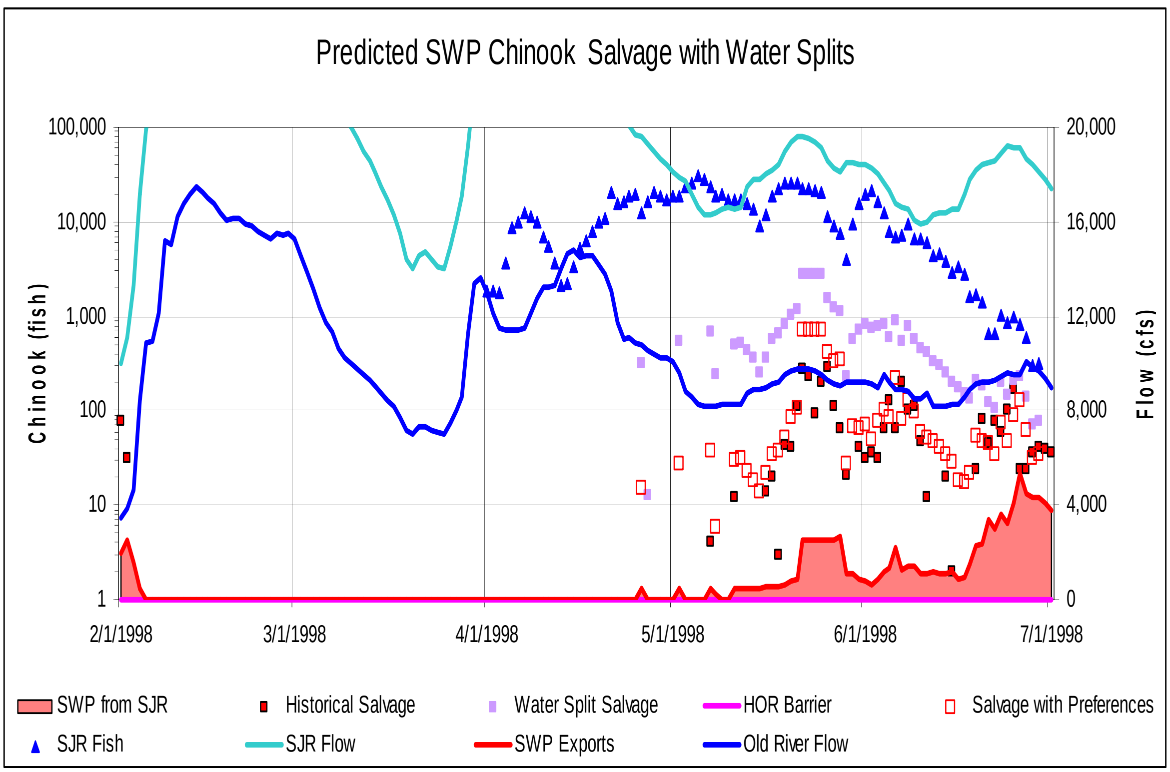


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Figure B-6

Daily Estimates of CVP and SWP Salvage Based on San Joaquin River Flows and Exports With Water Splits Only and With Assumed Fish Preferences Compared to Observed CVP and SWP Salvage for February–June 1998

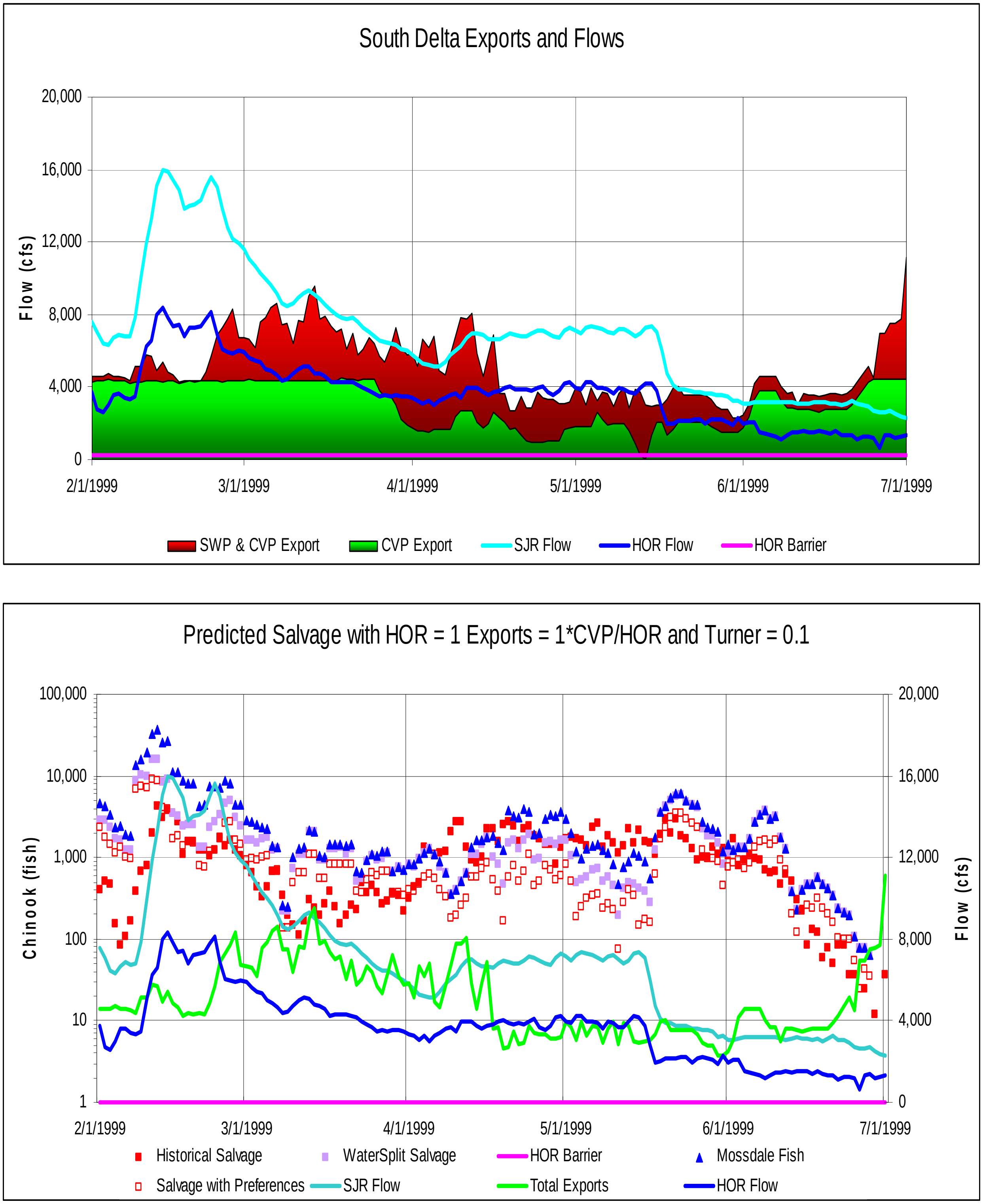

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Figure B-7

Daily San Joaquin River Flows and Exports Compared With Mossdale Unmarked Chinook Salmon Abundance and Combined CVP and SWP Salvage during February–June 1999

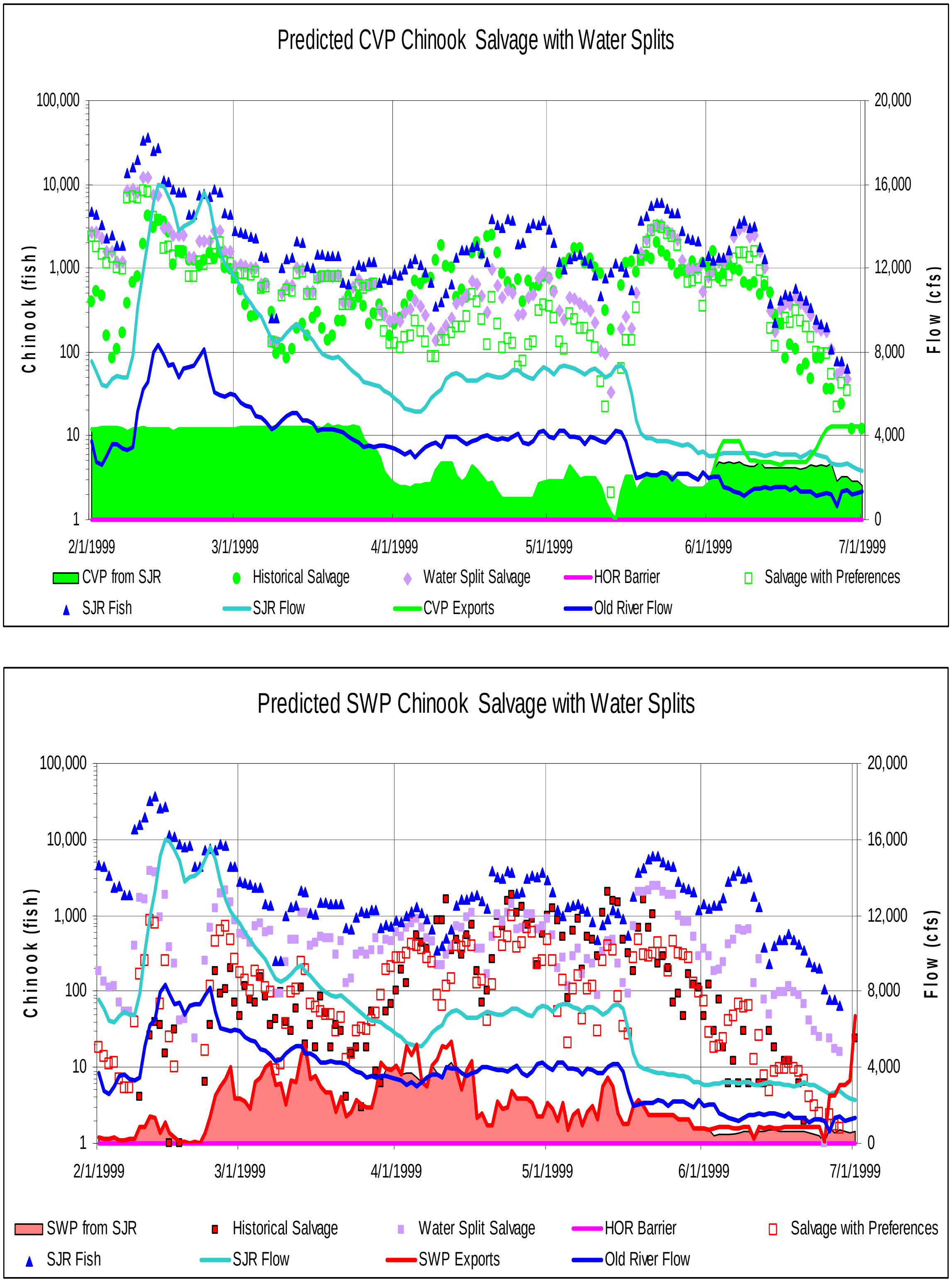

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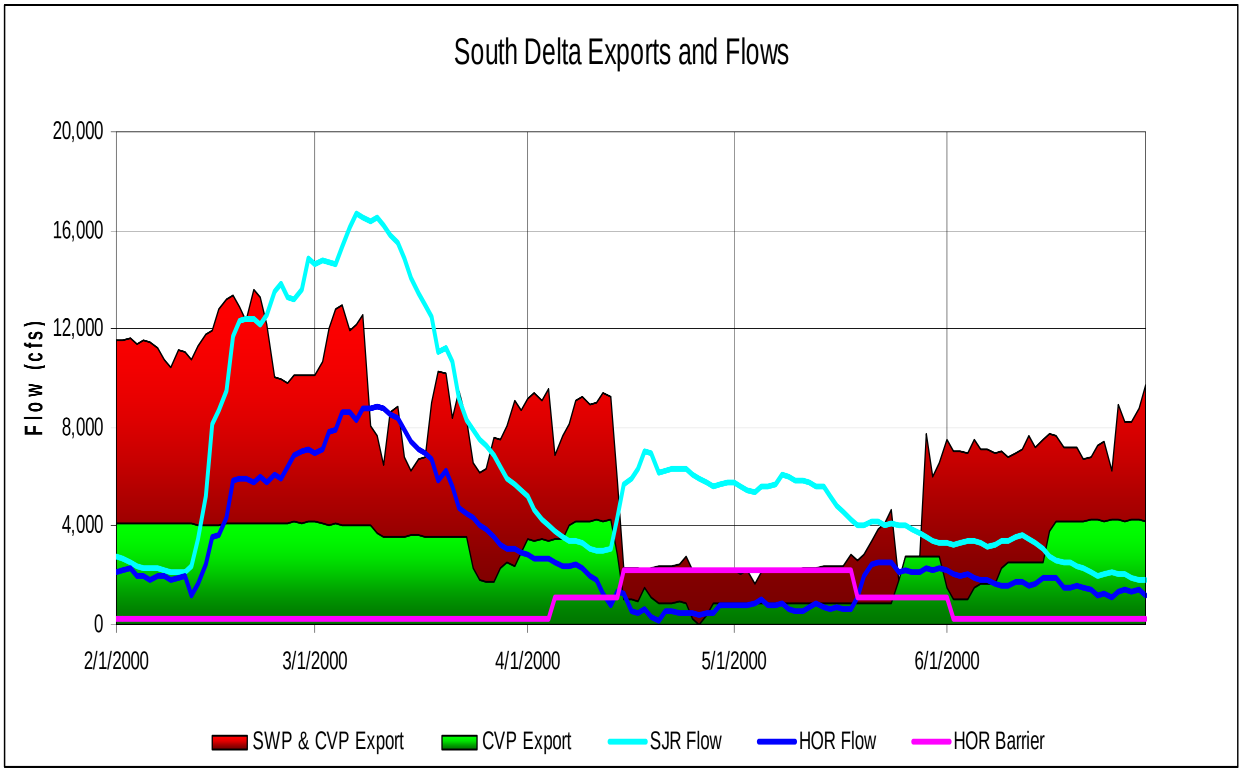
Figure B-8

Daily Estimates of CVP and SWP Salvage Based on San Joaquin River Flows and Exports With Water Splits Only and With Assumed Fish Preferences Compared to Observed CVP and SWP Salvage for February–June 1999



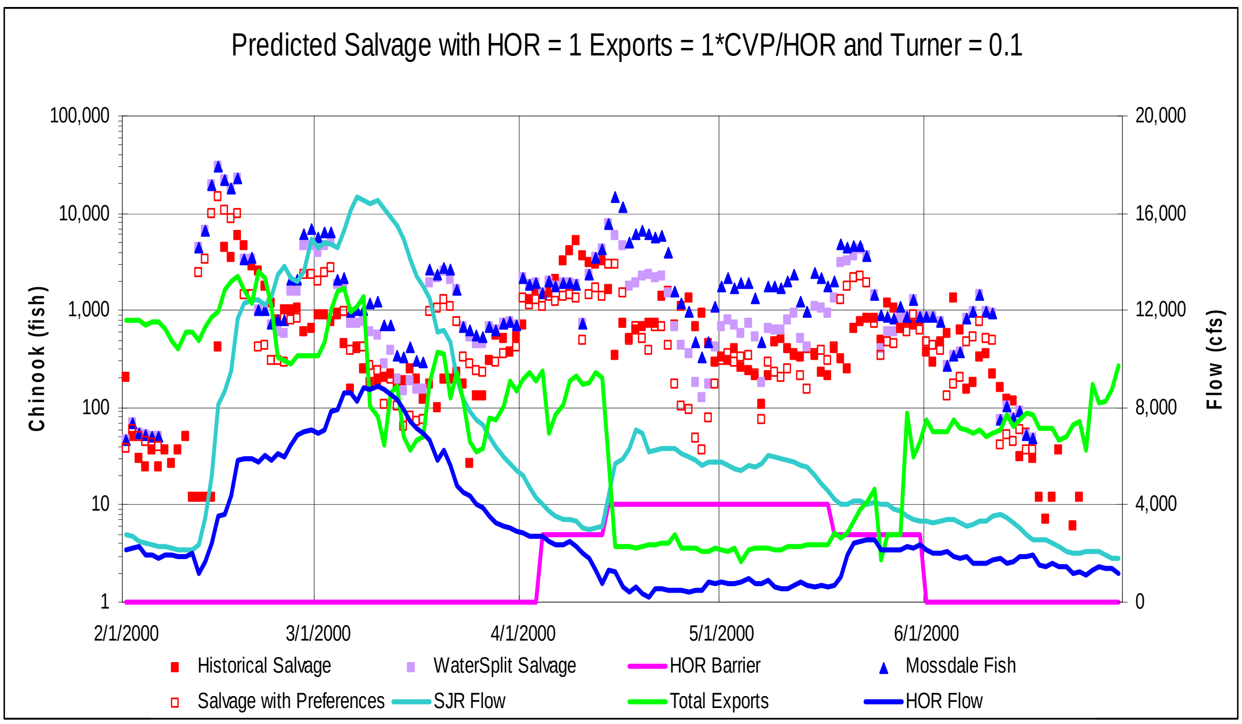


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Figure B-9

Daily San Joaquin River Flows and Exports Compared With Mossdale Unmarked Chinook Salmon Abundance and Combined CVP and SWP Salvage during February–June 2000

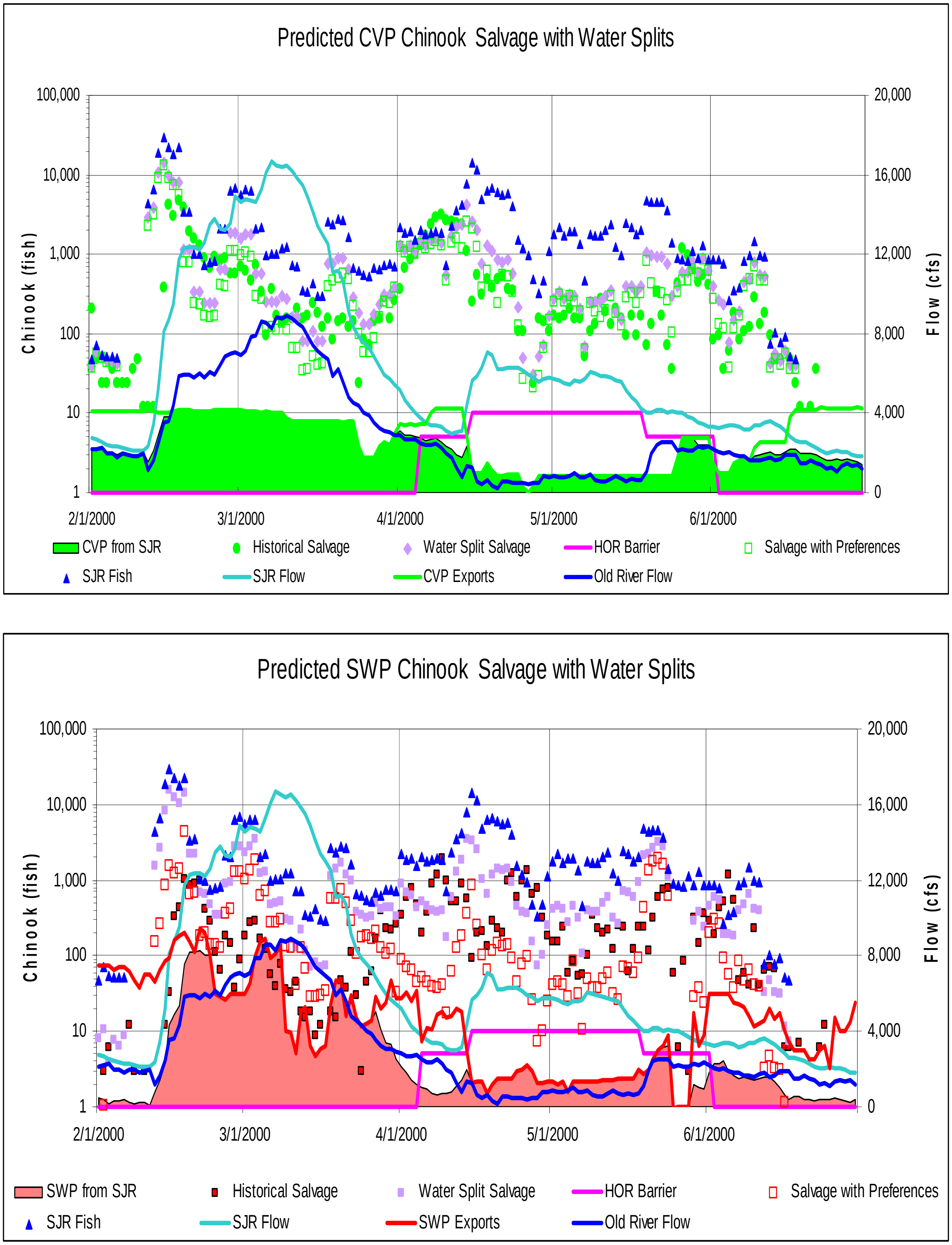

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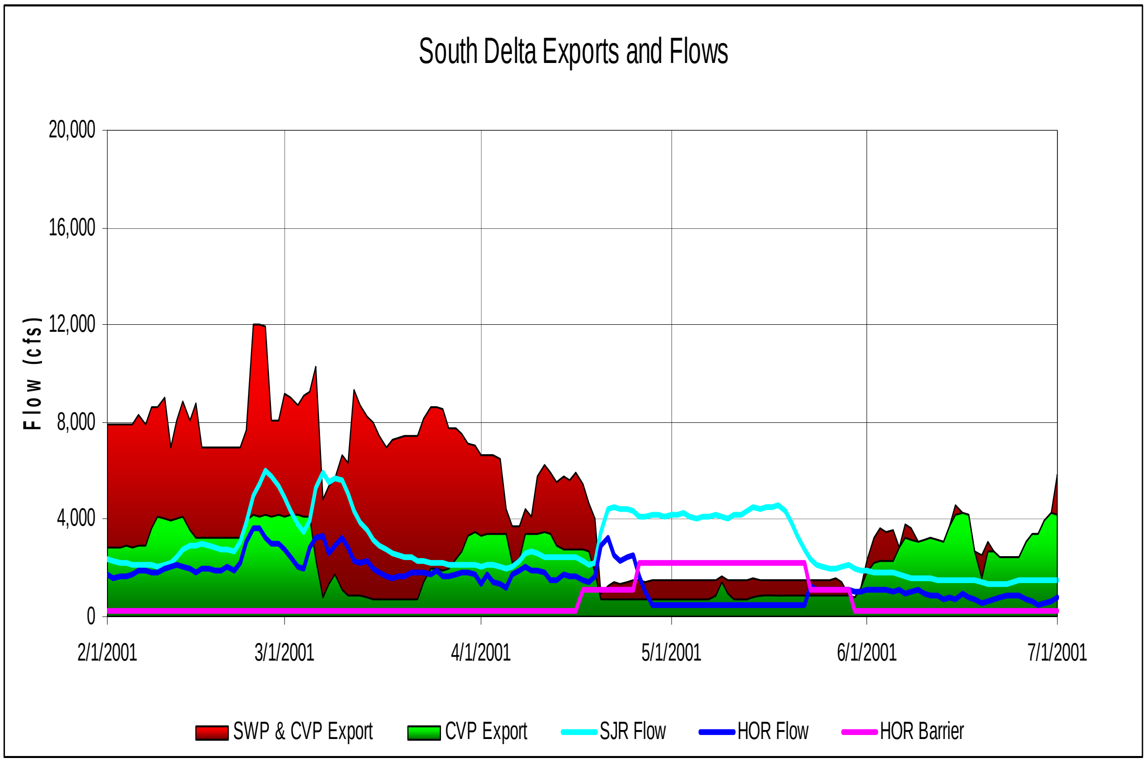
Figure B-10

Daily Estimates of CVP and SWP Salvage Based on San Joaquin River Flows and Exports With Water Splits Only and With Assumed Fish Preferences Compared to Observed CVP and SWP Salvage for February–June 2000



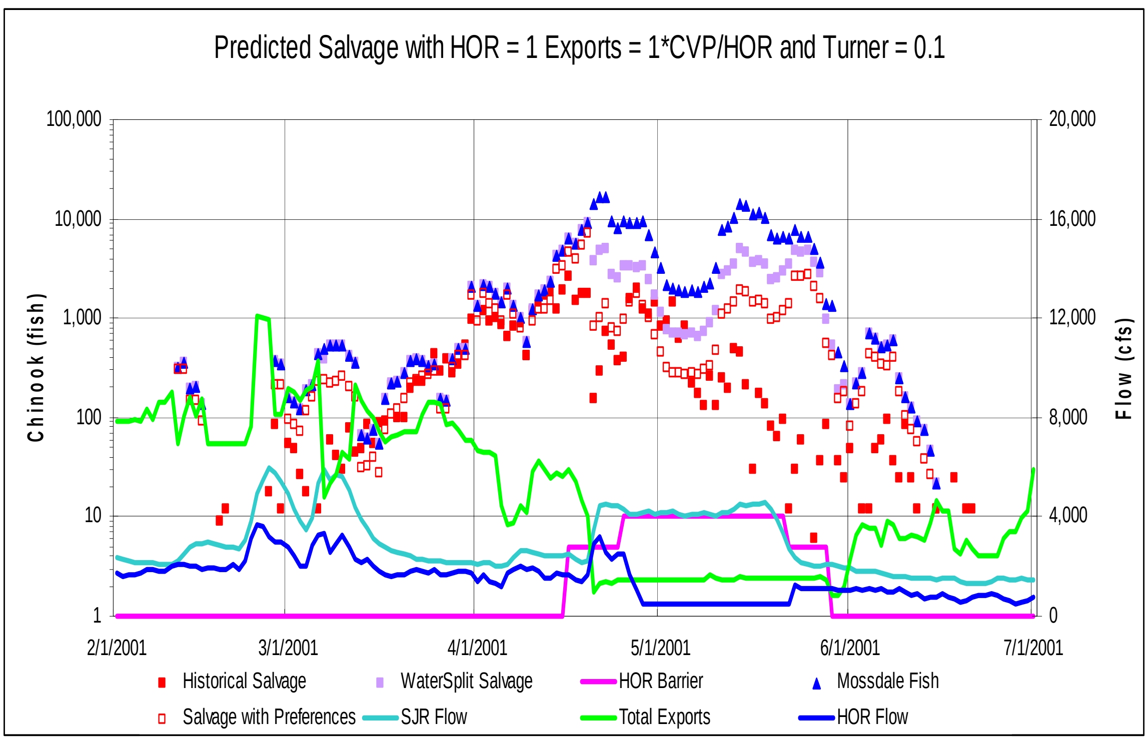


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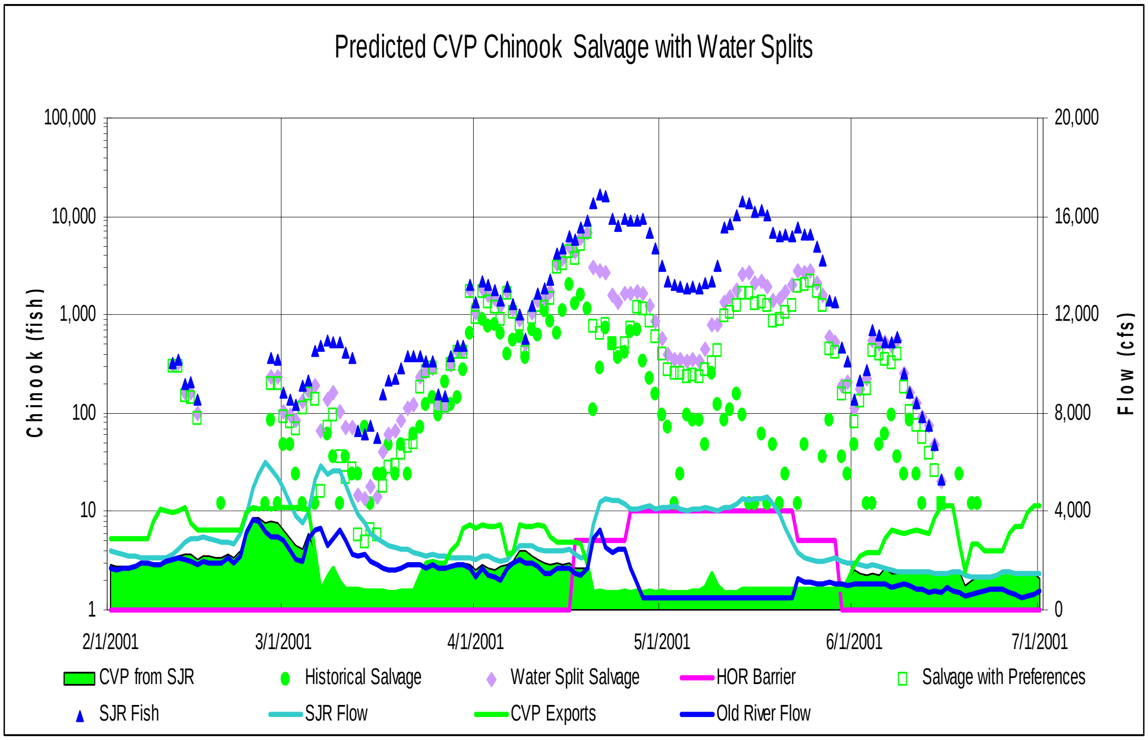
Figure B-11

Daily San Joaquin River Flows and Exports Compared With Mossdale Unmarked Chinook Salmon Abundance and Combined CVP and SWP Salvage during February–June 2001



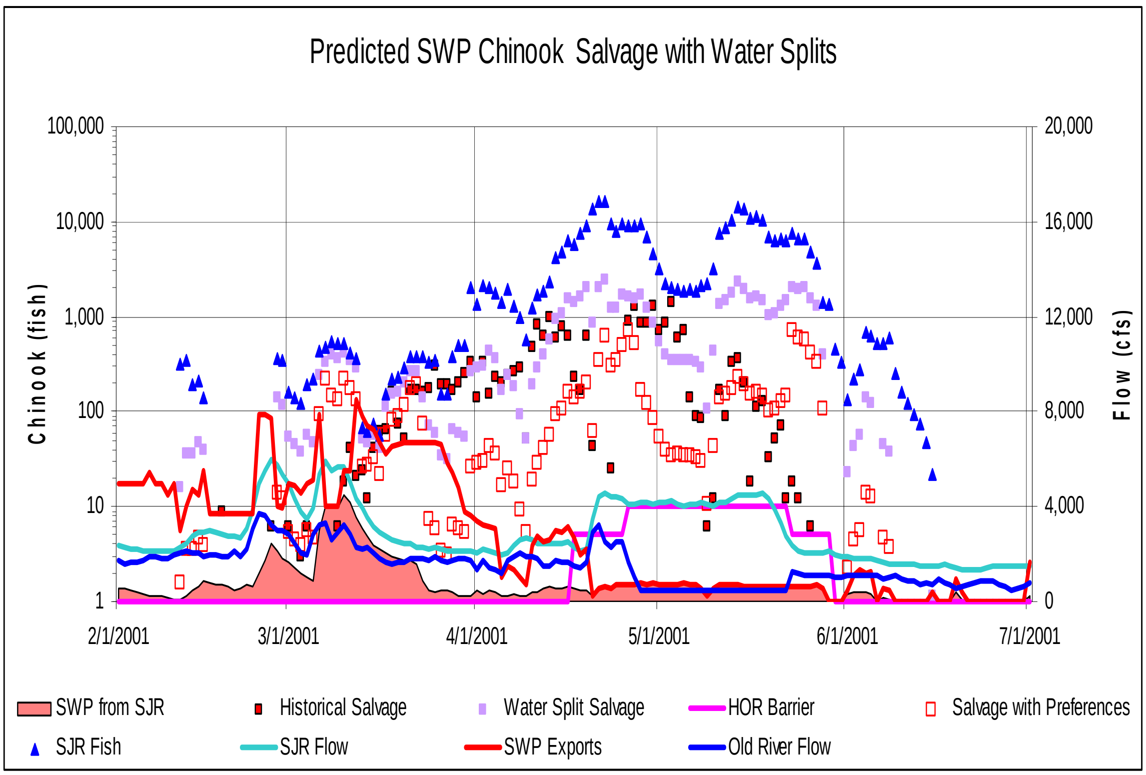


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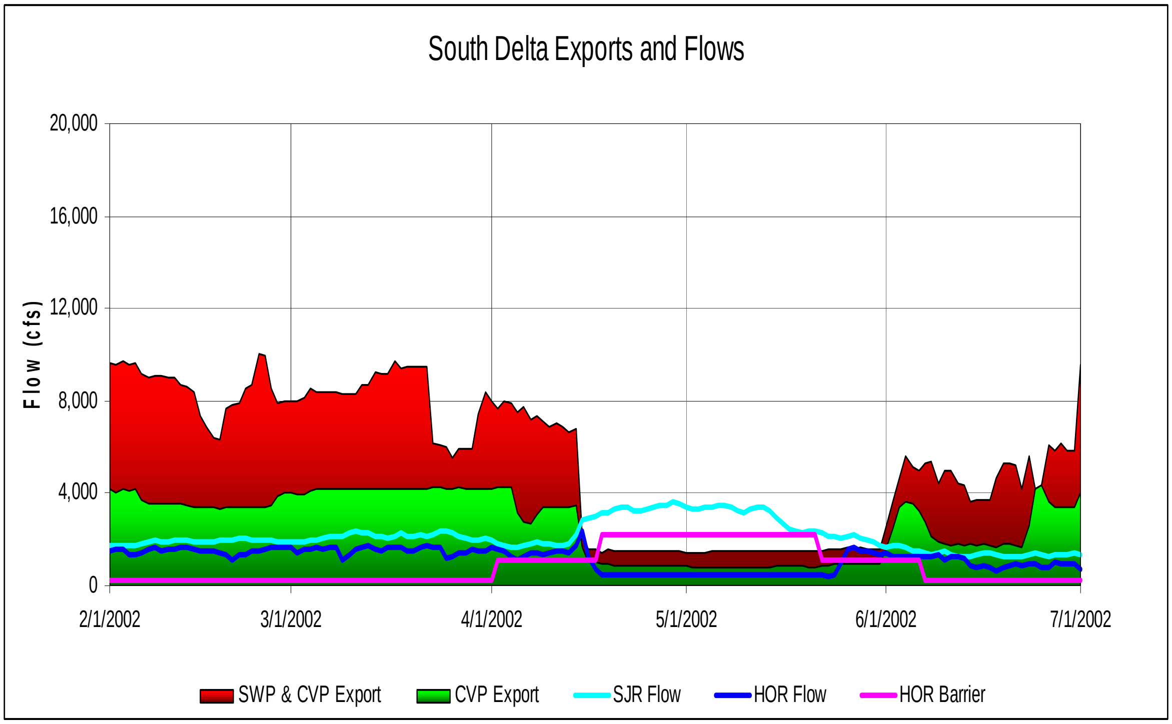
Figure B-12

Daily Estimates of CVP and SWP Salvage Based on San Joaquin River Flows and Exports With Water Splits Only and With Assumed Fish Preferences Compared to Observed CVP and SWP Salvage for February–June 2001



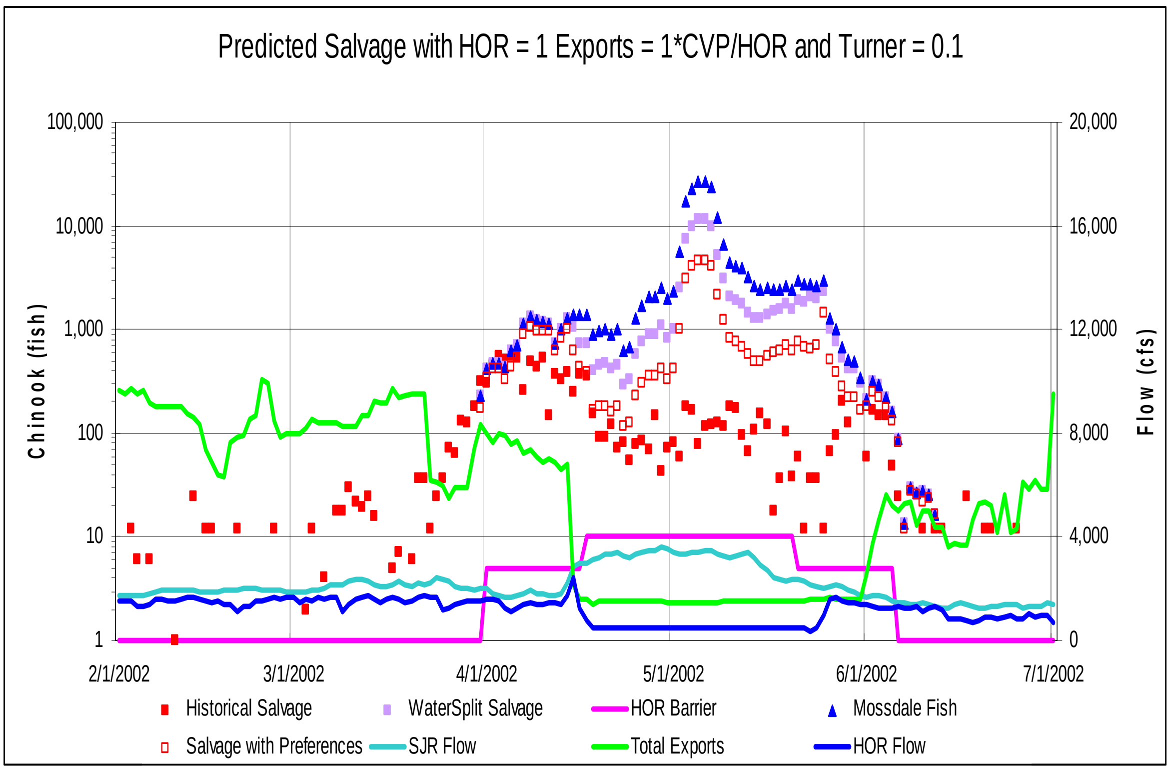


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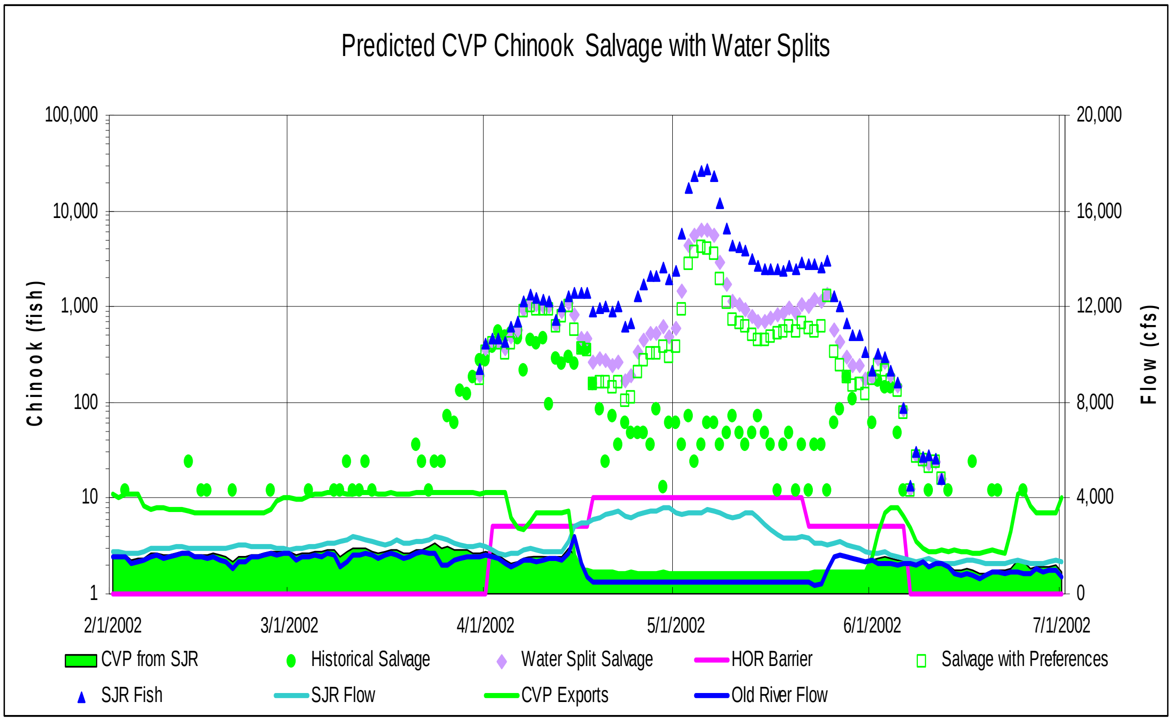
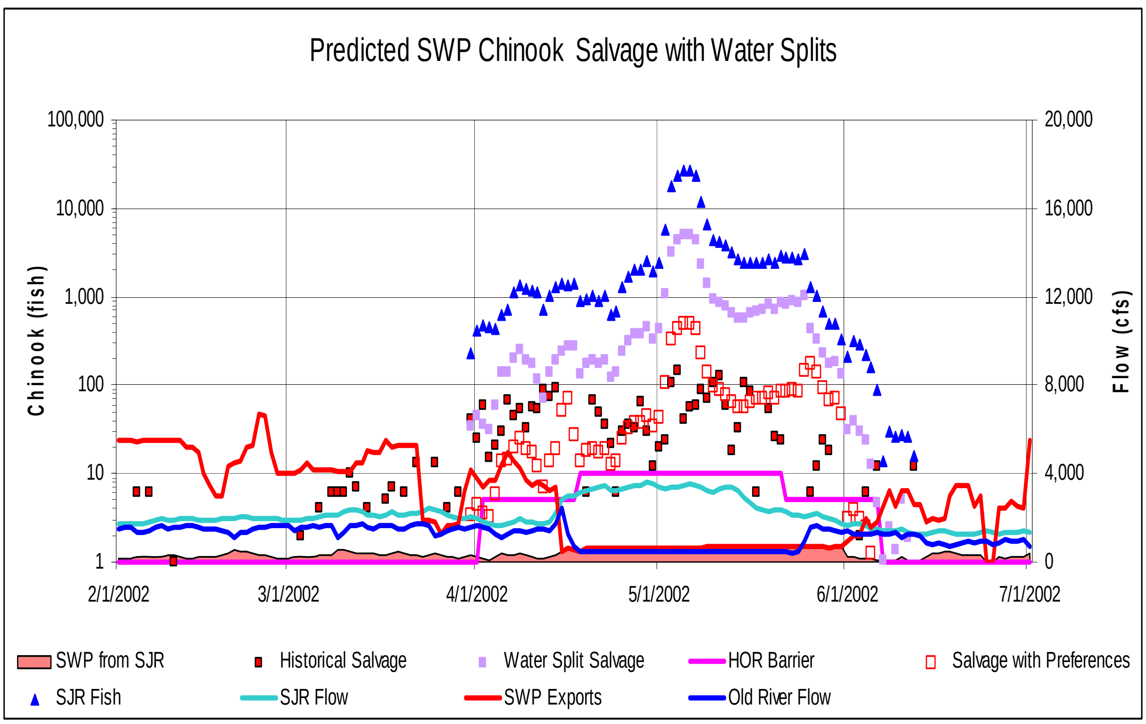
Figure B-13

Daily San Joaquin River Flows and Exports Compared With Mossdale Unmarked Chinook Salmon Abundance and Combined CVP and SWP Salvage during February–June 2002





No reduced HOR fish preference when the barrier is installed.

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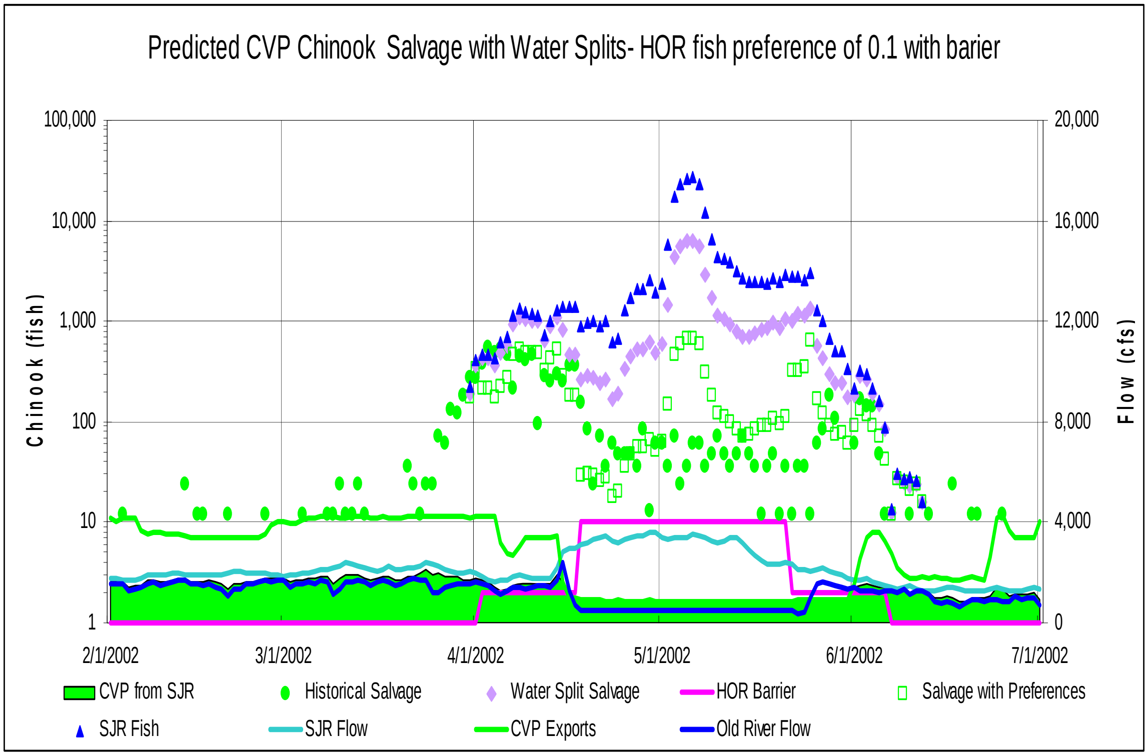
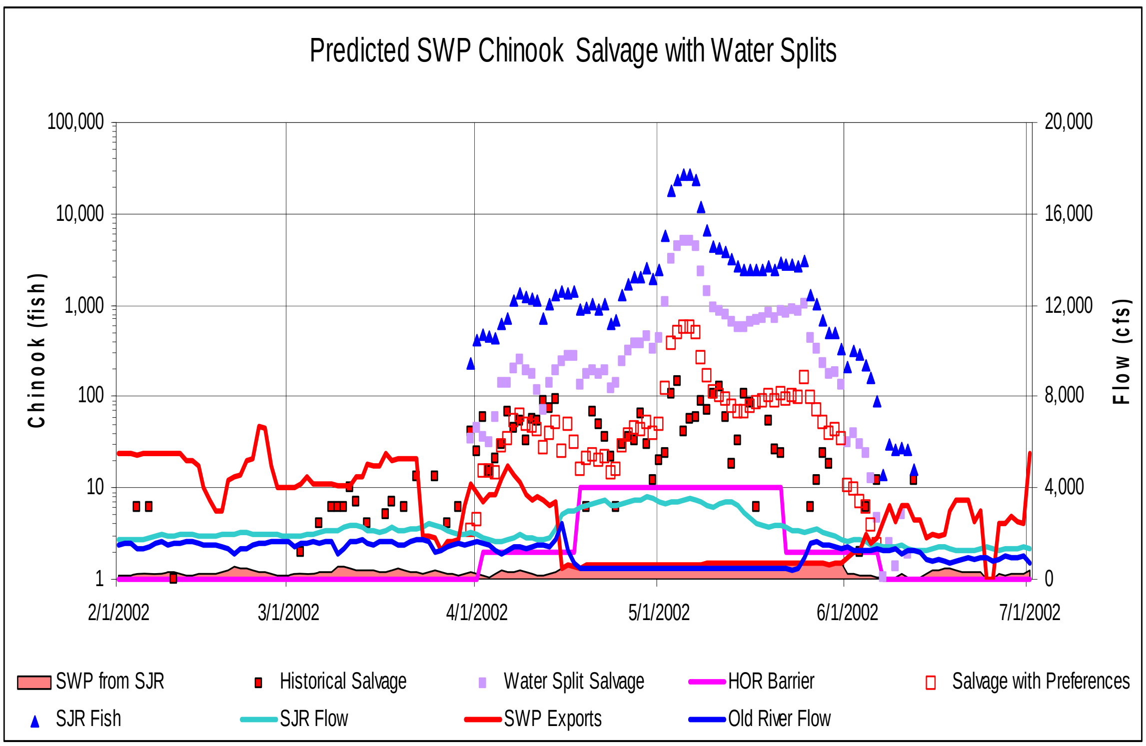
Figure B-14a

Daily Estimates of CVP and SWP Salvage Based on San Joaquin River Flows and Exports With Water Splits Only and With Assumed Fish Preferences Compared to Observed CVP and SWP Salvage for February–June 2002





With head of Old River fish preference of 0.1 when the barrier is installed.

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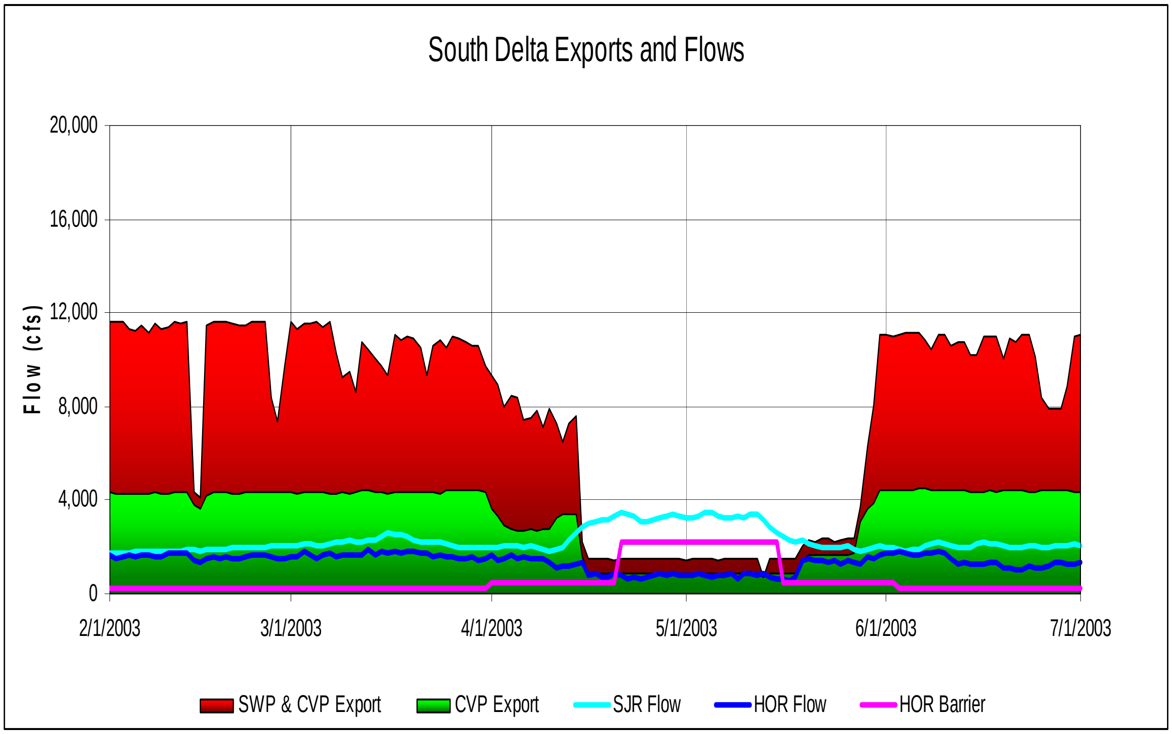
Figure B-14b

Daily Estimates of CVP and SWP Salvage Based on San Joaquin River Flows and Exports With Water Splits Only and With Assumed Fish Preferences Compared to Observed CVP and SWP Salvage for February–June 2002



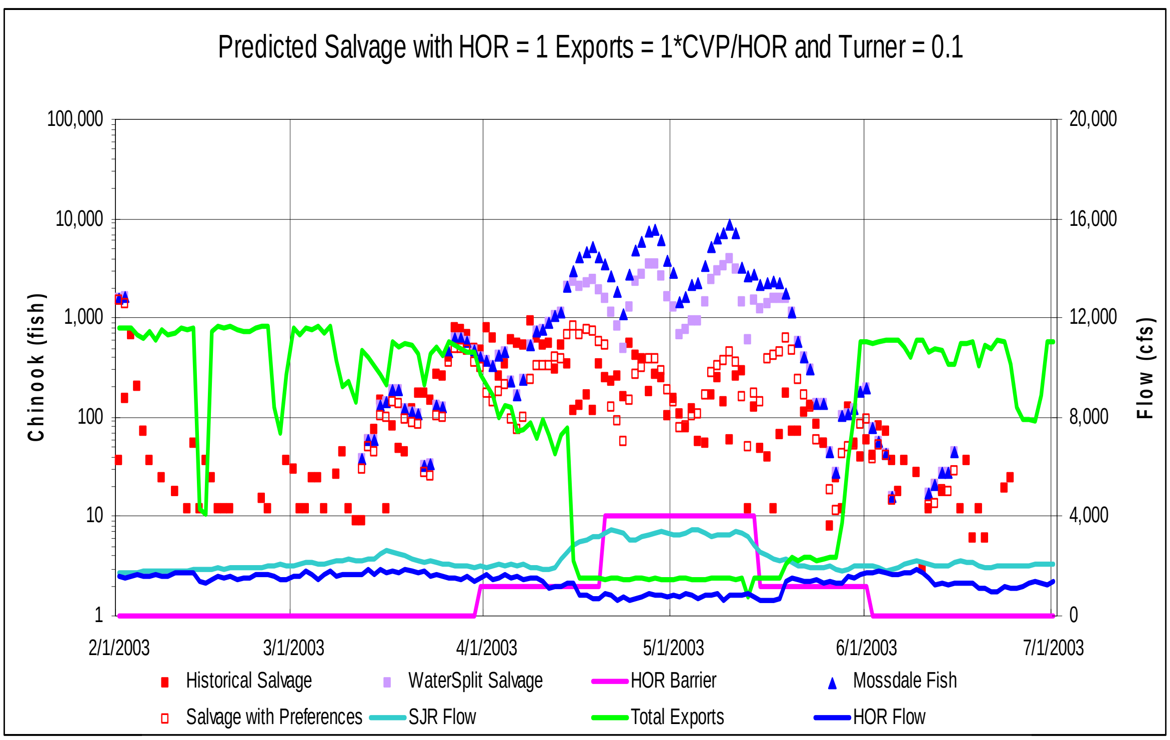


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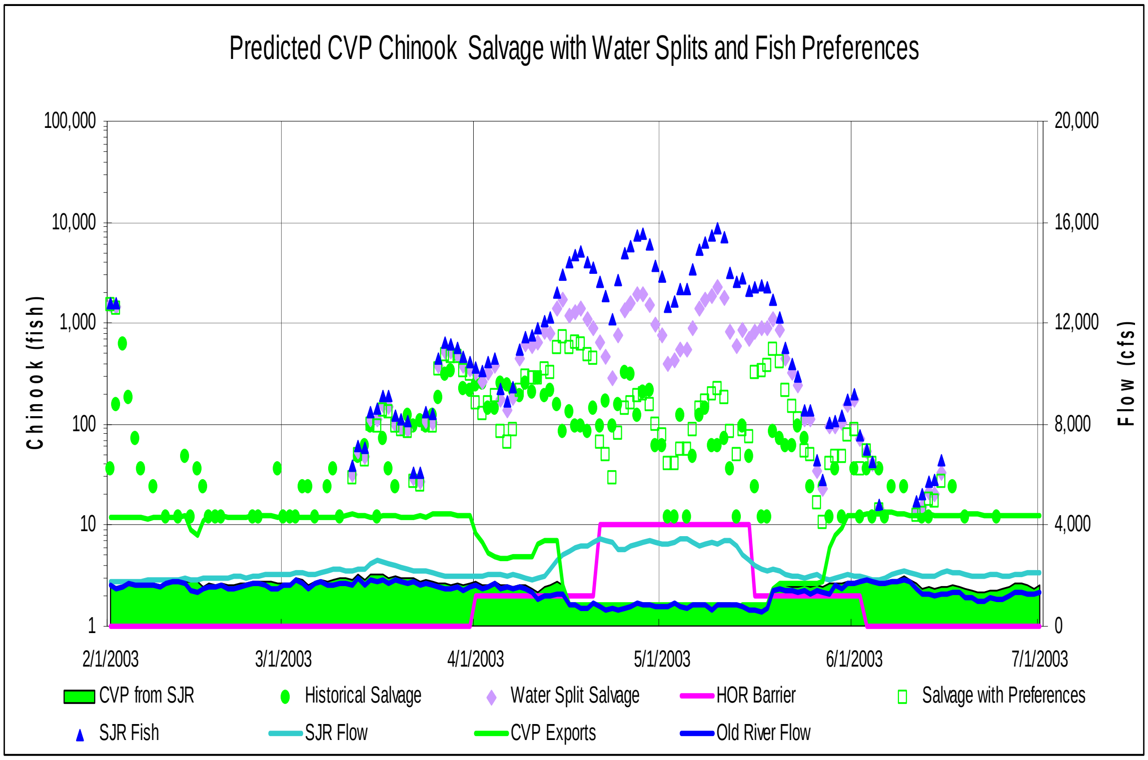
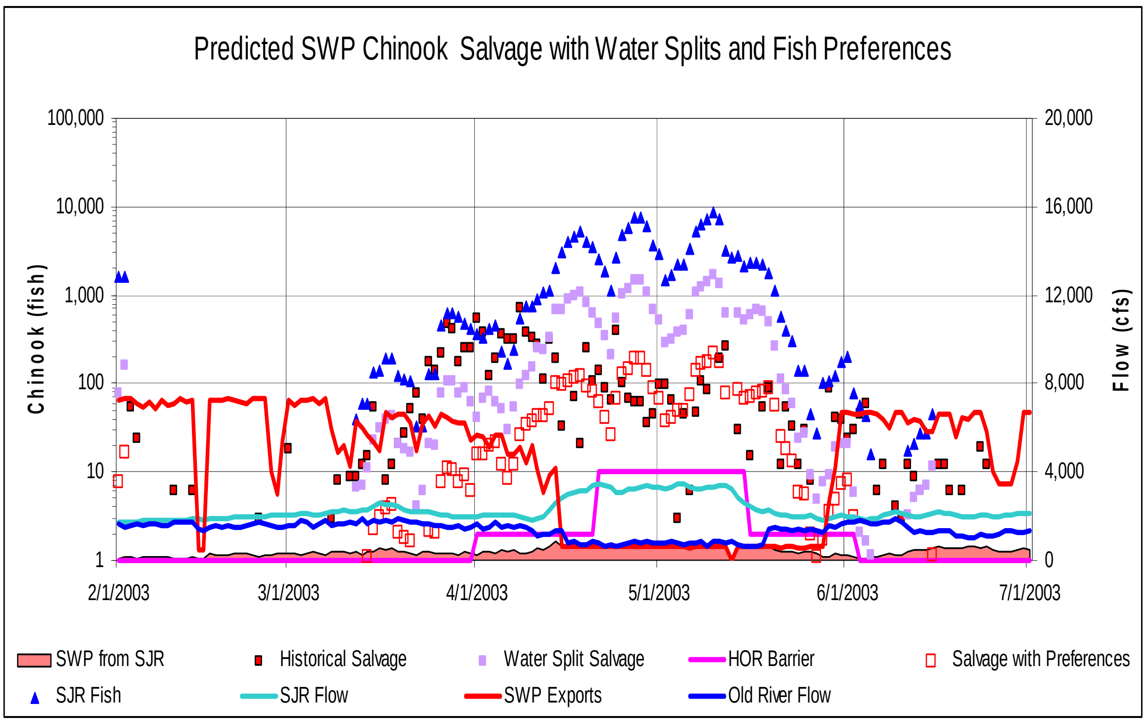
Figure B-15

Daily San Joaquin River Flows and Exports Compared With Mossdale Unmarked Chinook Salmon Abundance and Combined CVP and SWP Salvage during February–June 2003





With head of Old River fish preference of 0.1 when the barrier is installed.

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Figure B-16

Daily Estimates of CVP and SWP Salvage Based on San Joaquin River Flows and Exports With Water Splits Only and With Assumed Fish Preferences Compared to Observed CVP and SWP Salvage for February–June 2003

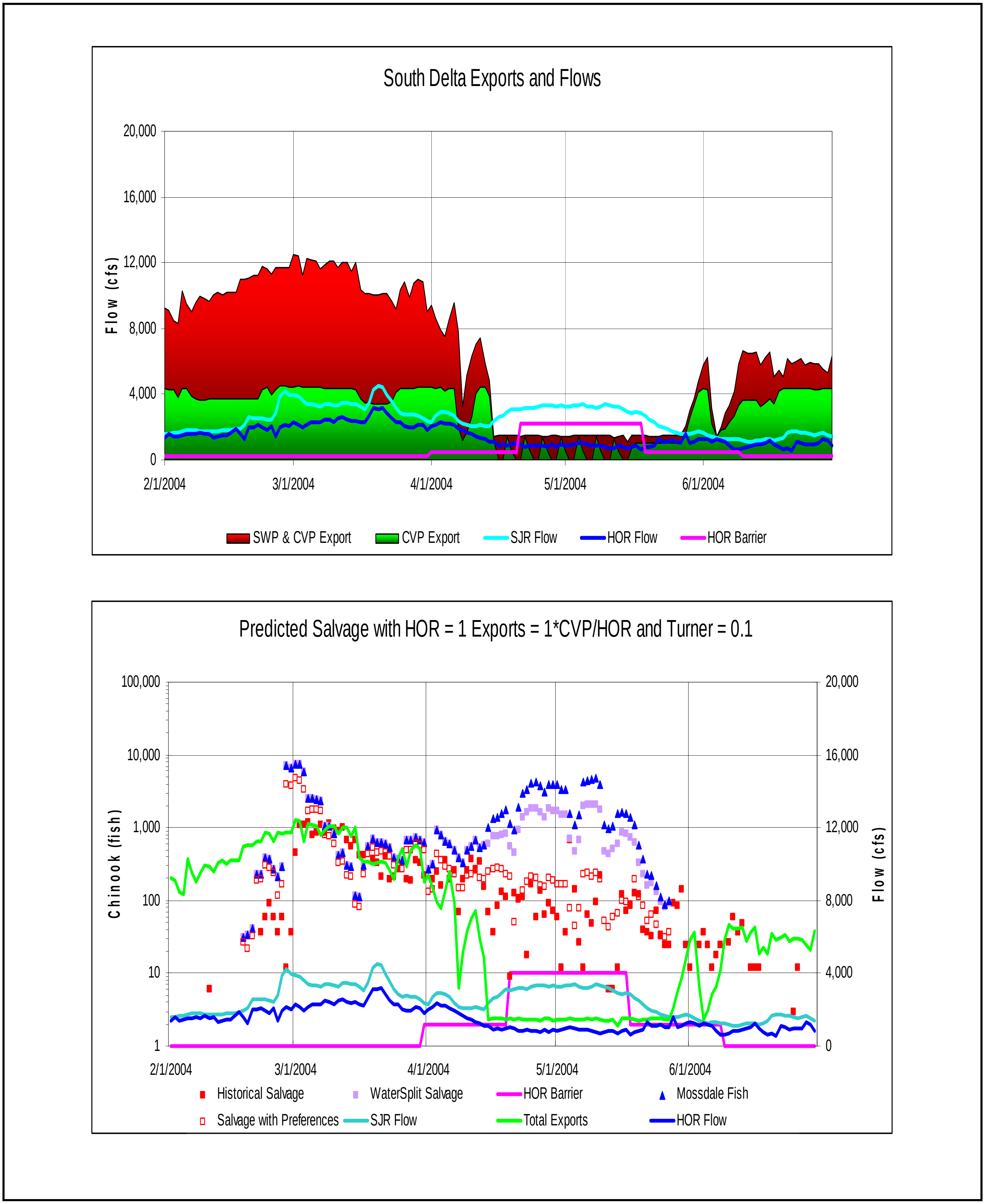

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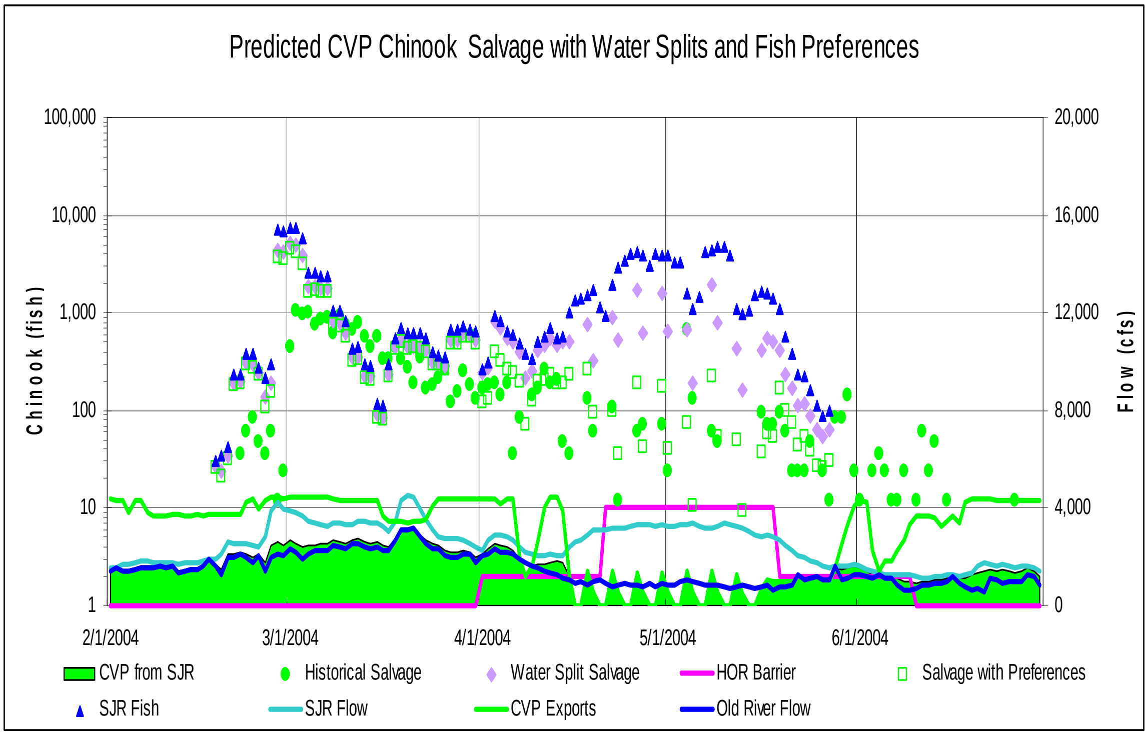
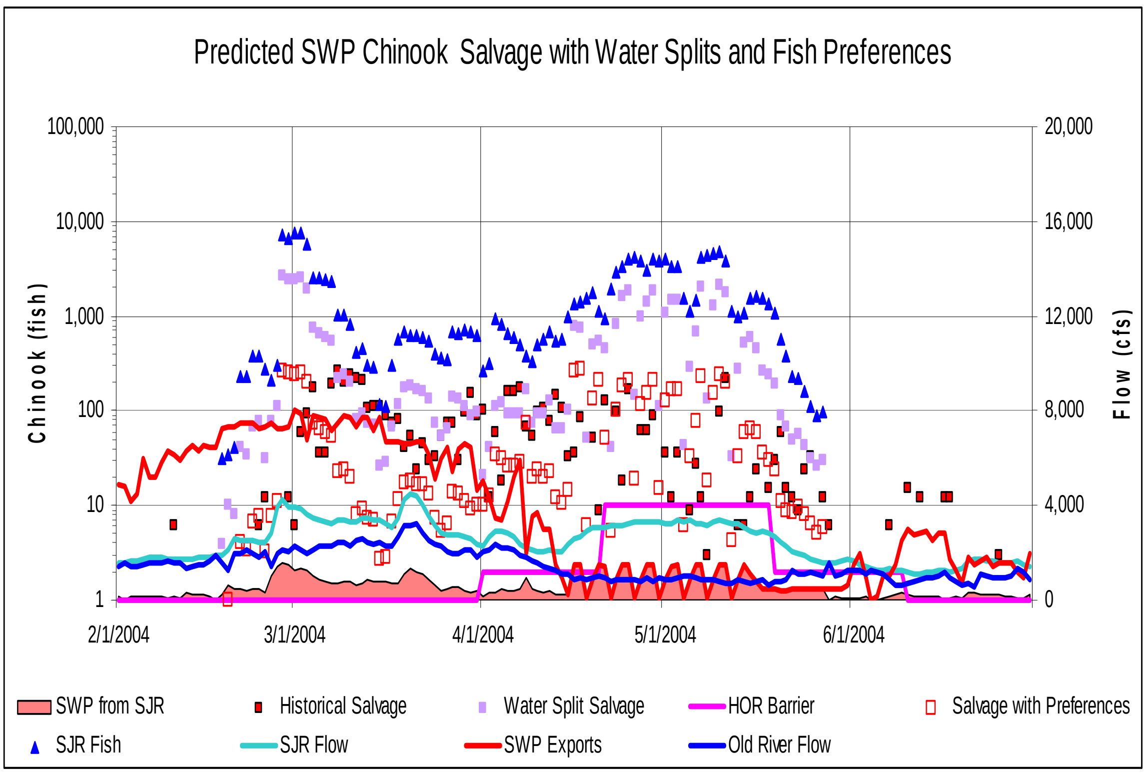
Figure B-17

Daily San Joaquin River Flows and Exports Compared With Mossdale Unmarked Chinook Salmon Abundance and Combined CVP and SWP Salvage during February–June 2004





With head of Old River fish preference of 0.1 when the barrier is installed.

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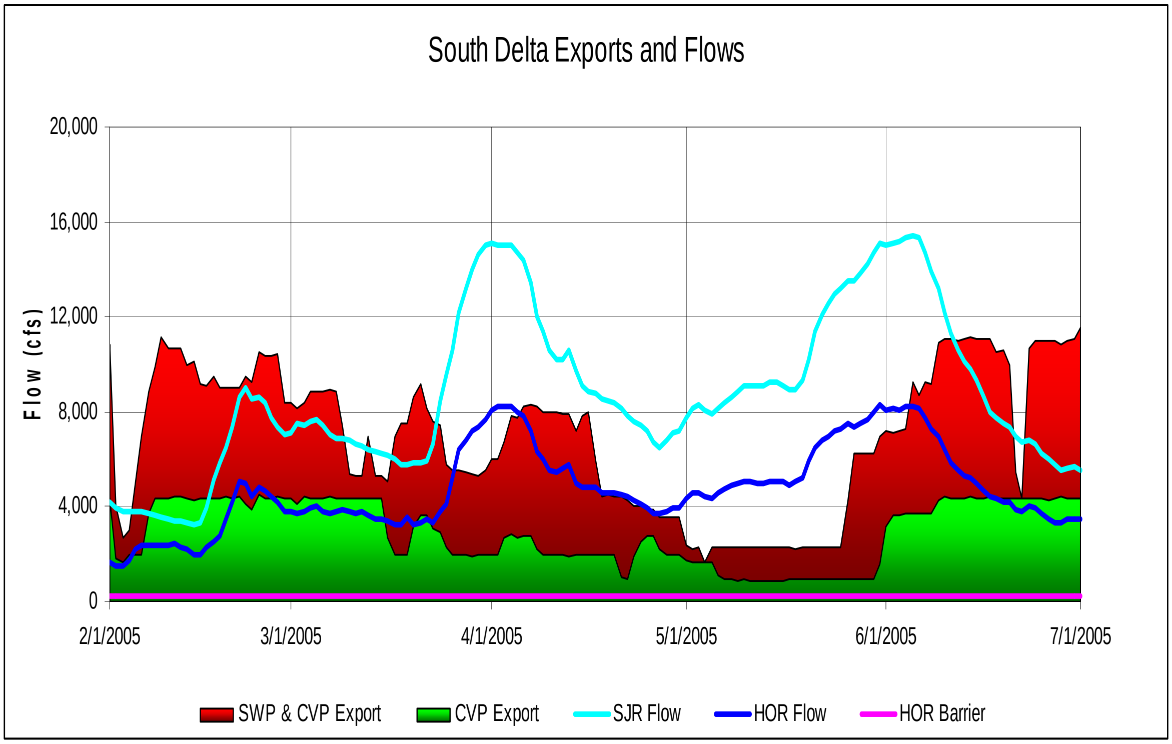
Figure B-18

Daily Estimates of CVP and SWP Salvage Based on San Joaquin River Flows and Exports With Water Splits Only and With Assumed Fish Preferences Compared to Observed CVP and SWP Salvage for February–June 2004



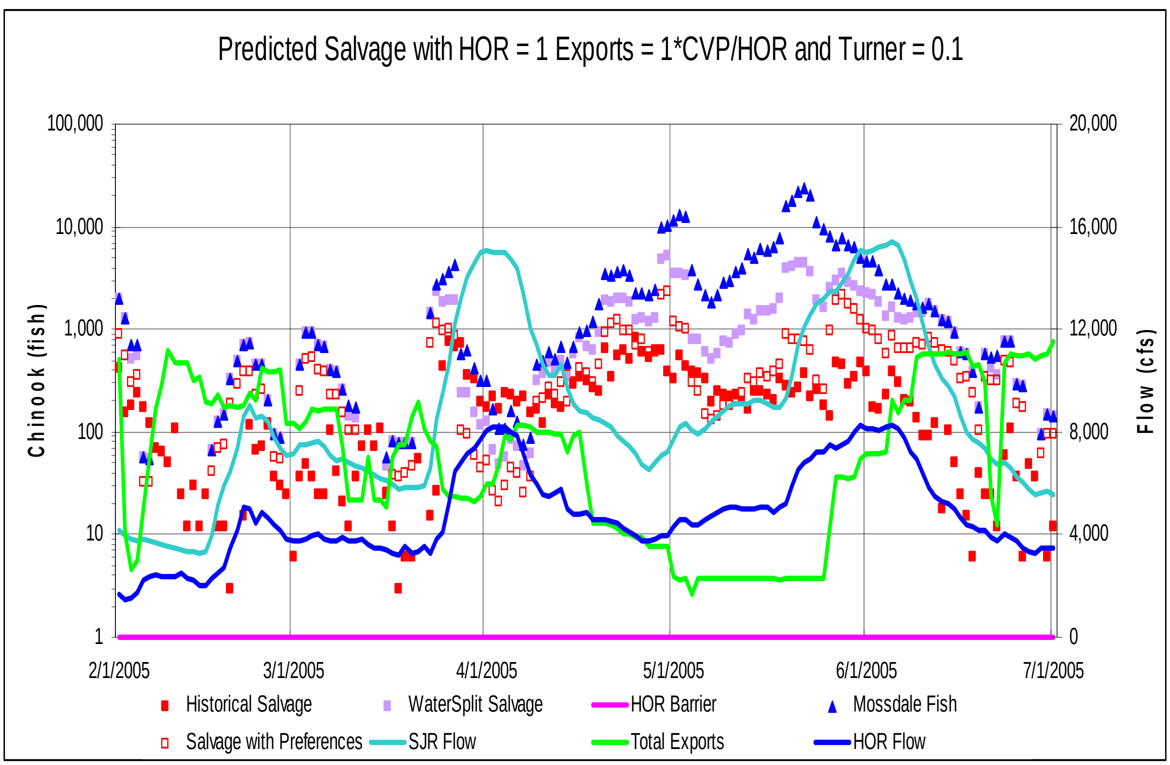


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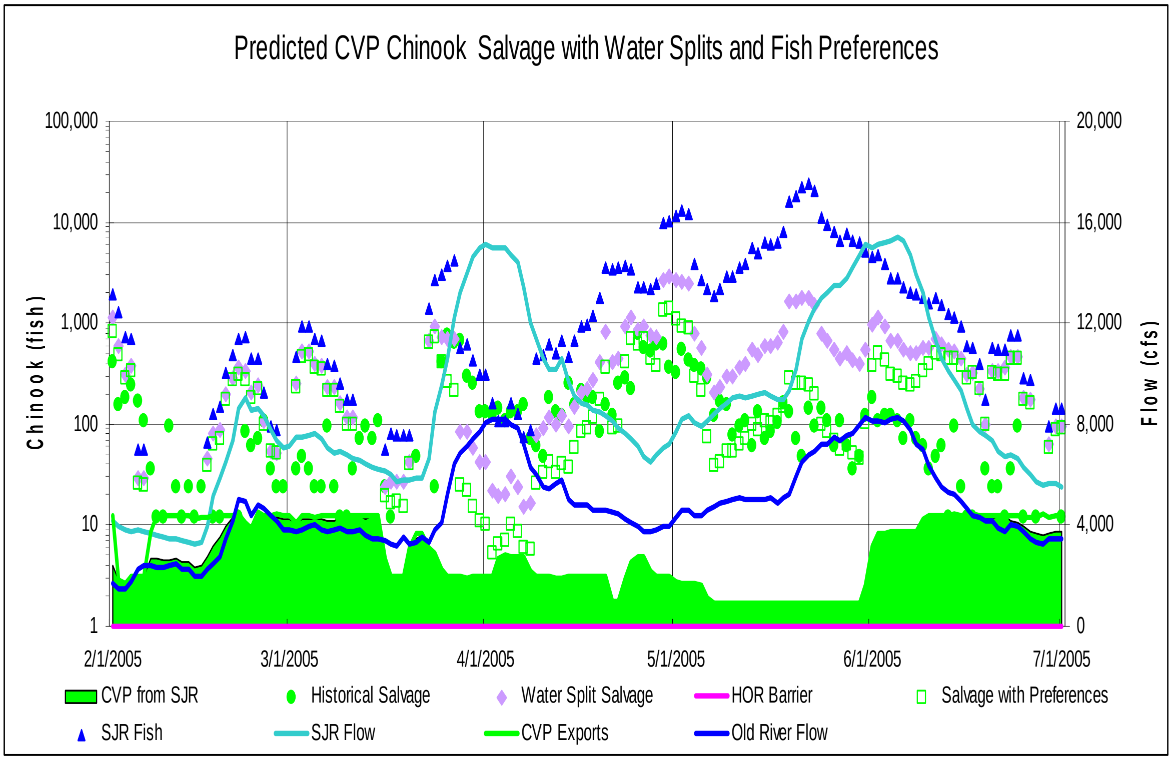
Figure B-19

Daily San Joaquin River Flows and Exports Compared With Mossdale Unmarked Chinook Salmon Abundance and Combined CVP and SWP Salvage during February–June 2005



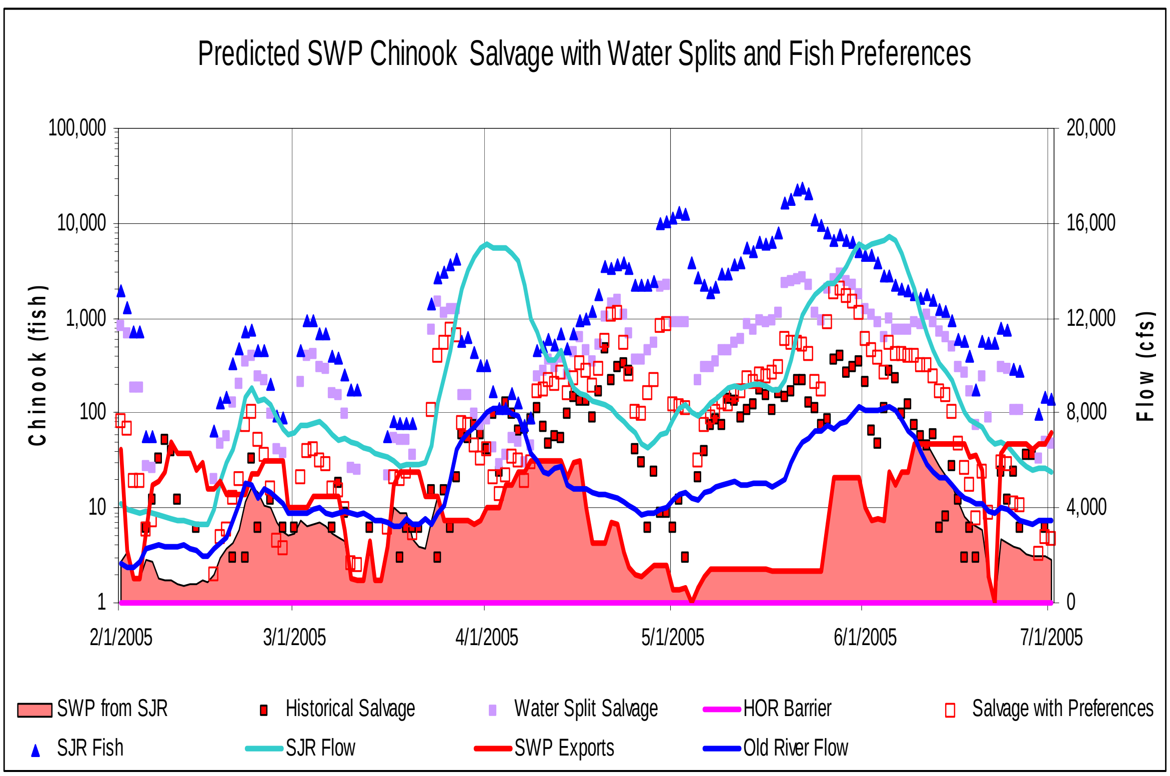


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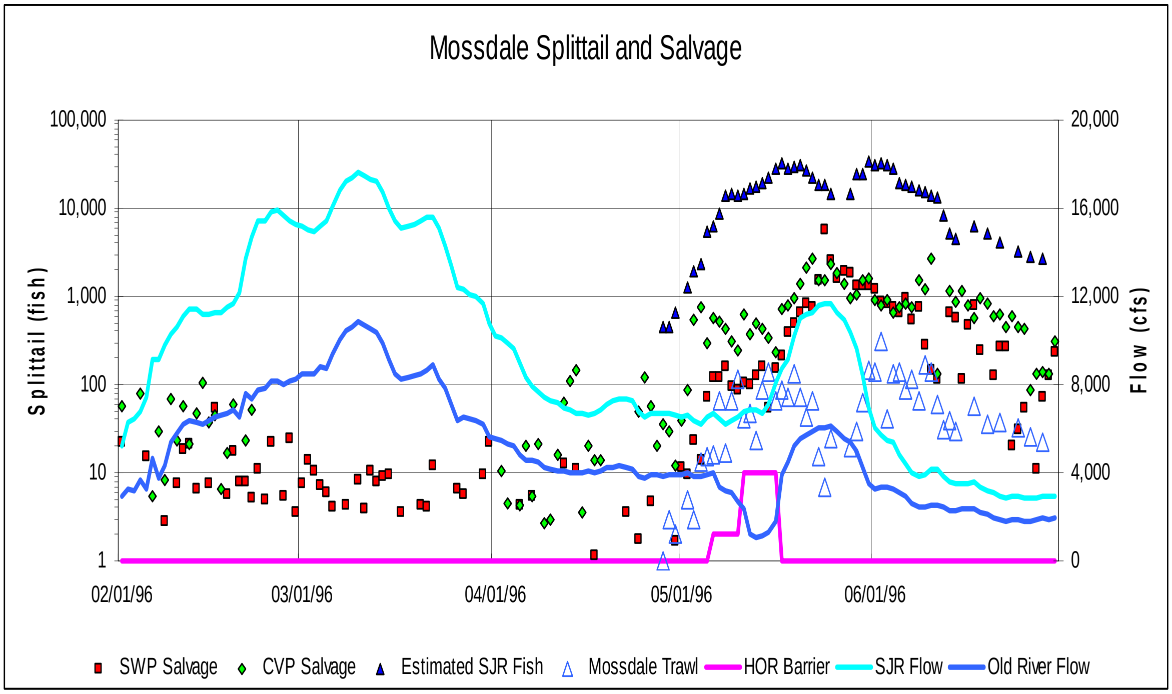
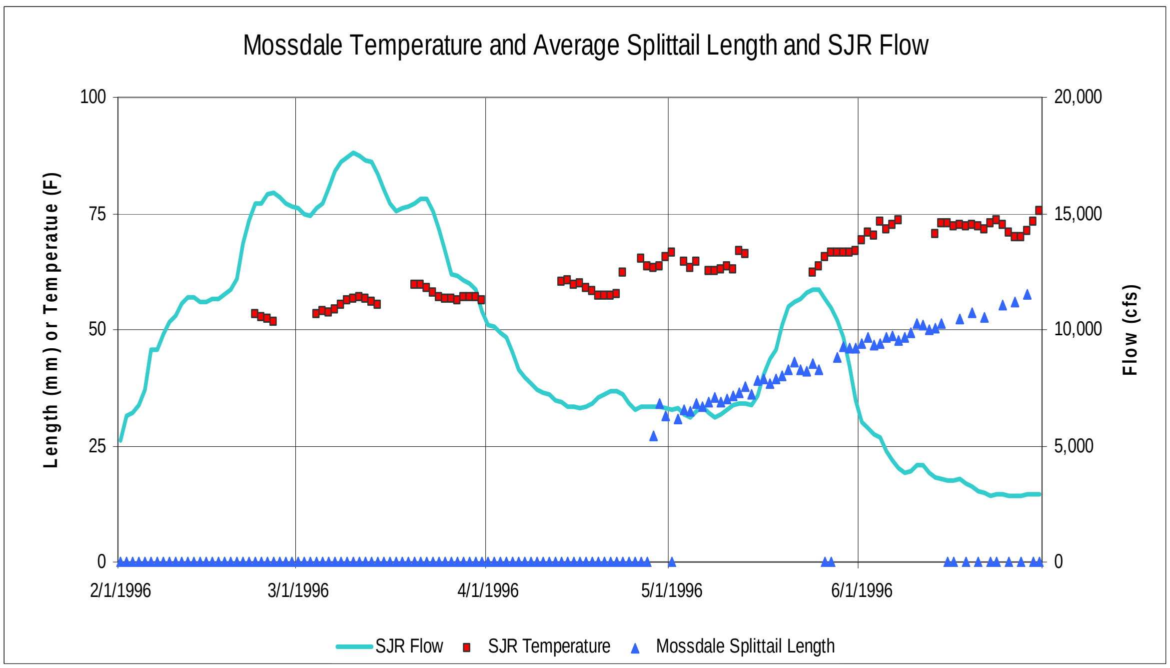
Figure B-20

Daily Estimates of CVP and SWP Salvage Based on San Joaquin River Flows and Exports With Water Splits Only and With Assumed Fish Preferences Compared to Observed CVP and SWP Salvage for February–June 2005





Bottom- San Joaquin River Temperatures (F) and Mossdale Trawl Splittail Average Length (mm) for 1996.

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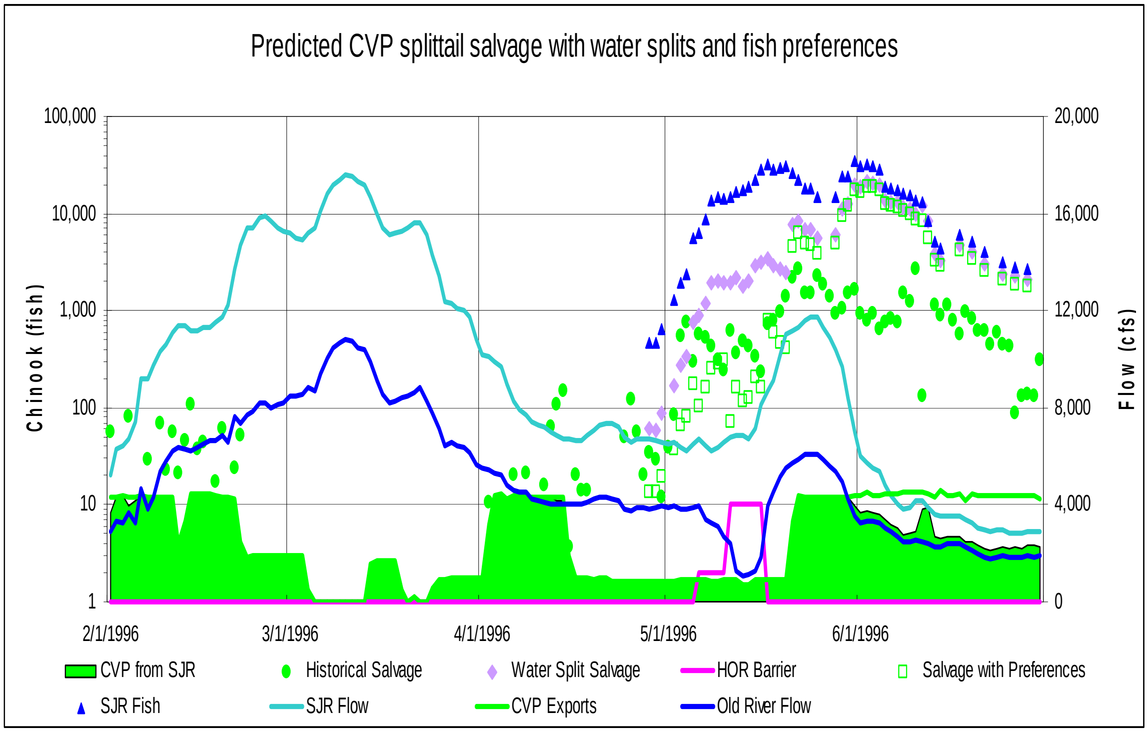
Figure B-21

Top-Daily San Joaquin River Flows With Mossdale Splittail Catch and 5-Day Average Abundance Estimates Compared to the CVP and SWP Splittail Salvage during February–June 1996



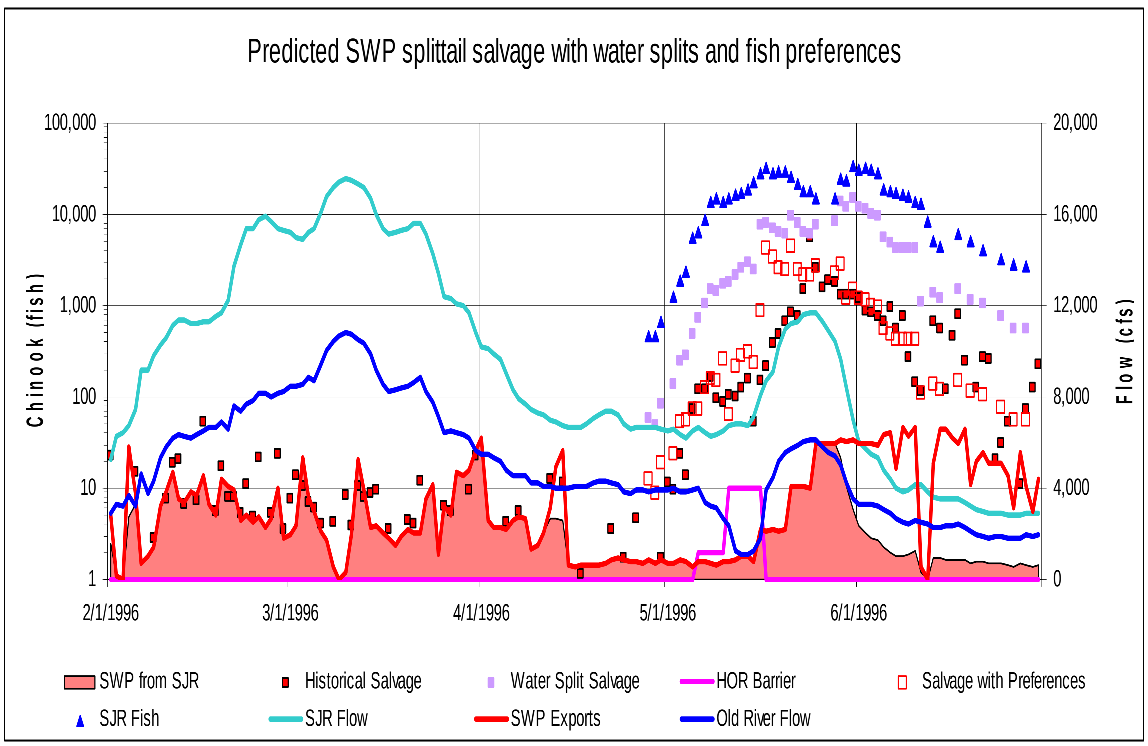


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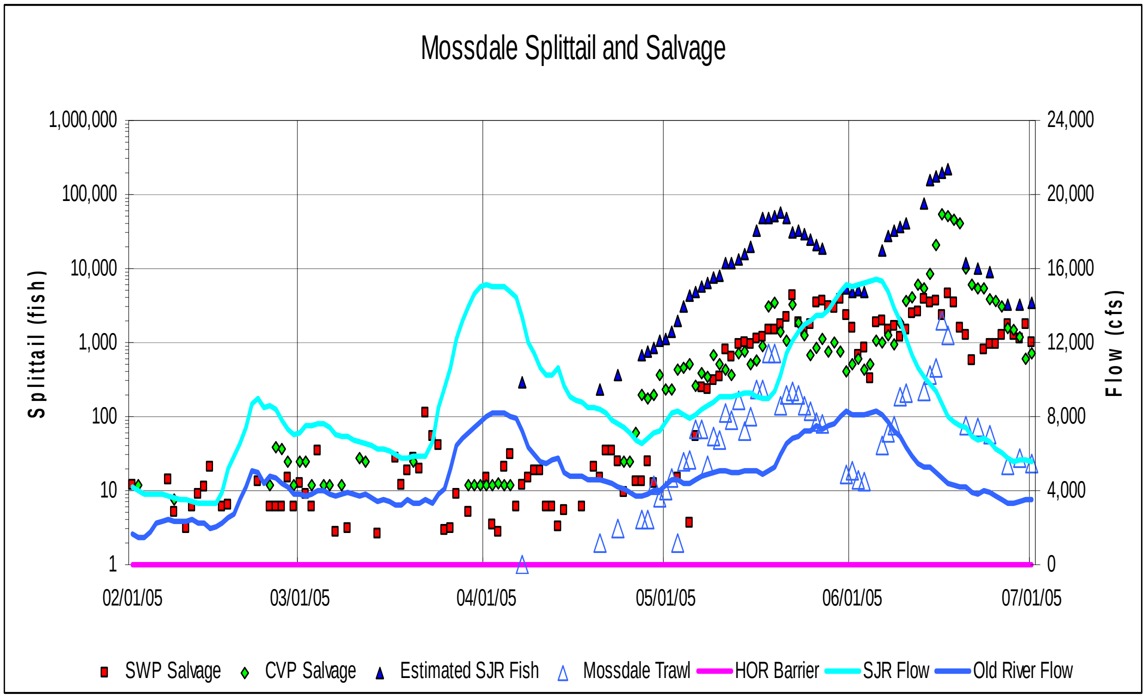
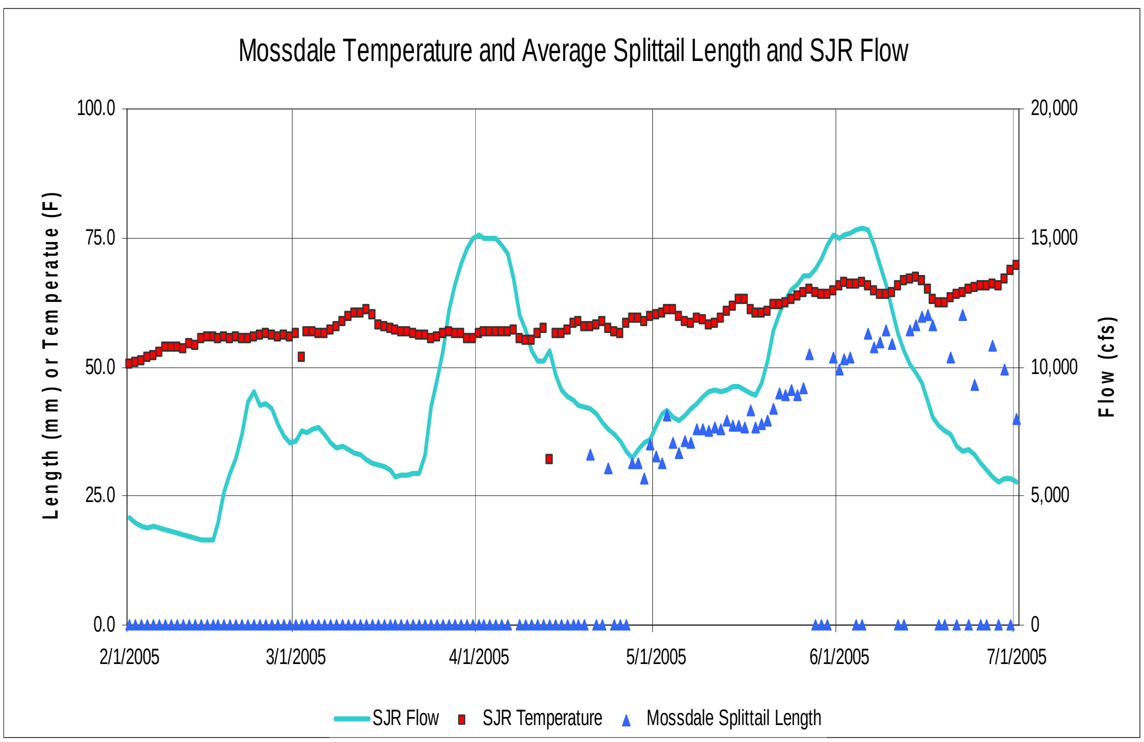
Figure B-22

Daily Estimates of CVP and SWP Splittail Salvage Based on San Joaquin River Flows and Exports With Water Splits Only and With Assumed Fish Preferences Compared to Observed CVP and SWP Splittail Salvage for February–June 1996





Bottom- San Joaquin River temperatures (⁰F) and Mossdale trawl splittail average length (mm) for 2005.

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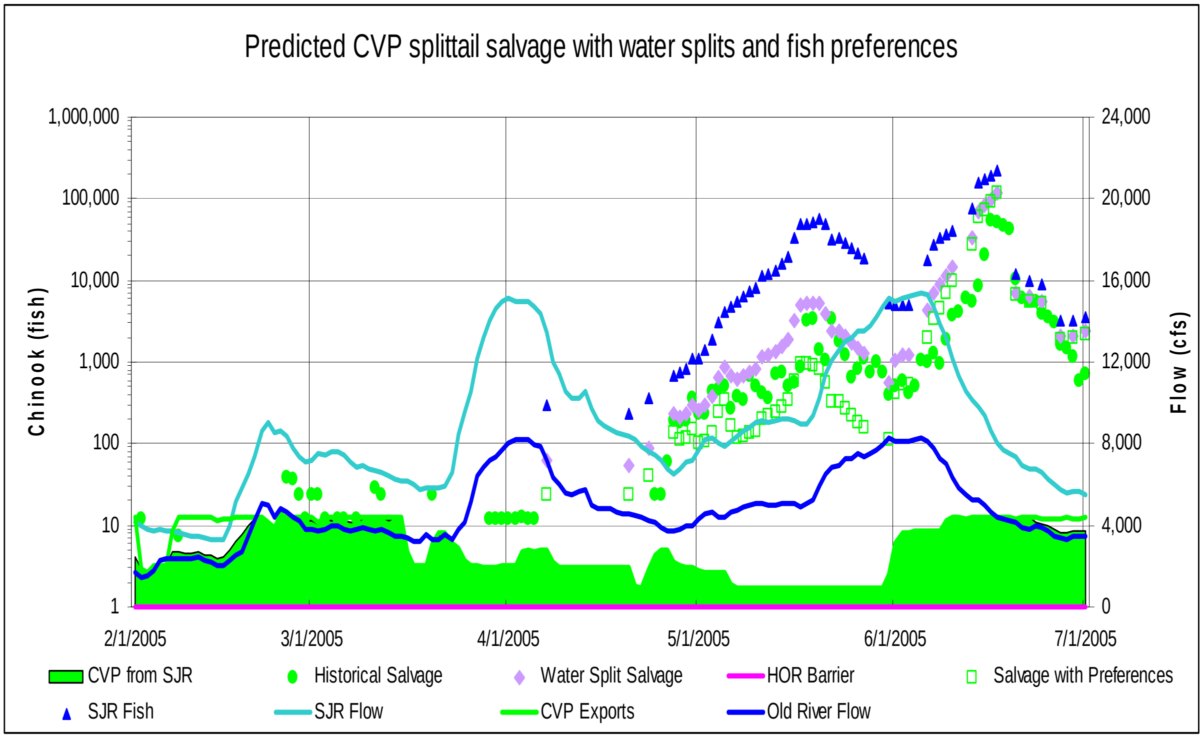
Figure B-23

Top-Daily San Joaquin River Flows With Mossdale Splittail Catch and 5-Day Average Abundance Estimates Compared to the CVP and SWP Splittail Salvage during February–June 2005



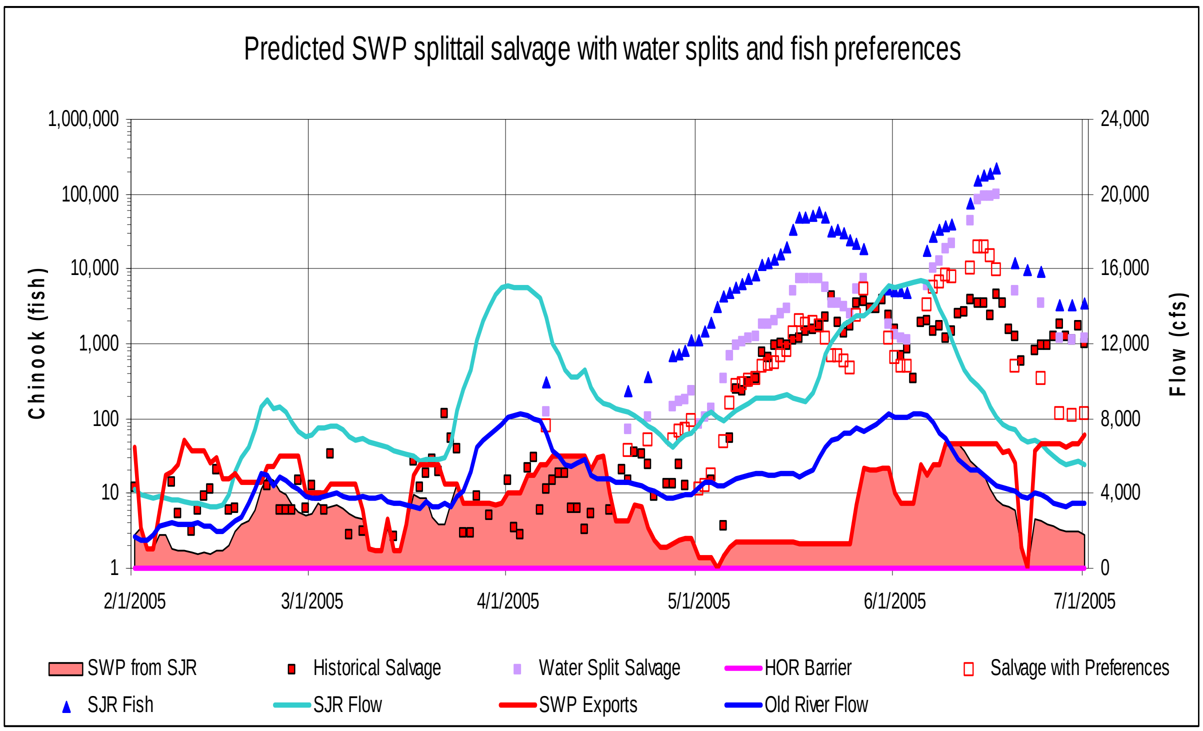


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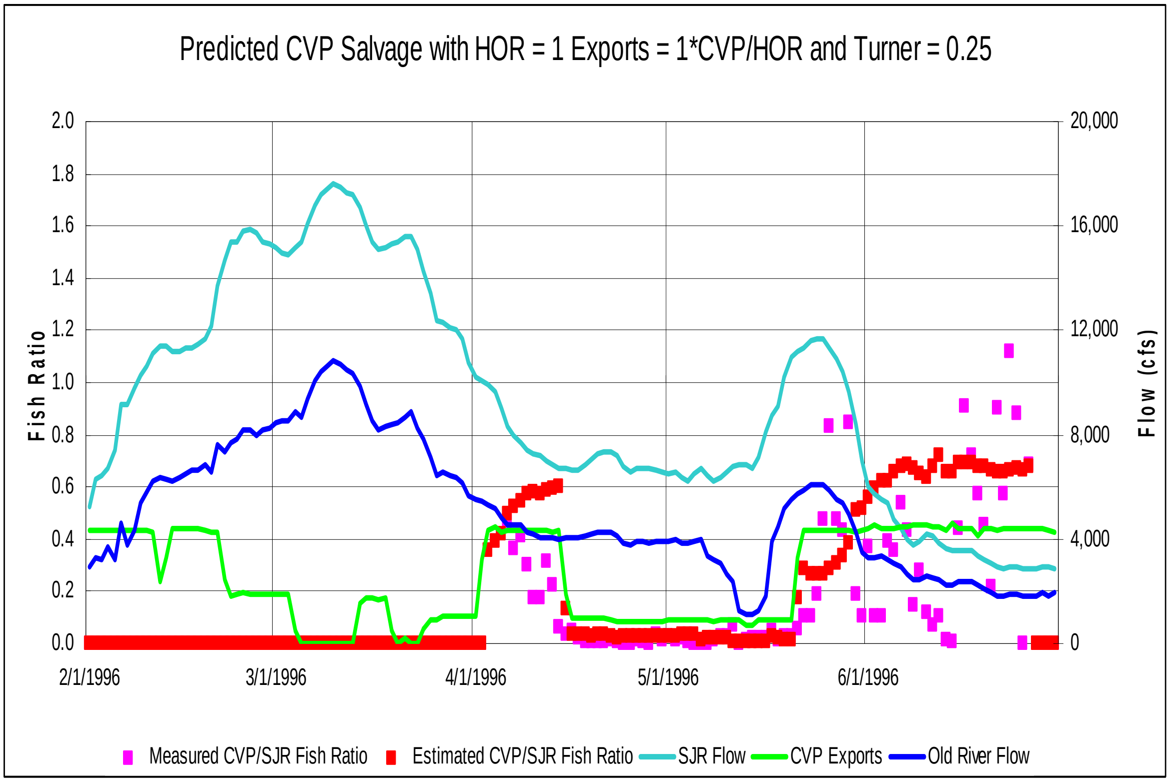
Figure B-24

Daily Estimates of CVP and SWP Splittail Salvage Based on San Joaquin River Flows and Exports With Water Splits Only and With Assumed Fish Preferences Compared to Observed CVP and SWP Splittail Salvage for February–June 2005



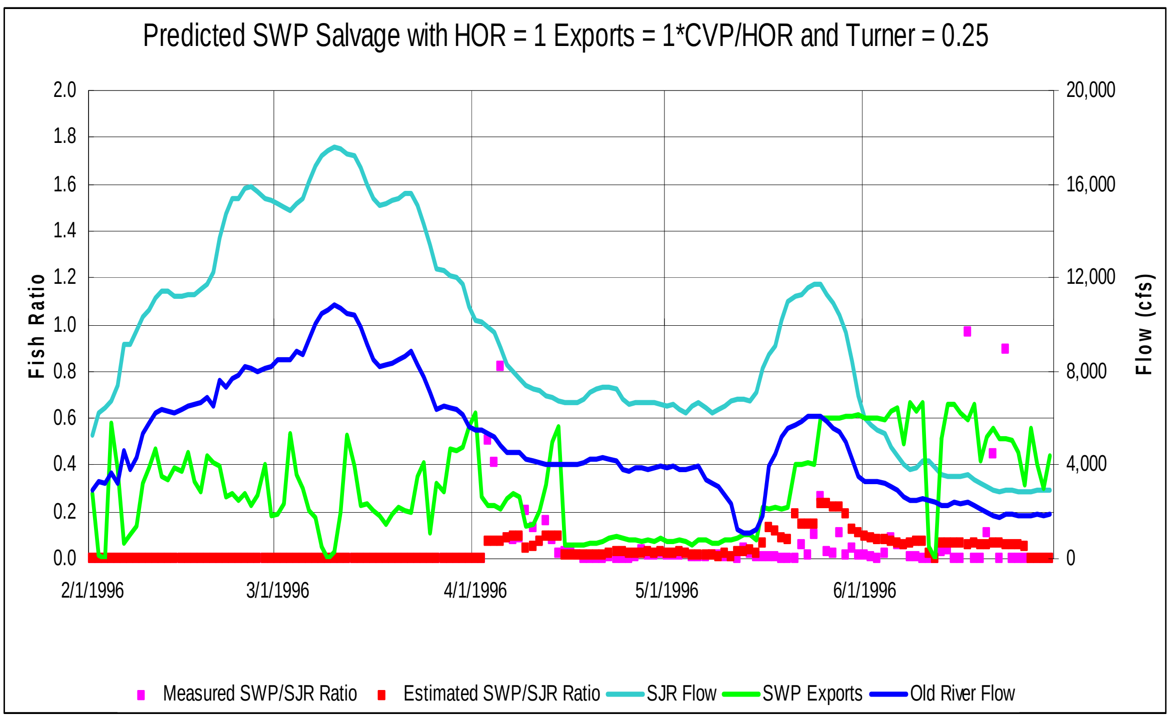


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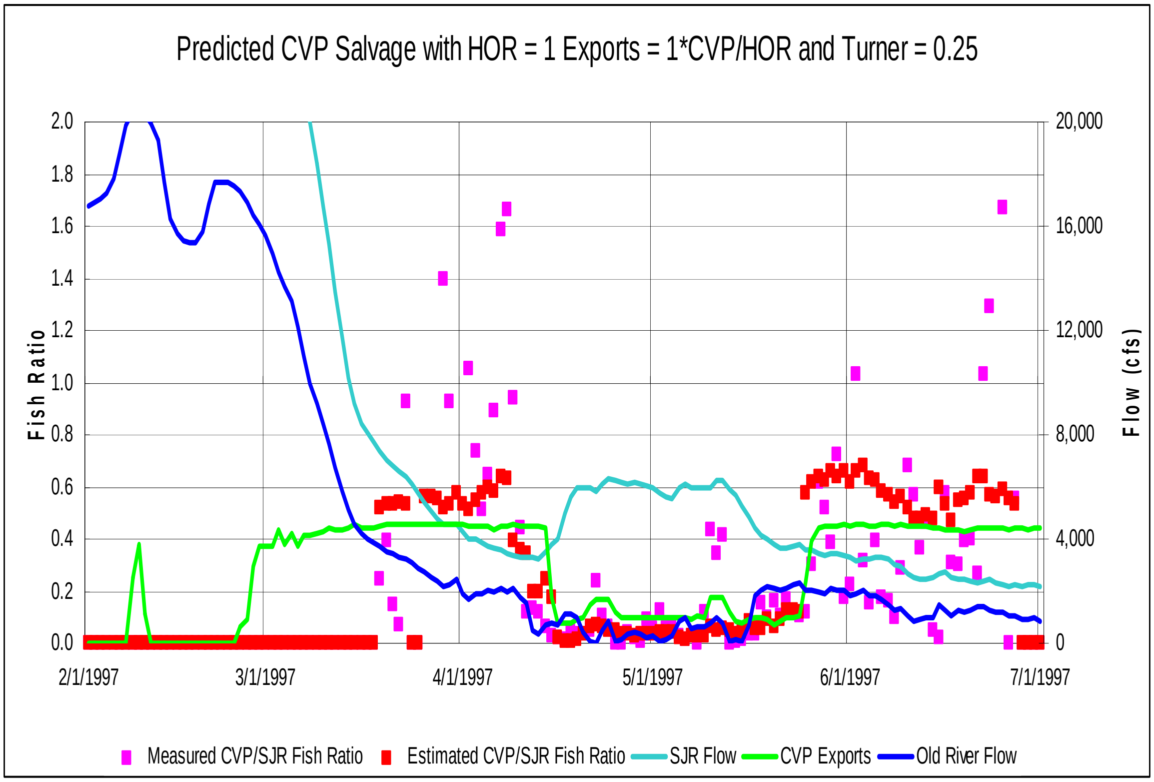
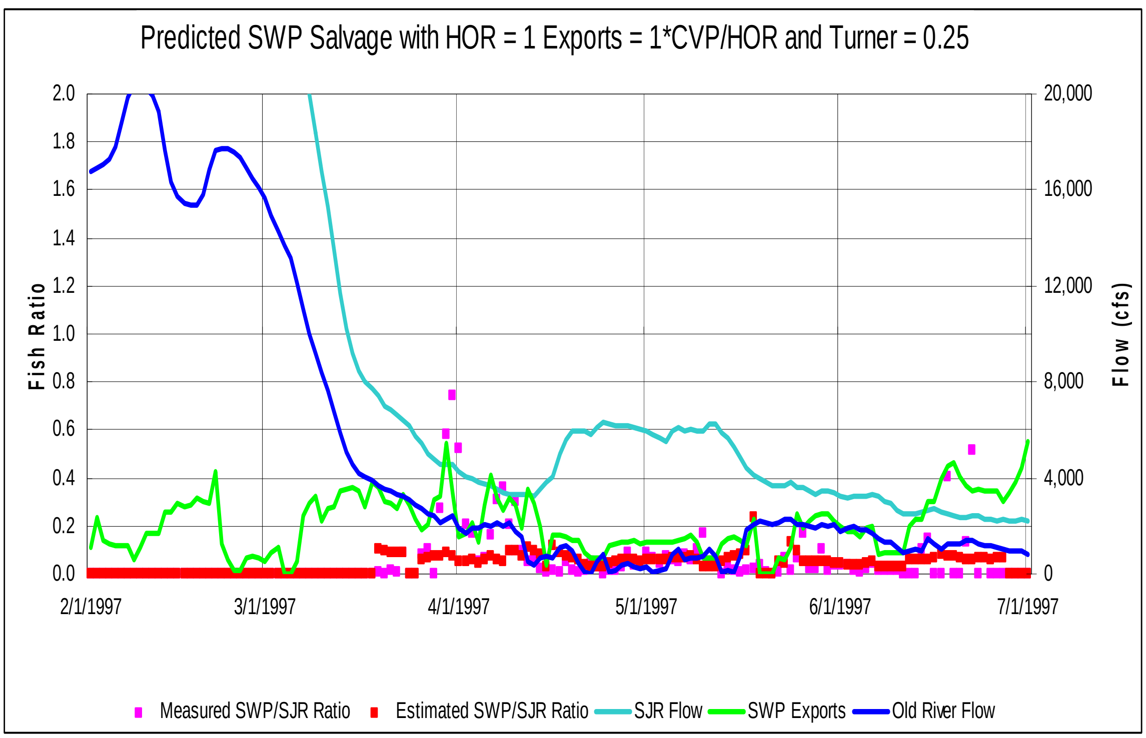
Figure B-25

Comparison of Estimated and Observed Daily Fraction of San Joaquin River Chinook Salmon at CVP Salvage and SWP Salvage for February–June of 1996



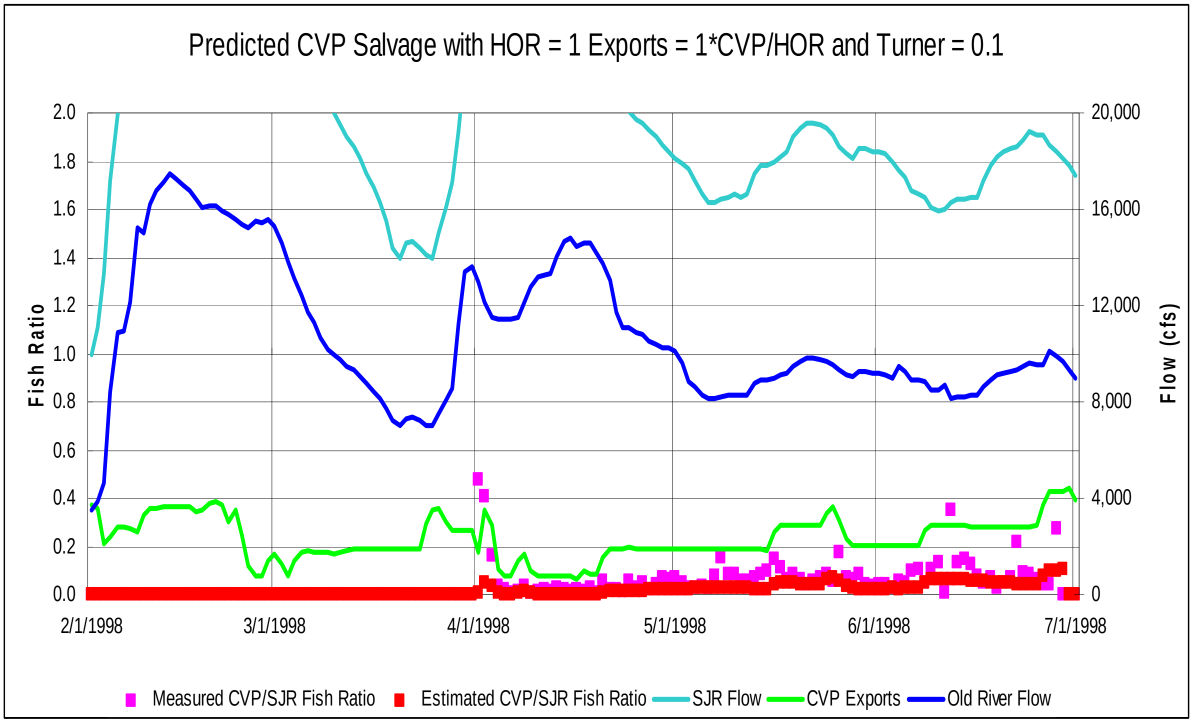


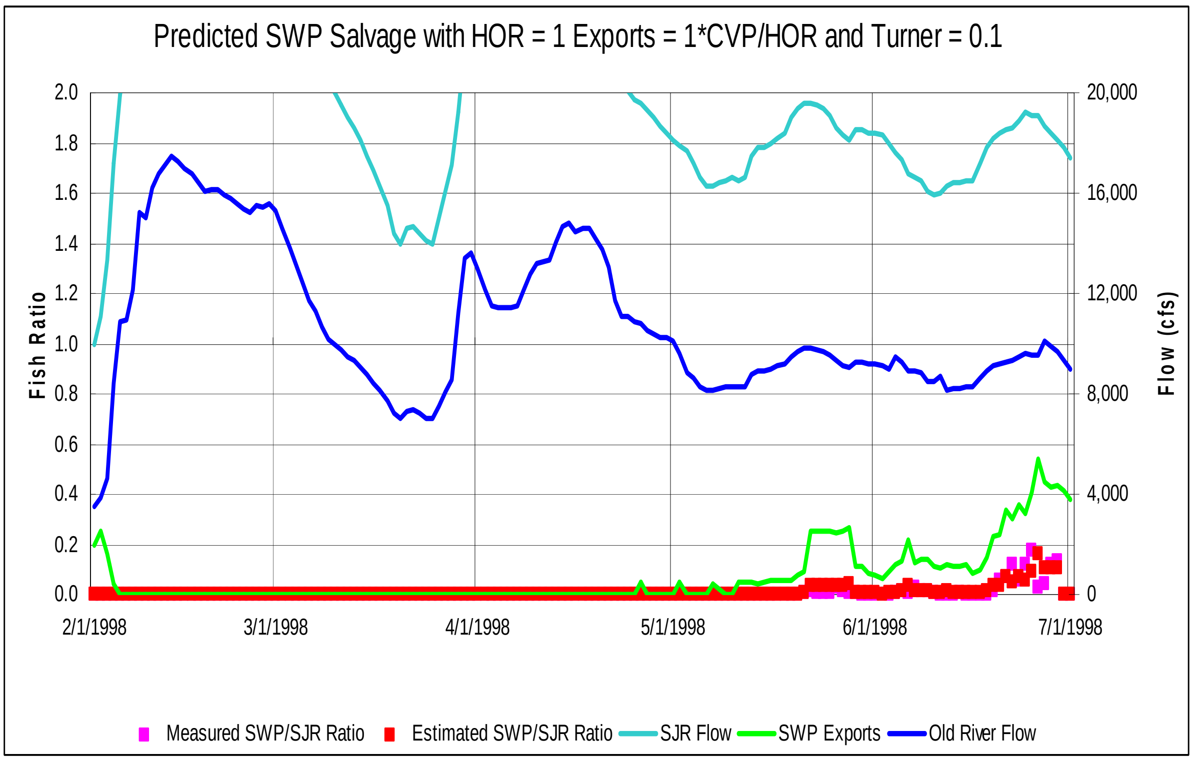
06757.06

Jones & Stokes

Figure B-26

Comparison of Estimated and Observed Daily Fraction of San Joaquin River Chinook Salmon at CVP Salvage and SWP Salvage for February–June of 1997





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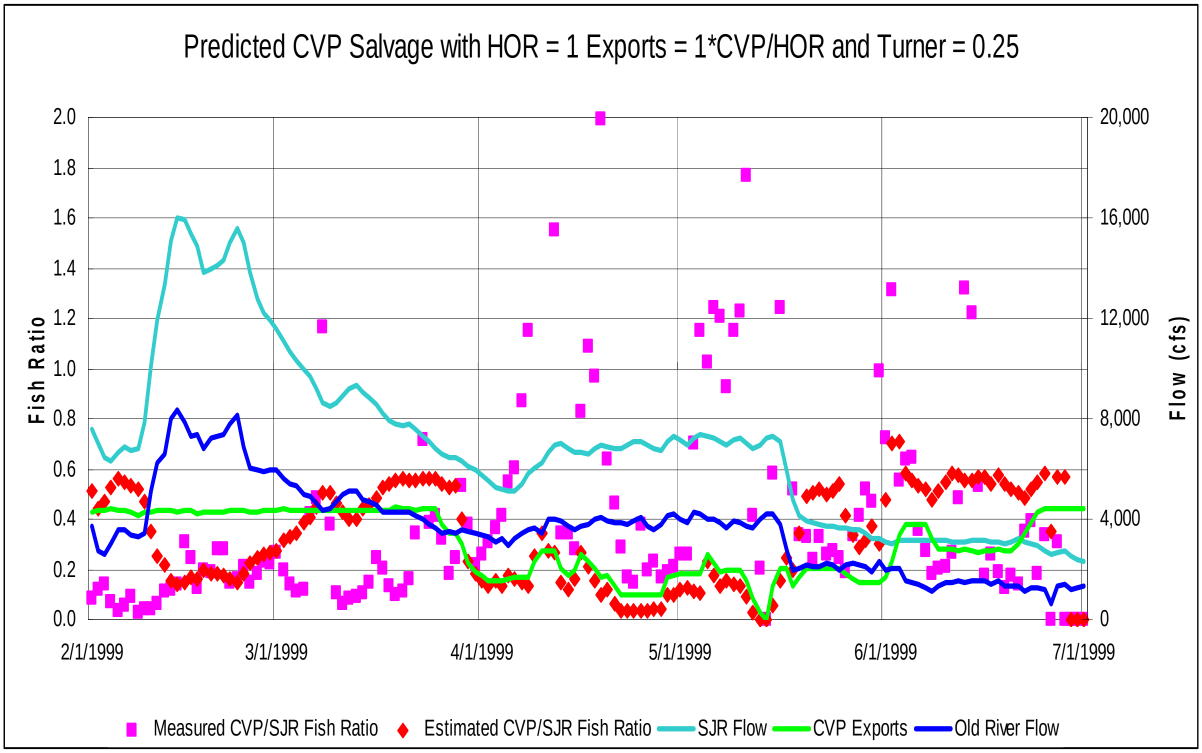
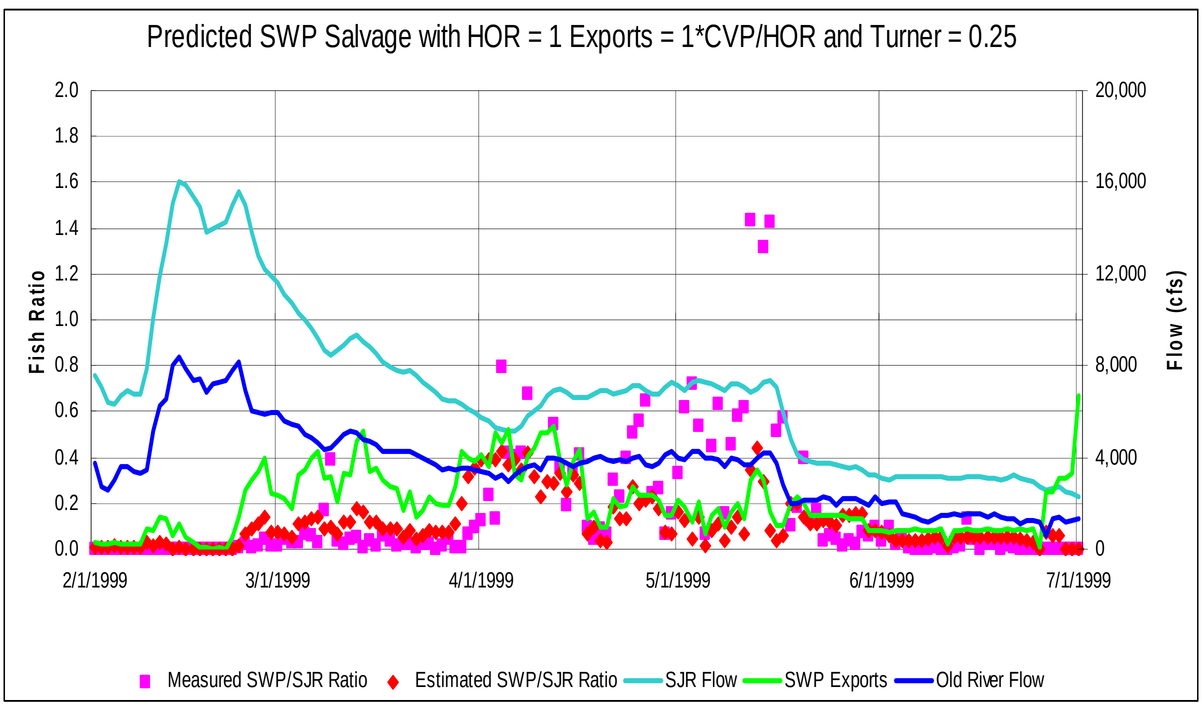
Jones & Stokes

Figure B-27

Comparison of Estimated and Observed Daily Fraction of San Joaquin River Chinook Salmon at CVP Salvage and SWP Salvage for February–June of 1998





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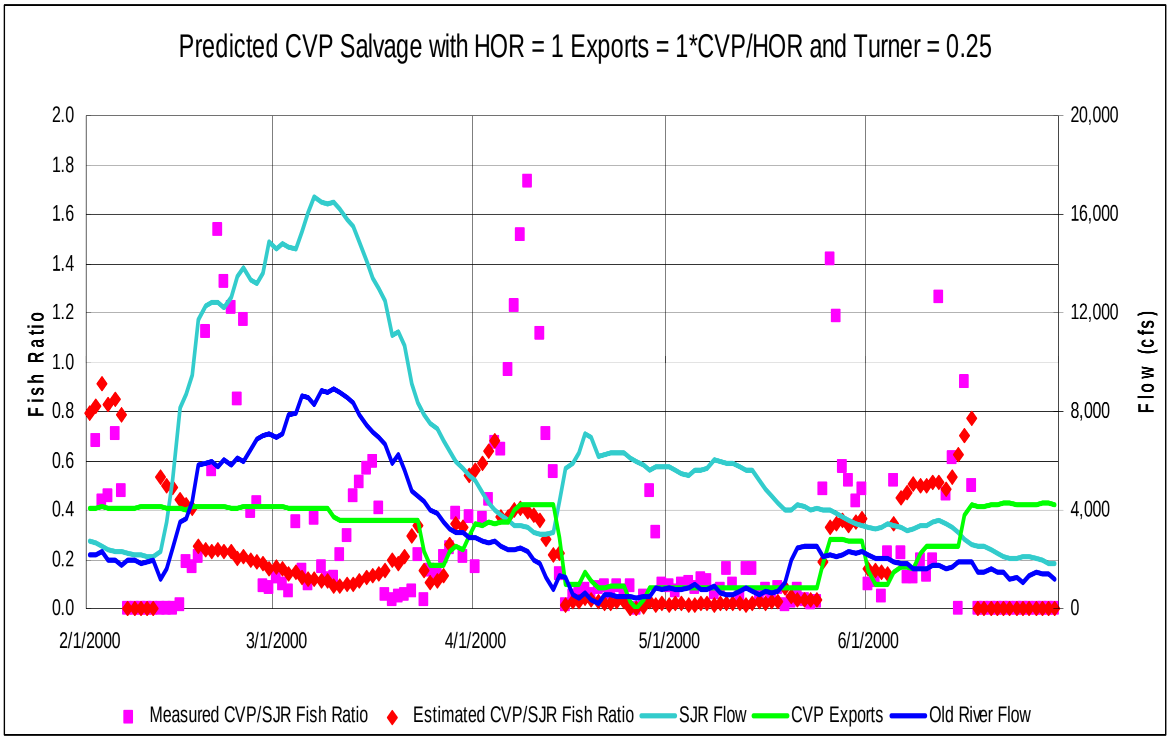
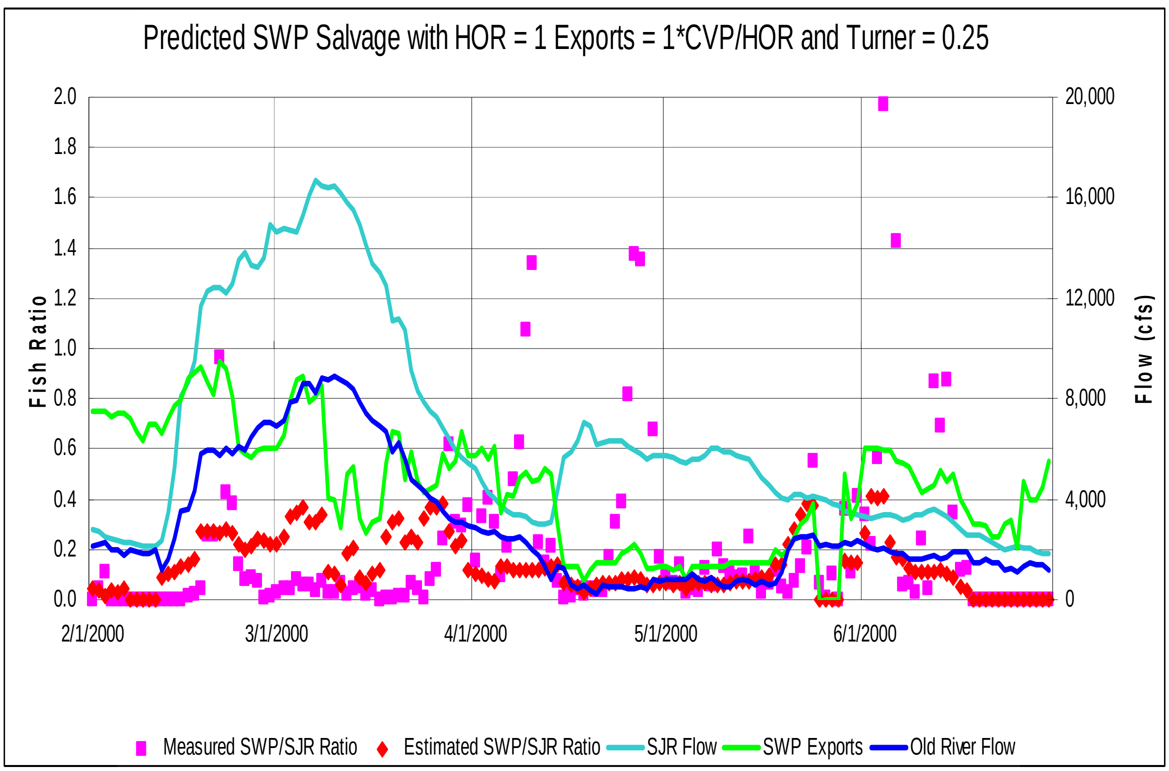
Jones & Stokes

Figure B-28

Comparison of Estimated and Observed Daily Fraction of San Joaquin River Chinook Salmon at CVP Salvage and SWP Salvage for February–June of 1999





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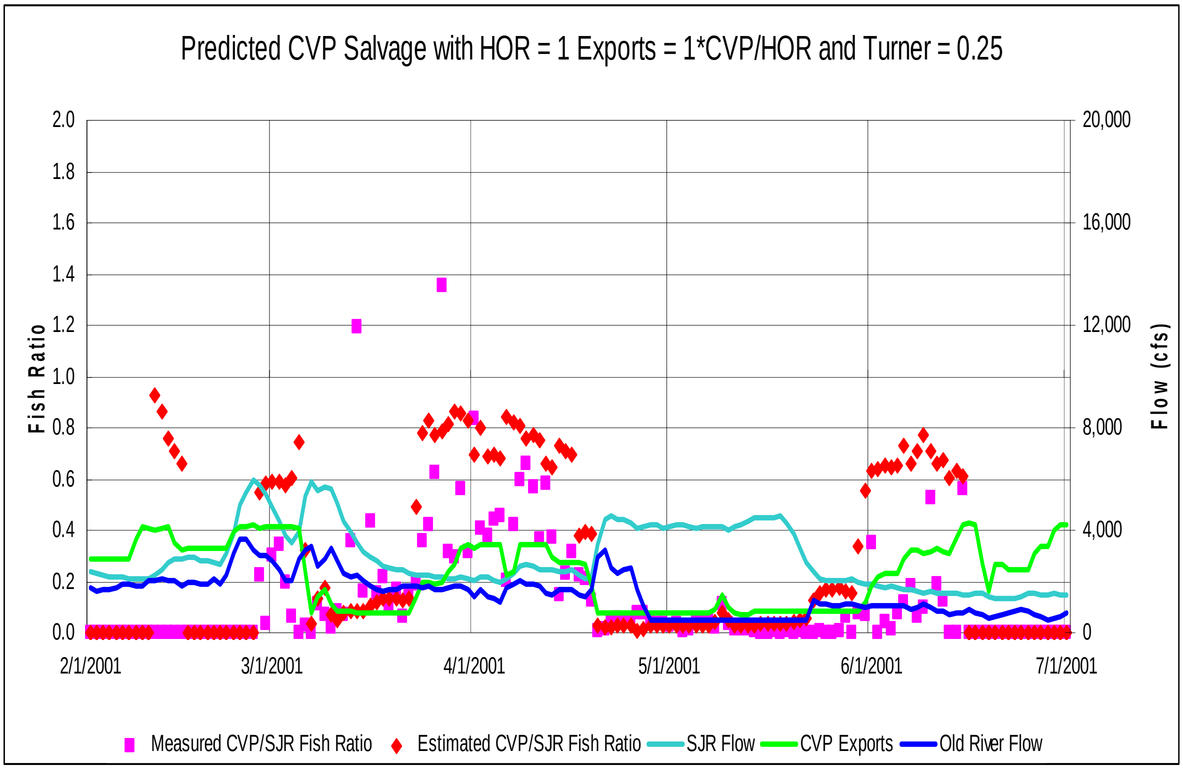
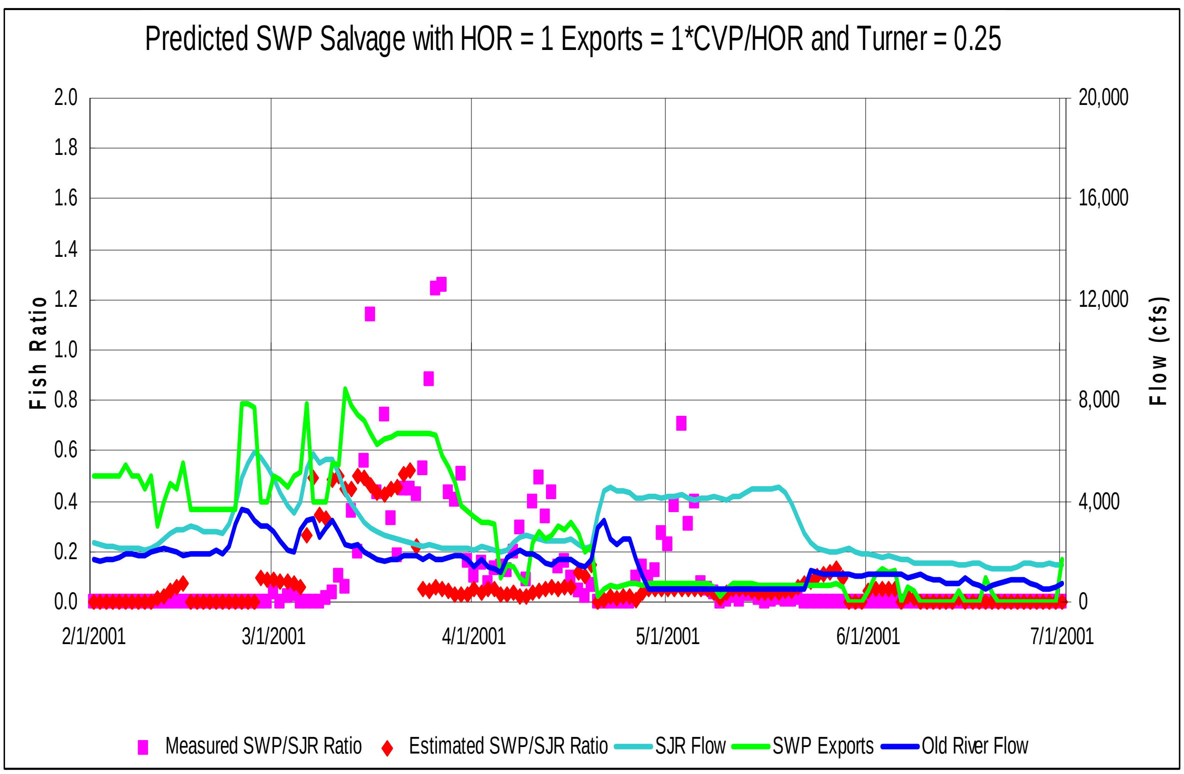
Jones & Stokes

Figure B-29

Comparison of Estimated and Observed Daily Fraction of San Joaquin River Chinook Salmon at CVP Salvage and SWP Salvage for February–June of 2000





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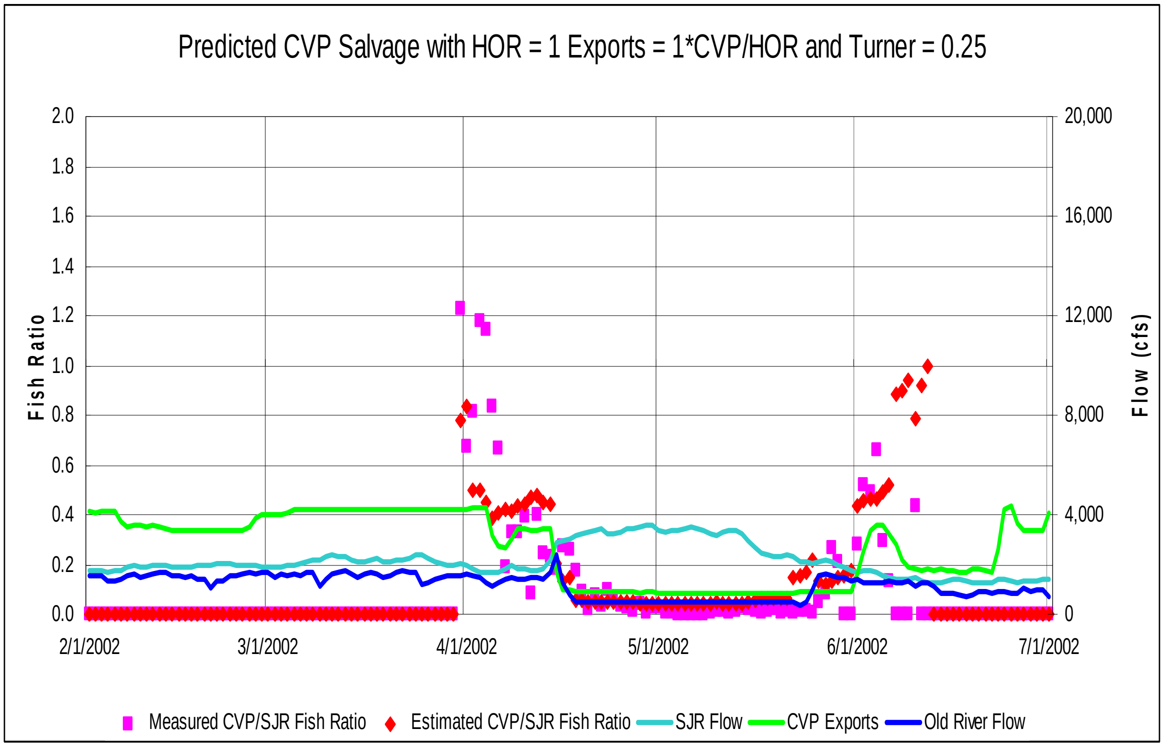
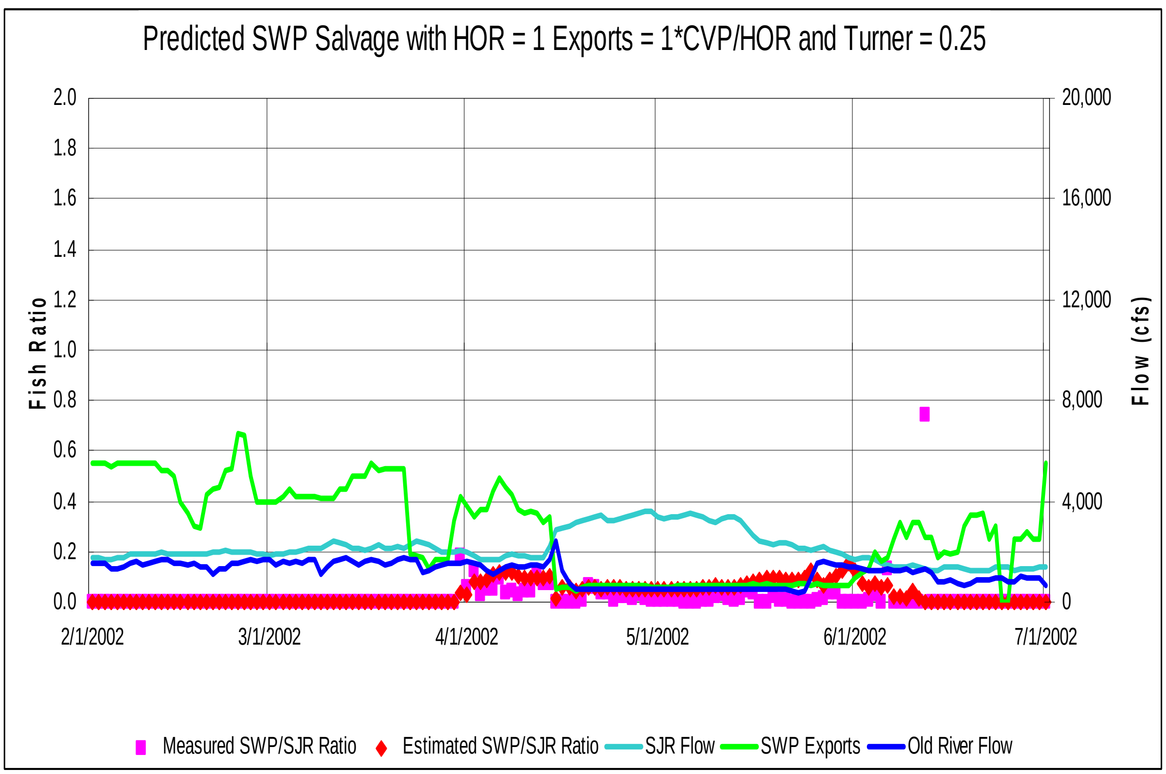
Jones & Stokes

Figure B-30

Comparison of Estimated and Observed Daily Fraction of San Joaquin River Chinook at CVP Salvage and SWP Salvage for February–June of 2001





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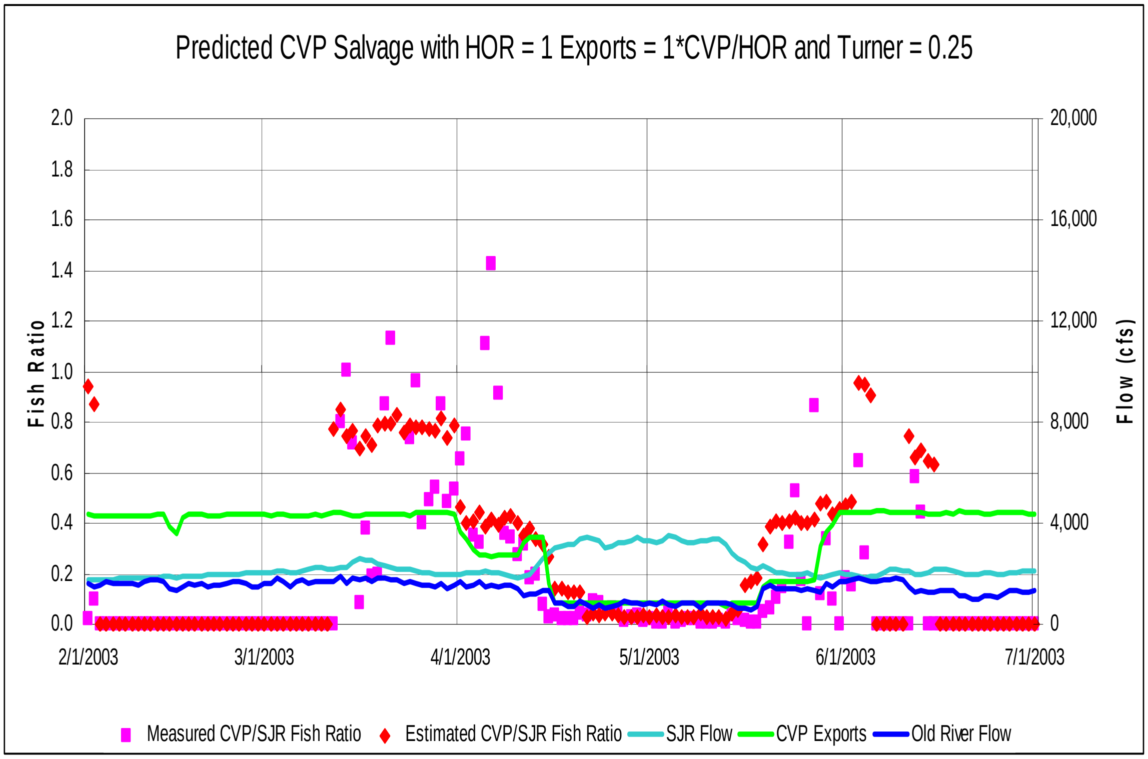
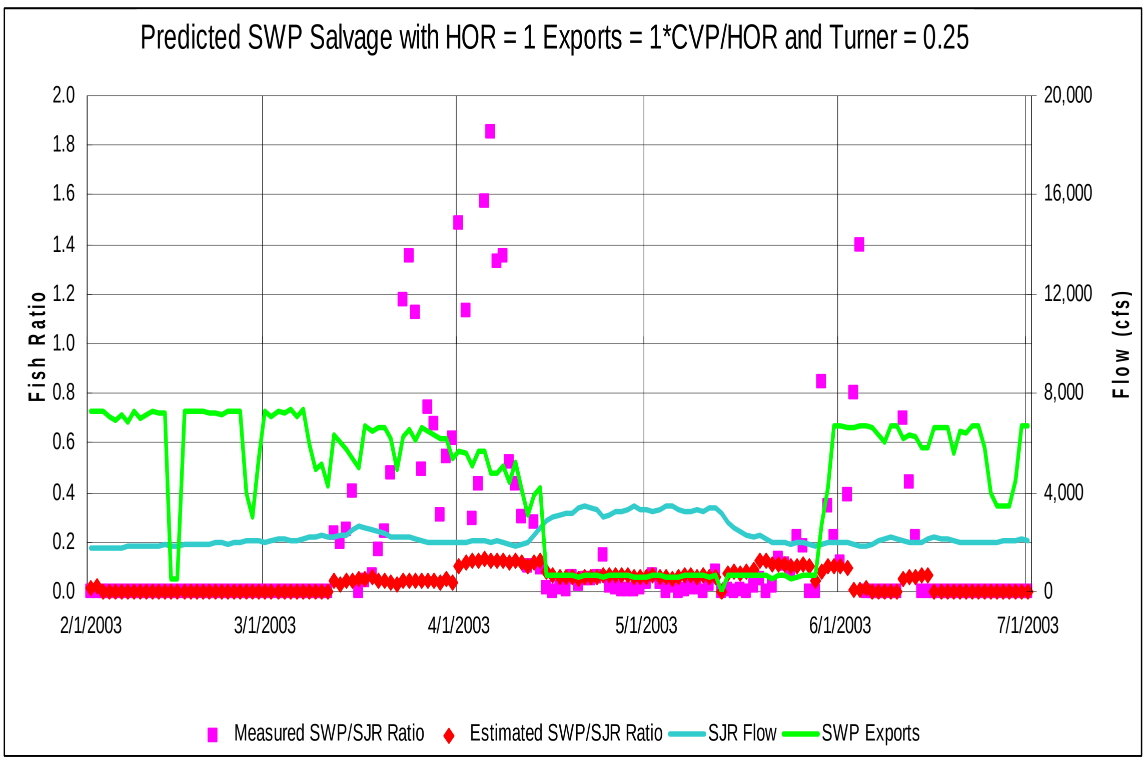
Jones & Stokes

Figure B-31

Comparison of Estimated and Observed Daily Fraction of San Joaquin River Chinook Salmon at CVP Salvage and SWP Salvage for February–June of 2002





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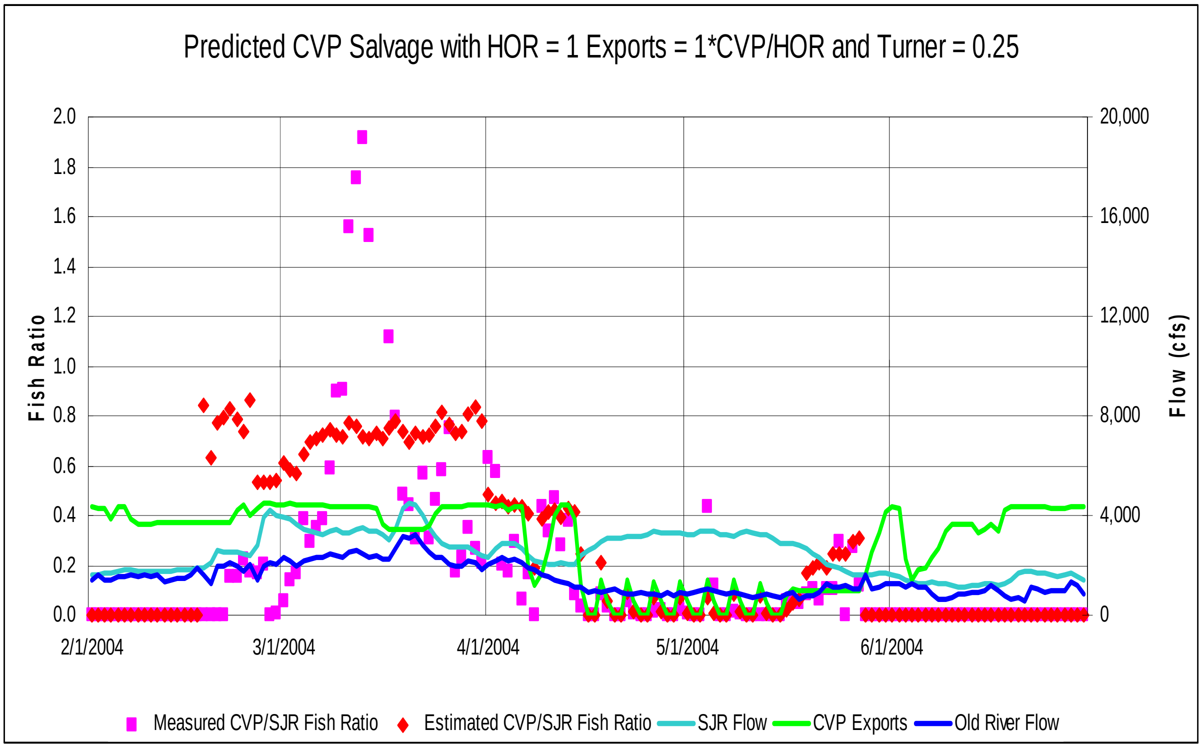
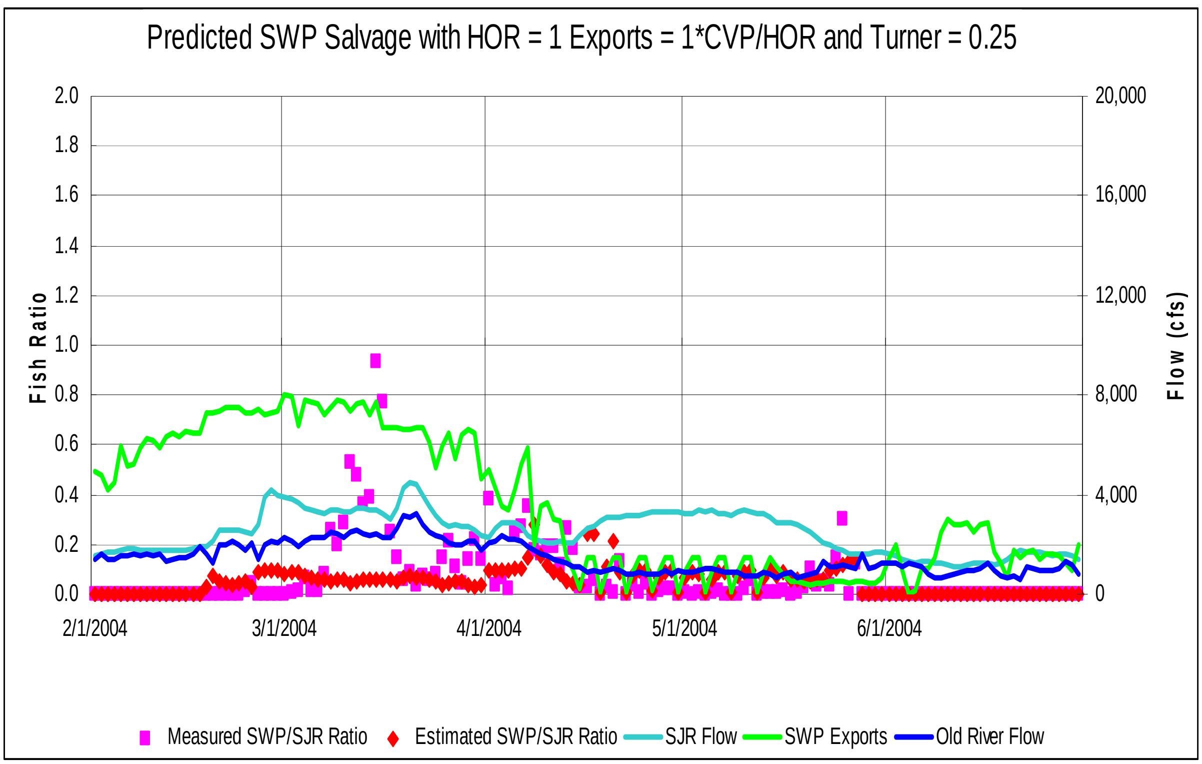
Jones & Stokes

Figure B-32

Comparison of Estimated and Observed Daily Fraction of San Joaquin River Chinook Salmon at CVP Salvage and SWP Salvage for February–June of 2003





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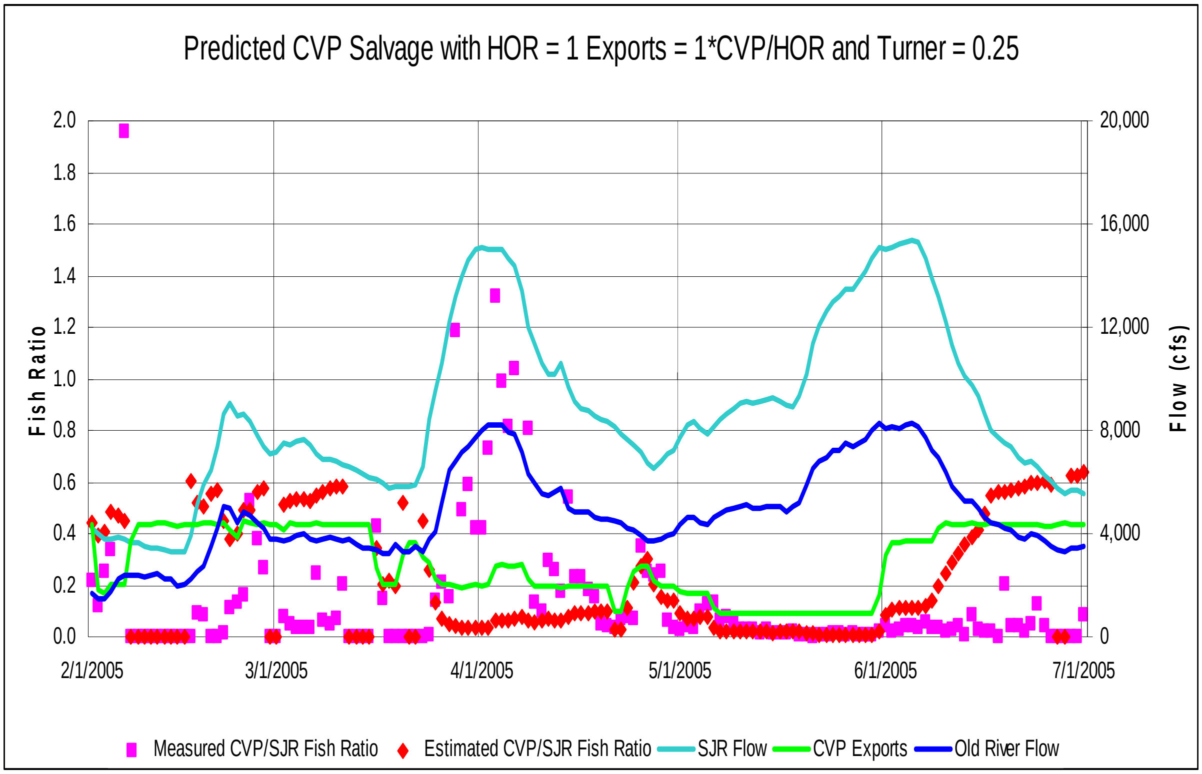
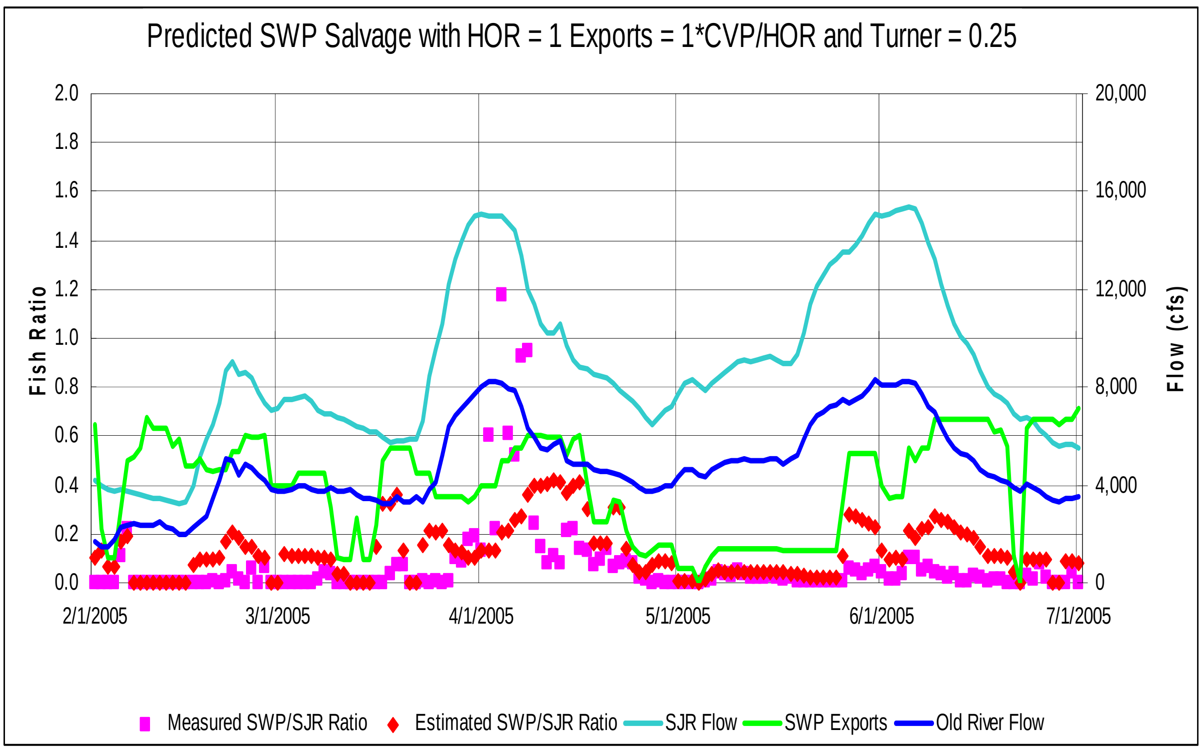
Jones & Stokes

Figure B-33

Comparison of Estimated and Observed Daily Fraction of San Joaquin River Chinook Salmon at CVP Salvage and SWP Salvage for February–June of 2004





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Jones & Stokes

Figure B-34

Comparison of Estimated and Observed Daily Fraction of San Joaquin River Chinook Salmon at CVP Salvage and SWP Salvage for February–June of 2005

Appendix C

San Joaquin River Juvenile Chinook Salmon Delta Pathway Survival Model

Appendix C

San Joaquin River Juvenile Chinook Salmon Delta Pathway Survival Model

This appendix describes an integrated Delta pathway survival model for San Joaquin River juvenile fall-run Chinook salmon that was developed to support the overall evaluation of the head of Old River barrier. Appendix B shows that the fraction of San Joaquin River fish that will reach Central Valley Project (CVP) or State Water Project (SWP) can be calculated from the San Joaquin River flow, exports, and the assumed flow splits and fish preferences in the salvage fraction evaluation model. The remaining task for the overall evaluation of the head of Old River barrier effectiveness is to determine the relative survival for (1) fish that are salvaged and trucked to Chipps Island and (2) fish that move toward Chipps Island in the Delta channels. The likely CVP salvage success is generally thought to be relatively high (e.g., 75% for Chinook salmon). However, the survival estimates for coded wire-tagged (CWT) fish moving to Chipps Island are generally lower (10% to 25%).

The Delta pathway survival model was developed to evaluate future Vernalis Adaptive Management Program (VAMP) scenarios and to support planning of head of Old River barrier operations based on either a temporary or permanent barrier system. The pathway survival model uses the data, hypotheses and assumptions already described in this report. The model helps to integrate the assumptions and demonstrates their effects on the estimated survival of juvenile San Joaquin River Chinook salmon to Chipps Island. The Delta pathway survival model includes these elements:

1. Migration pathways
2. Travel time distributions
3. Survival along each pathway (i.e., daily mortality)
4. Head of Old River barrier operations
5. San Joaquin River flow and CVP and SWP exports
6. Delta channel flow splits and fish preferences
7. CVP and SWP salvage losses (i.e., predation, louver efficiency)

These elements each introduce uncertainty in estimating the benefits of the head of Old River barrier installation, and the potential fish survival benefits of a future head of Old River gate facility. The flow splits and fish preferences determine the routes of travel for migrating fish. Travel times through these pathways describe the duration of exposure to various sources of mortality. The pathway survival rates may depend on the habitat, predation, and water quality conditions along each pathway. The head of Old River barrier will shift the travel routes and travel times, blocking the direct pathway to CVP and SWP salvage. Flows, exports, and fish preferences will determine the relative fractions of out-migrants that are exposed to each pathway. The CVP and SWP salvage losses determine the number of fish that are trucked and released upstream of Chipps Island.

The pathway survival model is an integrated analysis that aims to express the consequences of several linked hypotheses, whereas statistical analysis aims to support or reject individual hypotheses. Many sources of uncertainty in the Delta reduce the utility of a statistical analysis of CWT recoveries to explain the mechanisms controlling San Joaquin juvenile Chinook salmon survival. As discussed in Appendix A, this complexity limits the utility of CWT data for assessing the benefits of the head of Old River barrier. The purpose of the Delta pathway survival model is to present a series of linked hypotheses that describe the mechanisms controlling survival of San Joaquin fall-run Chinook salmon through the south Delta, and to provide an analytical framework for investigating alternative hypotheses through comparisons of model results.

Survival Model Structure and Function

The pathway survival model was developed to evaluate the effectiveness of the head of Old River barrier for increasing survival from Mossdale to Chipps Island. Fish enter the model above or below the head of Old River barrier near Mossdale, move down Old River or Turner Cut, and then to salvage with subsequent trucking to Chipps Island, or migrate down the San Joaquin River channels to Chipps Island. Under certain conditions when Old River flows are higher than exports fish may also move down Old River, and continue past salvage to Chipps Island. Mortality is experienced in transit between locations, at the salvage facilities, and at salvage release.

The model includes several switches for adjusting the coefficients and assumed flow and export conditions. Many of the variables including flow-split preferences, mortality rates, and efficiencies are fractions, and can be controlled on the interface screen of the head of Old River barrier model using dials and sliders.

There are several graphs that display some of the basic model inputs and outputs over time including the number of fish surviving to different locations, flows, and the head of Old River barrier conditions. Outputs of the model can be exported as text to a Microsoft Excel file, for comparisons between different model results.

All of the flow split equations and fish preferences described for the salvage model are used in the pathway survival model. Each day fish enter the model based on the estimates at Mossdale, or the known number of fish released as a

VAMP CWT group. This population then travels down the various pathways based on the travel time estimates described above, and experiences mortality until it reaches Chipps Island where it is added to the cumulative estimate of survival to Chipps Island.

When the barrier is open, fish movement into Old River is a function of flow in the mainstem and the exports. CVP and SWP pumping combine to form the total exports, which directly influence the head of Old River diversion rate. The fraction of fish moving into Old River (‘Old River Fraction’) is then expressed as a function of the flow split described above in the context of the head of Old River barrier regime.

Old River to Salvage Pathway

If diverted at the head of Old River, fish move down Old River and Grant Line Canal towards the CVP and SWP fish salvage facilities. Some fish expire before reaching salvage. Travel time follows a specified distribution, and the daily mortality rate reduces the number making it to the salvage facilities each day. The flow split and fish split at CVP is a function of flow through Old River and CVP exports. Under many conditions fish may not follow the flow split, and may preferentially select a pathway due to behavior, physical conditions, or tidal flow conditions. These preferences are included as variables in the model.

Salvage success at CVP is a function of predation, louver efficiency and other physical losses. The variable ‘CVP Improvements’ was included to evaluate the benefits of assumed improvements in the CVP salvage facilities. It is a simple multiplier which decreases the specified CVP loss. Salvage success at SWP salvage is also affected by the delay in the Clifton Court Forebay. Mortality in the forebay (‘Pre Screen Loss’) is defined in terms of a daily mortality rate (fraction) times the travel time estimated as CCF volume/export volume ratio. A variable ‘SWP Improvements’ was included to allow users to game changes in the SWP system. Salvaged fish are assumed to be released the next day near Chipps Island.

Turner Cut to Salvage Pathway

Fish that are not diverted to Old River move to Turner Cut with a specified travel time and daily mortality. The Turner Cut mortality is a daily rate applied for 5 days. Net flows in Turner Cut are often reversed (moving upstream towards the SWP and CVP pumping plants). Turner Cut connects with Empire Tract, Middle River, Victoria Canal, and West Canal on its way upstream to the Clifton Court Forebay intake and the DMC intake along Old River, but these channels are combined in the pathway model.

Because there is a very strong tidal flow in the San Joaquin River at Turner Cut, the evaluation model assumes that the fish preference at the Turner Cut diversion is about 0.1 of the actual diversion flow fraction. With the head of Old River barrier in place, most of the salvaged fish use the Turner Cut diversion.

Fish entrained at Turner Cut experience delay due to structural and flow conditions. Travel time distribution for this pathway was estimated from CVP and SWP recoveries of below head of Old River CWT release groups. Mortality is set as a daily loss rate for this pathway.

CVP and SWP Salvage Efficiency

Tracy fish Facility Studies Volume 3 (1995) reports on Chinook salmon and striped bass louver efficiencies for releases made in April and May of 1993. The primary louvers had an efficiency of about 60% and the secondary louvers had an efficiency of about 80%, for an overall efficiency of about 50%. The Chinook salmon were from the Mokelumne hatchery with an average length of 75 mm in April and 100 mm in May. Lower efficiencies (25% overall) were observed in a test with just one Tracy pump, at a flow of 800 cubic feet per second (cfs). It is possible that the approach velocity may not have been high enough to trigger the avoidance response required to avoid the louvers.

Tracy fish Facility Studies Volume 7 (1998) reports on efficiency testing of the secondary louvers using natural fish collected in the holding tanks and downstream of the double louvers in the secondary louver channel. The CVP secondary louver efficiency should be higher than the primary louvers because there is a double louver in the secondary channel (two chances for the fish to avoid the louver array). The secondary efficiency is the number separated in the holding tank compared to the total number in the sieve net and the holding tank. Because the secondary channel has a double louver, the efficiency of the secondary louvers is expected to be higher than the primary louvers. The secondary efficiency would be:

Secondary Efficiency = Louver Efficiency + Louver Efficiency * (1-Louver Efficiency)

The overall efficiency is the primary times the secondary because only the separated fish from the primary louver enters the secondary channel. Table C-1 demonstrates the differences, and gives the overall facility efficiency, assuming the 3 louvers have the same basic efficiency for each fish size. The uncertainty in the estimates of basic louver efficiency is relatively large, so these values are just given to indicate the reduction in separation as the basic louver efficiency declines because of low pumping or small fish size.

Table C-1. Tracy Fish Facility Salvage Efficiency for a Range of Louver Efficiencies

Single Louver Efficiency	Primary Louver Efficiency	CVP Secondary Louver Efficiency	CVP Overall Efficiency
0.1	0.1	0.19	0.019
0.2	0.2	0.36	0.072
0.3	0.3	0.51	0.153
0.4	0.4	0.64	0.256
0.5	0.5	0.75	0.375
0.6	0.6	0.84	0.504
0.7	0.7	0.91	0.637
0.8	0.8	0.96	0.768
0.9	0.9	0.99	0.891
1.0	1.0	1.0	1.0

We will assume that the overall Tracy Fish facility has a maximum salvage efficiency of 50% for relatively large fish (100 mm), and that this efficiency decreases with smaller fish or lower pumping (because of lower louver sweeping velocities).

The SWP Skinner Fish Facility uses the same size louver design (1 inch louvers with 1 inch spacing) but the size of the louver racks are smaller, so fish need to avoid the louvers for a shorter distance (and shorter time) than at the CVP facility. In addition, the velocity of water approaching the SWP primary louvers can be adjusted by closing off one or more louver bays. Nevertheless, the louver efficiency is assumed to be similar (50%) because the SWP does not have double louvers in the secondary channel. The CVP and SWP efficiencies may vary with pumping rate, and with the size and type of fish. The data analysis will actually begin by assuming that all the fish reaching the exports are salvaged (100% efficiency). It is likely that the actual number of fish reaching exports is perhaps twice the number estimated in the CVP and SWP salvage facilities.

Turner Cut to Chipps Island Pathway

Fish that are not diverted at Turner Cut move through the San Joaquin River channels to Chipps Island. Fish moving through this San Joaquin River pathway experience a specified daily mortality with a distribution of travel times that was estimated from CWT recoveries. The number of fish surviving to Chipps Island is the sum of fish moving along each pathway.

Travel Times

Travel times from point of release to point of collection have been estimated from CWT recoveries at CVP, SWP and Chipps Island. The travel time distributions represent the probability of recapturing a fish with a given travel time. The distribution from above the head of Old River to the CVP salvage is the shortest; the travel time distribution to the SWP salvage is especially bi-modal. This may be related to delay in the Clifton Court Forebay, but may also be related to the two possible pathways of moving down Old River and Turner Cut diversion.

The travel time distributions make it possible to estimate the range of travel times that a given proportion of fish will take between two points. These travel estimates are important because the longer travel time pathways will experience the greatest mortality from predation and other habitat conditions. The head of Old River barrier may change the overall mortality by affecting the proportion of fish that travel pathways of different lengths—thereby experiencing different travel times and different levels of migration mortality.

Model Control Variables

The model flows and exports were specified as daily values for the March 1 through June 30 simulation period. The head of Old River installation was specified as open (1), under construction (1), or closed (10). Daily fish at Mossdale were specified as a specific year of measured abundance, or as a specified pattern for general analysis. For example, specifying 5,000 fish each day during April and May would allow the fate of these 305,000 fish to be evaluated. The barrier could be installed for the 30-day VAMP period or for the entire 61 days of April and May.

Model Performance

A series of model runs were conducted using these input variables for flow, export, head of Old River barrier, and the Mossdale fish abundance. The survival with and without the head of Old River barrier was compared for each year of flows and exports. The results for each year with and without the barrier installed are shown in Table C-2. The initial settings used for these comparative simulations were:

1. Head of Old River barrier leakage = 1%
2. Preference for Old River = 0% [100% fish follow flow split]
3. Preference for the San Joaquin River at Turner Cut = 90% [10% follow diversion flow]
4. Daily in-stream mortality rate = 1%

5. Central Valley Project Louver efficiency = 50%
6. State Water Project Clifton Court Forebay Loss

Pumping Rate	Loss Fraction
a. 0	0.80
b. 750	0.14
c. 1500	0.08
d. 2250	0.04
e. 3000	0.025
f. 3750	0.012
g. 4500 or greater	0.000

7. State Water Project Louver efficiency = 75%
8. Salvage release mortality = 5%

Table C-2. Fraction of Fish Surviving to Chipps Island with and without the head of Old River Barrier

Year	Historical Head of Old River Barrier Regime	Percent of Fish Surviving to Chipps (Without Head of Old River Barrier)		Percent of Fish Surviving to Chipps (With Head of Old River Barrier)	
		Marked	Unmarked	Marked	Unmarked
1996	Absent	11.62%	56.55%	2.19%	0.63%
1997	Present	41.53%	0.00%	27.09%	15.56%
1998	Absent	21.09%	44.20%	2.28%	1.01%
1999	Absent	4.56%	19.42%	2.67%	19.94%
2000	Present	38.84%	69.52%	5.61%	36.12%
2001	Present	0.23%	27.57%	0.15%	14.70%
2002	Present	16.34%	10.26%	15.14%	13.62%
2003	Present	11.66%	27.63%	5.61%	25.24%
2004	Present	0.12%	21.94%	0.00%	25.52%
2005	Absent	0.93%	4.30%	0.30%	5.72%
Average Year	Absent	40.94%	11.84%	3.76%	7.18%

In-stream mortality estimates are uncertain. These travel-time mortality rates represent the most important information gap in analyzing the head of Old River barrier effectiveness. The head of Old River barrier shunts fish away from Old River (and the CVP and SWP salvage facilities) down the San Joaquin River channel to Turner Cut (possible diversion to salvage) and continuing through the Delta to Chipps Island. The fraction of fish that are diverted at Turner Cut is the second most important factor with substantial uncertainty. The travel time from Mossdale to salvage through Turner Cut is considerably longer than the travel time down Old River to salvage. Under low flow conditions, even when exports are reduced during the VAMP period, about half of the San Joaquin River flows can be diverted at Turner Cut. Therefore, it is possible that the shorter pathway through Old River could result in higher survival if salvage of these fish is successful.

Similarly, there are habitat and water quality conditions that may result in higher in-stream mortality rates along the San Joaquin River channel. Fish out-migrating past the Stockton Deepwater Ship Channel will experience minimal cover, high predator densities, potentially higher temperatures, and may experience high mortality. In this instance passage through Old River to salvage, despite salvage losses, may offer higher survival than “natural” migration down the San Joaquin River channels to Chipps Island.

These model results suggest that the head of Old River barrier may not always benefit fall Chinook salmon out-migrants, especially under low flow conditions. These results, however, cannot be corroborated without measured or estimated survival. Survival estimates might be determined from relationships to observable habitat conditions using something like the Ecosystem Diagnosis and Treatment system (www.mobrand.com). These initial model results appear to question the utility of the head of Old River barrier and reduced exports (i.e., VAMP conditions) for increasing juvenile out-migrant survival, especially during low flow periods.

Given that the head of Old River barrier could provide managers with additional control of the South Delta, a permanent structure may be useful and result in increased out-migrant survival under certain conditions. Pathway mortality estimates will be necessary to effectively operate a permanent head of Old River gate. The pathway survival model (using confirmed mortality estimates) may allow the gate to be operated to achieve increased survival for fall Chinook salmon out-migrants through informed and adaptive operations of a permanent head of Old River barrier structure.

Sensitivity Analysis

Sensitivity analysis (SA) was conducted to determine how specified model parameters affect the simulated survival estimates (Saisana et al. 2005; Saltelli et al. 2004). Each parameter was modified (one at a time) over the range of expected values. The model was run eleven times for each variable between 0–100% of the factor range at ten percent increments. Daily in-stream mortality was modified between 0–10% for each reach, holding all other reaches at 1%. The performance metric was the fraction of Mossdale fish surviving to Chipps Island.

For the sensitivity tests 1,000 fish per day were released at Mossdale from March 1 to May 31. We used the ten-year daily averages of flows and exports. Both an open and closed head of Old River barrier condition were used for the SA of all variables except for the SA of the head of Old River barrier itself where other variables were held constant and the head of Old River barrier was modified. Fish move quickly (i.e., in 5 days) from the head of Old River to Turner Cut.

However, some in-stream mortality occurs during this transition. With the barrier in place 99% of fish follow this pathway and experience this reach mortality. This model is mildly sensitive to this variable. However, because the Mossdale to Turner segment of the mainstem pathway is relatively quick in-stream mortality is less important through this segment versus others (i.e. Turner to Chipps or Turner to salvage).

The pathway survival model is highly sensitive to the San Joaquin River mortality rate (from Turner Cut to Chipps Island). Regardless of the head of Old River barrier configuration we assume that 1% of fish travel this pathway due to leakiness. With the barrier out approximately half of the fish do so. The average travel time from Turner Cut to Chipps Island is about 12 days. Daily mortality in this reach is between 0% and 10%, and is likely close to about 1% per day.

The pathway survival model demonstrated a weak response to Old River mortality, because the travel time to salvage was quite short. The model was somewhat sensitive to Turner Cut diversion mortality with the head of Old River barrier in place.

The pathway survival model is sensitive to delay and mortality in the Clifton Court Forebay, which may be a significant contributor to loss in the system. The model is sensitive to the louver efficiency, and somewhat sensitive to improvements in other salvage losses. Without the barrier in place the survival is sensitive to the louver efficiency. With the barrier in place fewer fish move to the CVP and SWP salvage facilities, and improvements become less important.

The sensitivity of survival to the head of Old River barrier installation was assessed by running the model with the head of Old River barrier open, or fully closed for the entire migration period. Under the default settings survival to Chipps is generally unchanged due to head of Old River barrier. This suggests that the benefits of the head of Old River barrier implementation are specific to the flows, exports, and assumed fish diversions (i.e., preferences) as well as the assumed travel-times and mortalities along each pathway.

Conclusions from the Pathway Survival Model

The pathway survival provided an opportunity to study alternative and competing hypotheses describing the potential benefits of a permanent head of Old River barrier. These analyses would be difficult to accomplish with field studies, although the results yield to the limitations of best available scientific information, rather than actual measurements of fish survival.

There is considerable uncertainty surrounding the analysis of the head of Old River barrier. Integration of the best-available information is the key to decision making under natural variability and uncertainty. The ultimate benefits from the head of Old River barrier are subject to numerous variables including flow/export conditions, survival during out-migration, and the success of the salvage pathway. Estimates of the head of Old River barrier benefits are further subject to sampling, measurement, and analytical errors. Integrative analysis can improve understanding and focus additional measurements on remaining uncertainty.

The principal uncertainty limiting the model results is in-stream survival as it relates to flow, habitat, and biological conditions. The direct Old River to salvage pathway may offer improved survival over the San Joaquin River pathway under low flow conditions. Under higher flow conditions it appears that the head of Old River barrier could benefit survival by excluding fish from salvage and shunting them directly to Chipps Island. The benefits of the salvage pathway likely increase as San Joaquin River flows decrease. It is likely that the head of Old River barrier could benefit fall Chinook salmon survival under moderate to high flow conditions, if the permanent gate could be closed at higher flows.

The impacts of environmental conditions during migration are assumed to be important. As fish travel more or less quickly through the system, they will experience a correspondingly smaller or greater amount of mortality. The flow splits and pathway preferences at these junctions will greatly impact survival in the system and the potential benefits of head of Old River barrier implementation under changing environmental regimes.

References

Saisana M., A. Saltelli, S. Tarantola. 2005. Uncertainty and sensitivity analysis techniques as tools for the quality assessment of composite indicators. *Journal Royal Statistical Society A*, 168 (2), 307-323.

Saltelli A., S. Tarantola, F. Campolongo, and M. Ratto. 2004. *Sensitivity analysis in practice. A guide to assessing scientific models.* John Wiley & Sons.

Appendix D

Previous Reports, Salvage Evaluation Files, and Delta Pathway Survival Model Files

[Appendix D is included as a CD.]

ICF Workshop 3 Submission to State Water Board
Attachment 3:
ICF Jones & Stokes (April 2008) Development of Modeling Tools for Evaluating Delta Smelt Protection Strategies
Appendix B: Evaluation of Delta Smelt Entrainment Events in 1995-2007

Prepared for California DWR

Appendix B

Evaluation of Delta Smelt Entrainment Events in 1995–2007

Introduction

The purpose of this evaluation is to explore the effects of CVP and SWP export pumping on the distribution and entrainment of delta smelt adults and juveniles. The contributions of adult delta smelt to CVP and SWP delta smelt salvage density from active swimming and from passive movement (tidal mixing) during reverse flow events are evaluated by examining the historical flow conditions and CVP and SWP salvage events. The possibility of reducing the adult and juvenile delta smelt salvage density by imposing various flow objectives is also discussed, based on these historical flow and salvage data. The daily CVP and SWP delta smelt salvage density and daily Delta flow conditions for the period 1995–2007 are presented and reviewed here, although the delta smelt density patterns from earlier years used in the EWA interactive modeling (1981–1994) workshops are quite similar and could be evaluated.

Some of the best information about the historical Delta smelt entrainment events is obtained from the daily CVP and SWP salvage data, in combination with the Delta flows during these events. Additional information can be obtained by comparing the daily Chipps Island trawls, which sample about 150 acre-feet (af) per day with ten 20-minute daytime trawls using a mid-water trawl at the surface. A few comments about the graphical display of this information will help identify the assumptions and the evaluation of various hypotheses about delta smelt behavior in response to exports or Delta flow conditions.

(1) CVP and SWP salvage data are evaluated as daily salvage density (fish/volume) patterns to remove the obvious correlation between the volume of daily pumping and the daily salvage of delta smelt, looking specifically for increases in delta smelt salvage density that may occur in response to Delta flow conditions. Units of fish per thousand acre-feet (taf) are appropriate for the density of delta smelt. There are 1,234 cubic meters in an acre-foot.

(2) When CVP export is greater than the head of Old River flow diversion, most of the head of Old River flow diversion is exported by the CVP pumps. Therefore, the fraction of San Joaquin River water in the CVP pumping volume is often higher than the fraction of San Joaquin River water in the

SWP pumping volume. Because the inflow of San Joaquin River water contains no delta smelt, the CVP salvage density of delta smelt is expected to be lower than the SWP salvage density of delta smelt if water transport moves the delta smelt towards the pumps. CVP salvage density will be more similar to SWP salvage density if delta smelt adults are swimming into south Delta channels.

(3) Some adult delta smelt may move into the south delta channels during the spawning period of late December through March. This active swimming of adults may be independent of flow conditions. Other adult delta smelt may be transported into the south Delta channels by reverse flows in Old and Middle River, or reverse QWEST flows or Threemile Slough flows from the Sacramento River. Changes in these flow conditions may change the number of adult delta smelt that are tidally mixed into the south Delta channels, but would not control the number that independently swim into the south Delta channels.

(4) Some salvaged delta smelt juveniles originate from delta smelt spawning in the south Delta channels. These juvenile smelt may show up in CVP and SWP salvage at about the same time and in about the same density. Other delta smelt juveniles may be tidally mixed into the south Delta from downstream habitat in Franks Tract or the lower San Joaquin River by reverse flows in Old and Middle River, or reverse QWEST flows, or Threemile Slough flows from the Sacramento River. Changes in these flow conditions may change the number of juvenile delta smelt that are tidally mixed into the south Delta channels, but would not control the number that have been spawned in the south Delta channels.

Conclusions from this evaluation are not summarized in the introduction to allow the reader to examine the evidence before being influenced by the author's thoughts. In examining the graphs for each year, consider these evaluation questions:

(1) Do periods of higher reverse Old and Middle River (ROMR) flows correspond with higher adult or juvenile delta smelt salvage density?

(2) Are the CVP and SWP delta smelt salvage densities for adults and juveniles similar, delayed, or independent?

(3) Do increased adult delta smelt salvage densities appear during low ROMR flows or during positive Old and Middle River (OMR) flows?

(4) Do increased juvenile delta smelt salvage densities appear gradually in response to higher ROMR flows, or do densities appear to rapidly increase and then decrease within a short period of time?

(5) Do reductions in ROMR flows (i.e., export reductions) appear to produce any reductions in adult or juvenile delta smelt salvage densities?

A short review of the annual regression of total salvage and average ROMR for December–March of 1993–2005 is presented at the end of this appendix. This regression was presented to Judge Wanger in support of ROMR limits to reduce the entrainment of delta smelt. An important question to consider as you review the daily flow and entrainment patterns is whether controlling ROMR during the January-June period is likely to substantially reduce the salvage of adult and juvenile delta smelt.

Graphs of Flows and Delta Smelt Salvage Density

The graphs of daily flows and daily CVP (green) and SWP (red) delta smelt salvage density use a logarithmic scale (on the left) for delta smelt density (fish/taf) because the density varies dramatically during the year. QWEST and OMR flows are shown with negative CVP (green) and combined (CVP + SWP) exports on an inverted linear scale (right). Negative Old and Middle River flows occur when SWP and CVP exports are greater than the head of Old River flow diversion, which often supplies most of the CVP pumping. The flows are shown with an inverted scale (negative on top) to allow the relationship between higher reverse flows and higher delta smelt density to be examined more directly. Most of the ROMR flow is supplied by the Delta Cross Channel (DCC) and Georgiana Slough diversions from the Sacramento River. These Sacramento River diversions are not expected to have high delta smelt densities. Reverse QWEST flows may indicate that lower San Joaquin water from Jersey Point or Antioch may be tidally mixed into Franks Tract and into Old River. Some of the reverse QWEST may be supplied from Threemile Slough, which may contain some delta smelt from Rio Vista or Cache Slough.

The graphs of Delta outflow and Chipps Island delta smelt density indicate the relative abundance near the confluence, which is considered to be prime habitat for delta smelt. The Chipps Island density may decrease as the adults move upstream to spawn, in response to a salinity or turbidity trigger. The Delta smelt density often increases in June and July, following the high juvenile CVP and SWP salvage density that is observed in May and June. These daily fish observations from the “two ends” of the Delta appear to fit together and describe the general life history migration patterns of the delta smelt.

This analysis was accomplished using the DayOPS spreadsheets for 1995–2007 that were prepared for interactive modeling workshops under contract with DWR. Although these workshop sessions were not held in 2007, because of the efforts to prepare for the Wanger Case testimony and hearings, this evaluation of historical delta smelt entrainment events from 1995 to 2007 illustrates the value of these spreadsheet models for integrating and visualizing the Delta flow and fish data. These evaluations of the daily data for 1995–2007 have not been shown previously. The protective measures adopted by Judge Wanger utilize several controls on ROMR flow during the spring recommended in the Pelagic Organism Action Plan (prepared by DWR and DFG) as well as by the USFWS. The daily graphs of Delta flows, exports, and salvage density patterns can be used to review the correlations between ROMR and delta smelt salvage, as well as investigate the protections that will likely be achieved using these limits on ROMR.

1995: Figure B-1a shows that CVP and SWP pumping was at maximum permitted capacity in January 1995, and ROMR flows were greater than 5,000 cubic feet per second (cfs). The peak adult delta smelt SWP salvage density (10/taf) occurred in January when ROMR flows were decreasing from 10,000 cfs to 5,000 cfs. QWEST was strongly positive in January and February, suggesting that these adult delta smelt were not tidally mixed from the lower San Joaquin or the lower Sacramento or the confluence region. These adult delta smelt may have actively moved into the south Delta in response to the large inflow event in early January. No juvenile delta smelt were entrained during 1995 at either CVP or SWP, presumably because all of the exports were supplied from the high San Joaquin River inflows. The OMR was positive at about 5,000 cfs in April and May. This unusual high outflow from the San Joaquin River may have moved all juvenile smelt downstream toward the estuary prior to the higher exports and ROMR conditions that developed by the end of June.

Figure B-1b shows the delta smelt density measured in the Chipps Island trawl in 1995. The measured delta smelt density was highest in December and early January with an average density of 200/taf. The density declined in January at about the same time that salvage density increased. This decline in Chipps Island density appears to be associated with the migration (i.e., dispersal) of delta smelt adults to upstream spawning areas. The dispersal of adult delta smelt may be triggered by the higher flows, reduced salinities, or higher turbidity associated with the first major inflow event. The Chipps Island density fluctuated between 10/taf and 100/taf until May when density (of juveniles) began to increase towards a density of about 100/taf in June and continued to increase to more than 500/taf in September as more of the population migrated downstream towards the confluence and Honker Bay. Chipps Island is located near the lower end of the estuary salinity gradient, which is assumed to be the most productive delta smelt habitat for the juvenile and pre-adult life stages. The pelagic habitat features that make this region of the Delta-estuary one of the most suitable habitats may be related to salinity preference, food abundance, or other unknown factors. The EC (µS/cm) at Chipps Island indicates the general response of salinity to Delta outflow. The EC was about 10,000 µS/cm in October-December, and then decreased to less than 1,000 µS/cm once the Delta outflow increased to more than 30,000 cfs in early January.

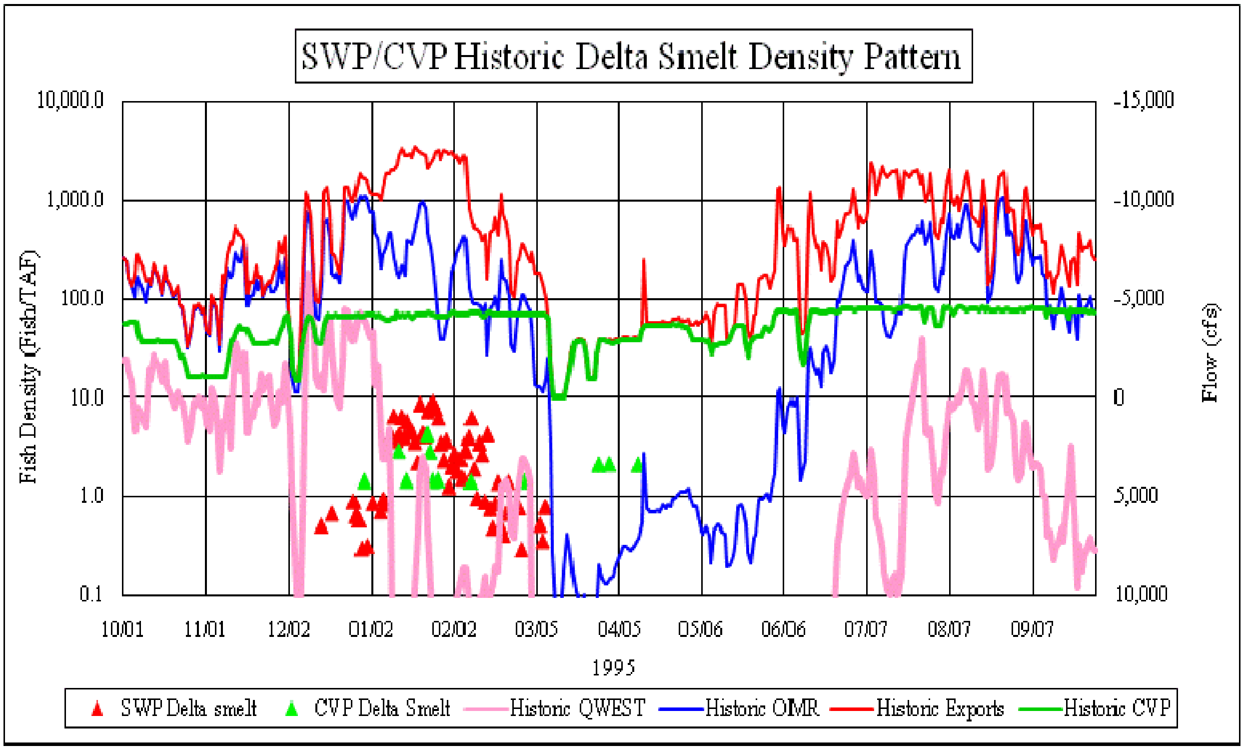

Figure B-1a. Historical CVP and SWP Delta Smelt Salvage Density and Delta Flows (QWEST and OMR) for 1995

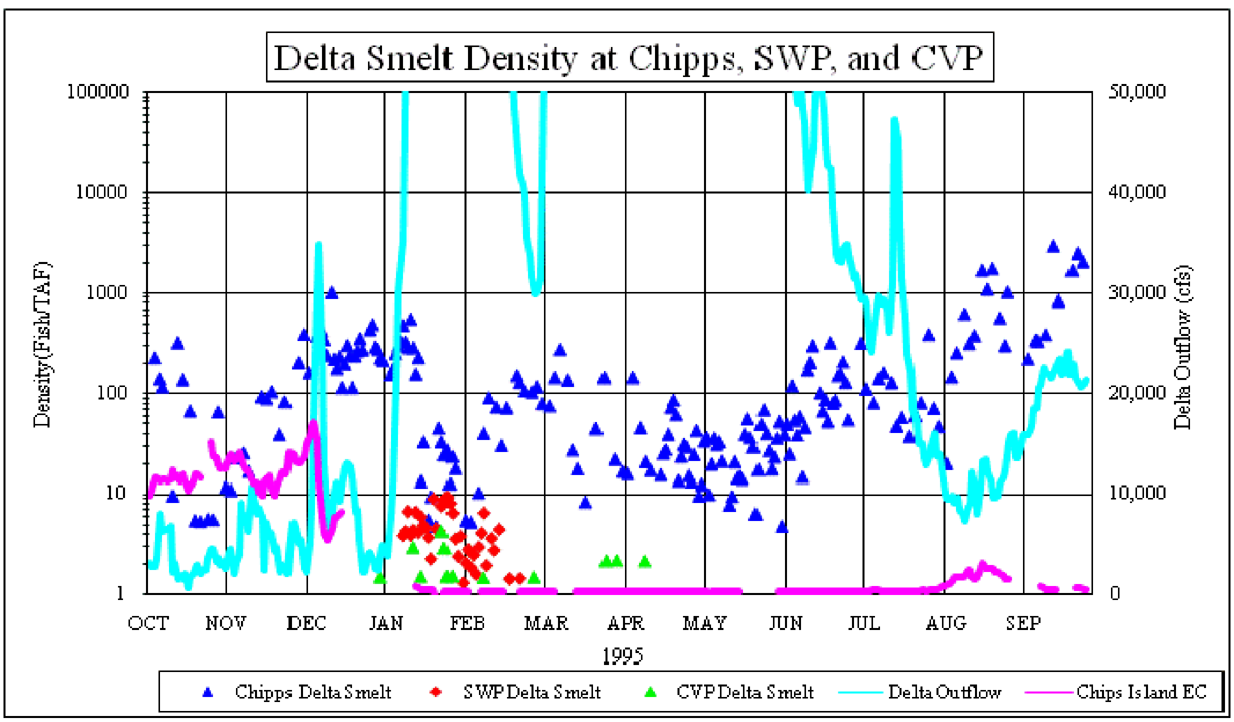

Figure B-1b. Delta Outflow and Chipps Island EC (μS/cm on right scale) and Delta Smelt Density for 1995

1996: Figure B-2a shows that SWP and CVP pumping was very high in January 1996. The peak adult density (20/taf) was observed in both CVP and SWP salvage in late January. The ROMR was greatest (10,000 cfs) and negative QWEST was greatest (5,000 cfs) in early January, prior to the major inflow in mid-January. The high salvage density may have been caused by these reverse flows, or the delta smelt may have moved into the south Delta in response to the major inflow event. The CVP and SWP salvage densities were low in the first half of January when pumping was highest (10,000 cfs), but some delay in tidal mixing and transport may be associated with the reverse QWEST and ROMR flows. Adult salvage at SWP was observed through February and March, although the OMR flows were positive. These adult delta smelt may have moved into the south Delta channels independently of the QWEST or ROMR flows, or may have initially moved into the south Delta during early January when ROMR and reverse QWEST were highest.

High juvenile delta smelt salvage densities were observed at CVP (1,000/taf) and SWP (200/taf) in early May. The pumping was low and the OMR flow was positive. It does not appear that ROMR flows were the source of these peak juvenile densities. These juveniles may have been spawned in the south Delta channels. The increased pumping in late May might have removed the remaining juveniles from the south Delta channels, but would not have drawn additional juveniles from Franks Tract or the lower San Joaquin, because QWEST was greater than 10,000 cfs until June.

Figure B-2b shows that the initial Chipps Island delta smelt density was relatively high (1,000/taf) in the fall of 1996, and declined to less than 100/taf in late January, at about the same time as adult salvage was observed in the south Delta. The Chipps Island density remained moderately high (200/taf to 1,000/taf) until May, when highest juvenile delta smelt salvage density was observed. Very high juvenile density (10,000/taf) was observed at Chipps Island in late June and July.

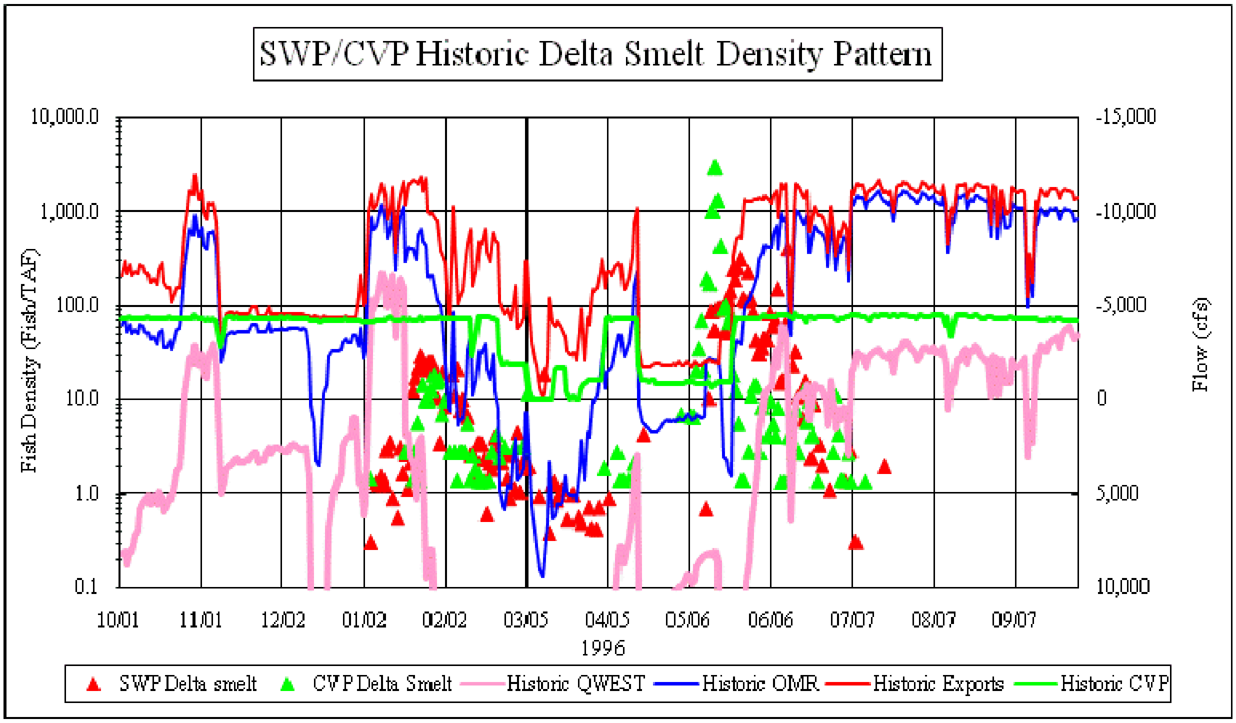

Figure B-2a. Historical CVP and SWP Delta Smelt Salvage Density and Delta Flows (QWEST and OMR) for 1996

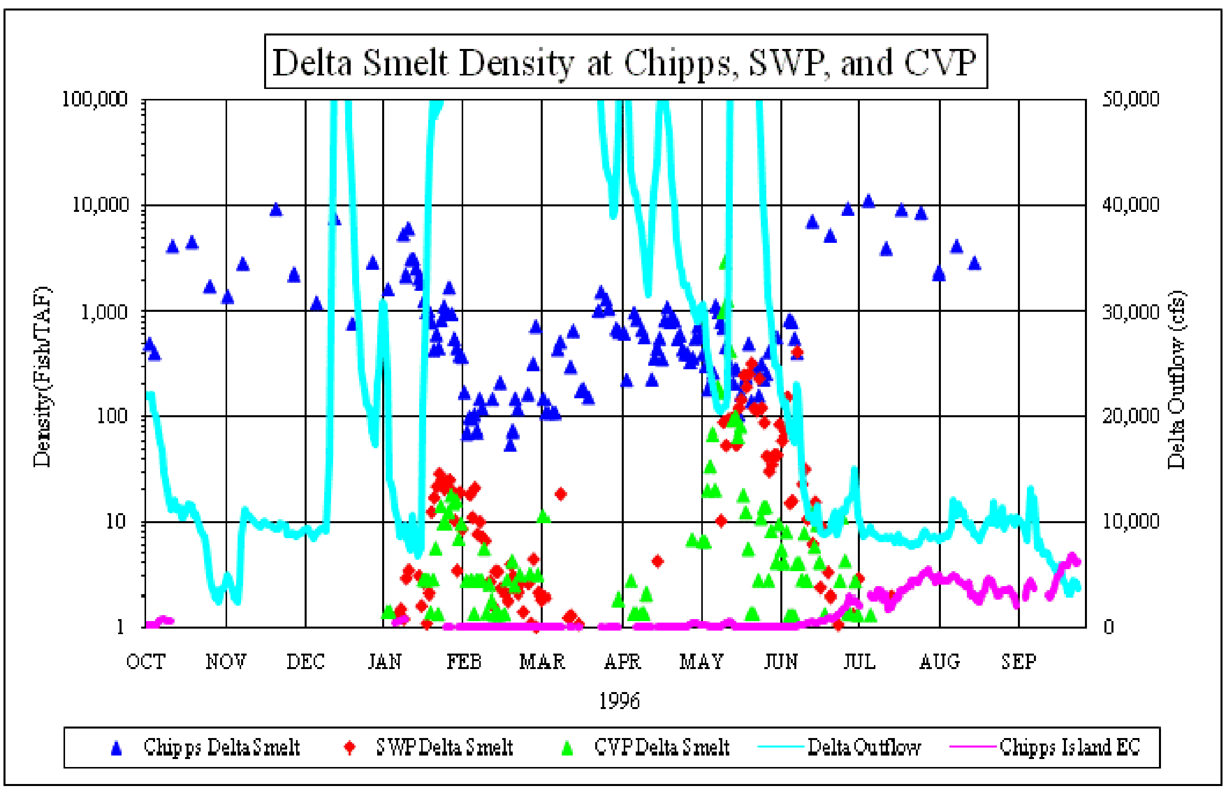

Figure B-2b. Delta Outflow and Chipps Island EC (µS/cm on right scale) and Delta Smelt Density for 1996

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1997: Figure B-3a shows that there was very low CVP and SWP pumping in January and February 1997. The peak adult density (10/taf) was observed in both CVP and SWP salvage in early March. There were no ROMR flows in January or February, so the more likely mechanism for these peak adult densities was that the adult delta smelt actively moved into the south Delta channels. High CVP salvage density was observed through March, although ROMR flows remained less than 5,000 cfs. The CVP density declined as the ROMR flows increased into early April. The CVP pumping was higher than the SWP pumping, and CVP density was higher than the SWP density throughout March.

Peak juvenile CVP and SWP salvage densities (1,000/taf) were observed in early April. QWEST was positive (5,000 cfs) and ROMR flows were about 2,000 cfs. There was no opportunity for these juvenile delta smelt to be tidally mixed from Franks Tract or the lower San Joaquin River. The more likely source for these juvenile delta smelt was the south Delta channels. The CVP salvage densities declined faster than the SWP densities in June, perhaps because the CVP pumps water primarily from Old River and Grant Line Canal. The head of Old River flows from the San Joaquin River may flush these channels more rapidly than the SWP pumping would flush the remainder of the delta smelt from the south Delta channels.

Figure B-3b shows that the initial Chipps Island delta smelt density was relatively high (500/taf to 1,000/taf) in the fall of 1997, and declined to about 10/taf in December, at about the same time as the high outflow and reduced salinity. Because there was no adult salvage of delta smelt in January or February, this decline at Chips Island might have been caused by most of the adults moving further downstream with the low salinity zone water (i.e., X2 position). Alternatively the adults might have dispersed upstream to other habitat regions, without showing up at salvage. The Chipps Island density remained low (10/taf) until May, when the juvenile delta smelt density increased to about 100/taf. This increase at Chipps Island was about a month later than the peak juvenile salvage in early May. Moderate juvenile delta smelt density (20/taf to 100/taf) was observed at Chipps Island in June through September.

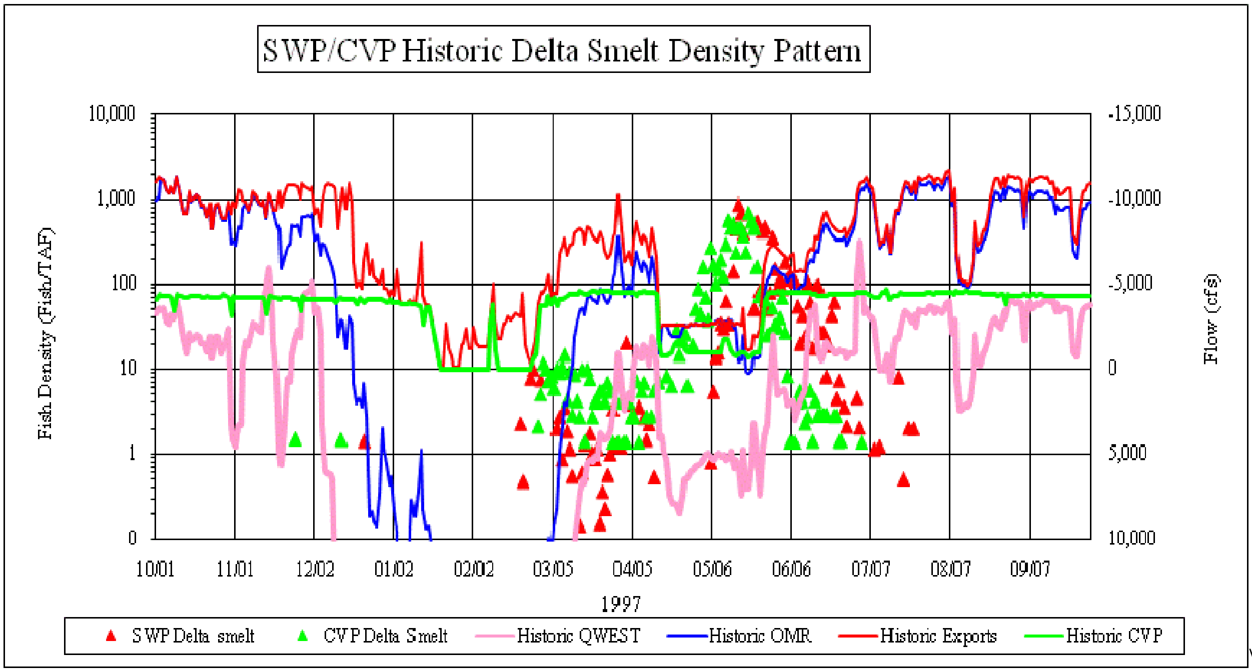

Figure B-3a. Historical CVP and SWP Delta Smelt Salvage Density and Delta Flows (QWEST and OMR) for 1997

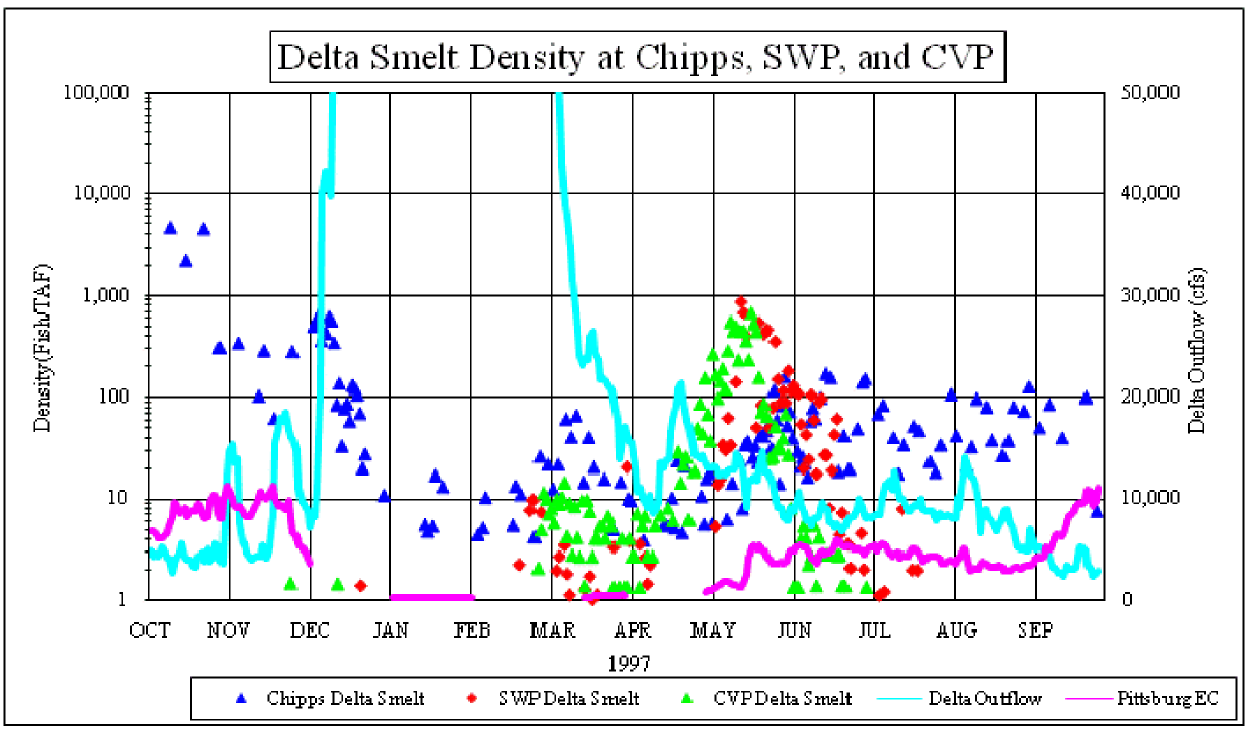

Figure B-3b. Delta Outflow and Pittsburg EC (µS/cm on right scale) and Delta Smelt Density for 1997

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Jones & Stokes

Figure B-3

1998: Figure B-4a shows that a few adult delta smelt (2/taf) were salvaged in late December, when ROMR flows were 10,000 cfs and QWEST reverse flows were greater than 5,000 cfs. SWP pumping was shut down until May. The peak CVP salvage adult density (10/taf) was observed in March, when OMR was greater than 5,000 cfs. As a result, these fish were not being pulled by flow to the pumps, and these fish are apparently swimming toward the CVP pumping intake in response to some other environmental factor.

There was almost no juvenile delta smelt salvage at CVP and SWP facilities in 1998, because the high San Joaquin River flows (>8,000 cfs through June) presumably flushed any juvenile delta smelt out of the south Delta. The OMR flows remained positive until late June.

Figure B-4b shows that the initial Chipps Island delta smelt density was relatively low (20/taf to 100/taf) in the fall of 1998, and increased in December to a peak of about 500/taf to 1,000 taf before declining to about 10/taf by the end of January, at about the same time as the high outflow and reduced salinity. Because there was no adult salvage of delta smelt in January or February, this decline at Chips Island might have been caused by most of the adults moving further downstream with the low salinity zone water (i.e., X2 position). Alternatively the adults might have dispersed upstream to other habitat regions, without showing up at CVP salvage (no SWP pumping until May). The Chipps Island density remained relatively low (10/taf to 100/taf)) until June, when the juvenile delta smelt density increased to about 100/taf.

Moderate juvenile delta smelt density (100/taf to 1,000/taf) was observed at Chipps Island in September. The salvage of delta smelt was very low in 1998, and other data sources must be evaluated to determine the relative abundance in the Delta. There were many other fish in SWP and CVP salvage during spring 1998 (e.g., splittail), but few delta smelt. The low juvenile salvage of delta smelt and the moderately low Chipps Island densities do not imply that the delta smelt abundance was low; because the 1998 Fall Mid-Water Trawl (FMWT) index was 420, higher than 1996 or 1997. The high San Joaquin River flows likely limited the juvenile salvage, and the high outflow through July likely limited the density at Chipps Island because the low salinity zone (X2) was located downstream of Chipps Island.

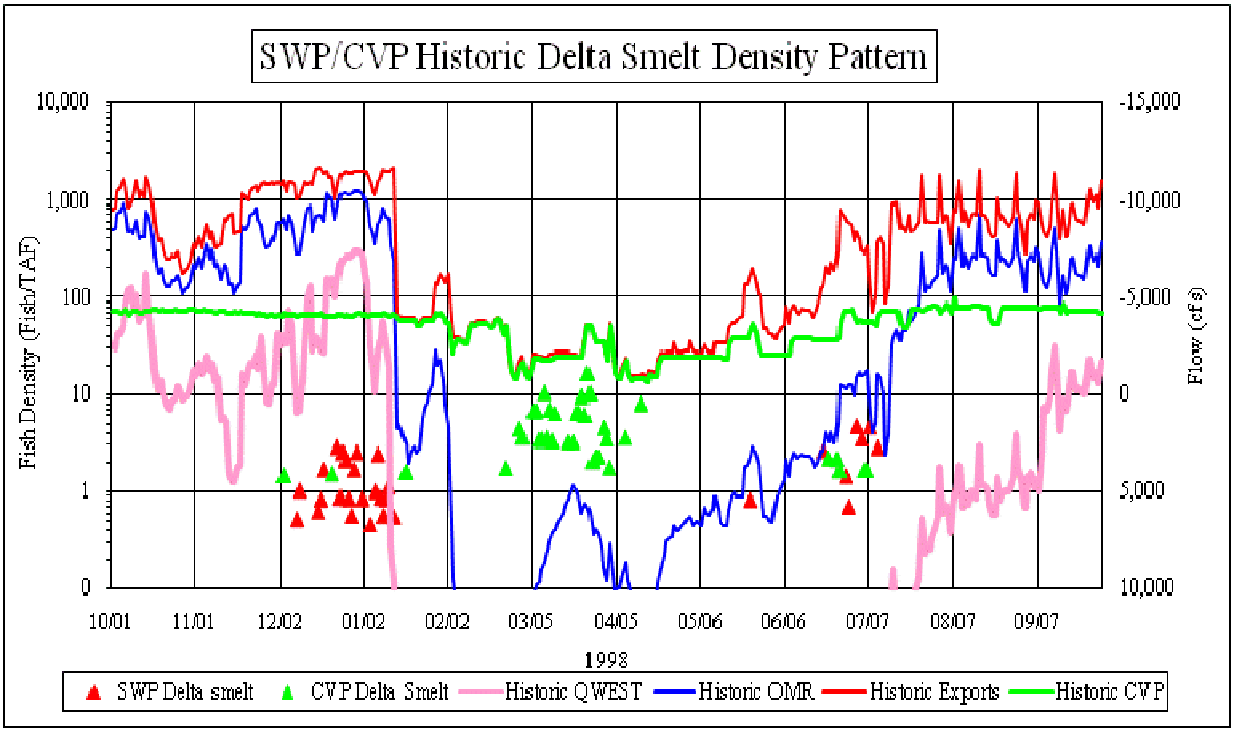

Figure B-4a. Historical CVP and SWP Delta Smelt Salvage Density and Delta Flows (QWEST and OMR) for 1998

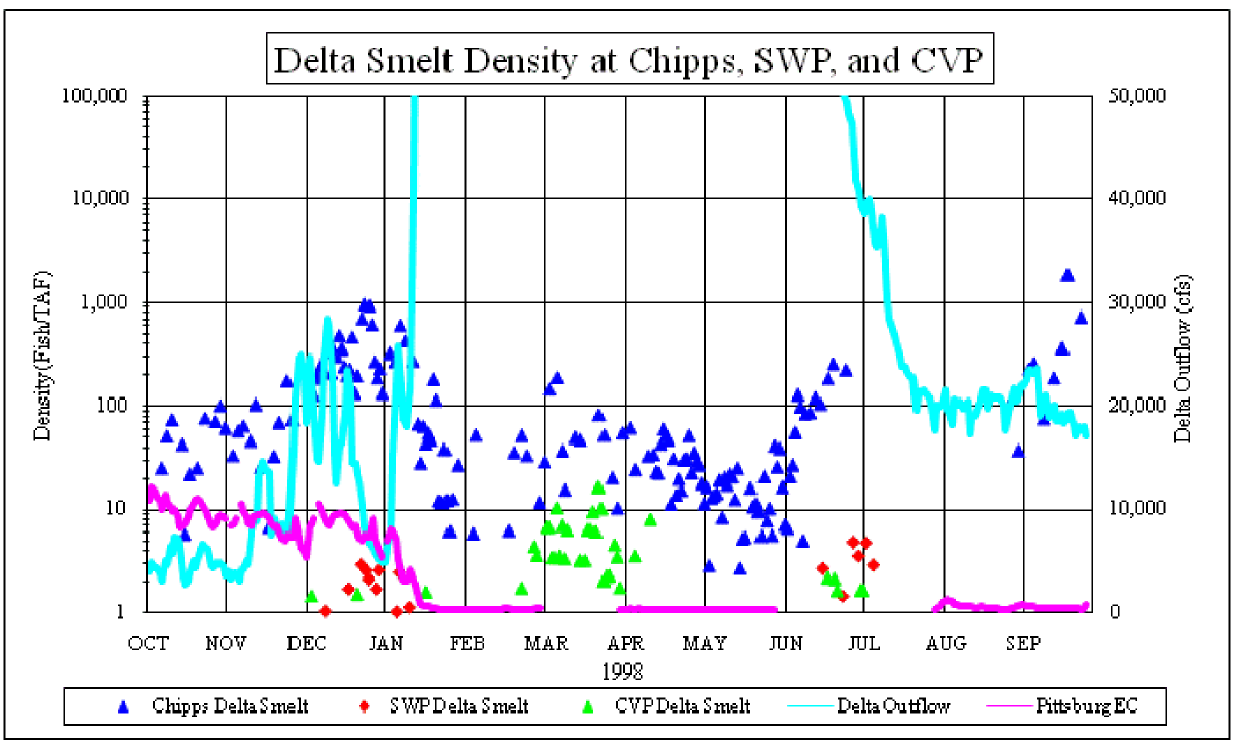

Figure B-4b. Delta Outflow and Pittsburg EC (μS/cm on right scale) and Delta Smelt Density for 1998

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Jones & Stokes

Figure B-4

1999: Figure B-5a shows that there was very low CVP or SWP pumping in December, January, and February 1999. The peak adult density (20/taf) was observed in CVP salvage in mid-February. There were no ROMR flows in February, and the peak CVP salvage density corresponded to the highest positive OMR flows of about 2,500 cfs, which were the result of the San Joaquin River flows of more than 10,000 cfs. Relatively low adult delta smelt salvage (2/taf) was observed through March and April at CVP and SWP. CVP and SWP pumping was reduced during the Vernalis Adaptive Management Plan (VAMP) period of mid-April to mid-May, and OMR was about 0 cfs.

Peak juvenile delta smelt salvage densities at SWP (1,000/taf) and CVP (500/taf) were observed in late May. High juvenile delta smelt salvage densities were observed at CVP and SWP through June. The ROMR flows were increasing from about 0 cfs in early May to about 5,000 cfs at the end of June. The QWEST flows were positive at about 5,000 cfs from mid-May through mid-June. These juveniles were not likely tidally transported from downstream of Jersey Point. Some may have been transported from Franks Tract, although it appears more likely that these juveniles were spawned in the south Delta channels. The ROMR flows were less than 2,500 cfs throughout the entire winter and spring of 1999, and QWEST flows were greater than 5,000 cfs (positive) until mid-June. These flow conditions did not prevent adult delta smelt from migrating into the south Delta channels, and did not prevent high juvenile delta smelt salvage densities at both CVP and SWP facilities in May and June.

Figure B-5b shows that the initial Chipps Island delta smelt density was relatively high (200/taf to 1,000/taf) in the fall of 1999, and decreased in early December to 100/taf with the high outflow and lower salinity. The Chipps Island density increased in late December and then declined in January to about 100/taf through April while outflow remained high. The peak juvenile salvage was in late May at CVP and June at SWP (low pumping). The Chipps Island density increased to a peak of about 1,000/taf in late June, and declined somewhat by the end of September as salinity increased to above 5,000 µS/cm.

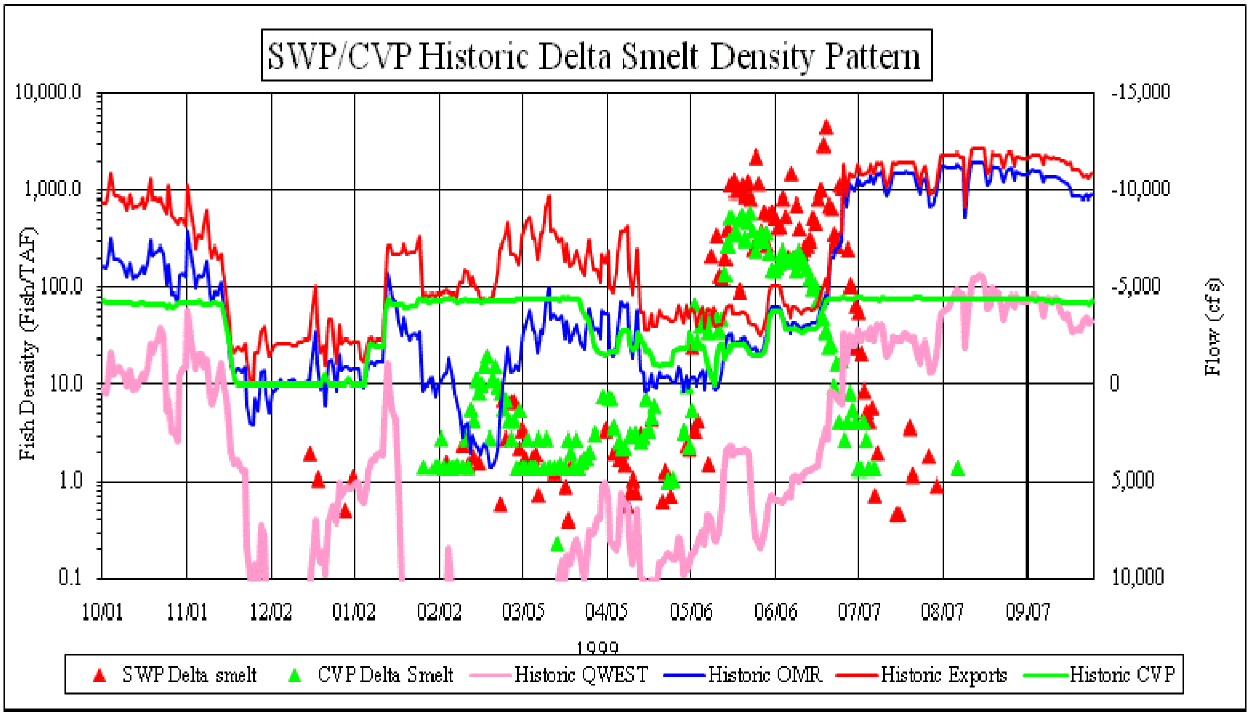

Figure B-5a. Historical CVP and SWP Delta Smelt Salvage Density and Delta Flows (QWEST and OMR) for 1999

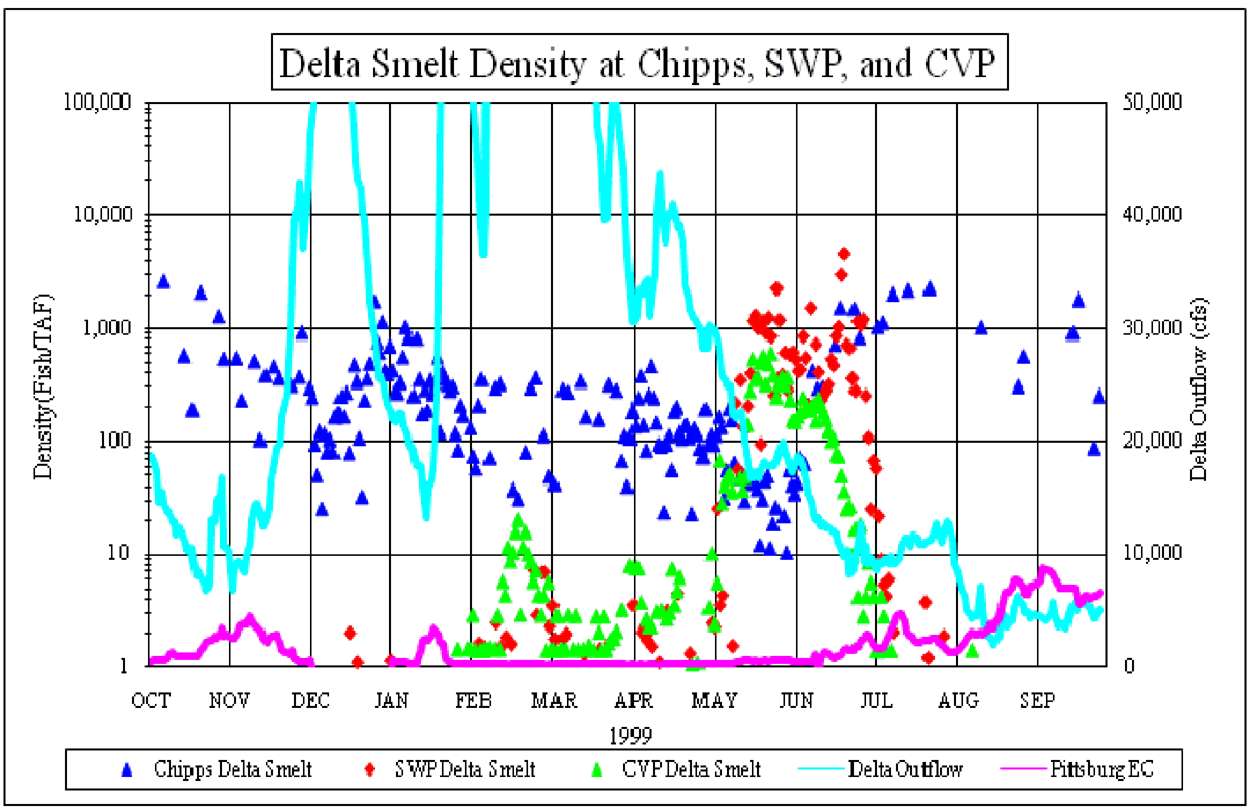

Figure B-5b. Delta Outflow and Pittsburg EC (µS/cm on right scale) and Delta Smelt Density for 1999

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2000: Figure B-6a shows CVP and SWP pumping increased to 10,000 cfs in early January of 2000, was reduced in late January, and remained at about 10,000 cfs from late January until mid-April, when it was reduced to about 2,000 cfs for the VAMP fish protection action. Adult delta smelt salvage was observed at CVP and SWP from early January through March of 2000. The peak adult density (20/taf) was observed in SWP and CVP salvage in mid-February. The ROMR flows were close to 10,000 cfs in early January and early February. The ROMR flows were less than 5,000 cfs in mid-February when the peak adult salvage density was observed, and were less than 5,000 cfs from late February through March when CVP and SWP salvage density remained greater than 2/taf. Because the QWEST flows were positive from mid-January through May, it does not seem likely that adult smelt were tidally transported from downstream of Franks Tract or from the confluence region. Neither ROMR flows nor reverse QWEST flows appear to be the major factor explaining CVP and SWP adult delta smelt salvage density during 2000.

Peak juvenile delta smelt salvage densities at SWP (1,000/taf) and CVP (500/taf) were observed in late May. High juvenile delta smelt salvage densities (100/taf) were observed at CVP and SWP through mid-June. The ROMR flows were increasing from about 2,000 cfs in early May to about 10,000 cfs at the end of June. The QWEST flows were positive until the end of May. These juvenile delta smelt salvaged in Mid-May and June most likely were spawned in the south Delta channels.

Figure B-6b shows that the peak Chipps Island delta smelt density in December and early January was relatively high (500/taf to 1,000/taf), and decreased in late January (with the high outflow and lower salinity) to less than 100/taf in February and March of 2000. The peak salvage density was observed in February, corresponding to the decline in density at Chipps Island. The Chipps Island density decreased to about 10/taf in May when the peak salvage density of juveniles was observed at CVP and SWP. The Chipps Island density increased to about 1,000/taf by July and remained high through September. There is some indication that the density was declining in September as the salinity increased to above 5,000 µS/cm.

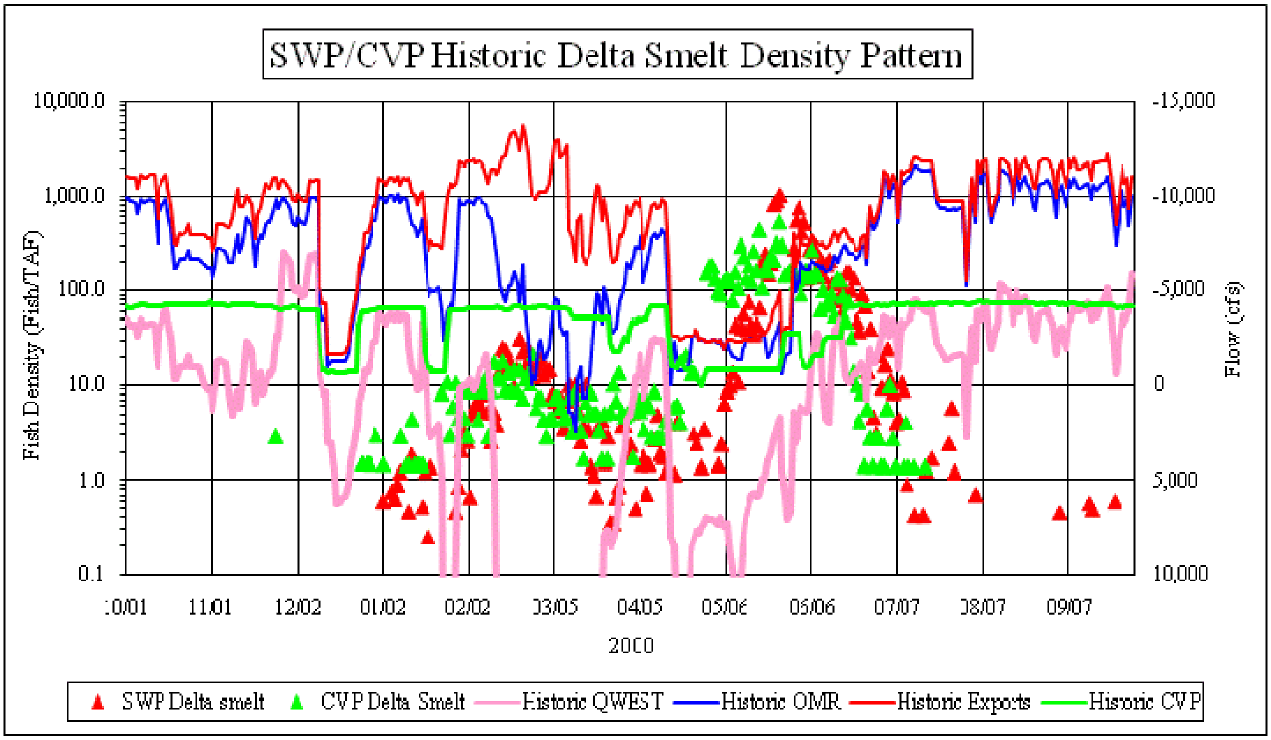

Figure B-6a. Historical CVP and SWP Delta Smelt Salvage Density and Delta Flows (QWEST and OMR) for 2000

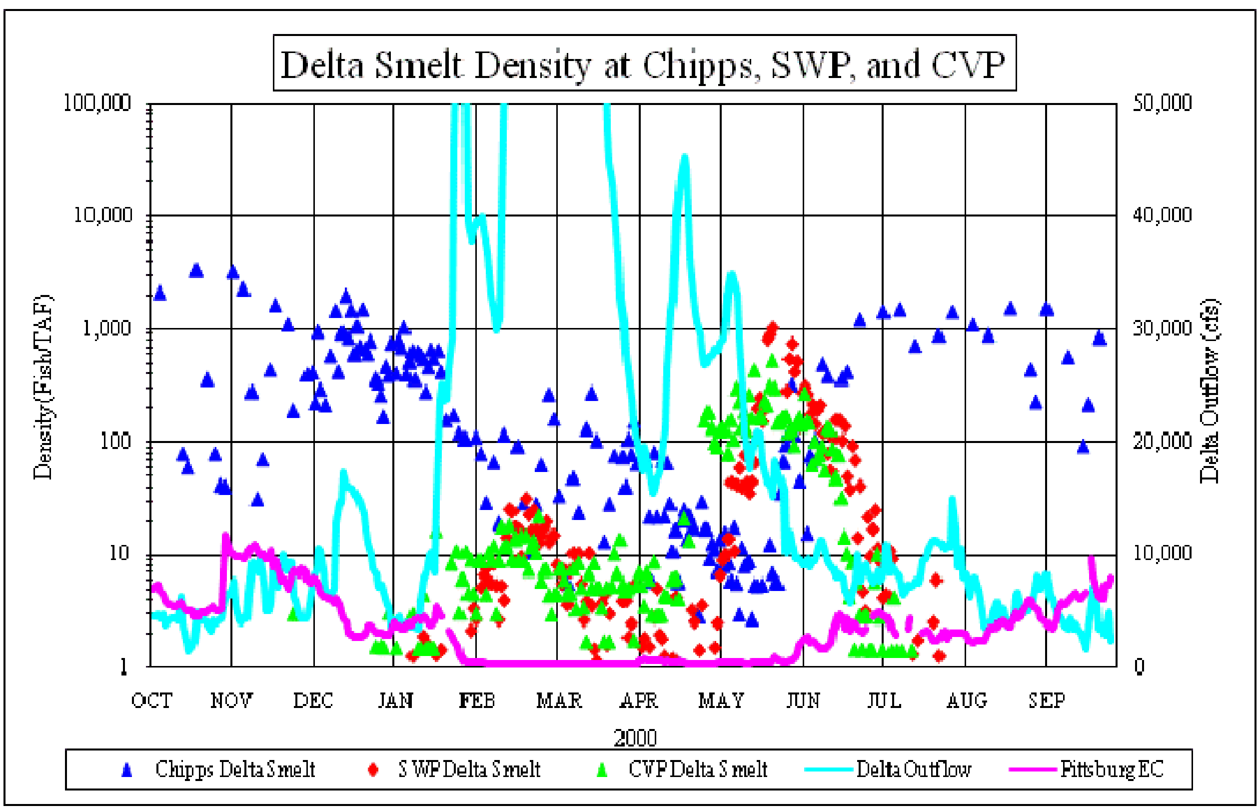

Figure B-6b. Delta Outflow and Pittsburg EC (μS/cm on right scale) and Delta Smelt Density for 2000

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Figure B-6

2001: Figure B-7a shows that the CVP and SWP pumping was about 9,000 cfs from October through December, about 6,000 cfs in January, and about 8,000 cfs in February and March of 2001. Adult delta smelt were observed in CVP and SWP salvage from November through March. The high pumping may have drawn some adults into the south Delta during the November-January period prior to the normal spawning migration event. The mid-February peak density of about 20/taf coincided with increased Delta outflow, although two similar storm events in January did not trigger adult migration into the south Delta, perhaps because the salinity was not reduced sufficiently to trigger the migration. The ROMR flows were close to 5,000 cfs in mid-February when the peak adult salvage density was observed and were about 5,000 cfs from late February through early April when CVP and SWP salvage density remained greater than 2/taf. Because the QWEST flows were positive from mid-February until early March, it does not seem likely that adult smelt were tidally transported from downstream of Franks Tract or from the confluence region during this period of peak adult density.

Peak juvenile delta smelt salvage densities at CVP (200/taf) were observed in early May, and peak densities at SWP salvage (1,000/taf) were observed in late May. The CVP juvenile delta smelt salvage densities declined rapidly to less than 10/taf by the end of May, although ROMR flows were increasing to 4,000 cfs. The rapid decline in CVP salvage density during May could have occurred because most of the CVP exports were from San Joaquin River water, with no juvenile smelt. The May peak in juvenile density occurred at the end of VAMP when ROMR flows were 2,000 cfs and QWEST flows were strongly positive at 4,000 cfs. These juvenile fish were most likely spawned in south Delta channels and not tidally transported from Franks Tract or the lower San Joaquin River habitat.

Figure B-7b shows that the peak Chipps Island delta smelt density was steady at about 100/taf through mid February of 2001. The Chipps Island density declined during February and March and was less than 10/taf in April. This decline corresponded to the peak salvage density in March. The Chipps Island density increased in May and was about 100/taf in early June, but declined to about 10/taf during the summer months, perhaps because the salinity was greater than 5,000 µS/cm.

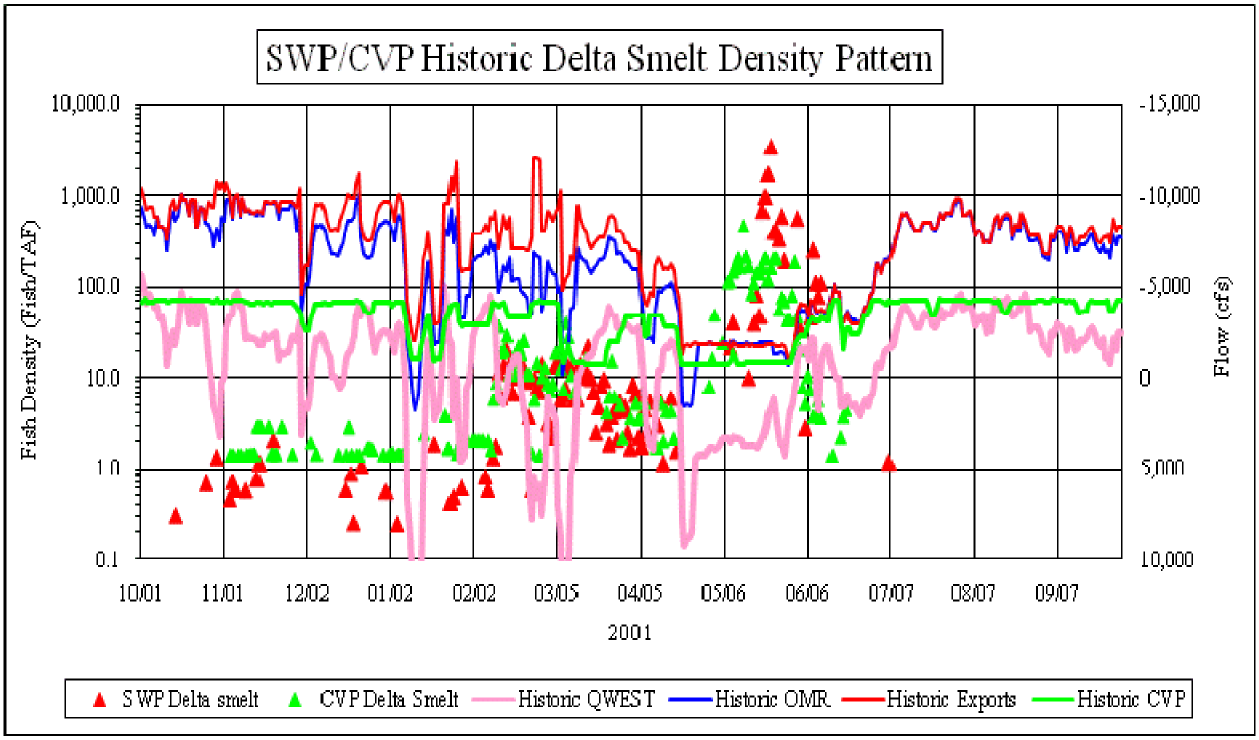

Figure B-7a. Historical CVP and SWP Delta Smelt Salvage Density and Delta Flows (QWEST and OMR) for 2001

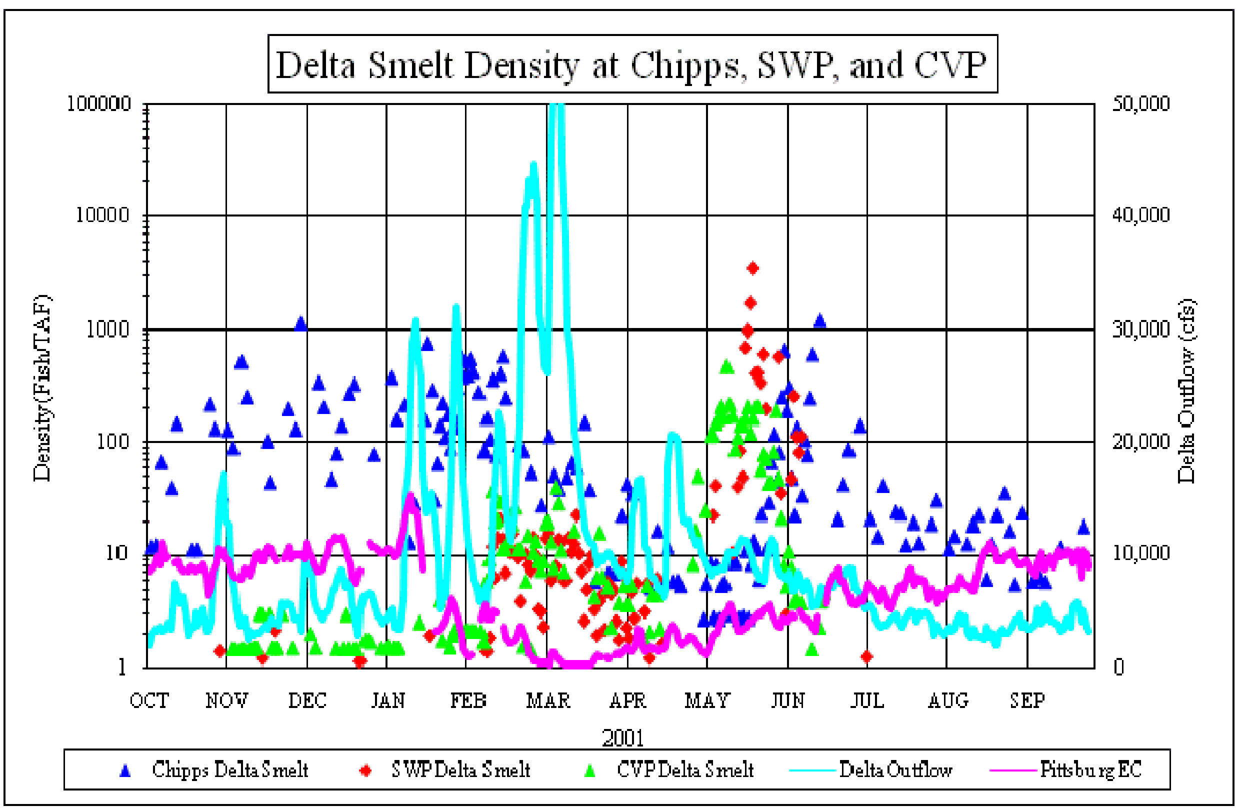

Figure B-7b. Delta Outflow and Pittsburg EC (μS/cm on right scale) and Delta Smelt Density for 2001

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Jones & Stokes

Figure B-7

2002: Figure B-8a shows that CVP pumping was about 4,000 cfs from October through mid-April, when pumping was reduced to about 850 cfs through May for VAMP. SWP pumping was about 6,000 cfs in January and February, about 5,000 cfs in February, and about 4,000 cfs in March and early April of 2002. Adult delta smelt were first observed in CVP and SWP salvage in mid-December, with ROMR flows of about 10,000 cfs. The peak adult salvage density of about 50/taf was observed in early January when the Delta outflow increased to more than 50,000 cfs. The QWEST flows were positive at 10,000 cfs during the peak salvage density, and ROMR flows were reduced to less than 5,000 cfs during this major outflow event. Reducing the ROMR flows would not likely have prevented these adult delta smelt from entering the south Delta channels in early January 2002.

Peak juvenile delta smelt salvage densities at CVP (500/taf) were observed through May, and peak densities at SWP salvage of more than 1,000/taf were observed in late May. The CVP juvenile delta smelt salvage densities declined rapidly to less than 10/taf by mid-June, although ROMR flows were increasing to 5,000 cfs at the end of May. The peak SWP juvenile density in mid-May occurred at the end of VAMP when OMR reverse flows were 2,000 cfs and QWEST flows were strongly positive at about 3,000 cfs. These juvenile fish most likely were spawned in south Delta channels or within the Clifton Court Forebay and not tidally transported from Franks Tract or the lower San Joaquin River habitat.

Figure B-8b shows that the Chipps Island delta smelt density was relatively low (20/taf to 80/taf) from November through March of 2002, and declined further in April. There was no discernable decline corresponding to the peak salvage density in early January. The Chipps Island density increased only slightly in June, and few were caught during July. There were no Chipps Island trawls in August or September of 2002.

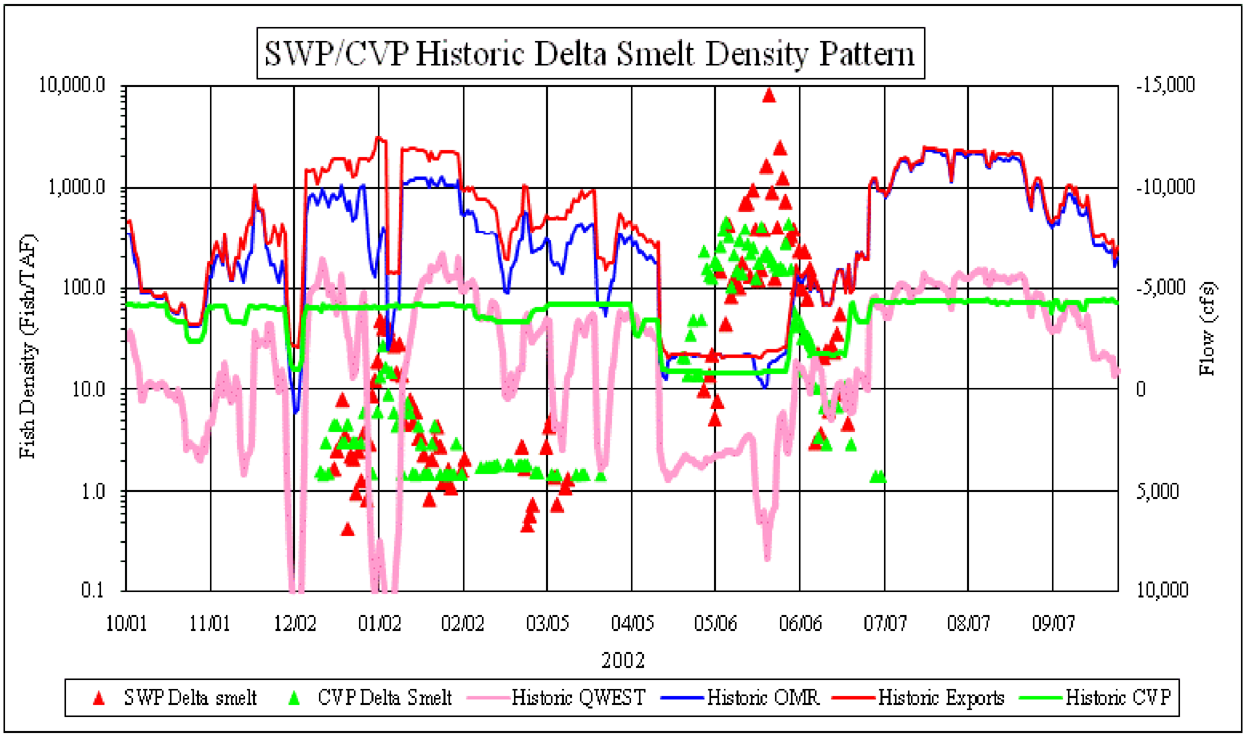

Figure B-8a. Historical CVP and SWP Delta Smelt Salvage Density and Delta Flows (QWEST and OMR) for 2002

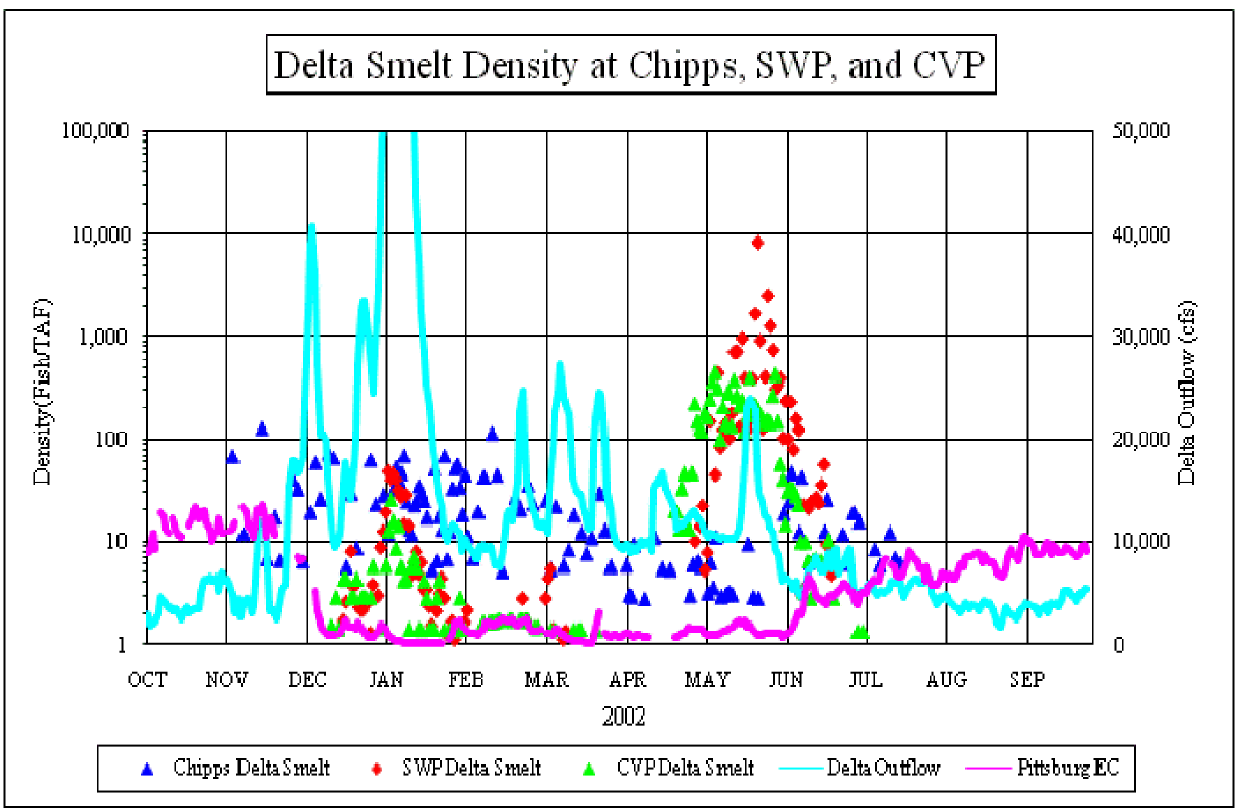

Figure B-8b. Delta Outflow and Pittsburg EC (µS/cm on right scale) and Delta Smelt Density for 2002

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Figure B-8

2003: Figure B-9a indicates that CVP pumping was about 4,000 cfs from October through mid-April when pumping was reduced to about 850 cfs through May for VAMP. SWP pumping was about 6,000 cfs in January and February, about 5,000 cfs in February, and 4,000 cfs in March and early April of 2003. Adult delta smelt first were observed in CVP and SWP salvage in mid-December, with ROMR flows increasing from 5,000 cfs to 10,000 cfs. The peak adult salvage density of about 20/taf to 50/taf was observed in late December and early January, when the Delta outflow was more than 50,000 cfs. The QWEST flows were reversed at about 2,000 cfs (DCC gates were closed) during the peak salvage density, and ROMR flows were about 10,000 cfs. Two Environmental Water Account (EWA) actions were taken to reduce the pumping in late December and mid-January. These actions reduced the adult delta smelt take, but did not reduce the salvage density.

Peak juvenile delta smelt salvage densities at CVP (500/taf) were observed in early May, and peak densities at SWP salvage (500/taf) were observed in mid-May. The low ROMR flows (less than 2,000 cfs) did not prevent relatively high delta smelt juvenile salvage densities. The CVP and SWP juvenile delta smelt salvage densities declined to less than 10/taf by early June, although ROMR flows were increasing to 5,000 cfs at the end of May. These juvenile fish most likely were spawned in south Delta channels or within the Clifton Court Forebay and were not tidally transported from Franks Tract or the lower San Joaquin River habitat.

Figure B-9b shows that the Chipps Island delta smelt density was relatively low (10/taf to 20/taf) in October and November, and increased to about 100/taf in January of 2003, following the high outflow and low salinity event. The peak adult delta smelt salvage density was also observed in January of 2003. The Chipps Island density declined in February and March, and remained low in May and June when the peak juvenile delta smelt salvage density was observed. The Chipps Island density remained low (10/taf to 50/taf) through September of 2003.

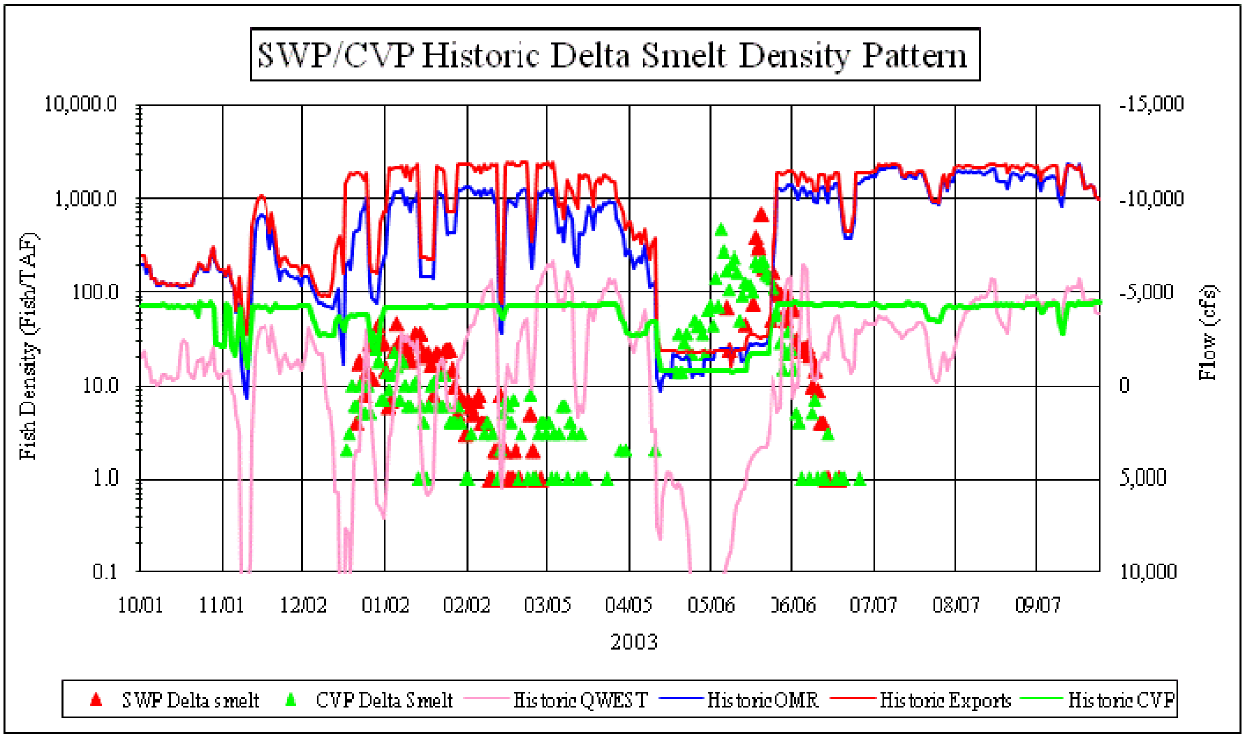

Figure B-9a. Historical CVP and SWP Delta Smelt Salvage Density and Delta Flows (QWEST and OMR) for 2003

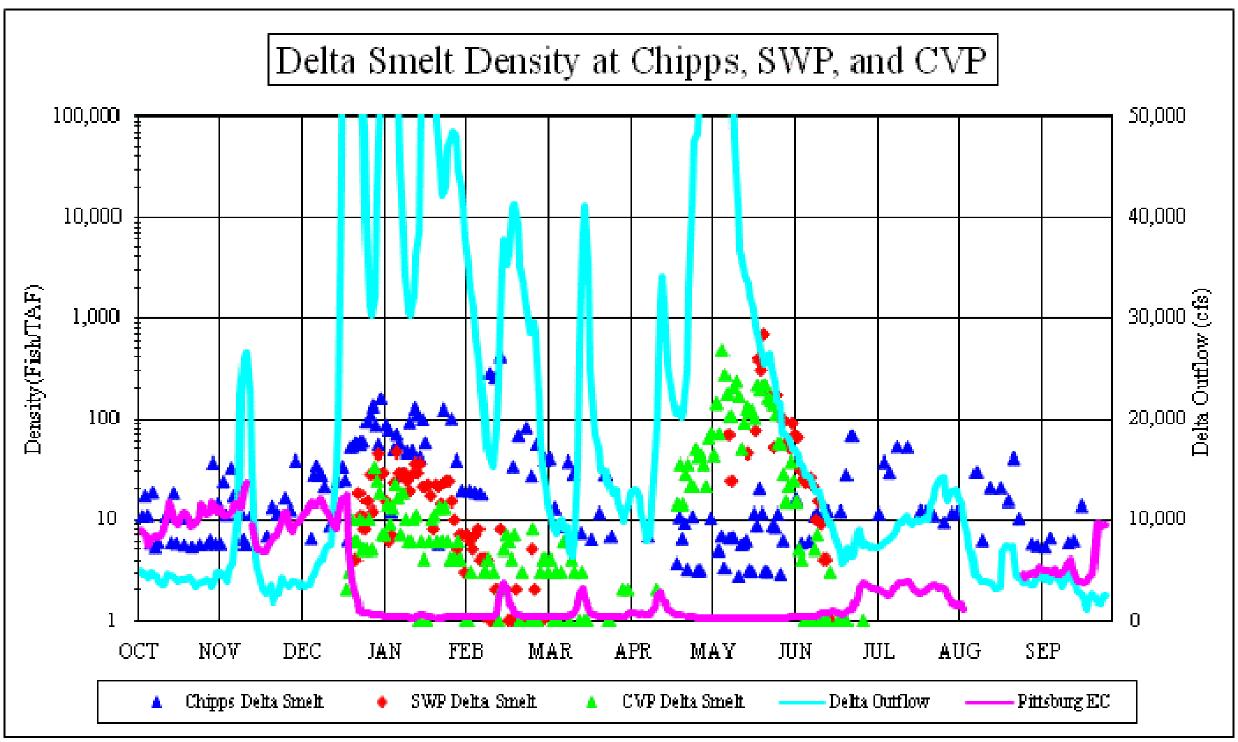

Figure B-9b. Delta Outflow and Pittsburg EC (µS/cm on right scale) and Delta Smelt Density for 2003

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Figure B-9

2004: Figure B-10a indicates that CVP and SWP pumping was relatively high from mid-December through early April, with ROMR flows of about 10,000 cfs. QWEST flows were fluctuating from reverse flows of almost 5,000 cfs in January to positive flows of more than 10,000 cfs in early January and late February. The adult delta smelt CVP and SWP salvage peak (20/taf) was observed in mid-January, with a second peak of adult density in late February. These two peaks in adult delta smelt salvage density peak were observed during nearly constant ROMR flows of about 10,000 cfs from mid-December through March.

The peak juvenile delta smelt salvage densities at CVP (100/taf) were observed in early May, and peak densities at SWP salvage (200/taf) were observed in late May of 2004. The low ROMR flows (less than 2,000 cfs) did not prevent relatively high delta smelt juvenile salvage densities, because these juveniles likely were spawned in the south Delta channels rather than being drawn towards the pumps by high ROMR flows. The CVP juvenile delta smelt salvage densities declined to less than 10/taf by early June, and the SWP delta smelt salvage densities were less than 10/taf by the end of June. The Jones Tract levee failure occurred on June 4, and SWP was reduced for a few days to prevent additional seawater intrusion during the filling of the Upper and Lower Jones Tract (about 150,000 af). The large ROMR flows caused by the Jones Tract levee failure do not appear to have tidally transported water with higher delta smelt densities into the south Delta from Franks Tract. These juvenile delta smelt most likely were spawned in south Delta channels or in the Clifton Court Forebay and were not tidally transported from Franks Tract or the lower San Joaquin River habitat.

Figure B-10b shows that the Chipps Island delta smelt density was relatively low (10/taf to 20/taf) from December through March of 2004 (no trawls in October or November). The two peaks of adult delta smelt salvage densities were similar in magnitude to the Chipps Island densities. The Chipps Island density remained low (10/taf to 20/taf) from June through September of 2004. The Chipps Island densities in 2002, 2003, and 2004 appear to be much lower than in previous years of 1995 to 2001.

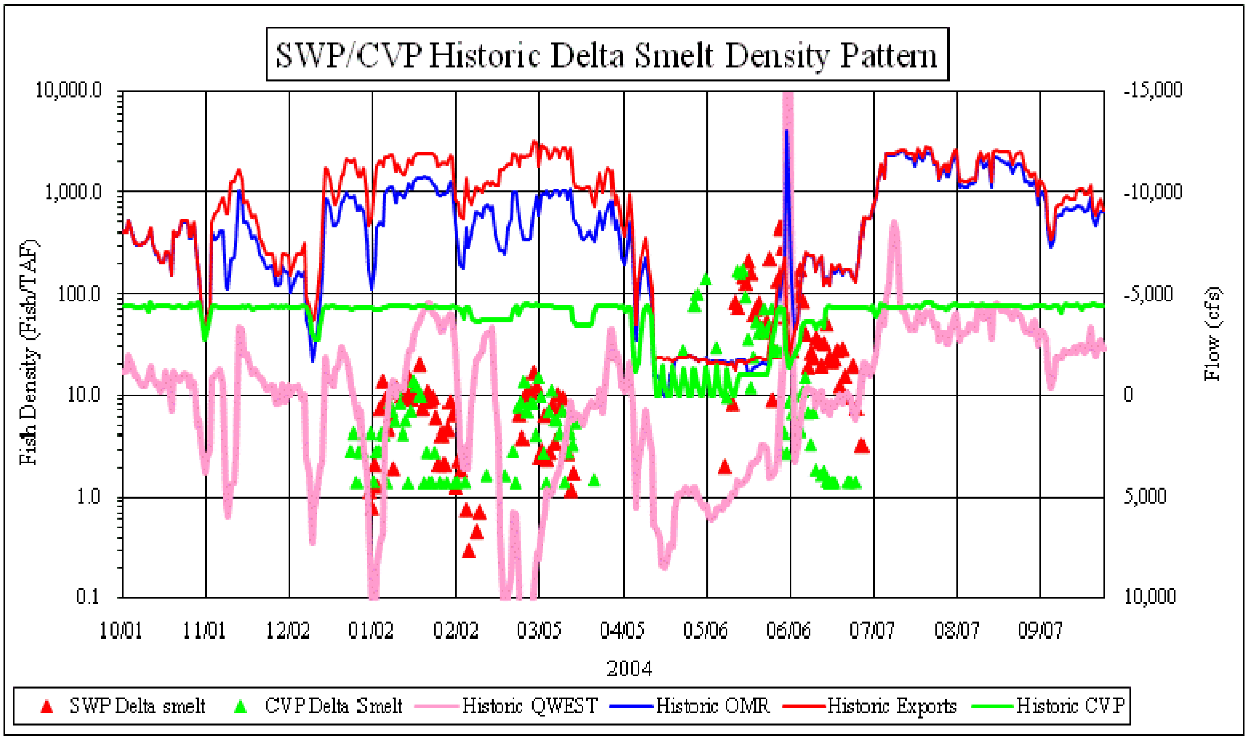

Figure B-10a. Historical CVP and SWP Delta Smelt Salvage Density and Delta Flows (QWEST and OMR) for 2004

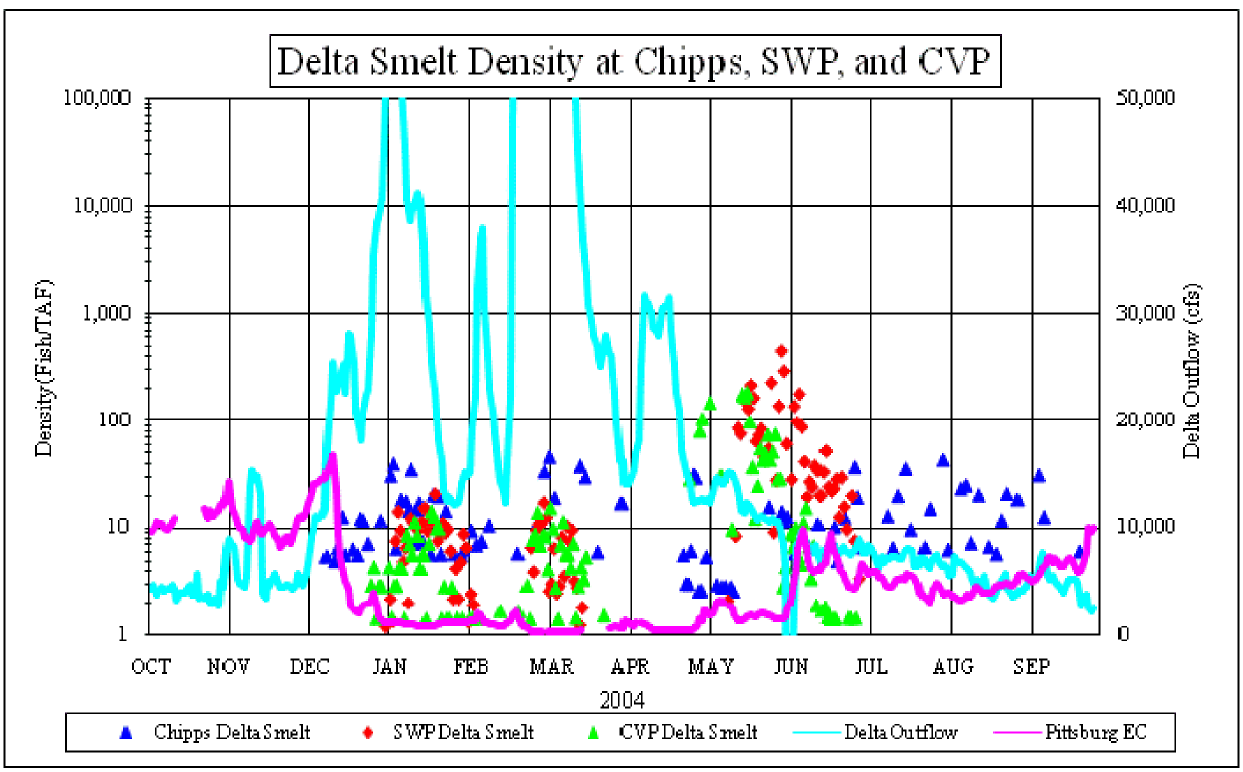

Figure B-10b. Delta Outflow and Pittsburg EC (µS/cm on right scale) and Delta Smelt Density for 2004

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Figure B-10

2005: Figure B-11a indicates that CVP pumping was constant at 4,000 cfs from October through mid-March of 2005, when pumping was reduced to about 2,000 cfs because San Luis Reservoir was full. SWP pumping was about 8,000 cfs in January and was reduced to 5,000 in February, March and early April because San Luis Reservoir was full. ROMR flows were about 7,500 cfs in December and January, but were reduced to less than 5,000 cfs in mid-February and were positive in late March and most of May. The peak adult delta smelt CVP and SWP salvage densities were low (5/taf) and were observed from mid-January to early February. The adult delta smelt salvage density peak was independent of the ROMR flows, which were nearly constant at about 7,500 cfs from mid-December through mid-February.

The peak juvenile delta smelt salvage densities at CVP and SWP were only about 10/taf in late May of 2005. The OMR flows were positive in early May and were less than 5,000 cfs when the juvenile salvage density was observed in late May and early June. These juvenile fish likely were spawned in the south Delta channels or in the CCF and were not tidally transported from Franks Tract or the lower San Joaquin River habitat. The high San Joaquin River inflows, which fluctuated between 4,000 cfs and 8,000 cfs in April, May, and June, apparently were effective in transporting most of the juvenile delta smelt toward the salinity gradient of the estuary. Relatively few were entrained in the CVP and SWP pumping.

Figure B-11b shows that the Chipps Island delta smelt density was moderately low (10/taf to 100/taf) from November through May of 2005. The Chipps Island density increased to 100/taf in early July and declined through September of 2005, perhaps because of higher salinity. The Chipps Island densities in 2005 remain similar to 2002–2004 and were much lower than in previous years of 1995 to 2001.

Another factor that may have influenced the salvage of delta smelt juveniles in May and June 2005 was the inflow of another juvenile fish from the San Joaquin River floodplain spawning and rearing habitat. The Sacramento splittail spawns in the riparian corridor and floodplains of the Sacramento, San Joaquin, and other Delta tributary rivers. The San Joaquin River flows were high (causing flooding) in March and April 2005. Although these peak flows were only 10,000 cfs to 15,000 cfs, there was apparently sufficient floodplain habitat inundated to produce a large number of juvenile splittail. They were measured as they migrated past Mossdale, just upstream of the head of Old River diversion to the export pumps in May and June, with average lengths of 30 mm in early May and about 50 mm at the end of June. The splittail juveniles were about the same size as the delta smelt juveniles in May and June.

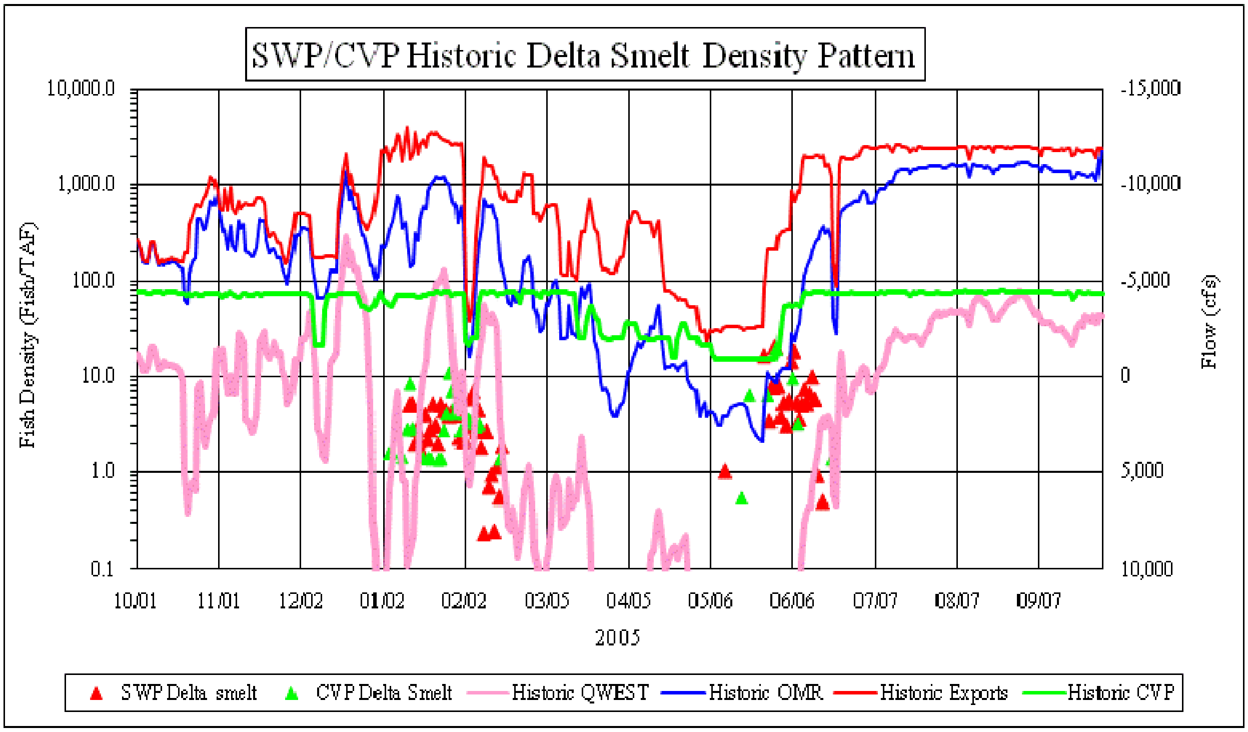

Figure B-11a. Historical CVP and SWP Delta Smelt Salvage Density and Delta Flows (QWEST and OMR) for 2005

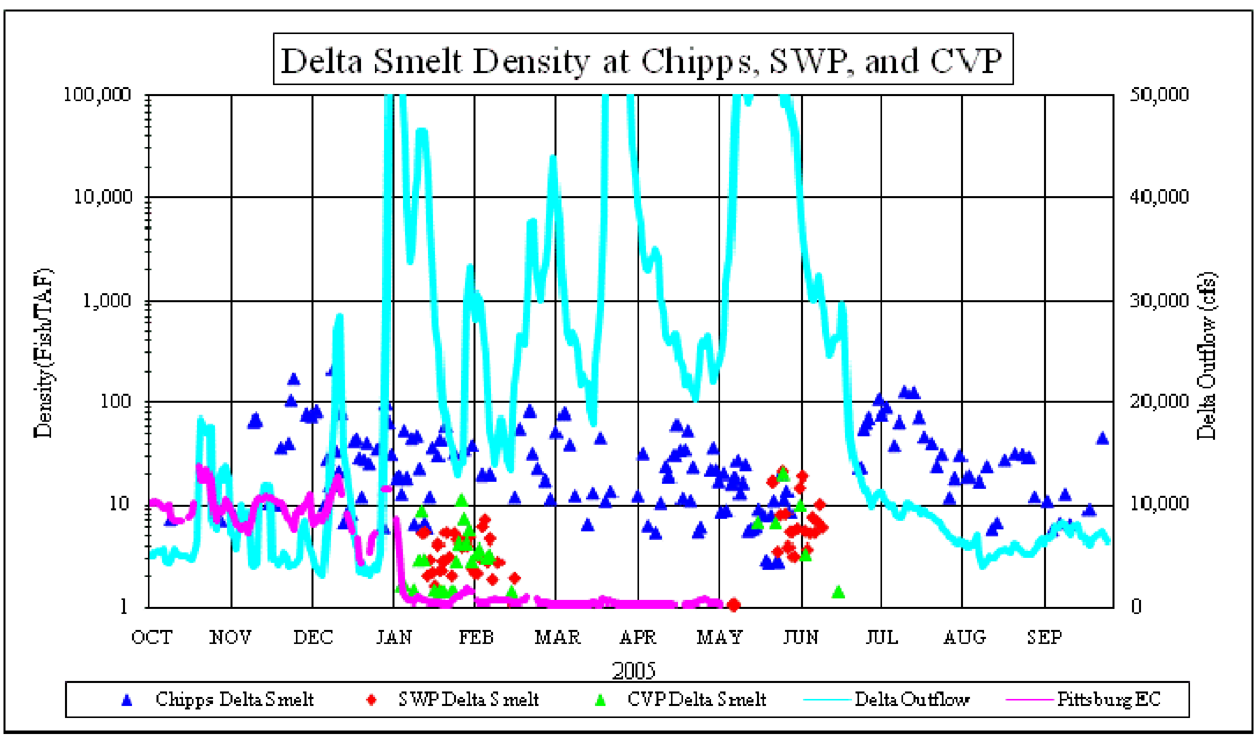

Figure B-11b. Delta Outflow and Pittsburg EC (μS/cm on right scale) and Delta Smelt Density for 2005

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Figure B-11c shows the San Joaquin River at Mossdale splittail density and the CVP and SWP splittail salvage density for 2005. The CVP splittail salvage density was higher than the SWP salvage density because more of the San Joaquin River water is exported at the CVP pumps. The CVP and SWP splittail salvage density was about 100/taf to 1,000/taf, while the delta smelt salvage density was only about 10/taf in May and June of 2005. The ability to count and identify fish is somewhat limited at these high fish densities. There was an abundance of juvenile fish at CVP and SWP salvage facilities in May and June of 2005, although delta smelt salvage was relatively low in 2005.

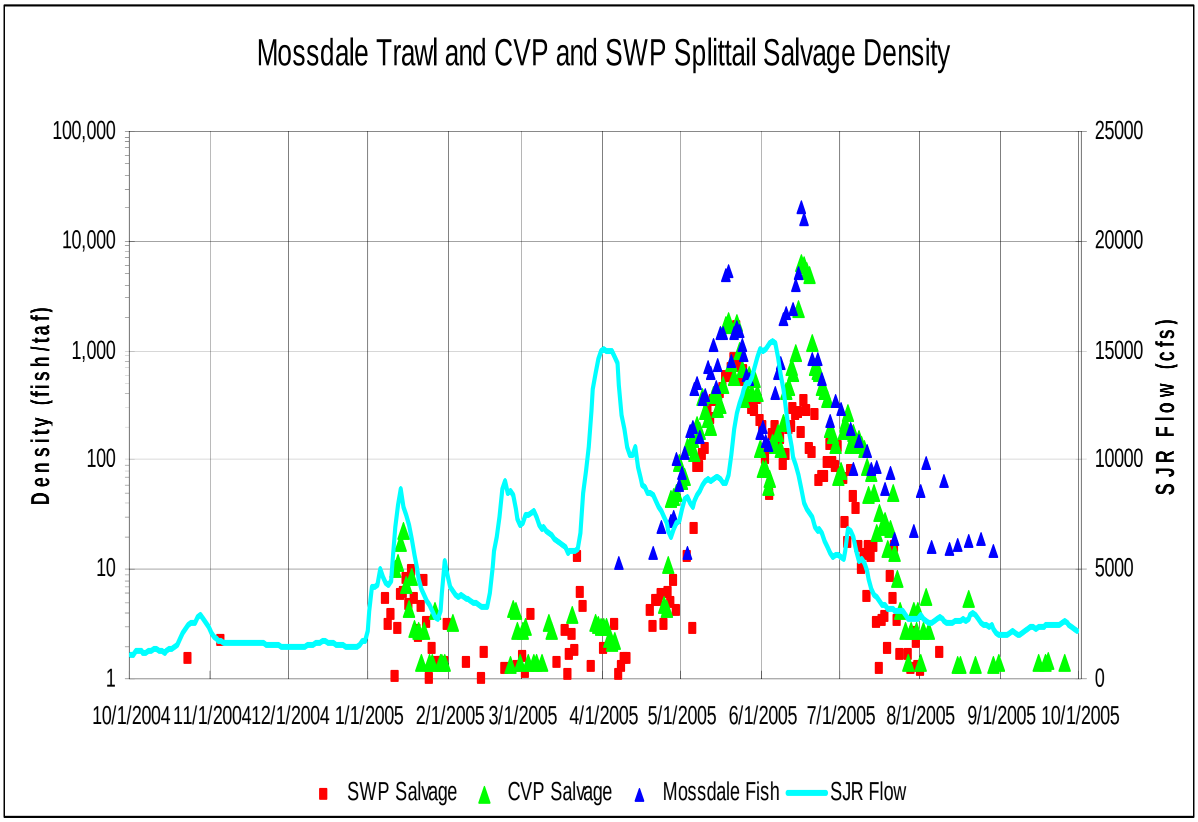

Figure B-11c. Historical CVP and SWP Splittail Salvage Density, Kodiak Trawl Splittail Density at Mossdale, San Joaquin River Flow Conditions for 2005

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2006: Figure B-12a indicates that CVP pumping was about 4,000 cfs from October through mid-March, when pumping was reduced to about 1,000 cfs because San Luis Reservoir was full. SWP pumping was about 8,000 cfs in late January and was reduced to about 4,000 in February, March and early April because San Luis Reservoir was full. OMR flows were positive in early January, and from mid-March through mid-June. Very few adult delta smelt were observed in CVP or SWP salvage during 2006. The highest CVP adult delta smelt salvage was in early March when OMR flows were about 0 cfs and QWEST was greater than 10,000 cfs positive. There were no juvenile delta smelt in the CVP or SWP salvage in 2006, presumably because all the exports in April and May of 2006 were supplied by San Joaquin River water that contained no delta smelt. Any delta smelt spawned in the south Delta channels were apparently transported downstream by the positive OMR flows of about 10,000 cfs in April and early May.

Figure B-12b indicates that the Chipps Island delta smelt densities were low relative to previous years and generally increased from December to February, and then decline in March and April. Figure B-12c shows that there were even higher densities of splittail in May and June 2006 than there were in 2005. CVP salvage was more than 1,000,000 splittail on June 6, 2006 (density of 100,000/taf). The possible effects of the large numbers of splittail that entered the Delta in May and June of both 2005 and 2006 on the rearing success (growth and survival) of delta smelt and other juvenile fish rearing in the Delta channels has not been investigated.

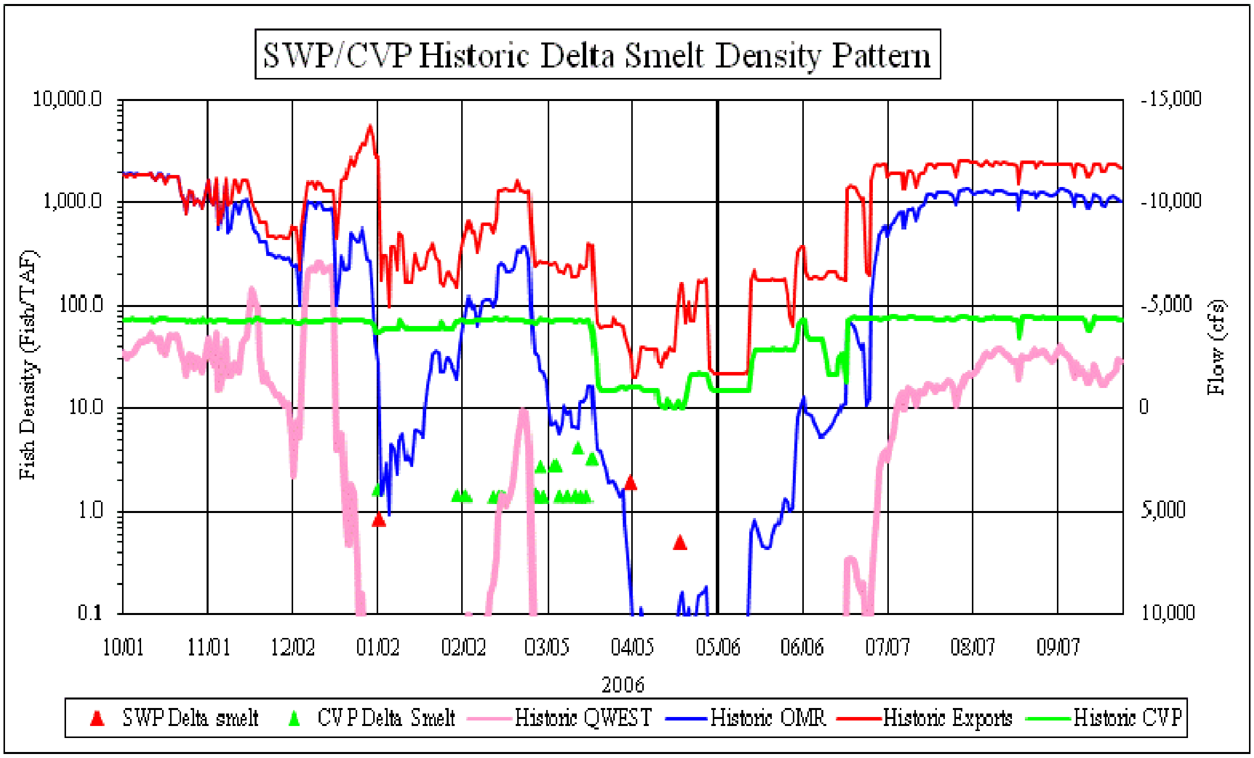

Figure B-12a. Historical CVP and SWP Delta Smelt Salvage Density and Delta Flows (QWEST and OMR) for 2006

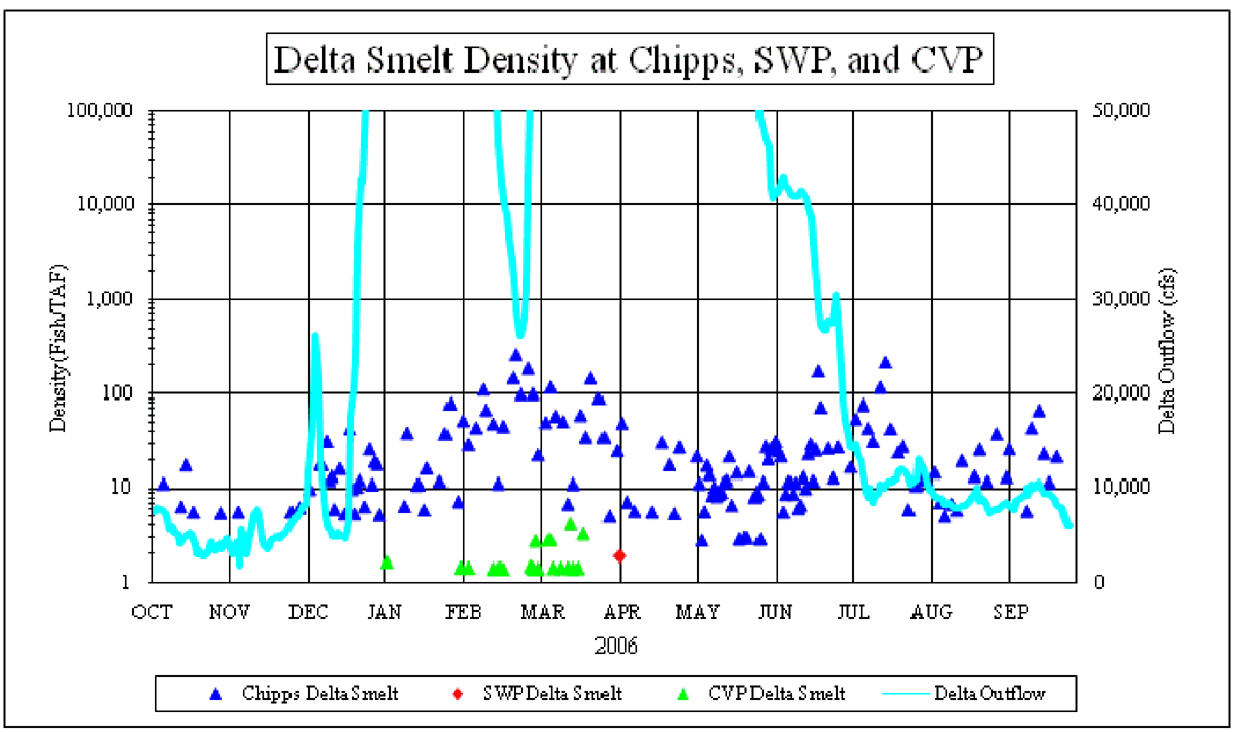

Figure B-12b. Delta Outflow and Delta Smelt Density for 2006

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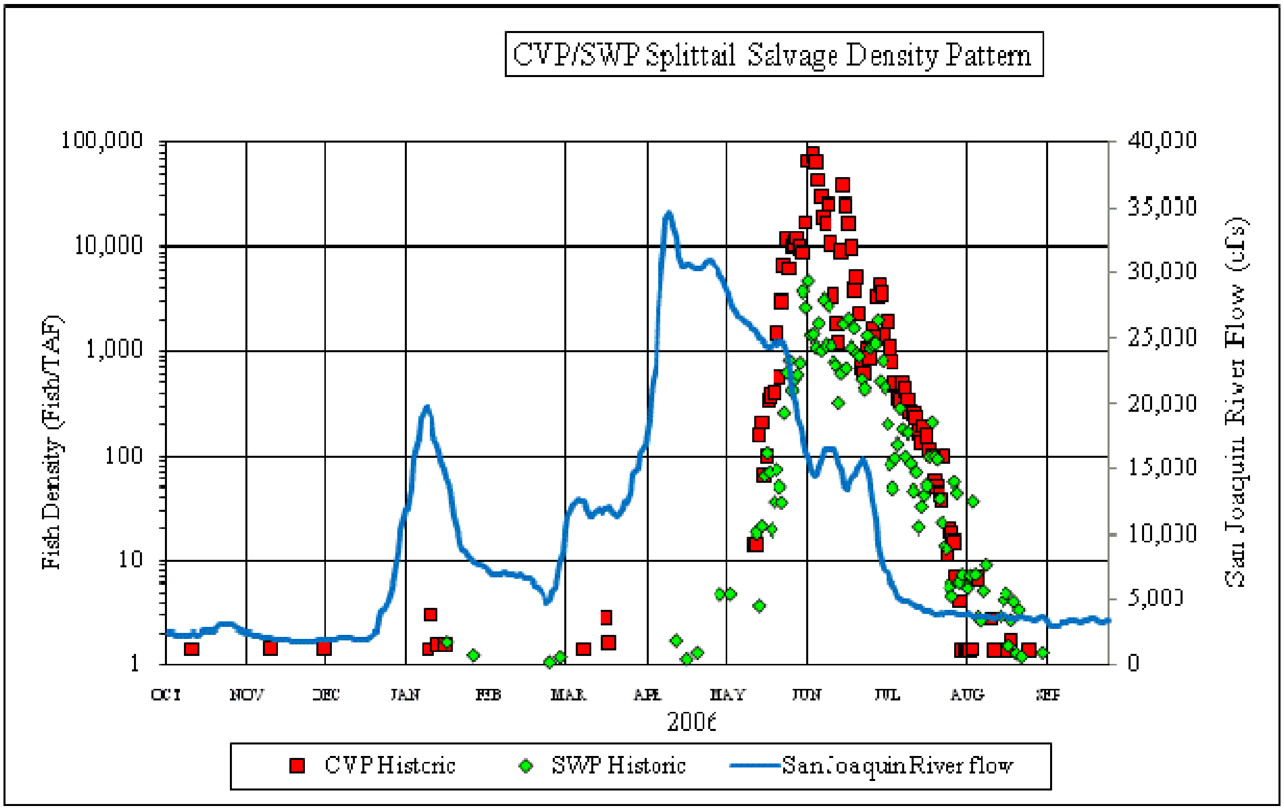

Figure B-**12c.** Historical CVP and SWP Splittail Salvage Density and San Joaquin River Flows for 2006

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Figure B-12

2007: Figure B-13 indicates that the Chipps Island delta smelt density remained low (5/taf to 50/taf) from October through May 0f 2007. The peak density of 50/taf in January was lower than many earlier years (1995–2001). There were almost no adult delta smelt salvaged in 2007 and the peak SWP juvenile delta smelt salvage density in June was only about 100/taf. The SWP pumping was reduced for several days in June of 2007 to reduce the entrainment of juvenile delta smelt because the population was thought to be very low.

The general pattern of Chipps Island delta smelt density was generally consistent from year to year and matched the CVP and SWP salvage density of adults and juveniles in the south Delta. These daily delta smelt density patterns appear to support the hypothesis that the majority of the adult delta smelt that are observed in the south Delta enter these channels during the adult migration (dispersal) from the confluence, which may be triggered by conditions associated with the first major inflow event of the winter.

Upon the recommendation of the Delta Smelt Work Group (DSWG), the Chipps Island trawl has been relocated to Benicia (beginning in August 2007), where salinity is higher than at Chipps Island and where delta smelt are not expected to be caught. However, this relocation of the trawling will eliminate the Chipps Island monitoring station for delta smelt. The Chipps Island trawl is the only monitoring location other than the CVP and SWP salvage facilities with a large enough sample volume to observe delta smelt during years with relatively low densities (less than 100/taf). It is the only location where daily trawls provide a daily estimate of delta smelt density.

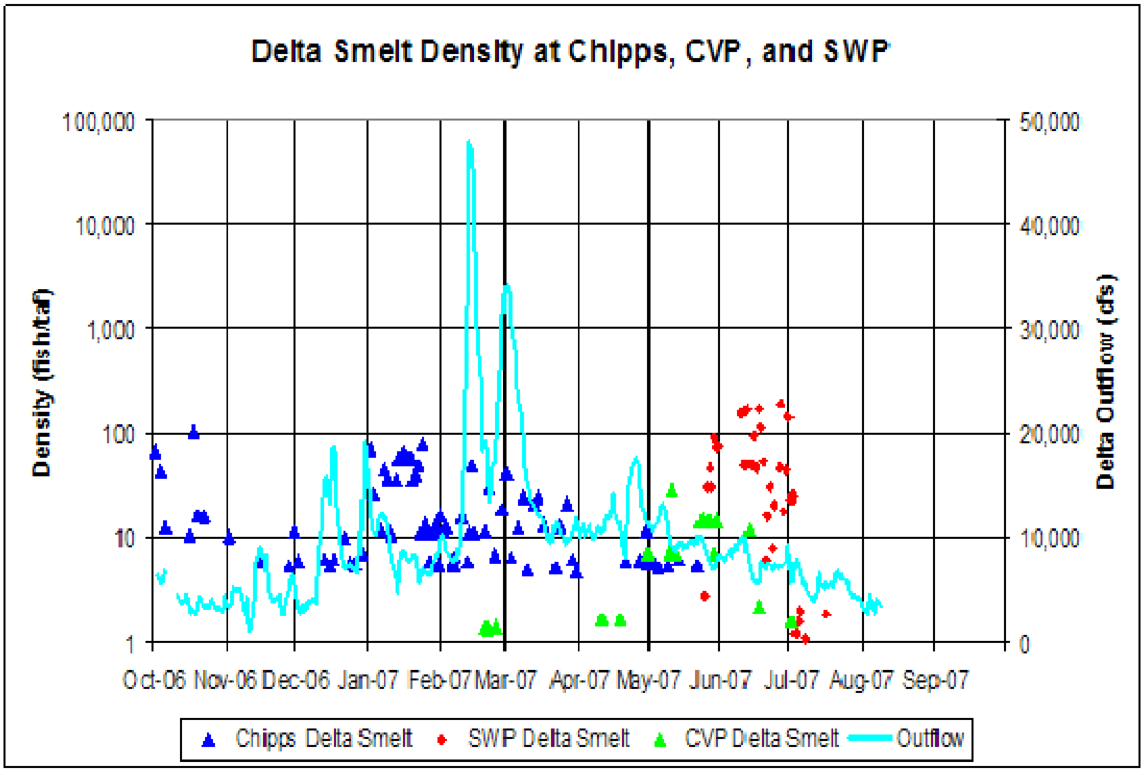

Figure B-13. Historical CVP and SWP delta smelt salvage density and Chipps Island Trawl delta smelt density and Delta Outflow for 2007

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Export Pumping and Juvenile Delta Smelt Removal Patterns

Juvenile delta smelt that are observed in CVP and SWP salvage may have been spawned in the south Delta channels, and may be removed from these channels by the CVP and SWP pumping (i.e., the pool filter effect). The San Joaquin River flows that are diverted down Old River will rapidly flush any juvenile smelt that emerge from the spawning areas along Old River or Grant Line Canal (6,000 af). We will assume that the ROMR flows are the effective flushing flows caused by CVP and SWP pumping, and that the total volume of the south Delta channels is about 200,000 af. If we consider the south Delta channels as a mixed volume with a uniform density of delta smelt, the average density (and abundance) will be reduced by this daily flushing volume fraction (i.e., loss rate). The flushing volume fraction can be estimated from the ROMR flow (cfs) times 2 (af/cfs-day) divided by the south Delta volume of 200,000 af.

For example, if the ROMR flows are 5,000 cfs, the flushing volume is 10,000 af/day, and the flushing fraction of 0.05 (i.e., 10,000 af/ 200,000 af) will reduce the average density by about 5% a day. The delta smelt removal pattern (i.e., delta smelt density reduction) caused by export pumping was calculated for 2000 assuming the initial delta smelt density was 1,000/taf on May 15. The initial May 15 delta smelt abundance in the south Delta therefore would have been about 200,000 delta smelt juveniles, which could have been spawned by about 1,000 adult delta smelt (i.e., 500 females with 1,500 eggs/female, and with a 25% survival rate to 20 mm assumed).

Figure B-14 shows that the calculated delta smelt depletion (i.e., density reduction) pattern generally matches the observed CVP and SWP salvage density decline for May and June 2000. This may support the assumption that a major fraction of the observed CVP and SWP juvenile delta smelt salvage originates as juveniles that were spawned in the south Delta channels, and are subsequently removed from the south Delta channels by the CVP and SWP pumping. Because there is some natural mortality (e.g., from predation, food limitation), it is expected that this calculated salvage density depletion pattern would remain higher than the observed salvage densities. A daily mortality rate of about 1% or 2% (1.5% assumed for the calculation) would shift the depletion pattern downward to match the measured salvage density decline more closely. Some of the juvenile delta smelt from the south Delta may also be actively swimming or tidally surfing (i.e., moving downstream with the ebb tides) toward the estuary salinity gradient.

The possible escape of some delta smelt juveniles from the south Delta is of great interest for managing delta smelt, especially if the downstream escape rate could be increased by reducing the ROMR flows or providing positive QWEST flows. However, it appears that fewer than 10% of the delta smelt juveniles escaped from the south Delta in 2000, because the majority of the juveniles can be accounted for by the removal by pumping (salvage density decline) and with a moderate (1.5%) mortality rate.

Because QWEST flows were about 5,000 cfs (positive) in mid-May and declined to reverse flows of about 5,000 cfs at the end of June, the tidal transport of delta smelt juveniles from Franks Tract or Jersey Point into the south Delta would have been relatively low at the observed peak density in late May. The ROMR flows were increasing during this period of juvenile delta smelt decline, which may have reduced the downstream escape of juvenile delta smelt from the south Delta. Examination of the juvenile delta smelt decline patterns in other years may help identify what fraction of the delta smelt juveniles originates from spawning in the south Delta channels, and how many are drawn into the south Delta from reverse QWEST or ROMR flow. Likewise, additional evaluation of other years may allow the fraction of the south Delta juvenile delta smelt that are removed at the salvage facilities by the CVP and SWP pumping, eliminated by predation and food limitation (mortality), or swimming (escaping) toward the salinity gradient at the confluence. This may allow more effective management actions to be formulated to match the flow conditions with the delta smelt population patterns.

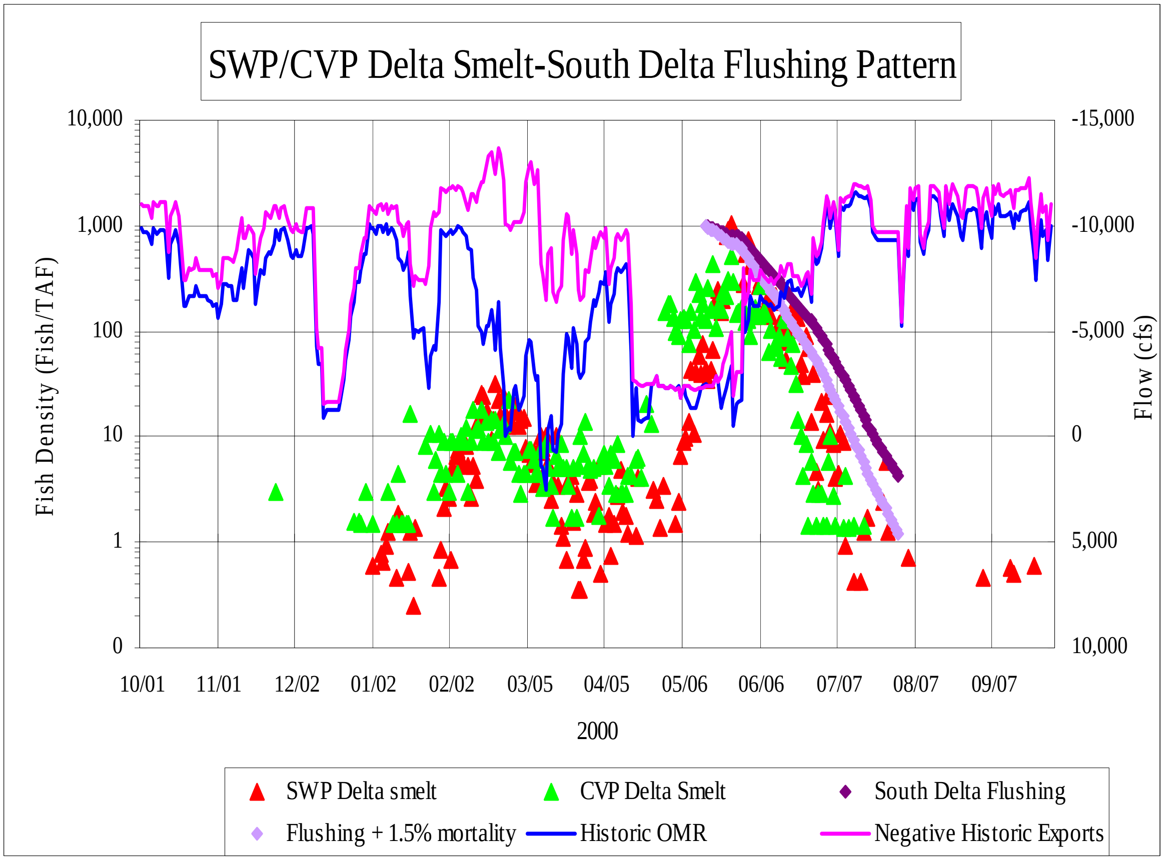

Figure B-14. Comparison of CVP and SWP Delta Smelt Salvage Densities with the Simulated Pattern of Removal by Export Pumping of Juvenile Delta Smelt for 2000

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Evaluation of Monthly Delta Smelt Salvage and Delta Flow Conditions

There has been considerable interest in various annual correlations or regressions (i.e., scatter plots) that show delta smelt or some other fish abundance variable (i.e., FMWT index) as a function of some Delta flow (i.e., outflow) or other environmental condition. Several of these annual relationships were shown as evidence in the Wanger decision. One graph indicated that the total annual CVP and SWP salvage of adult delta smelt in December–March increased as the average OMR flow in December–March was more negative (more flow from central Delta toward the exports). This and similar relationships have been used to identify and evaluate the major factors causing annual variations in delta smelt abundance, or other annual fish abundance variable.

Figure B-15a shows the relationship between combined adult delta smelt salvage (for December–March) and the average December–March OMR flow for 1980–2007. This relationship appears to suggest that the salvage of adult delta smelt could be controlled by reducing pumping during this 4-month period to reduce the ROMR to some flow objective (between -2,000 cfs and -5,000 cfs). The recent period of 1993–2005 shown as evidence in the Wanger case is indicated with red boxes. However, this relationship is not as strong if earlier years are included in the regression. This relationship does not account for the large differences in delta smelt abundance observed from year to year in the FMWT surveys.

The apparent correlation between combined salvage and ROMR flow is partially explained by the obvious increase in salvage with more pumping (ROMR). Figure B-15b shows the relationship between ROMR flow and combined salvage density (fish/taf) for 1980–2007. The recent period of 1993–2005 is indicated with red boxes. The regression with salvage density is much weaker because the direct effect of pumping on salvage is removed. There have been relatively high average December–March delta smelt densities in some years with high average ROMR flows, but there also have been relatively low densities in other years with high ROMR flows, as well as moderate densities in years with lower ROMR flows.

If ROMR flows were the dominant factor leading to higher adult delta smelt salvage, this relationship would be consistent from month to month. The daily data reveals that the period of high delta smelt density persists for only 2–6 weeks each year, and it does not always correspond to periods of high ROMR flows. The appearance of high adult delta smelt salvage densities at both SWP and CVP are generally independent of ROMR flows, and more likely to follow increased Delta outflow and reduced salinity at Chipps Island or Pittsburg.

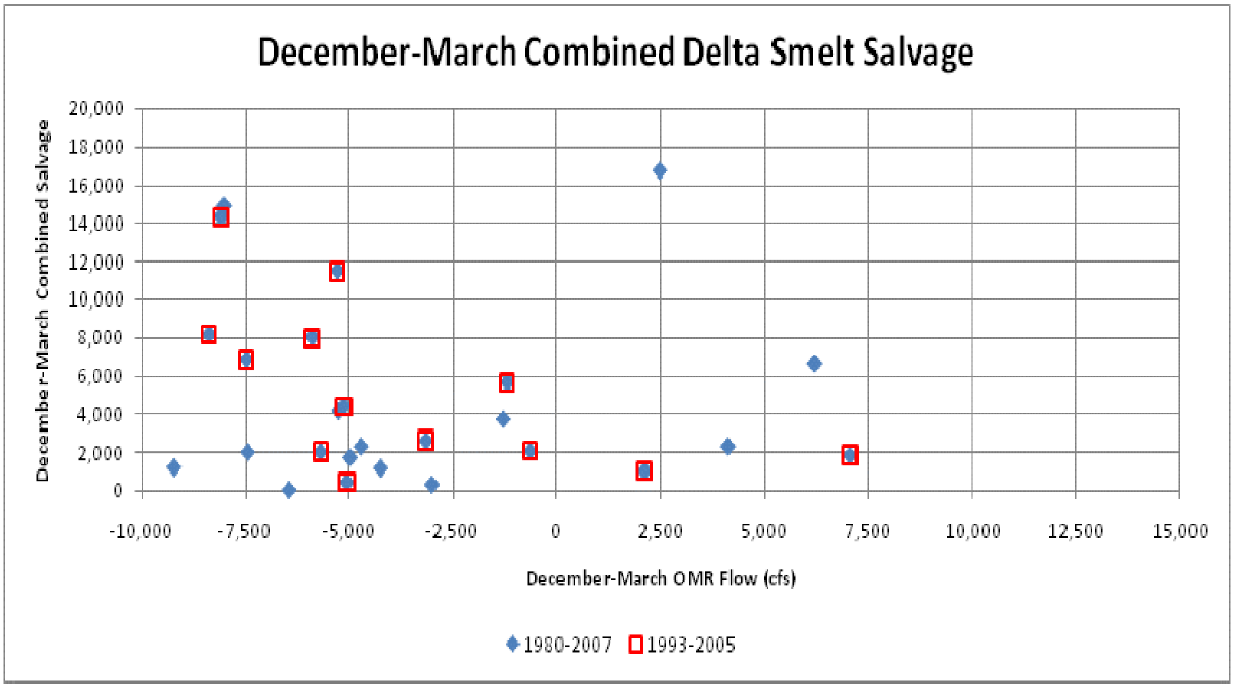

Figure B-15a. Relationship between Average December–March Old and Middle River (OMR) Flow and Combined Adult Delta Smelt Salvage for 1980–2007 (with 1993–2005 shown with red boxes).

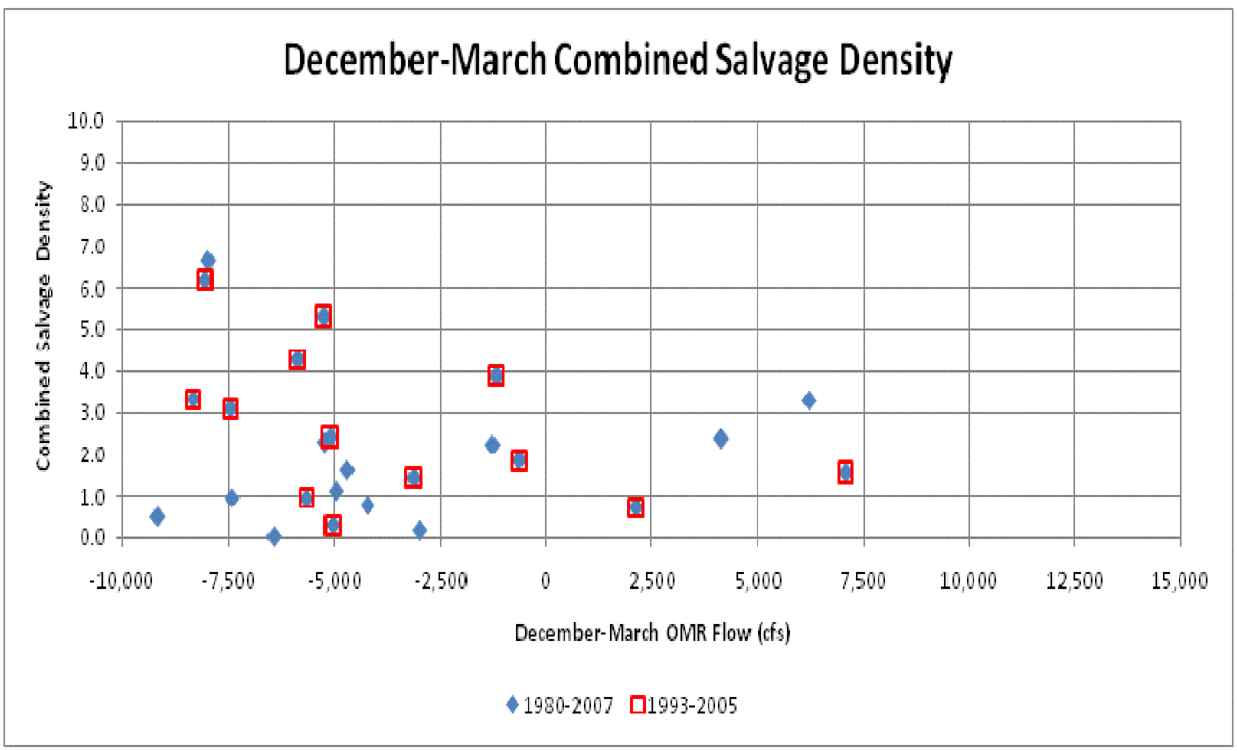

Figure B-15b. Relationship between Average December–March OMR Flow and Adult Delta Smelt Salvage Density for 1980–2007 (with 1993–2005 shown with red boxes)

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Figure B-16a shows the relationship between OMR flows and adult delta smelt salvage for the months of December–March for 1980–2007. Figure B-16b shows the corresponding relationship between OMR flows and adult salvage density for the months of December–March for 1980–2007. A logarithmic scale is used because the range of salvage and salvage density has been quite large. Because often the majority of adult delta smelt are observed in a single month and are not observed in CVP and SWP salvage for all 4 months in each year, there is a wide range of salvage and salvage density within each year. The January data (red boxes) indicate the strongest relationship with OMR flows. It appears likely that reducing ROMR flows will prevent adult delta smelt salvage only in those months when adult delta smelt are independently moving into the south Delta in preparation for spawning. Reverse OMR flows may not be drawing these adult delta smelt into the south Delta. Reducing pumping during periods of relatively high salvage density (i.e., 2/taf) may be effective in reducing salvage. This was the strategy used by the EWA during 2001–2006.

Evaluations of annual correlations between average flows and fish abundance indices are likely to be overly simplistic because they combine the detailed interactions between environmental conditions and life-stage responses into a general long-term relationship that is assumed to explain the observed variation in the delta smelt abundance or other biological variable. A more realistic picture (i.e., conceptual model) of the variations in delta smelt abundance, distribution, and migration patterns is more likely to emerge from careful evaluation of the daily flows and water quality conditions (salinity and turbidity) and the daily CVP and SWP salvage and Chipps Island trawl density, in addition to the bi-weekly 20-mm surveys and the monthly Kodiak trawls and monthly FMWT surveys.

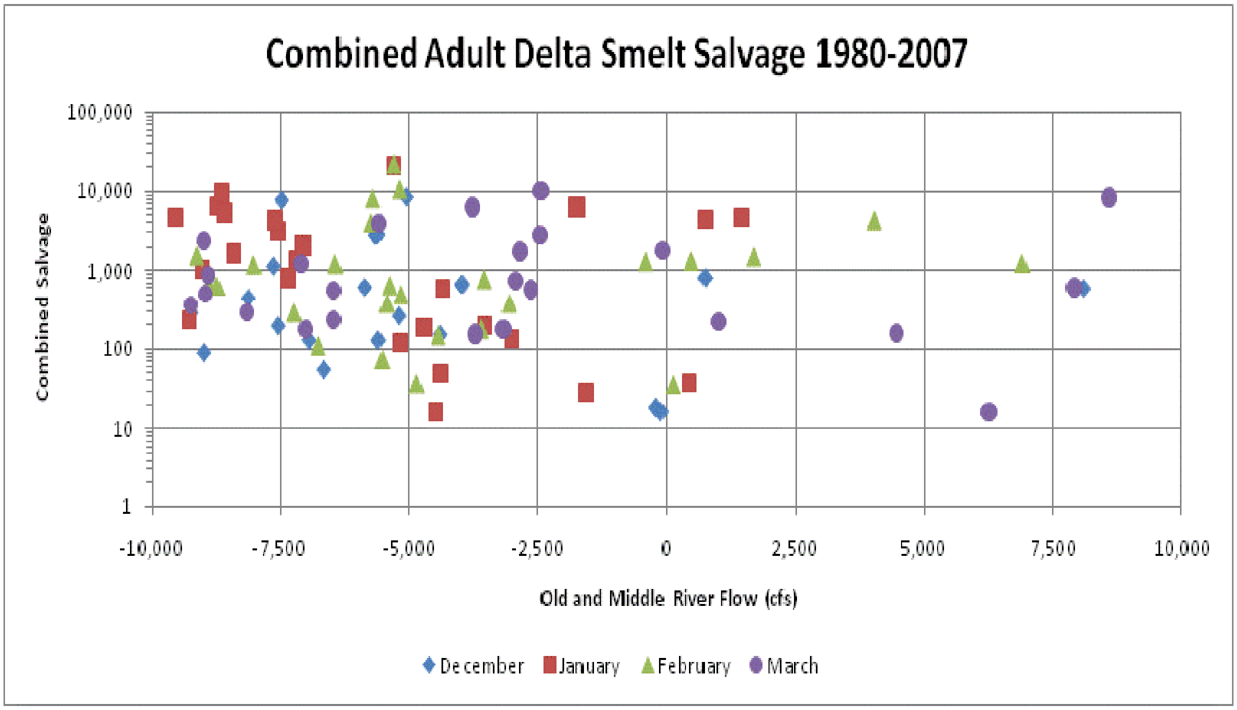

Figure B-16a. Relationship between Monthly OMR Flow and Monthly Adult Delta Smelt Salvage for December–March of 1980–2007

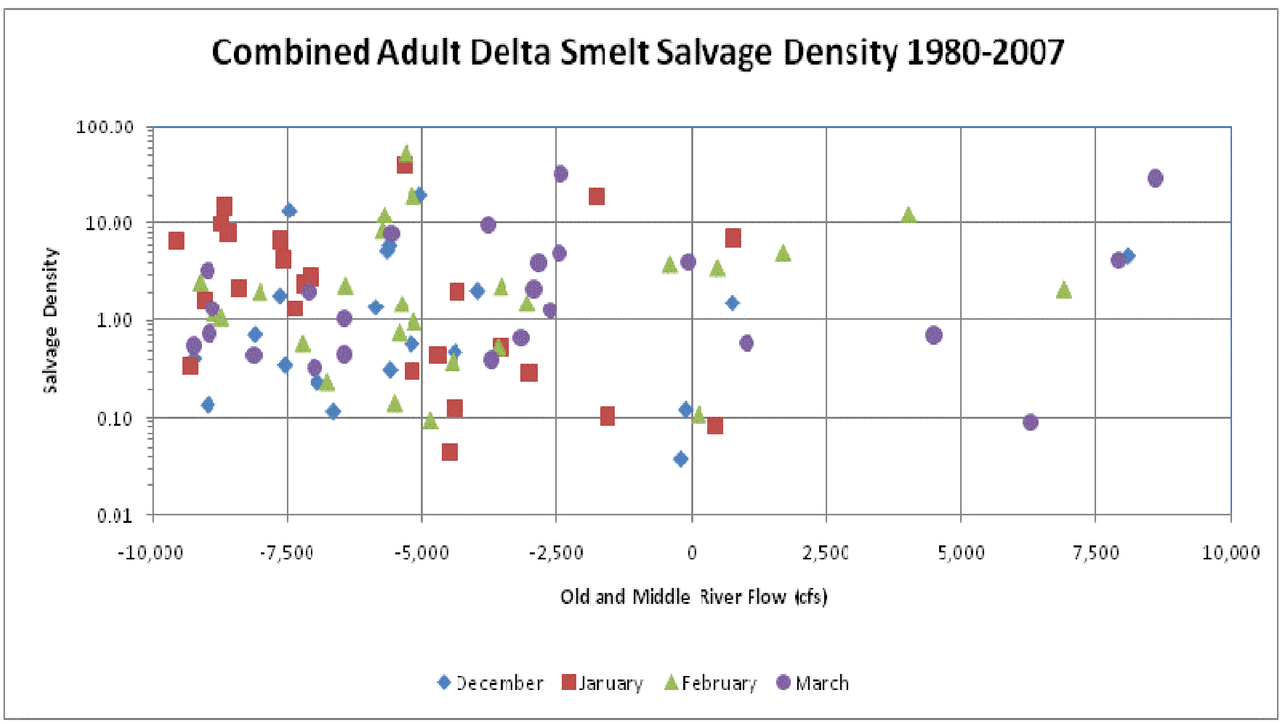

Figure B-16b. Relationship between Monthly OMR Flow and Monthly Adult Delta Smelt Salvage Density for December–March of 1980–2007

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Conclusions

The daily Delta flows and water quality conditions (EC and turbidity) provide the basic habitat and environmental conditions that likely govern delta smelt growth and survival and that may influence spawning migration and the subsequent movement of juvenile delta smelt toward the confluence and the low-salinity zone of the estuary. The life-history trajectories for delta smelt can be identified by careful examination of the available historical abundance (density) data provided by the CVP and SWP salvage records as well as the daily Chipps Island trawling.

Delta smelt adults appear to migrate into the south Delta channels in response to environmental conditions associated with the first major Delta outflow event (>25,000 cfs outflow) after mid-December. The salinity associated with this high outflow is reduced to about 1,000 µS/cm in the vicinity of Chipps Island and Pittsburg. The peak adult delta smelt salvage densities are often similar at the CVP and SWP salvage facilities. It appears likely that the majority of adult delta smelt enter the south Delta by active swimming, not by being transported by reverse flows or tidal mixing. The density of delta smelt at Chipps Island (mid-water trawl) shows a coincident decrease, confirming that this is likely a general migration pattern from the confluence region into the upstream Delta channels that may be more suitable for successful spawning. Because the early juveniles are poor swimmers, it is possible that adults seek shallow tidal slough habitat without any strong net flows for spawning to allow the larval delta smelt life-stage several weeks of passive tidal movement. Juveniles may move downstream and enter channels with a substantial net downstream flow when they are ready to migrate toward the salinity gradient of the estuary, often located near the confluence or Chipps Island region.

Regulation of reverse QWEST or ROMR flows is unlikely to exert much of a control on this upstream spawning migration event (dispersal). Reducing the CVP and SWP pumping during this period of peak adult delta smelt density will reduce the take of adult delta smelt, but may leave more of these adults in the south Delta. The peak density of adult delta smelt is often about 10/taf to 20/taf and the period of peak density lasts about 2–6 weeks (15–60 days).

The 1995–2007 Delta smelt salvage data suggest that the peak juvenile density is also not strongly controlled by reverse QWEST or ROMR flows. These juveniles, with a peak density of about 500/taf to 1,000/taf, likely were spawned in the south Delta channels from the adults that migrated into the south Delta during the January–March period. These juveniles could be allowed to move toward the salinity gradient at the confluence by reducing the CVP and SWP pumping throughout the juvenile life stage (April through June).

Approaches to Increasing Survival of Delta Smelt

Historical Protective Measures

Reducing the pumping during periods of high adult delta smelt salvage density was the major strategy used by the EWA for fish protection actions from 2001 to 2006. This was effective in reducing the take of adult delta smelt during the periods when these export reductions were made. However, the reduced pumping for EWA protection had a water cost of about $150/af (EWA purchase price), and during the peak salvage density of 10/taf, each adult delta smelt saved from pumping required about 100 af or about $15,000 worth of water.

A substantial shutdown of the CVP and SWP pumps during the 3-month period of peak juvenile abundance (April through June) likely would allow most of the naturally surviving juveniles that were spawned in the south Delta channels to migrate downstream toward the confluence. This action has been partially implemented during the VAMP period, when SWP and CVP exports have been substantially reduced for a month each year since 1995. However, the water cost of the necessary reduced pumping during this 3-month period (assuming the combined CVP and SWP pumping was reduced by 5,000 cfs for 60 days) potentially would be about 500 taf ($75 million value at $150/af). The number of juvenile delta smelt that would be protected by these actions may be limited because of the potentially high mortality from predation and higher temperatures in June. Based on the maximum juvenile delta smelt density of about 100/taf observed in CVP and SWP salvage, the population in the south Delta that could be protected by these export reduction measures would be about 200,000. If all of these juveniles were protected with a water cost of $75 million, the cost per juvenile would be about $375 per juvenile.

Protective Measures during 2008

The current strategy, based partly on the premise that SWP and CVP pumping pulls adult and juvenile delta smelt toward the pumps, where they are subsequently entrained, came into effect in early December 2007, when Judge Oliver Wanger issued a court ruling reducing CVP and SWP water exports from the Delta from December to June. The ruling specified certain situations that would require pumping operations to be reduced. One of those thresholds occurred on December 25, 2007, when water turbidity increased to 12 NTU at a south Delta monitoring site. The ROMR flows were reduced to less than 2,000 cfs for a 10-day period to reduce the possibility that adults would move into the south Delta.

Additional ROMR flow criteria will be imposed in 2008 to reduce the potential take of adult and juvenile delta smelt. These criteria will continue until June 20. If this protective strategy is also adopted in the re-consultation of the CVP-SWP Operating Criteria and Plan (OCAP), pumping may be restricted in future years in an attempt to reduce the potential movement of adult delta smelt into the south Delta channels.

It will be difficult to evaluate the effectiveness of this protection strategy, because there is not a daily monitoring location at Jersey Point or Franks Tract to determine the relative abundance (density) of delta smelt that might be drawn toward the pumps. The CVP and SWP salvage densities will continue to be measured, but determining the number that might have been taken with full pumping will be difficult without a reference monitoring station. Even the Chipps Island trawling station has been eliminated by the DSWG, so this historical reference monitoring location data no longer will be available for comparison with the salvage densities.

Alternative Protection Strategy

An alternative protective strategy to consider for reducing the take and impacts on the delta smelt population from CVP and SWP pumping could be rescuing and relocating entrained adult delta smelt. Salvaged adult delta smelt could be hand-separated into special holding tanks and subsequently released into the Cache Slough or Suisun Marsh channels, where spawning and juvenile survival without entrainment is much more likely. The crews of fish biologists needed to implement this strategy 24 hours per day, 7 days per week, and the cost of separate holding tanks and adult release boats likely would be less than $1 million each year. Based on the historical salvage data, between 1,000 and 10,000 adult delta smelt could be collected and released into the most suitable spawning regions of the Delta each year. Increased pumping and successful salvage of delta smelt adults would remove the maximum number of adults from the south Delta prior to spawning and protect this portion of the population from entrainment as juveniles. No further reduction in CVP or SWP pumping would be needed in the spring.

The existing CVP and SWP salvage efficiency (louvers, predation, holding, trucking, release) for adult delta smelt is somewhat uncertain, but is likely less than 50%. There are some indications that moderate efforts to implement predator removal, hand separation of adult delta smelt, and improved release methods would allow at least a 50% success rate for salvaging and relocating adult smelt to Cache Slough or other suitable spawning areas. There may be other ways to improve the salvage efficiency for adult delta smelt during the 2-week to 8-week period of moderate adult salvage (>2/taf).

This alternative protection strategy might at first appear counterintuitive—pump more, not less, to save fish from entrainment? Increased pumping during peak adult densities would, however, maximize the number of delta smelt adults that could be safely removed from the south Delta by the CVP and SWP salvage facilities.

This alternative strategy for increasing the survival of the fraction of the delta smelt population that currently are spawning in the south Delta channels should be objectively evaluated alongside the more traditional EWA strategy to reduce pumping during the peak densities, or the current strategy to regulate (i.e., reduce) the ROMR or reverse QWEST flows, which are assumed to transport more adult delta smelt into the south Delta channels.

Daily Monitoring of Delta Smelt

It is recommended that the Chipps Island trawling station be returned to Chipps Island to allow the actual seasonal density of delta smelt to be monitored accurately. An additional daily Kodiak trawl station should be established at Jersey Point or in Franks Tract to monitor the daily delta smelt density in the region that is assumed to be the source of adult and juvenile delta smelt in the CVP and SWP salvage. If the transport of these adults and juveniles from Franks Tract or the lower San Joaquin River is thought to be an important factor that needs regulation, opening the DCC should be considered as part of the recommended protection strategy. The DCC diversion will supply about 2,000 cfs to 4,000 cfs to the ROMR flows toward the CVP and SWP pumping. This DCC diversion will increase the QWEST flows and should reduce any tidal mixing or transport of delta smelt from Franks Tract or the lower San Joaquin River habitat.

ICF Workshop 3 Submission to State Water Board
Attachment 4:
ICF International (December 2010) Stockton Deep Water Ship Channel Demonstration Dissolved Oxygen Aeration Facility Project Final Report
Appendix A: Possible SJR DO TMDL Implementation Procedures
Prepared for California DWR

POSSIBLE SJR DO TMDL IMPLEMENTATION PROCEDURES

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December 2010

ICF International. 2010. *Possible SJR DO TMDL Implementation Procedures*. December. (ICF 00508.10). Sacramento, CA. Prepared for: California Department of Water Resources, Sacramento, CA.

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Acronyms

af	acre-feet
BOD	biological oxygen demand
CBDA	California Bay-Delta Authority
cfs	cubic feet per second
CVP	Central Valley Project
CVRWQCB	Central Valley Regional Water Quality Control Board
DO	Dissolved Oxygen
DWR	Department of Water Resources
DWSC	Deep Water Ship Channel
EC	electrical conductivity
ENOD	excess net oxygen demand
LC	loading capacity
NEPA	National Environmental Policy Act
NPDES	National Pollutant Discharge Elimination System
RWCF	Regional Wastewater Control Facility
SJR	San Joaquin River
SWP	State Water Project
TMDL	Total Maximum Daily Load
TWG	Technical Work Group
UOP	University of the Pacific
USACE	United States Army Corps of Engineers
VAMP	Vernalis Adaptive Management Program
VSS	volatile suspended solids
WDR	Waste Discharge Requirements

Appendix A
Possible SJR DO TMDL Implementation Procedures

Introduction

This appendix supplements the *Stockton Deep Water Ship Channel Demonstration Dissolved Oxygen Aeration Facility Project Final Report* prepared by ICF International. It provides information about a possible scenario of how the Demonstration Aeration Facility (Aeration Facility) could be operated in the future as part of the San Joaquin River (SJR) Dissolved Oxygen (DO) Total Maximum Daily Load (TMDL) implementation program.

In its Final Staff Report for the SJR DO TMDL Basin Plan Amendments, the Central Valley Regional Water Quality Control Board (CVRWQCB) generally discussed the need for procedures that could allocate responsibility for low-DO concentrations observed in the SJR's Deep Water Ship Channel (DWSC). However, neither the CVRWQCB nor the SJR DO TMDL Technical Work Group (TWG) developed specific procedures for determining how much responsibility for measured DO objective deficits should be assigned to the three general causes of low DO—DWSC geometry, reduced flows, and biochemical oxygen demand (BOD) loads—or to individual BOD load sources. The development and approval of such accounting procedures by CVRWQCB and stakeholders will be necessary for the future operation of the Aeration Facility (as part of the TMDL implementation program), which could be used to reduce periods of low-DO concentrations in the DWSC. Such accounting procedures could ultimately be used to formally apportion responsibility for DO objective deficits in the DWSC, guide Aeration Facility operation, and allocate costs associated with Aeration Facility operation.

This appendix is divided into two main sections, each of which describes an important SJR DO TMDL implementation program topic related to the accounting procedures briefly described above.

1. **Review of the Final Staff Report for the SJR DO TMDL Basin Plan Amendments**. This section identifies the regulatory framework for the SJR DO TMDL implementation program by excerpting and discussing key portions of the CVRWQCB's 2005 Basin Plan Amendments and Final Staff Report (Central Valley Regional Water Quality Control Board 2005). This review identifies the TMDL accounting and reporting procedures that must be developed (and approved by stakeholders and CVRWQCB staff) for the future SJR DO TMDL implementation program.
2. **Suggested SJR DO TMDL Implementation Accounting Procedures**. This section identifies possible SJR DO TMDL accounting procedures that could be used for estimating the effects of SJR and DWSC flows, upstream river algae concentrations, and Stockton Regional Wastewater Control Facility (RWCF) effluent concentrations on the combined inflow BOD to the DWSC and the resulting DO concentrations in the DWSC. These daily accounting procedures may provide a reliable framework for understanding the causative factors of low DO in the DWSC and assigning proportional responsibilities to stakeholders for Aeration Facility operation (or other

implementation measures) to meet the DO objective. If approved by RWQCB staff and stakeholders, these proposed accounting procedures could also provide a reporting framework to demonstrate compliance with the SJR DO TMDL implementation program.

Figure 1a shows how the regulatory framework (described in the first section) was the basis for the development of the accounting procedures (described in the second section). The basic conceptual model for the SJR DO TMDL implementation program is shown in the upper left portion of the diagram. Periods of low DO in the DWSC are generally considered to be the result of three factors: DWSC geometry, low flows, and high BOD loads from upstream river algae or treated wastewater effluent. The basic implementation measures are shown in the upper right portion of the diagram; these were identified in the Final Staff Report as wastewater BOD load reductions, operation of the City of Stockton RWCF nitrification facility, operation of the Aeration Facility, increased SJR flows, and reduced river algae BOD loads. The bottom of the diagram shows the TMDL accounting procedures that could be used to estimate the relative contributions of the factors causing low-DO concentrations in the DWSC, and evaluate the benefits (increased DO) from various implementation measures, including the operation of the Aeration Facility.

Should these suggested TMDL implementation accounting procedures be approved by the CVRWQCB and stakeholders, next steps will include development of a monitoring strategy and development of an operations strategy for the Aeration Facility. Recommendations for these two strategies conclude this appendix.

Review of the SJR DO TMDL Implementation Program

This first section of the appendix reviews the SJR DO TMDL implementation program, and identifies the regulatory basis for the TMDL accounting procedures. The framework proposed by CVRWQCB staff for the SJR DO TMDL implementation program was based on the concept of excess net oxygen demand (ENOD), which was defined in the 2005 Basin Plan Amendments and Final Staff Report as the excess oxygen demand measured at the location of minimum DO concentration in the DWSC. The basic idea was that load allocations (i.e., reductions) for oxygen demanding substances (BOD loads), necessary augmentation of SJR or DWSC flow, and required compensation for the effects of DWSC geometry (increased depth and travel time) on DO concentrations may only be needed when the minimum DO measured in the DWSC was below the DO objective (i.e., 5 mg/l from December–August and 6 mg/l in September–November).

These TMDL calculations of ENOD and the effects of flows, geometry, and BOD loads on DWSC DO were generally described in the Final Staff Report sections "Excess Net Oxygen Demand and Total Maximum Daily Load" (Section 4.4), "Waste Load and Load Allocations" (Section 4.5), and "Program of Implementation" (Section 4.6) (Central Valley Regional Water Quality Control Board 2005). The major concepts introduced in these sections of the Final Staff Report are reviewed and discussed below to provide the regulatory basis for developing possible TMDL accounting procedures. Some excerpts (inset) from the Final Staff Report (Central Valley Regional Water Quality Control Board 2005) are provided here with some review comments to introduce the purpose and need for the suggested SJR DO TMDL accounting procedures.

From 4.4 Excess Net Oxygen Demand and Total Maximum Daily Load

> "When dissolved oxygen concentrations in the DWSC are below Basin Plan objectives, the assimilative capacity of the water column for net oxygen demand has been exceeded. For the purpose of this TMDL, net oxygen demand is defined as the net rate by which all chemical, biological, and physical mechanisms in the water column either add or remove dissolved oxygen (pounds of oxygen demand per day). When the rate of oxygen removed from the water column is greater than the rate by which it is added, there is a decrease in the dissolved oxygen concentration. The net rate of oxygen demand over and above the loading or assimilative capacity, at the point of lowest DO concentration in the DWSC, is referred to as the ENOD."
>
> "This TMDL and associated control program allocates responsibility for reduction of ENOD such that the Basin Plan DO objectives are attained in the DWSC. This TMDL assigns 100% of the responsibility for reducing ENOD to those parties collectively responsible for each of the three contributing factors: 1) sources of oxygen demanding substances; 2) DWSC geometry; and 3) reduced DWSC flow." (Page 35 of Final Staff Report)

This paragraph introduces the basic concept that the parties (i.e., stakeholders) are collectively responsible for reducing the ENOD (i.e., DO deficit) and that the TMDL will be implemented with an adaptive control program that requires some changes or management actions to reduce or eliminate the ENOD to meet the DWSC DO objective at all times.

From 4.4.1 Loading Capacity

"DO concentrations in the DWSC are affected by the relative rate of chemical and physical mechanisms that remove oxygen from the water column (oxygen demand) versus those that add oxygen (re-aeration). At any particular point in the river, when the rate of all oxygen demanding mechanisms are greater than the rate of all the re-aeration mechanisms, DO concentrations decrease (and visa versa). Net oxygen demand will be expressed as pounds of oxygen per day."

"The loading capacity (LC) of the DWSC is the amount of net oxygen demand that can be present at any point in the DWSC such that Basin Plan DO objectives are not violated. This does not include consideration of a margin of safety or other factors that reduce loading capacity. In equation form LC is given by:

$$LC = \{DO_{sat} - DO_{obj}\} \times Q_{DWSC} \times 5.4 \qquad \text{(Eq 4-1)}$$

"where DO_{sat} is the saturation DO concentration, which is itself a function of water temperature, in milligrams per liter; DO_{obj} is the applicable Basin Plan DO objective in milligrams per liter; Q_{DWSC} is the net daily flow rate through the DWSC4 in cubic feet per second; and 5.4 is a unit conversion factor that provides LC, in terms of pounds of oxygen per day. It can be seen from the above equation that LC is a function of flow through the DWSC and temperature (to the extent that temperature affects DO_{sat})." (Page 36 of Final Staff Report)

The ideas that there is a natural oxygen balance and that some oxygen demanding load (i.e., BOD) can be assimilated by the natural reaeration of the river or DWSC (without violating the DO objective) are introduced in this section. Equation 4-1 provides an estimate of the amount of DO that is missing from the DWSC at the point of minimum DO concentration, which is caused by the balance between the daily BOD decay and the daily reaeration. Because the natural reaeration within the DWSC increases as DO concentration decreases, estimates of the inflowing oxygen demands (i.e., BOD) and the rate of BOD decay are needed to calculate the maximum daily assimilative capacity (pounds of BOD) for the DWSC. The maximum loading capacity for the DWSC would occur when the measured DO concentration was reduced to the DO objective. An oxygen balance (i.e., sources and sinks) calculation for the DWSC is needed to estimate the maximum BOD load capacity of the DWSC. Possible calculations of the DWSC DO-BOD balance are introduced later in this appendix.

From 4.4.2 Excess Net Oxygen Demand

"In equation form, the general concept of ENOD is represented by the following:

$$ENOD = \{DO_{obj} - DO_{meas}\} \times Q_{DWSC} \times 5.4 \qquad \text{(Eq 4-2)}$$

where DO_{obj} is the applicable Basin Plan DO objective in milligrams per liter; DO_{meas} is the measured DO concentration, in milligrams per liter; Q_{DWSC} is the net daily flow rate through the DWSC in cubic feet per second; and 5.4 is a unit conversion factor that provides ENOD in terms of pounds of oxygen per day." (Page 38 of Final Staff Report)

The basic idea introduced with the ENOD calculation is that SJR DO TMDL implementation measures will only be required when the minimum DO in the DWSC is below the DO objective. The ENOD calculation is an approximate estimate of the amount of oxygen that would need to be added each day (from the Aeration Facility) to increase the minimum DWSC DO to the DO objective. The daily excess net oxygen demand is not equivalent to the BOD load reduction (lb/day) that may eliminate the DO impairment. The minimum DO in the DWSC is the result of the cumulative decay of BOD (about 10% per day), balanced with the cumulative surface reaeration that increases with the DO saturation deficit. The results from the DWSC DO Model, as described in Appendix A of the 2008 Operations Report (ICF International 2010b), indicate that a reduction of about 4 mg/l of BOD will increase the minimum DO in the DWSC by about 1 mg/l.

From 4.4.4 Total Maximum Daily Load

> "When excess net oxygen demand exists, it is the combined effect of all load and non-load related contributing factors present at that time. Although they do not represent a discharge of an oxygen-demanding substance or precursor, the effect of the DWSC geometry and reduced flow through the DWSC magnifies the impact of waste loads and loads of oxygen demanding substances by reducing the loading capacity and hence increasing excess net oxygen demand." (Page 39 of Final Staff Report)

This paragraph introduces the general idea that oxygen-demanding loads (i.e., BOD) and other factors (e.g., flows and geometry) will be included in the TMDL control (implementation) program. But the methods for relating flow and geometry to the measured ENOD were not presented. Possible procedures for accounting for the effects of these flow and geometry factors on DWSC DO concentrations are introduced and described later in this appendix.

From 4.5.1 Apportioning Excess Net Oxygen Demand

> "The two contributing factors of DWSC geometry and reduced flows through the DWSC are not loads of a substance for which mass or concentration limits can be assigned. Instead, these factors reduce the oxygen demand loading capacity of the DWSC available to assimilate loads of oxygen demanding substances, thereby increasing excess net oxygen demand. To eliminate the DO impairment, a combination of source controls to reduce the oxygen demand from upstream loads, combined with measures to restore the loading capacity impacted by the two non-load related factors, must be implemented such that excess net oxygen demand is eliminated."

> "Those parties collectively responsible for each contributing factor will need to coordinate with those responsible for the other factors to implement control measures that eliminate excess net oxygen demand (plus the margin of safety). This TMDL does not specify the relative responsibility among these three factors. Entities responsible for each of the three main contributing factors will need to determine among themselves the relative responsibility that will be assumed by each contributing factor."

> "Credit for source controls or alternate measures implemented after 12 July 2004 will count towards satisfying the excess net oxygen demand either apportioned to the associated contributing factor or allocated to specific sources of oxygen demanding substances and their precursors. This will require the ability to establish a baseline to quantify the amount of impairment reduction achieved by the various source controls and/or alternate measures to ensure equitable participation from all responsible entities." (Pages 40-41 of Final Staff Report)

These paragraphs emphasize the shared responsibility among stakeholders to implement control measures that will eliminate the ENOD, and that the allocation of responsibility should be determined by the stakeholders themselves. The possibility of credits for reducing ENOD through source controls or alternative measures (e.g., aeration facilities) is introduced. The need to establish a baseline for tracking and accounting for multiple control measures is also introduced. Suggested accounting procedures for determining responsibility for ENOD and credits for source controls and other measures are described in this appendix. The suggested accounting procedures would use the historical conditions as the baseline, and would include methods for adjusting the observed flows, BOD loads, and aeration operations to estimate the effects of each factor on the observed DWSC DO conditions.

From 4.5.2 Waste Load and Load Allocations to Point and Non-Point Sources

> "A number of studies have generated data to evaluate the impact of City of Stockton RWCF effluent, loads of algae, and other sources on the DO impairment in the DWSC. Based on the relative contribution of BOD_u loads calculated from historical data discussed above, 30 percent of the responsibility for excess net oxygen demand apportioned to loads of oxygen demanding substances is allocated as a waste load, WLA_{RWCF}, to the RWCF. Based on best professional judgment, 10 percent of the responsibility for reducing excess net oxygen demand is allocated as a reserve [unassigned] to address unknown sources and impacts, and known or new sources that have an insignificant impact. This includes unknown impacts from waste load allocations to existing NPDES permitted discharges other than the Stockton RWCF. The remaining 60 percent of ENOD is allocated as a load allocation, LA_{NPS}, to non-point sources of algae and/or precursors in the watershed."

> "The complexities of determining the relative contributions to oxygen demand in the DWSC are numerous. Most important is an understanding of the mechanisms by which the various carbonaceous and nitrogenous compounds are oxidized in the DWSC and how these mechanisms are affected by variables such as flow, temperature, and environmental factors. More data and analysis are needed to understand the dynamics of these different mechanisms. Modeling is also needed to evaluate the net effect of these mechanisms on DO concentrations. The specific data needs and the studies that must be performed to provide this data are discussed in Section 4.6."

> "The allocations between the various point and non-point sources may be modified in a revision to this TMDL based on the findings of future studies regarding the relative impact of these sources on oxygen demand in the DWSC." (Pages 41-42 of Final Staff Report)

These paragraphs describe the initial allocations of responsibility for reducing the BOD loads that contribute to any observed ENOD conditions (DO deficit). The possibility that additional information about the load and non-load factors would be useful and that the TMDL load allocation might be revised based on new information is introduced. Possible procedures for estimating the relative contributions to the DWSC DO concentrations and the corresponding responsibility for operating the Aeration Facility to reduce or eliminate the low DO conditions are developed and described later in this appendix.

From 4.6.1 Phased Implementation Approach

"Although there is adequate scientific understanding to support a general allocation of responsibility for excess net oxygen demand described in Section 4.5, there is inadequate understanding at this time to support more detailed waste load or load allocations to specific sources of oxygen demanding substances and their precursors. Various agricultural drainage and irrigation districts are currently in the process of establishing a contract for the bulk of the field studies with the California Bay-Delta Authority (CBDA). The [CBDA sponsored] modeling studies in the DWSC are recently underway. This program of implementation also describes the actions being taken by various agencies responsible for DWSC geometry and reduced flow through the DWSC to study and then implement measures to reduce their associated impacts on excess net oxygen demand conditions in the DWSC."

<u>Source Control and Implementation Studies</u>

"As the sources of oxygen demanding substances and their linkages to the DO impairment are better understood, those sources linked to the DO impairment will be required to implement measures to reduce or eliminate their contribution to the impairment. Some of these proposed measures may directly control the source, and others may provide alternate means of reducing the impact to less than that apportioned in the TMDL."

<u>Study of Alternative Implementation Measures for Non-Load Related Factors</u>

"The aeration feasibility and demonstration project is a two-phased project that starts with a small-scale feasibility study of different aeration technologies that may be effective in the DWSC. This first phase will also include the design of a monitoring network to measure the impact of aeration on DO concentrations in the DWSC. Once the preferred technologies are identified by the feasibility study, the next phase of the project will be the construction and operation of a large-scale demonstration project using the aeration technologies determined most effective in the DWSC. The purpose of this large-scale project is twofold. First, the purpose is to collect performance and cost data for consideration in development of the final phase of the program of implementation. The second purpose is to begin improving DO conditions prior to development and implementation of the final phase."

"As currently planned by the California Bay-Delta Authority, construction of the aeration demonstration project will be financed by Proposition 13 funds. A group of various agencies in the watershed are currently negotiating an assurance agreement to provide the resources needed to operate, maintain, and monitor the performance of the aerators after construction." (Pages 44-47 of Final Staff Report)

These paragraphs provide the most direct connection between the Aeration Facility studies and the SJR DO TMDL implementation (control) program. However, the methods for determining responsibility for the ENOD conditions or assigning credits for the Aeration Facility operations were not specified. The various funded studies of the DWSC and DWSC upstream river water quality were anticipated to provide additional information that would be used to finalize the TMDL control program. How much of the ENOD conditions could be reduced or eliminated by the Aeration Facility was not known. Likewise, the effects of the RWCF nitrification facility on DWSC DO concentrations could not be accurately anticipated without further studies. The possible TMDL accounting procedures described in this appendix could be used to estimate the effects of these control measures on the DWSC DO conditions (i.e., TMDL credits).

From 4.6.2 Actions Addressing Point Sources

> "As described in Section 4.5, the City of Stockton RWCF will receive a waste load allocation equivalent to 30 percent of the excess net oxygen demand apportioned to loads of oxygen demanding substances. The magnitude of this 30 percent allocation is variable depending upon the excess net oxygen demand conditions in the DWSC. This allocation is for excess net oxygen demand, at the point of lowest DO concentration in the DWSC, expressed in units of pounds of oxygen per day."
>
> "This waste load allocation of oxygen demand in the DWSC, however, must be converted and expressed in terms of effluent concentration or mass load limits for constituents in the RWCF discharge. This will require understanding the linkage between a given quantity of a oxygen-demanding constituent in the RWCF and the corresponding impact on DO concentration in the DWSC. Further field and modeling studies are required to understand the specific mechanisms in the DWSC that convert RWCF constituents into oxygen demand and how they are impacted by numerous environmental variables. Of particular interest is how reduced flow through the DWSC influences the amount of oxygen demand that is exerted from the City of Stockton ammonia loads in the DWSC." (Page 48 of Final Staff Report)

This paragraph describes the need to understand how flow may reduce (i.e., dilute) the effects from RWCF ammonia oxidation and BOD decay on the DWSC minimum DO concentrations. This section implies that the planned RWCF nitrification facility may have a major effect on the ENOD conditions. Because operation of the nitrification facility began in 2007, and testing and evaluation of the Aeration Facility began in 2008, the effects from these two major TMDL control measures should be separately and accurately evaluated.

From 4.6.3 Actions Addressing Non-Point Sources

> "As described in Section 4.5, sixty percent of the responsibility for ENOD is apportioned to nonpoint sources of algae and its precursors. Consistent with the Conditional Waivers for Discharges from Irrigated Lands (Resolution No. R5-2003-0105), and for the purpose of this control program, non-point source discharges are discharges from irrigated lands. Irrigated lands are lands where water is applied for producing crops and, for the purpose of this control program, includes, but is not limited to, land planted to row, field, and tree crops, as well as commercial nurseries, nursery stock production, managed wetlands and rice production."
>
> "Many mechanisms are known or are suspected of influencing the growth, transport, and decay of algae in the DWSC. Of particular interest are the growth dynamics of algae as it is conveyed downstream through the watershed. Better understanding of these dynamics is needed to determine how specific sources of algae, and specific sources of nutrients that contribute to algal growth, are linked to DO concentrations in the DWSC." (Page 51 of Final Staff Report)

This paragraph indicates that results of the (planned) upstream river water quality studies would be used to determine the effects of agricultural drainage on upstream algae growth and subsequent BOD loads entering the DWSC. The results from the upstream studies conducted from 2005 to 2007 are now available and have been incorporated into the accounting procedures for upstream river algae concentrations that are described in this appendix.

From 4.6.4 Actions Addressing Deep Water Ship Channel Geometry

"The DWSC geometry reduces the efficiency of mechanisms that supply oxygen to the water column, like natural surface re-aeration and algal photosynthesis. At the same time, the DWSC geometry magnifies the impact of oxygen demanding substances (e.g., ammonia) that reduce DO concentrations in the water column. The net effect is that the DWSC reduces the loading capacity, and hence worsens excess net oxygen demand conditions in the DWSC for a given load of oxygen demanding substances."

"The USACOE is the primary entity responsible for the existing and any future deepening in the DWSC. The Port of Stockton is the entity responsible for any future berth deepening at its facilities along the DWSC."

"Because DWSC geometry does not discharge any substances, however, no waste load or load allocations can be assigned to entities responsible for the DWSC geometry. Instead, the CVRWQCB will rely upon its authority under Section 401 of the CWA to require that the cumulative effects on excess net oxygen demand conditions caused by future changes in DWSC geometry are adequately mitigated."

"The USACOE has already attempted to provide some level of mitigation for past DWSC geometry alterations. Between 1984 and 1987, the DWSC was deepened from 30 feet below MLLW to 35 feet below MLLW. As part of their National Environmental Policy Act (NEPA) documentation for that project, the USACOE performed modeling that estimated the deepening could reduce loading (assimilative) capacity by as much as 2,500 pounds of oxygen per day (USACOE 1990). To mitigate this impact, the USACOE constructed and now operates [with the Port of Stockton] a jet aeration system in the DWSC near where the San Joaquin River enters the DWSC at Channel Point." (Page 52 of Final Staff Report)

These paragraphs introduce the concept of allowing mechanical aeration facilities to compensate for the existing and future effects of the DWSC geometry on the low DO observed at the Rough and Ready Island (RRI) monitoring station. The effects of aeration facilities are included in the proposed TMDL accounting procedures.

From 4.6.5 Actions Addressing Reduced Flow through the Deep Water Ship Channel

"The impact of reduced flow on excess net oxygen demand conditions in the DWSC has been well documented under current DWSC geometry and variable loading conditions. As flow into the DWSC at a given DO concentration is reduced, less oxygen demand can be exerted before DO concentrations drop below the Basin Plan objectives. It has also been hypothesized that increased DWSC residence times increases how much of the oxygen demand from upstream loads of oxygen demanding substances is exerted in the DWSC. Although relationships between reduced flow through the DWSC and the DO impairment are fairly well understood, further field analysis and modeling studies are required to better understand the specific oxidation mechanisms, and how they are affected by flow, both within the DWSC and upstream." (Page 53 of Final Staff Report)

This paragraph mentions but does not provide specific details about the impacts of reduced flow on DO concentrations in the DWSC. The suggested TMDL accounting procedures include the effects of river flow on the upstream algae loading and the effects of the DWSC flow on dilution of the RWCF discharges and residence time in the DWSC. The proposed accounting procedures would enable an accurate evaluation of the effects of increased flow on the minimum DO concentrations in the DWSC.

From 4.6.6 Consideration of Alternative Implementation Measures

"Alternate implementation measures may be needed as a substitute for direct control of certain causative factors if on-going studies show that certain causative factors cannot be successfully mitigated by direct controls. It may also be necessary to rely on short-term alternate implementation measures as longer-term control measures take more time to implement and become effective. The CVRWQCB will need to consider if alternate implementation measures that are proposed by those responsible for certain contributing factors are acceptable. In order to be acceptable, any alternative implementation measures proposed for consideration by the CVRWQCB must adequately address the impact on the DO impairment and must not degrade water quality in any other way. If alternate implementation measures are selected to address certain impacts, load allocations in a revision to this TMDL will need to be converted and expressed in terms of these alternate implementation measures or their impact on excess net oxygen demand conditions in the DWSC."

"After a better understanding of the sources and linkages is obtained by the additional studies described in Section 4.6.1, the CVRWQCB may also consider allowing a portion of waste load and load allocation to be met through a load-trading program. The details of such a program would need to be developed as part of a revision to this TMDL that establishes more detailed waste load and load allocations." (Page 55-56 of Final Staff Report)

This paragraph introduces the concept of using alternative control measures (e.g., Aeration Facility) to reduce or eliminate low DO conditions in the DWSC. It mentions the possibility that upstream dischargers of BOD loads might purchase shares in the Aeration Facility operation to reduce or eliminate the low DO conditions in the DWSC. The technical guidelines for identifying the daily responsibilities for low DO conditions and estimating credits that might be assigned to the Aeration Facility, the nitrification facility, or to increased flows are not provided. Possible accounting procedures for estimating responsibilities for low DO conditions and determining credits for the nitrification facility or flow management actions are described in this appendix.

Suggested SJR DO TMDL Implementation Accounting Procedures

This second section of the appendix introduces the calculations that could be used to estimate the daily contributions from the various factors causing low DO concentrations in the DWSC. Based on the description of the SJR DO TMDL implementation program in the Final Staff Report, a possible accounting procedure has been developed for review by the CVRWQCB staff and stakeholders that could provide a method for tracking the implementation of the SJR DO TMDL control measures. This possible accounting procedure is based on daily estimates of the major factors causing periods of low DO within the DWSC, including the effects of geometry on reaeration and algae growth, the effects of tidal flow on transport and mixing, and the effects of flow on upstream river algae loads, the dilution of the Stockton RWCF effluent, and the travel time within the DWSC (to Turner Cut). The results from more detailed modeling of the SJR water quality (e.g., algae) conditions, the tidal dilution and transport of the RWCF effluent, and the DWSC stratification and tidal mixing are included in the proposed accounting procedures. The accounting procedures are formulated in a spreadsheet that allows measured data from a specified calendar year to be selected for the TMDL accounting and evaluation of contributing factors and BOD loads. Graphics of river flows, travel times, algae concentrations, effluent concentrations, and the resulting DWSC DO concentrations are presented within this spreadsheet. Changes in historical conditions (e.g., higher flows, reduced BOD) can be specified in the accounting tool to determine the effects of flows, river algae, RWCF effluent concentrations, and the Aeration Facility on the resulting minimum DO concentrations in the DWSC.

A series of simplified relationships between the SJR flow and water quality conditions, the DWSC inflow, and the RWCF discharge concentrations and the resulting DO profile in the DWSC are calculated. Because the basic elements of the most important relationships between SJR and DWSC flow and water quality parameters (e.g., algae, BOD, DO, ammonia, temperature) are included, it can be considered a quantitative-descriptive model for the SJR DO TMDL. Because various implementation measures are included in the calculations, the incremental effects of each factor can be identified by running several comparative calculations with the daily accounting tool. The daily accounting calculations can be used to track the effects of daily changes in river conditions and BOD loads, as well as the improvements (i.e., credits) from control measures (e.g., nitrification, aeration) on the DWSC DO concentrations.

Organization of Accounting Procedures

Figure 1b shows a flowchart depicting the framework for the TMDL daily accounting tool. There are three major accounting segments: the upstream SJR tributaries, the tidal transport from Mossdale past the head of Old River (diversion) to the Stockton RWCF discharge and into the DWSC, and the tidal downstream movement and longitudinal DO profile in the DWSC.

The first segment of the accounting tool includes the upstream SJR tributaries and calculates the corresponding river algae concentration (biomass or BOD) at Mossdale. This segment calculates the river conditions at Mossdale, based on upstream flows and other conditions. The measured flow (at Vernalis), temperature, turbidity, DO concentration, and estimated algae concentration (biomass or

BOD) are the variables that will be used for estimating downstream effects on DWSC DO concentrations. Salt (electrical conductivity [EC]) concentrations can be used to help calibrate the flow (water budget). The SJR selenium TMDL implementation measures that will reduce the future San Luis Drain discharge of salt and algae biomass into Mud Slough are included in this upstream segment. Stanislaus River releases from New Melones Reservoir to provide higher flows necessary to meet the salinity objective are included in the upstream segment. Chlorophyll fluorescence and diurnal DO fluctuations at the Mossdale water quality monitoring station are used to estimate the river concentrations of algae biomass.

The second segment of the daily accounting tool is the downstream tidal movement and associated changes in river conditions between Mossdale and the DWSC (e.g., settling of turbidity, algae growth, zooplankton grazing, reaeration and BOD decay). This segment includes the diversion of water from the SJR into Old River and the effects of Central Valley Project (CVP) and State Water Project (SWP) export pumping and the south Delta temporary barriers (i.e., weirs) on this diversion flow, as well as the effects of the head of Old River barrier (or gate) as an implementation measure to increase the downstream flow in the DWSC. This segment also includes the tidal dilution of the Stockton RWCF discharge. The nitrification facility that was added by the City of Stockton to its tertiary treatment facility in 2007 is a major implementation measure that is located within this segment of the TMDL accounting tool.

The third segment of the daily accounting tool is the longitudinal DO profile conditions in the DWSC. Because the tidal movement in the DWSC is about 2 miles between high tide (6 feet) and low tide (2 feet), the DO profile conditions in the DWSC between the SJR inflow at channel point (Mile 39.5) and Turner Cut (Mile 32.5) are estimated for both low-tide and high-tide conditions. The effects of the DWSC geometry on temperature stratification, algae growth and settling, and reaeration are included in the calculations for the DWSC. These effects can be adjusted with user-specified parameters. The major implementation measures that are included in the DWSC segment of the accounting tool are the Port of Stockton / United States Army Corps of Engineers (USACE) aeration facilities (Dock 13) and the Aeration Facility (Dock 20).

The development of this simplified TMDL accounting tool was only possible because of the many water quality measurements that are routinely obtained by DWR, USGS, and other agencies, as well as the research and modeling efforts funded by CALFED within the DWSC and upstream in the SRJ above Vernalis. This daily flow and water quality accounting tool is an extension of the SJR water quality Data Atlas effort that was part of the DWSC Modeling and Upstream Studies, funded by CALFED and DFG-ERP. These previous measurements and modeling efforts are summarized and simplified in the daily accounting calculations.

Because there is variability in the observed conditions, there will always be a range of possible effects from upstream conditions and implementation measures on the observed or expected DO conditions in the DWSC. The range of possible changes in the DWSC DO concentrations in response to upstream conditions or implementation measures can be explored by changing some of the uncertain parameters in the daily accounting tool. The effects of this uncertainty can be identified by comparing the measured DO profiles within the DWSC to the accounting tool calculations for various upstream conditions. The accounting tool provides a unified procedure for considering all of the changing river conditions and potential implementation measures. The daily accounting tool can be used to identify likely responsibilities for observed low DO conditions in the DWSC (i.e., ENOD) and to estimate TMDL credits for implementation measures through time. Several example calculations for recent years (2001–2010) are shown to demonstrate the capabilities and limitations of the daily accounting tool.

Segment 1—Estimating River Algae Concentrations at Mossdale

The first segment of the daily accounting tool uses water quality measurements at Vernalis or Mossdale to estimate the river algae pigment and algae biomass concentrations at Mossdale. The daily calculations of upstream river conditions were derived from results of the UC Davis nutrients and algae studies, the DFG-ERP Upstream Studies for the SJR DO TMDL, and results from the TMDL watershed model (SJR-WARMF) that was developed as part of these upstream studies (Systech 2008). The goal is to estimate the seasonal pattern of algae biomass, which is assumed to depend on the seasonal light and temperature patterns as well as the SJR flow (i.e., travel time for algae growth).

The major implementation measures in this segment are the reductions in the San Luis Drain discharge (flow, salinity, nutrients, and algae biomass) to Mud Slough that are the result of the SJR-selenium TMDL, and the possible additional releases from New Melones Reservoir to reduce salinity to meet the Vernalis EC objective. Both of these measures will change the river flows and may change the Mossdale algae concentrations.

Available Data

DWR maintains a continuous water quality monitoring station at Mossdale. This station has recorded hourly (or 15-minute) measurements of temperature, EC, pH, and DO and has more recently begun measuring turbidity and algal fluorescence. This provides an extensive historical database for evaluating the SJR water quality as it enters the tidal zone (SJR estuary). DWR also collected water samples on a monthly basis at Mossdale until about 1997 to measure nutrients and algae pigment (chlorophyll and phaeophytin). DWR continues to collect monthly water quality samples at Vernalis, which can be used to compare with the Mossdale monitoring records of DO, pH, and algal fluorescence. UC Davis collected semi-monthly (two per month) water quality and algae samples at Vernalis and Mossdale from 2000 to 2005 as part of a regional nutrients and algal productivity study. Some 10-day BOD measurements were collected in 2004 to coordinate with the TMDL studies at Mossdale, Vernalis, and Maze (SJR upstream of the Stanislaus).

Bi-weekly water quality samples were collected in the summers of 2000 and 2001 at Vernalis and Mossdale (and other upstream stations) for special studies (funded by CALFED) for the SJR- DO TMDL investigations (Kratzer et al 2004). Measurements of chlorophyll, nutrients, 5-day and 10-day biochemical oxygen demand (BOD5 and BOD10) were made during the summer of 2001 by DWR as part of the DWSC studies for the SJR DO TMDL (Lehman 2004). This assortment of nutrients, volatile suspended solids (VSS), algal pigment (chlorophyll and phaeophytin), and BOD, together with the monitoring of algal fluorescence, DO, and pH were used to develop relationships for estimating the daily algae biomass at Mossdale.

Algae Biomass (BOD) Calculation Methods

Measurements of water quality at Mossdale provide the most direct method for estimating the algae biomass and BOD concentration in the SJR as it flows into the tidal river zone between Mossdale and the DWSC. Relationships between monitoring records of DO, pH, and algal pigment fluorescence will be used to estimate the daily algae biomass and resulting BOD at Mossdale. The calculation method will use the 15-minute measurements of DO, pH, and algal fluorescence at Mossdale to estimate the daily algae biomass and total BOD concentration in the river. This method is briefly described below.

The seasonal pattern Mossdale daily DO range (maximum DO – minimum DO) has been found to correlate fairly well with the seasonal pattern of Mossdale algal fluorescence and the UCD extracted algal pigment (chlorophyll a plus phaeophytin). The approximate match indicates that each 1 mg/l of daily DO range is equivalent to about 25 µg/lµg/l of extracted pigment (or algal pigment fluorescence). Although high DO concentrations will decrease from surface reaeration, the relationship between the daily DO range and algae biomass appears to be linear. The available Mossdale DO and algal fluorescence data for 2000–2010 are shown here to demonstrate the method and show the seasonal correlation between these two monitoring variables and the more limited extracted chlorophyll data.

A similar match between the seasonal pH pattern and the daily DO range has consistently matched the algal fluorescence and extracted pigment concentrations. The diurnal DO range is produced by the photosynthesis of the river algae that releases about the same amount of oxygen as the increased algal biomass. The maximum observed daily DO range is about 5 mg/l in low-flow summers. A similar reduction in the dissolved CO_2 in the water is required during photosynthesis. But because the alkalinity of the river moderates the carbonate equilibrium, the ph increases as the CO_2 is taken up for algae biomass. The daily DO range appears to be linear with algal biomass or chlorophyll, while the pH increases above 7.5 (no algae), indicating a doubling of the algae concentration for each 0.5 increment of pH value above 7.5. Although the low CO_2 concentrations (high pH) will increase from reaeration with the atmosphere, the historical data indicates that the maximum pH can be used to estimate the algae biomass at Mossdale. The approximate correlation that was found to match the historical pH, daily DO range and algal fluorescence (pigment) data at Mossdale is given in Table A-1.

Table A-1. Approximate Relationship between Mossdale pH and Mossdale Algae Pigment Concentration (µg/l)

Mossdale Maximum Daily pH	Approximate Daily DO Range (mg/l)	Approximate Algae Pigment Concentration (µg/l)
7.5	0	0
8.0	1	25
8.5	2	50
9.0	4	100
9.5	8	200

Review of Measured Algae Pigment and Daily DO Range at Mossdale

The calculation methods for estimating SJR algae biomass and BOD are demonstrated in this section by showing the available measurements of daily DO range, daily pH, and algae pigment concentrations (µg/l) for 2000–2010. The seasonal patterns, the effect of low SJR flows, and the general correspondence between these alternative measures of algae biomass are demonstrated with the following annual graphs of Mossdale water quality data.

Figure 2a shows the daily minimum and maximum DO at Mossdale for 2000, with the saturated DO concentration shown for comparison (left scale of 0–20 mg/l). The daily minimum DO is usually equal to the saturated DO, but the daily maximum DO is often higher than saturated DO during the summer months of June–September because of algal photosynthesis. The daily DO range (maximum DO –minimum DO) is shown at the bottom of the graph. The daily SJR flows at Vernalis are shown to indicate the period of time when flows are relatively low, which corresponds to periods when there would be several days for algae growth upstream of Vernalis (right scale of 0–5,000 cfs). The effects of algae photosynthesis on the daily DO range at Mossdale appears to be greatest when the Vernalis flows are less than about 3,000 cfs during the spring and summer months. The maximum daily DO range was about 4 mg/l in July and August when the Vernalis flows were about 2,000 cfs.

Figure 2b shows the daily minimum and maximum algal fluorescence at Mossdale, along with extracted algae pigment (chlorophyll and phaeophytin) concentrations for 2000. The fluorescence measurements generally must be adjusted with a calibration factor to match the extracted algae pigment concentrations. The daily DO range is shown for comparison with the algal fluorescence and the extracted algal pigment concentration data. The graph scales were set to demonstrate that each 1 mg/l of daily DO range corresponds to about 25 µg/l of algal pigment (or calibrated fluorescence). The empirical estimate of algae pigment based on the maximum pH at Mossdale (Table A-1) is also shown. The maximum pH of about 9.0 measured in July and August would correspond to an estimated algae pigment concentration of about 100 µg/l. The highest algae pigment concentrations of about 50–75 µg/l in July correspond to the highest measured fluorescence, highest daily DO ranges, and highest pH values. The seasonal pattern was similar for each of these estimates of algae biomass, with increasing concentration in late June (as flows decreased to less than 3,000 cfs), highest concentrations in July, and declining concentrations in August and September.

Figure 3a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale with the SJR flows at Vernalis shown for reference for 2001. The SJR flows were considerably lower than in 2000, with flows of about 1,500 cfs from mid-June through mid-October. The daily DO range was a maximum of 6 mg/l in mid-June and was about 4 mg/l in July, but was only about 2 mg/l in August and September. Figure 3b shows the daily minimum and maximum algal fluorescence at Mossdale, along with extracted algae pigment concentrations for 2001. The highest extracted algae pigment concentrations were about 75 µg/l in June and July. The daily DO range and the estimate of algae pigment based on daily pH values are also shown. The maximum estimates of algae pigment were about 100–125 µg/l in June and July, with declining concentrations in August and September. The seasonal pattern was similar for each of these estimates of algae biomass , with increasing concentration in late May (as flows decreased to less than 3,000 cfs), highest concentrations in June and July, with declining concentrations in August and September.

Figure 4a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale with the SJR flows at Vernalis shown for reference for 2002. The SJR flows were similar to 2001 flows, with flows of less than 1,500 cfs from early-June through mid-October. Minimum flows of about 1,000 cfs were measured in August and early September. The daily DO range was about 5 mg/l in June; about 4 mg/l in July, August, and early September; and about 2 mg/l in October. Figure 4b shows the daily minimum and maximum algal fluorescence at Mossdale, along with extracted algae pigment concentrations for 2002. The highest extracted algae pigment concentrations were about 150 µg/l in July and August. This was twice the maximum algae pigment measured in 2000 or 2001. The measured fluorescence values fluctuated between 75 µg/l and 150 µg/l in the months of June–September 2002. The daily DO range and the estimate of algae pigment based on daily pH values for 2002 matched the measured fluorescence pattern. The maximum estimates of algae pigment were about 75–125 µg/l in June–September, with declining concentrations in October. The seasonal pattern was similar for each of these estimates of algae biomass, with algae pigment concentrations greater than 50 µg/l for the entire June–September period.

Figure 5a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale for 2003, with the SJR flows at Vernalis shown for reference. The SJR flows were about 2,000 cfs in June and about 1,500 cfs in July, August, and September. The daily DO range was about 4 mg/l in June to early August, and was a maximum of about 5 mg/l in mid-August, with decreasing values in September and October. Figure 5b shows the daily minimum and maximum algal fluorescence at Mossdale, along with extracted algae pigment concentrations for 2003. The fluorescence device was changed in April 2003 from a Turner Model 10 to a Turner SCUFA unit, with a different calibration factor. The highest extracted algae pigment concentrations were about 100–125 µg/l in June–August, with one very high measurement of 225 µg/l in mid-August. The fluorescence also peaked at 200–250 µg/l in mid-August 2003, with corresponding high measurements of pH and daily DO ranges at Mossdale. The estimates of algae pigment based on the daily DO range and daily pH values matched the measured fluorescence pattern for 2003. The maximum estimates of algae pigment were about 50–100 µg/l in June–August, with the peak of 125 µg/l in mid-August and declining concentrations in September. The seasonal pattern was similar for each of these estimates of algae biomass, with algae pigment concentrations greater than 50 µg/l for the entire June–September period.

Figure 6a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale for 2004, with the SJR flows at Vernalis shown for reference. The SJR flows were similar to 2001 flows, with flows of less than 1,500 cfs from early-June through mid-October. Minimum flows of about 1,000 cfs were measured in July, August, and September 2004. The daily DO range was about 6 mg/l in early June, was about 4 mg/l from mid-June to mid-August, and was 2–4 mg/l from mid-August through September. Figure 6b shows the daily minimum and maximum algal fluorescence at Mossdale, along with extracted algae pigment concentrations for 2004. The highest extracted algae pigment concentrations were about 125–175 µg/l in June and early July. The measured fluorescence values fluctuated between 75 µg/l and 150 µg/l in June and July and were less than 75 µg/l in August (data is missing for September). The estimates of algae pigment based on daily DO range and daily pH values for 2004 matched the measured fluorescence pattern. The maximum estimates of algae pigment were about 75–125 µg/l in June and July, but were decreasing in August and were about 50 μg/l in September. The seasonal pattern was similar for each of these estimates of algae biomass, with algae pigment concentrations greater than 50 μg/l from late May through September.

Figure 7a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale for 2005, with the SJR flows at Vernalis shown for reference. The SJR flows were very high until mid-July of 2005. The SJR flows were about 2,500 cfs in August, September, and October of 2005. Because of the high flows, the daily DO range was greater than 2 mg/l only from mid-July to mid-September of 2005. Figure 7b shows the daily minimum and maximum algal fluorescence at Mossdale, along with extracted algae pigment concentrations for 2005. The highest extracted algae pigment concentrations were only about 50 μg/l in July and August. The measured fluorescence values fluctuated between 25 μg/l and 50 μg/l in July and August. The estimates of algae pigment based on daily DO range and daily pH (missing pH in July) matched the measured fluorescence pattern for 2005. The maximum estimates of algae pigment were about 50–75 μg/l in July and August. The seasonal pattern was similar for each of these estimates of algae biomass, with algae pigment concentrations greater than 50 μg/l only in July and August 2005.

Figure 8a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale for 2006, with the SJR flows at Vernalis shown for reference. The SJR flows were very high the entire year. The SJR flows were less than 4,000 cfs only in August and September. Because of the high flows, the daily DO range was a maximum of 2 mg/l only in late July. Figure 8b [data not yet available] shows the daily minimum and maximum algal fluorescence at Mossdale, along with extracted algae pigment (chlorophyll and phaeophytin) concentrations for 2006. The high flows prevented any substantial algae biomass concentrations at Mossdale in 2006.

Figure 9a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale for 2007, with the SJR flows at Vernalis shown for reference. The SJR flows were less than 3,000 cfs for the entire year. The SJR flows were less than 1,500 cfs from mid-June to mid October. The SJR flows were about 1,000 cfs in July, August, and September 2007. The daily DO range was greater than 2 mg/l from June through mid-September, with maximum values of 4–6 mg/l from mid-June to mid-August. Figure 9b [data not yet available] shows the daily minimum and maximum algal fluorescence at Mossdale, along with extracted algae pigment concentrations for 2007. The maximum algae pigment concentrations were likely about 100 μg/l, based on the daily DO range values in July and August.

Figure 10a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale with the SJR flows at Vernalis shown for reference for 2008. The SJR flows averaged about 2,500 cfs in January–April, with a Vernalis Adaptive Management Program (VAMP) pulse flow of 3,000 cfs from April 20–May 20, and then were less than 1,000 cfs from mid-June through September. The daily DO range was between 4 mg/l and 6 mg/l in June, July, and August (September DO data is missing), corresponding to the low flow period in 2008. Figure 10b shows the daily minimum and maximum algal fluorescence at Mossdale for 2008, along with extracted algae pigment concentrations from Vernalis (DWR data). The highest monthly algae pigment concentration was more than 250 μg/l in early June. The July pigment concentration was about 100 μg/l, and the August, September, and October pigment concentrations were about 50 μg/l. The measured fluorescence values were highest in early June, with values of 100–150 μg/l in June, 75–100 μg/l in July, and about 50 μg/l in August. The estimates of algae pigment based on daily DO range and daily pH (September DO and pH data is missing) were about 100–150 μg/l in June and July and about 75–

125 µg/l in August. These estimates from DO and pH measurements were higher than the pigment concentrations and fluorescence values in July and August.

Figure 11a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale for 2009, with the SJR flows at Vernalis shown for reference. The SJR flows were very low all year, with flows of about 1,000 cfs in June and just 500 cfs from mid-July to mid-September. The daily DO range showed an unusual high value of 4 mg/l in mid-March to mid-April when the SJR flow was just 1,000 cfs. The daily DO range was 2 mg/l during the mid-April to mid-May when the flows were about 2,500 cfs. The daily DO range in the summer months was 4–6 mg/l in June, greater than 6 mg/l in July (DO data missing in August), and was 2–4 mg/l in September. Figure 11b shows the daily minimum and maximum algal fluorescence at Mossdale for 2009, along with extracted algae pigment concentrations from Vernalis (DWR data). The algae pigment concentration in mid-March was about 75 µg/l. The highest monthly algae pigment concentration (missing in June) was about 125 µg/l in July, but was only 50 µg/l in August, and less than 25 µg/l in September. The estimates of algae biomass from the DO and pH data in June and July were 100–200 µg/l, somewhat higher than the fluorescence and algae pigment concentrations. The 2009 algae pigment and fluorescence values were lower than in several previous years, although the 2009 flows were the lowest observed in recent years.

Figure 12a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale for 2010, with the SJR flows at Vernalis shown for reference. The SJR flows were higher than 3,000 cfs from April through June and decreased to about 1,500 cfs from mid-July to mid-September. The daily DO range was about 2 mg/l at the end of March, was 4–6 mg/l from mid-July to mid-August, and declined to about 2 mg/l in September. Figure 12b shows the daily minimum and maximum algal fluorescence at Mossdale for 2010, along with extracted algae pigment concentrations from Vernalis (DWR data). The highest monthly algae pigment concentration was just 75 µg/l in early August. The measured fluorescence values were highest in mid-July, with values of 100–150 µg/l, with values of 75-125 µg/l in August, and 25–75 µg/l in September. The estimates of algae pigment based on daily DO range and daily pH were about 100–150 µg/l in the second half of July, decreased to about 50–75 µg/l in August, and were less than 50 µg/l in September. These estimates from DO and pH measurements were similar to the fluorescence values in July, August, and September of 2010.

These data from 2000–2010 clearly demonstrate the seasonal pattern of maximum algae pigment in the summer months of June–September and the effects of low SJR flow (less than 3,000 cfs) on the measured algae pigment and the corresponding daily DO range and maximum pH values. The last step in the segment 1 calculations is to estimate the BOD concentrations corresponding to the algae biomass (pigment) patterns.

Calculating the Algal Biomass and BOD

Assuming the pigment content (mass pigment/biomass) of algae is about 1.25%, there would be about 12.5 µg/l of pigment (chlorophyll plus phaeophytin) for each 1 mg/l of algae biomass. Because each 1 mg/l of daily DO range (maximum – minimum) was shown with the 2000–2010 Mossdale data to be equivalent to about 25 µg/l of algal pigment, each 1 mg/l of daily DO range would also be equivalent to about 2 mg/l of algae biomass and about 3 mg/l of ultimate (long-term) BOD. Because the maximum daily DO range was about 5 mg/l (in 2001, 2002, 2003, and 2004 with summer flows of about 1,000 cfs to 1,500 cfs), the peak estimated river algae pigment concentration was about 125 μg/l, and the estimated peak algae biomass (VSS) was about 10 mg/l with an ultimate BOD estimate of about 15 mg/l. Because some higher algal fluorescence and algal pigment concentrations of 150-200 μg/l were measured (in 2002, 2003, and 2004) but the maximum daily DO range did not exceed 5-6 mg/l, the daily DO range may provide a minimum estimate of algae pigment concentration (and biomass). The daily maximum pH measurements were about 9.0 in most years and were 9.5 for a few periods in low-flow years; these values confirm the maximum algae pigment concentrations during the summer months were about 100 μg/l in most years (pH value of 9.0) with a few peak pigment concentrations of 200 μg/l (pH value of 9.5) in some low-flow years.

DWR conducted an algal assay and BOD study in the DWSC during the summer of 2001 (Lehman 2004). Some of the basic relationships identified in this study indicate that algal dynamics in the SJR and DWSC are similar to those observed in other rivers. Lehman used field measurements, algal growth assays (C-14 uptake and DO changes), and laboratory BOD measurements to determine the chemical content and growth of algae in the SJR and DWSC. Organic carbon and organic nitrogen measurements suggested the carbon content of about 50% and a nitrogen content of about 10%, with a phosphorus content of about 1%. Of particular interest was the amount of oxygen produced per chlorophyll that was measured during photosynthesis. These measurements suggest that a 1 mg/l DO range would match the daily photosynthetic DO production from about 25 μg/l of algal pigment with full sunlight.

The City of Stockton collected algal pigment and VSS (biomass) and BOD5 measurements at Mossdale and Vernalis in the summer of 2001 (Jones & Stokes 2002). Comparing the maximum values measured in June and July when the SJR flow at Vernalis was less than 1,500 cfs provides a general indication of the ratio between these algal biomass variables. The maximum VSS (biomass plus detritus) was about 12–15 mg/l. The maximum algal pigment was 100–125 μg/l. The maximum measured 5-day BOD values were about 6 mg/l. Assuming a 10% BOD decay rate, the 5-day BOD would be about 40% of the ultimate BOD, the 10-day BOD would be about 9 mg/l (60% of the ultimate BOD), and the ultimate BOD would be about 15 mg/l (2.5 times the 5-day BOD). These values are similar to the assumed relationships used here for the Mossdale algae accounting calculations. An algal pigment concentration of 125 μg/l would correspond to an estimated VSS (biomass) concentration of about 10 mg/l, and the ultimate BOD concentration would be about 15 mg/l. UC Davis collected BOD10 values during 2004 in cooperation with the RWQCB TMDL studies. The maximum summer algal pigment concentrations were 150 μg/l, and the maximum BOD10 values were about 12 mg/l, corresponding to an ultimate BOD of about 20 mg/l. Considering the uncertainty in the BOD and the chlorophyll measurements, these values are similar to the assumed relationships used here for the accounting procedures.

The peak algae pigment concentrations were not consistently measured through the summer low-flow period and were not observed when the summer flow at Vernalis was greater than about 1,500 cfs. Travel time in the river channel upstream of Vernalis and other factors such as temperature and turbidity (light) may play some role in producing the maximum algae biomass at Mossdale. Based on river geometry data in the DSM2-SJR model developed by DWR, the variation in the travel time in the 65-mile reach of the SJR between Mud Slough (Mile 121) and Mossdale (Mile 56) would be about 4 days at a flow of 500 cfs, 3.5 days at 750 cfs, 3.1 days at 1000 cfs, 2.5 days at 2,000 cfs, and 2 days at 3,000 cfs. The Tuolumne and Stanislaus River inflows increase the river flow and reduce the travel time from Vernalis (Mile 72) to Mossdale (Mile 56). An upstream SJR flow of more than 1,000 cfs would reduce the travel time to less than 3 days and would limit the algae biomass concentration at Mossdale to less than the maximum observed algae pigment of 150–200 µg/l (corresponding to 12–16 mg/l of VSS and 18–24 mg/l of BOD). Only low-flow periods during the summer months will result in maximum algal biomass and corresponding BOD concentrations at Mossdale.

Because the algae biomass at Mossdale is difficult to estimate from seasonal factors (i.e., temperature and light) and SJR flow alone, the measured daily DO range at Mossdale is suggested as the preferred TMDL accounting method to estimate the daily algae biomass and corresponding BOD at Mossdale. Because this is a very important estimate of the upstream effects on the DWSC DO conditions, these daily algae concentration estimates should be confirmed with the daily pH and algal fluorescence monitoring. These monitoring estimates should also be confirmed during the summer months of June through September with weekly (or daily) measurements of BOD10, VSS, and extracted algal pigment (perhaps sampled by the City of Stockton). Calculations of how much of the river algae biomass at Mossdale will be transported downstream to the DWSC will be described in the second segment of the TMDL accounting procedures.

Segment 2—Estimating DWSC Flow and Inflow BOD Concentrations

The effects from the City of Stockton RWCF effluent concentrations on the DWSC inflow concentration of BOD is the most accurately measured factor that may contribute to low DO conditions in the DWSC. The National Pollutant Discharge Elimination System (NPDES) permit and Waste Discharge Requirements (WDR) for the Stockton RWCF have for many years mandated a full set of effluent concentration measurements as well as river station water quality sampling. These river sampling data and effluent measurements can be used to estimate the inflow BOD concentration increments contributed by the RWCF discharge to the DWSC. The DWSC flow will dilute the RWCF effluent concentrations before entering the DWSC. The goal of the second segment of the TMDL accounting procedures is to convert the RWCF effluent measurements and the DWSC flow into an equivalent daily BOD concentration entering the DWSC. The estimated Mossdale algae concentration and the DWSC flow are used to estimate the inflow BOD from upstream Mossdale algae in the second segment of the TMDL accounting procedures. The BOD contribution from the RWCF can be compared to the effects from the SJR algae BOD concentrations at Mossdale to identify the relative contributions of these two major sources of BOD into the DWSC. The effects of the combined BOD inflow concentration on the DO concentration profiles in the DWSC can be determined with a DO-BOD balance calculation for the DWSC. The response of the DWSC DO profile and the minimum DO to the inflow BOD is calculated in the third segment of the TMDL daily accounting tool.

The two major implementation measures that are included in the second segment of the TMDL accounting procedures are the barrier (or gate) at the head of Old River and the RWCF nitrification facility. As required by the CVRWQCB in the 2003 WDR Permit, the City of Stockton constructed a nitrification facility in 2006 that removes almost all of the ammonia from RWCF effluent. The ammonia-N is converted to nitrate-N using a nitrifying bio-tower, so the ammonia concentration from the oxidation ponds is (after nitrification) discharged to the river as nitrate (with no remaining oxygen demand). This removal of ammonia-N concentration (now measured as the effluent nitrate-

N concentration) represents a TMDL credit (i.e., BOD reduction) for the City of Stockton. The effects of the nitrification on the historical BOD from the RWCF discharge can be calculated in the second segment of the TMDL accounting tool. The effects of the head of Old River barrier (or gate) on the DWSC flow can also be calculated in the second segment of the accounting tool. The daily flow without the barrier/gate will be less than 50% of the Vernalis flow, while the daily flow with the barrier/gate would be about equal to the Vernalis flow. This increased flow would provide a greater dilution of the RWCF effluent and reduce the inflow BOD to the DWSC.

Estimating DWSC Flow

Not all of the SJR flow measured at Vernalis will enter the DWSC because about half of the flow will be diverted into Old River, about 3 miles downstream of Mossdale. There are several tidal flow measurement stations downstream of Old River (i.e., SJR at Lathrop, SJR at Garwood Bridge, and in the DWSC at RRI). However, the net daily flow is sometimes difficult to estimate from these tidal flow measurements. In most cases the USGS Garwood tidal flows and the DWR Lathrop tidal flows provide a reliable net flow estimate, but the net flow is more uncertain when it is less than about 500 cfs.

An estimate of the DWSC net flow can be made from the Vernalis flow and the SWP and CVP export pumping in the South Delta near Tracy. This provides a good estimate of the river flow that transports algae biomass downstream from Mossdale and dilutes RWCF discharge before it enters the DWSC. The general flow split at the head of Old River is about 50% each way (i.e., into Old River and downstream to Stockton). However, CVP and SWP export pumping increases the Old River diversion and reduces the DWSC flow. The DWSC flow can be estimated as:

DWSC Flow (cfs) = 50% of Vernalis Flow (cfs) – 5% of CVP and SWP Pumping (cfs)

This equation indicates that DWSC flow will be very low whenever the CVP and SWP export pumping is more than 10 times the Vernalis flow. This can happen during the summer low-flow period if the Vernalis flow is less than 1,500 cfs. The temporary barriers that DWR installs in Old River near the DMC intake, Grant Line Canal, and Middle River can reduce the effect of pumping on the DWSC flow. The DWSC flows are increased to the Vernalis flow minus about 500 cfs of leakage when the rock barrier at the head of Old River is installed during the VAMP period (April–May) to protect downstream migration of juvenile Chinook salmon or during the fall (September–October) to improve the SJR attraction flow for adult Chinook salmon upstream migration. A permanent gate would likely have a bypass flow of about 500 cfs for dilution of the Tracy treated wastewater effluent. The RWCF discharge (of about 40 cfs) should be added to the estimated or measured SJR flow at Garwood or Lathrop. The DWSC flow is important for estimating the fraction of the Mossdale River algae biomass that will reach the DWSC and for estimating the dilution of the RWCF effluent.

Estimating River Algae Biomass Reduction between Mossdale and the DWSC

The next calculation in the second segment of the accounting procedures is an estimate of the reduction in the Mossdale algae biomass before it enters the DWSC. This reduction in algae biomass is caused by settling, decay of the algae, and zooplankton grazing of the algae in this tidal reach of the SJR, between Mossdale and the DWSC. Algae may continue to grow in this reach, but because the river depth increases, the average light level is reduced and the measured algae concentrations generally decline between Mossdale and the DWSC. The loss of the algae biomass is estimated as a function of travel time, with an assumed daily loss rate that can be specified in the TMDL accounting calculations. The daily loss rate is generally about 10–20% per day for this tidal reach of the SJR.

The travel time is calculated from the channel volume between Mossdale and the DWSC (estimated to be about 3,500 acre-feet (af) at low tide, and about 5,000 af at high tide). The channel surface area is about 500 acres between Mossdale and the DWSC, with an average depth of about 7 feet at low tide and 10 feet at high tide. Using the low-tide volume estimate, the travel time for water between Mossdale and the DWSC is calculated as:

Travel Time (days) = 0.5 x 3,500 (af)/ River Flow (cfs)

Because 1 cfs of flow for a day is equivalent to about 2 af, a flow of 1,000 cfs would have a travel time of about 1.75 days. A flow of 500 cfs would have a travel time of about 3.5 days. A flow of 250 cfs would have a travel time of about 7 days. These travel time estimates were generally confirmed with several dye studies conducted by Dr. Gary Litton from the University of the Pacific (UOP) in 2008 between Old River and the DWSC (ICF International 2010a).

If the net algae loss rate (i.e., growth minus settling and grazing) was assumed to be 10% per day, the algae biomass would be reduced by about 15% for a flow of 1,000 cfs, by about 30% for a flow of 500 cfs, and by about 50% for a flow of 250 cfs. These loss rates are difficult to estimate from VSS, algae pigment, or BOD5 measurements because of the strong tidal mixing along the river reach that mixes the RWCF effluent and river water over several miles each day. The City of Stockton's river sampling at three upstream stations (R1 at Brandt Bridge, R2 at Garwood Bridge, and R2a at Navy Bridge)and in the DWSC at R3 (NA 48) can be used to provide a rough estimate for the algae loss rate during the summer low flow period.

Figures 13a and 13b shows the City of Stockton VSS and algae pigment concentration measurements at R1 (Brandt Bridge) and at R2 (Garwood Bridge) and R2a (Navy Bridge) for 2008. Brandt Bridge is at Mile 48, about 8 miles upstream from Navy Bridge at Mile 40. Mossdale is about 8 miles further upstream, so only about half of the travel time and VSS reduction is measured between these stations. During the summer months of 2008 the Vernalis flow was about 1,000 cfs and the algae pigment concentrations were reduced to about 25% of the R1 concentrations at stations R2 and R2a. Figure 13c and 13d show that the VSS and algal pigment concentrations were reduced to about 50% of the R1 concentrations at R2 and R2a. The DWSC flow would have been less than 500 cfs, and the measured net tidal flows were less than 250 cfs most of the summer. If the DWSC flow was 250 cfs, the travel time would have been about 7 days, and a 10% daily decay rate would reduce the Mossdale VSS or algae biomass concentrations to about 50% by the time it entered the DWSC. A daily decay rate of 20% would reduce the Mossdale VSS or algae concentrations to about 20% by the time it entered the DWSC. This loss rate between Mossdale and the DWS is uncertain, but the effects of various assumed loss rates can be compared with the TMDL accounting procedures tool.

For the TMDL accounting procedures, a lower daily loss rate (of 5%) may result in the maximum responsibility for DWSC DO conditions from the upstream river algae BOD contributions. For example, a Vernalis flow of 1,000 cfs would result in an algae pigment concentration of about 150 µg/l and would correspond to a river algae biomass of 12 mg/l and a BOD concentration of about 18 mg/l at Mossdale. This relatively low river flow of 1,000 cfs would allow the maximum algae biomass to grow at Mossdale, but a low daily loss rate would allow the maximum fraction of the Mossdale BOD concentration to enter the DWSC. For example, if the DWSC flow was 500 cfs (no export pumping), the algae loss from Mossdale to the DWSC would be about 15% (3 days travel time) and the BOD entering the DWSC would be about 15 mg/l. With 5,000 cfs of export pumping, the DWSC flow would be reduced to about 250 cfs, and about 75% (5 days travel time) of the river algae would enter the DWSC. A higher loss rate would cause less of the river algae BOD to enter the DWSC and would result in a lower contribution (i.e., lower responsibility) from upstream algae sources.

Estimating the DWSC Inflow DO Concentration

The river flow and the river algae (BOD) can be used to estimate the inflow DO concentration, which is needed for calculating the DWSC DO profile. The BOD decay that is estimated for this SJR reach can also be used to calculate the DO concentration at the DWSC. The calculation uses the Mossdale BOD concentration and the specified BOD loss rate and reaeration rate to determine how much of a DO deficit (below DO saturation) would remain at the downstream end entering the DWSC. The calculation is based on the simple idea that the daily BOD decay will be balanced by the daily reaeration, which is dependent on the DO deficit. The accounting procedures tool calculates the remaining river algae BOD at the DWSC inflow, and then estimates the inflow DO:

Inflow BOD (mg/l) = Mossdale BOD x (1–BOD decay rate) ^ Travel Time (days)

The BOD decay rate is measured to be about 0.1 per day at 20°C. The actual decay rate might be higher if zooplankton grazing consumes the algae at faster than the standard decay rate. The BOD decay rate may be less in cooler water temperatures, or if there are new BOD materials forming from algae growth. The range of likely BOD decay rates is about 5% to 15% per day. As the river BOD decays it will consume oxygen and lower the DO in the river. But surface reaeration will raise the DO whenever it is less than DO saturation. The daily source of DO from reaeration is usually calculated as a function of the DO deficit from saturation:

Daily Reaeration (mg/l) = (Saturated DO – River DO) x Reaeration Rate (per day)

The DO monitoring in the DWSC to measure the effectiveness of the Aeration Facility has found that the DWSC reaeration rate is about 20% per day, as described in Appendix A of the 2008 Operations Report (ICF International 2010b). The reaeration rate in the SJR between Mossdale and DWSC should be higher because the water depth is less and the water velocity is higher. The DO and BOD of the river will be in equilibrium. The daily BOD decay (i.e., River BOD x BOD decay rate) will balance the daily reaeration source. Rearranging the terms for the daily DO consumed and the daily DO reaeration source provides an estimate of the inflow DO to the DWSC:

Inflow DO (mg/l) = Saturated DO – Inflow BOD (mg/l) x BOD Decay Rate / Reaeration Rate

The diluted RWCF BOD concentration (described next) will contribute to the river BOD and reduce the inflow DO just upstream of the DWSC. The accounting calculations assume that the inflow DO will be in equilibrium with the combined inflow BOD from the RWCF effluent and the river algae transported downstream from Mossdale.

For example, if the BOD decay rate was specified as 10% per day and the reaeration rate was specified as 40% per day (2 times the DWSC value), the equilibrium DO deficit would be about 25%

of the inflow BOD concentration (i.e., 0.1/0.4 = 25%). If the river algae and RWCF combined BOD was about 8 mg/l, the DO deficit would be about 2 mg/l, and the inflow DO would be about 6 mg/l (in summer months when the saturated DO was 8 mg/l). The VSS and DO concentrations measured at the City of Stockton river sampling stations R1, R2, and R2a can be used to estimate the BOD decay and the reaeration rate, by matching the decay of VSS and the DO deficits for the recent years of data (2000–2010).

Stockton RWCF Effluent Measurements

The NPDES permit and WDR issued by the CVRWQCB for the Stockton RWCF have effluent and river sampling requirements. To comply with these limits, measurements are made daily or weekly; these provide an accurate description of RWCF effluent quality as well as the volume of effluent discharged each day. Because the City of Stockton has made many changes to its wastewater treatment facilities, and because the inflow BOD from Stockton canneries has decreased, the most recent effluent quality data (dating to 2007) are most representative of future estimates of the City of Stockton BOD loads and possible TMDL nitrification credits.

The City of Stockton submits the effluent measurements in monthly self-monitoring reports to the CVRWQCB, and these measurements were included in the Data Atlas files that were originally produced for the DWSC modeling and upstream river water quality studies, funded by CALFED and CBDA (last updated in 2007). These daily data files have been updated to September 2010. Graphics from these Data Atlas files will be shown here to demonstrate the calculation of DWSC inflow BOD concentrations from the Stockton RWCF discharge, as diluted by the DWSC flow.

The basic water quality measurements of the Stockton RWCF effluent include the following.

- Effluent daily flow (mgd)
- BOD5 (mg/l)
- 5-day carbonaceous BOD (CBOD5) (mg/l)
- Total suspended solids (TSS) (mg/l)
- VSS (mg/l)
- Hardness (mg/l)
- Alkalinity (mg/l).
- Ammonia-nitrogen (NH3-N) (mg/l).
- Nitrate-nitrogen (NO3-N) (mg/l).
- Nitrite-nitrogen (NO2-N) (mg/l).
- Total Kheldahl nitrogen (TKN) (mg/l).
- Organic-nitrogen (organic-N) (mg/l).
- Total dissolved solids (TDS) (mg/l).
- EC (uS/cm).
- Temperature (°F).

- DO (mg/l).

Effluent flow (mgd) is converted to cubic feet per second (cfs) to be compared to the river flow (i.e., dilution factor). Because the City of Stockton operates large oxidation ponds (with storage capacity), the tertiary treatment facility (and effluent) was often shut down on the weekends to reduce operating expenses. A 5-day moving average discharge is used to estimate the daily effluent contribution (inflow) to the DWSC. This 5-day moving average also accounts for the tidal mixing of the effluent over several days in the river before entering the DWSC.

Measurements of BOD5 and CBOD5 are used to estimate the ultimate (total) BOD concentration (and load) from the RWCF. The BOD5 and CBOD5 measurements are traditionally made at 20°C (68°F). The carbonaceous BOD (CBOD) measurement is made after adding a biocide to inhibit the nitrifying bacteria from growing. This eliminates the contribution of ammonia in the CBOD5 measurement. Comparison of CBOD5 and BOD5 provides an estimate of the nitrogenous BOD NBOD5, although this difference has usually been relatively small and suggests that not much of the ammonia was nitrifying in the 5-day BOD measurements. CBOD5 has been the primary measurement of CBOD in recent years; ammonia-N has been used to estimate the ultimate NBOD.

The particulate material in the effluent is measured by filtering and drying water samples. This provides a measure of the particulates or TSS in the effluent. The organic fraction is determined by combustion of the filtered TSS materials to determine the VSS. Comparison of these measurements (both were made in some years) indicates that the VSS concentration is generally greater than 80% of the TSS concentration. TSS has been the primary effluent particulate measurement in recent years. Both TSS and VSS measurements are usually made for the river samples.

Estimating Stockton RWCF BOD Contribution and Possible Nitrification Credit

The Stockton RWCF BOD concentration and nitrification credit calculations are relatively simple. The Stockton RWCF effluent discharge and effluent BOD concentration are used to estimate the total inflow BOD entering the DWSC. The inflow BOD concentration from the RWCF effluent depends on the DWSC flow. Because the DWC flow is variable and uncertain, a representative river flow of 200 cfs was used for demonstrating the daily accounting procedures. The inflow CBOD and the inflow NBOD are separately estimated to account for the large effects of RWCF ammonia (prior to 2007) and to allow the RWCF nitrification credits to be estimated (since 2006).

The first step in the Stockton RWCF accounting procedures is to convert the daily effluent concentration measurements into daily ultimate BOD concentration estimates. The CBOD5 and the BOD5 measurements are multiplied by a factor of 2.5, because the assumed BOD decay rate (at 20°C) is 0.1 per day, so that about 40% of the ultimate BOD would decay and consume oxygen in the first 5 days (i.e., 0.9^5 = 0.4). The TSS measurements are assumed to be organic (VSS) and are multiplied by 1.5, because each 1 mg/l of organic matter is assumed to consume about 1.5 mg/l of oxygen during decay. The ammonia-N concentration is multiplied by a factor of 5 because about 5 mg/l of DO are required to oxidize (nitrify) 1 mg/l of ammonia-N to 1 mg/l of nitrate-N. The total effluent BOD would be the combination of the CBOD5 or TSS estimate of ultimate CBOD plus the ammonia-N estimate of ultimate NBOD. The estimated effluent total BOD concentration will then be diluted by the DWSC flow prior to entering the DWSC. The estimate of the NBOD concentration (from effluent ammonia) entering the DWSC is:

Inflow NBOD = RWCF Discharge (cfs) x 5 x NH3-N (mg/l) / [River flow (cfs) + Discharge (cfs)]

The estimate of the DWSC inflow CBOD from CBOD5 or from TSS measurements can be similarly calculated as:

Inflow CBOD (from CBOD5) = Discharge (cfs) x 2.5 x CBOD5 (mg/l) / [River Flow (cfs) + Discharge (cfs)]

Inflow CBOD (from TSS) = Discharge (cfs) x 1.5 x TSS (mg/l) / [River Flow (cfs) + Discharge (cfs)]

The daily river flow at the RWCF discharge location and entering the DWSC is seasonally variable and somewhat uncertain. Therefore, the effects of the RWCF effluent ammonia-N and CBOD5 or TSS on the daily DWSC inflow CBOD and NBOD are shown for an average discharge of 50 cfs with a representative river flow of 200 cfs. A river flow of 200 cfs would reduce (i.e., dilute) the DWSC inflow BOD concentration to about 20% of the RWCF effluent BOD concentration (i.e., 50 / [50+200] = 0.2). The actual daily DWSC inflow BOD concentration would be less than this calculated inflow BOD when the river flow was higher than 200 cfs, and would be greater than this calculated inflow BOD when the river flow was lower than 200 cfs. A river flow of 450 cfs would reduce the DWSC inflow BOD to half the calculated value (10% effluent BOD) for the representative flow of 200 cfs. A river flow of 75 cfs would increase the DWSC inflow BOD to twice the calculated value (40% of effluent BOD) for the representative flow of 200 cfs.

RWCF BOD Contributions for 2000–2010

The RWCF discharge and effluent concentration measurements for 2000–2010 are shown here to demonstrate the suggested TMDL accounting procedures for the RWCF effluent. The reduction in the RWCF effluent ammonia-N concentrations since 2007 demonstrates the effects of the RWCF nitrification facility on reducing the BOD inflow to the DWSC. This reduction is the basis for the suggested RWCF nitrification credit calculations.

Figure 14a shows the Stockton RWCF daily and 5-day moving average discharge for 2000. The RWCF effluent discharge was highest in the winter (rainfall) period and averaged about 50 cfs most of the year. The monthly average effluent flows are given as magenta colored squares. The 5-day moving average effluent flow can be used to account for the week-end shut-downs and the tidal mixing in the river, but even the 5-day moving average discharge is somewhat variable. Therefore a representative effluent discharge of 50 cfs will be used in the example accounting procedure calcualtions. The 2001–2010 RWCF daily discharges were similar to the 2000 values, and graphs for these years will not be shown (the data is available in the accounting tool).

Figure 14b shows the daily BOD5, CBOD5, and TSS concentrations of the RWCF effluent for 2000. The 5-day CBOD measurements were generally less than 5 mg/l with some values of 10 mg/l in the winter period. These CBOD values are relatively low compared to the permitted monthly average CBOD concentration of 10 mg/l. The 5-day BOD concentrations were usually not much higher than the CBOD values, but increased to 15–20 mg/l in a few periods during the winter period. Apparently not much of the ammonia was being oxidized in the 5-day BOD tests. The TSS concentrations were generally a little higher than the 5-day BOD and ranged from about 5 mg/l to 25 mg/l. The 2001–2006 BOD5, CBOD5, and TSS concentrations of the RWCF effluent were generally similar to the 2001. The BOD5, CBOD5, and TSS concentrations of the RWCF effluent since 2007 have been much lower than the 2000 data because of improvements in the tertiary treatment (i.e., constructed wetlands and additional filters). Graphs for these years will not be shown (the data is available in the accounting tool).

Figure 14c shows the RWCF effluent concentrations of ammonia-N, nitrate-N, organic-N and total N for 2000. The nitrate-N was less than 1 mg/l except in the spring (April-June) when it increased to a maximum of about 10 mg/l. The organic-N was about 5 mg/l all of the year. The ammonia-N concentration was about 25 mg/l in January and again in November and December. The ammonia-N concentration generally declined in the spring and summer (from oxidation pond uptake for algae growth) and was a minimum of less than 5 mg/l in May–August.

Figure 14d shows the calculated BOD entering the DWSC with an assumed discharge of 50 cfs and representative river flow of 200 cfs for 2000. The RWCF effluent CBOD5 and TSS concentrations result in a CBOD estimate of about 3–5 mg/l entering the DWSC. These are moderate BOD concentrations that may be oxidized in the DWSC and balanced by surface reaeration without causing low DO. The calculated CBOD concentration entering the DWSC would be 50% of the RWCF effluent CBOD5, because the ultimate CBOD will be 2.5 times the CBOD5, but the assumed river flow of 200 cfs would reduce the CBOD concentration to 20% (i.e., 2.5 x 0.2 = 0.5). The CBOD concentration entering the DWSC based on the TSS concentration would be about 30% of the RWCF effluent TSS concentration, because the effluent CBOD would be 1.5 times the TSS, and the assumed river flow of 200 cfs would reduce the effluent CBOD concentration to 20% (i.e., 1.5 x 0.2 = 0.3). The CBOD inflow estimate based on TSS was similar but often higher than the estimate based on the CBOD5. Because the RWCF effluent ammonia-N concentration will require about 5 mg/l of oxygen for each 1 mg/l of ammonia-N, the NBOD entering the DWSC would be equal to the ammonia-N for the assumed river flow of 200 cfs (i.e., 5 x 0.2 = 1).

Figure 15a shows the measured RWCF effluent nitrogen concentrations for 2001. The ammonia-N concentration was about 25 mg/l in January and February, but was more variable, between 5 mg/l and 20 mg/l, in the remainder of the year. The nitrate-N concentration was low in the winter, increased to 10–15 mg/l in April and May, and was low through the summer but increased to 5 mg/l in December. This occasional oxidation of the ammonia-N to nitrate-N in the oxidation ponds reduced the NBOD concentrations. The organic-N concentration was relatively uniform at about 3–5 mg/l through the year. The total-N concentration was 30 mg/l in January and February, declined to about 15 mg/l from May through September, and increased to about 20–25 mg/l in October–December. Figure 15b shows the calculated DWSC inflow CBOD and NBOD concentrations for a representative river flow of 200 cfs for 2001. The calculated CBOD concentration entering the DWSC was generally less than 5 mg/l throughout the year. The NBOD concentration dominated the estimated inflow BOD entering the DWSC from the RWCF effluent. The calculated NBOD entering the DWSC was greater than 10 mg/l in July and August and may have contributed to low DO in the DWSC if the river flow was less than 200 cfs.

Figure 16a shows the 2002 ammonia-N concentration was less than 10 mg/l in early January and increased to 25 mg/l in early March. The ammonia-N concentration was reduced to less than 5 mg/l from early April through July 2002. The increase in NBOD during August and September may have coincided with low DO in the DWSC. Figure 16b shows the calculated DWSC inflow CBOD and NBOD concentrations for an assumed RWCF discharge of 50 cfs with a representative river flow of 200 cfs for 2002.

Figure 17a shows the Stockton RWCF effluent concentrations of ammonia-N and nitrate-N for 2003. The 2003 ammonia-N concentration was 25 mg/l from January through May, was less than 10 mg/l from June through October, and then increased to 20 mg/l by the end of the year. Figure 17b shows the calculated DWSC inflow CBOD and NBOD concentrations for an assumed RWCF discharge of 50 cfs with a representative river flow of 200 cfs for 2003.

Figure 18a shows the Stockton RWCF effluent concentrations of ammonia-N and nitrate-N for 2004. The ammonia-N concentration was about 12 mg/l in January and February and December. The ammonia-N decreased to between 10 and 20 mg/l from March through November. This was somewhat higher ammonia-N concentration during the summer than in most previous years. Figure 18b shows the calculated CBOD and NBOD inflow concentrations for 2004 with an assumed discharge of 50 cfs and representative river flow of 200 cfs was 10-15 mg/l during most of the low flow summer period of June through September. This relatively high NBOD during the summer months may have contributed to low DO conditions in the DWSC during 2004.

Figure 19a shows the Stockton RWCF effluent concentrations of ammonia-N and nitrate-N for 2005. The ammonia-N concentration was 20-25 mg/l from January through April, and was less than 10 mg/l only in June. The ammonia-N increased to 20 mg/l in September and was 25 mg/l at the end of the year. Figure 19b shows the calculated CBOD and NBOD inflow concentrations for 2005 with an assumed discharge of 50 cfs and representative river flow of 200 cfs. The calculated NBOD concentrations entering the DWSC were higher than 10 mg/l from August through October, and may have contributed to low DO conditions in the DWSC during 2005.

Figure 20a shows the Stockton RWCF effluent concentrations of ammonia-N and nitrate-N for 2006. The ammonia-N concentration was 20–25 mg/l from January through April, and was 10–15 mg/l in June, July, and August. The ammonia-N decreased to less than 10 mg/l in September and October, and was 10–15 mg/l in November and December. The nitrate-N concentrations increased from about 5mg/l in September to about 15 mg/l in December, as the nitrification facility began operation. Figure 20b shows the calculated CBOD and NBOD inflow concentrations for 2006 with an assumed discharge of 50 cfs and representative river flow of 200 cfs. The nitrification facility was first operated in the late summer of 2006 and the ammonia-N concentrations were reduced and the nitrate-N concentrations were increased. As the RWCF ammonia-N was converted to nitrate-N in the bio-towers, the calculated inflow BOD to the DWSC was reduced to between 5 and 15 mg/l in the fall months. The nitrification credit can be estimated from the effluent nitrate-N concentration, assuming that the nitrate-N concentration was usually less than 1 mg/l without the nitrification bio-towers. The calculated inflow BOD credit (from reduced ammonia-N) was about 5–15 mg/l during these first months of operation of the nitrification facility.

Figure 21a shows the Stockton RWCF effluent concentrations of ammonia-N and nitrate-N for 2007. The ammonia-N concentrations were somewhat variable from January through June, but were consistently less than 3 mg/l for the remainder of the year. This was a dramatic reduction in ammonia-N compared to previous years. The nitrate-N concentrations were 20–25 mg/l in January and February, decreased in the spring to less than 5 mg/l in June and July, and then increased to 20 mg/l by the end of the year. Figure 21b shows the calculated CBOD and NBOD inflow concentrations for 2007 with an assumed discharge of 50 cfs and representative river flow of 200 cfs. The 2007 calculated NBOD concentration were somewhat variable during the winter (first winter of nitrifying bio-tower operation). The nitrification credits (i.e., reduction in ammonia-N) can be estimated from the measured nitrate-N concentration, since nitrate concentrations were generally less than 1 mg/l in previous years without nitrification. The nitrification credit is not 25 mg/l throughout the year because the oxidation ponds usually reduced the ammonia-N concentrations in the spring and summer period.

The effluent nitrate-N concentration is recommended as the best estimate of the nitrification credit. This nitrification credit can also be expressed as the NBOD concentration that would have entered the DWSC if the nitrification facility were not operating. For 2007, this nitrification BOD reduction credit was 15–25 mg/l in January and February, decreased to a minimum of 5 mg/l in June and July, and then increased to about 15–20 mg/l in November and December. Because the ammonia-N concentration was already reduced in the oxidation ponds during the summer months, the nitrification credits were also lowest (5–10 mg/l) during the summer months. Nevertheless, this was a major reduction in the BOD entering the DWSC and likely improved the DO conditions in the DWSC compared to what they would have been without the nitrification facility.

Figure 22a shows the Stockton RWCF effluent concentrations of ammonia-N and nitrate-N for 2008. The ammonia-N concentrations were generally less than 1 mg/l. The nitrate-N concentrations were 15–20 mg/l from January through May, decreased in the spring to about 10 mg/l in July, and then increased to 20 mg/l from October through December. Figure 22b shows the calculated CBOD and NBOD inflow concentrations for 2008 with an assumed discharge of 50 cfs and representative river flow of 200 cfs. The calculated CBOD concentrations entering the DWSC were less than 2 mg/l. The nitrification credit for the reduction in the NBOD concentration (shown at nitrate inflow concentrations) would depend on the DWSC flow.

Figure 23a shows Stockton RWCF effluent concentrations of ammonia-N and nitrate-N for 2009. The ammonia-N concentrations were generally less than 1 mg/l. The nitrate-N concentrations were 15–20 mg/l from January through May, decreased in the spring to about 10 mg/l in July, and then increased to 20 mg/l from October through December. Figure 23b shows the calculated CBOD and NBOD inflow concentrations for 2009 with an assumed discharge of 50 cfs and representative river flow of 200 cfs. The ammonia-N concentrations were consistently less than 1 mg/l during 2009. The calculated nitrification credits for the reduction in the NBOD concentration entering the DWSC for the representative flow of 200 cfs were about 25 mg/l in January and February, were reduced to about 15 mg/l in April and May, were a minimum of about 5–10 mg/l in June and July, and were increased to 25 mg/l in September and October, and were 15-25 mg/l in November and December. This was a substantial reduction in the NBOD concentrations entering the DWSC most of the year. The actual nitrification credit would depend on the DWSC flow.

Figure 24a shows the Stockton RWCF effluent concentrations of ammonia-N and nitrate-N for 2010. The ammonia-N concentrations were generally less than 1 mg/l. The nitrate-N concentrations were 15–20 mg/l from January through May, decreased in the spring to about 10 mg/l in July, and then increased to 20 mg/l from October through December. Figure 24b shows the calculated CBOD and NBOD inflow concentrations for 2010 with an assumed discharge of 50 cfs and representative river flow of 200 cfs. The calculated nitrification credits in 2010 with the representative flow of 200 cfs were about 25 mg/l in January and were reduced to a minimum of about 10–15 mg/l in the summer period. The nitrate-N concentrations will presumably increase to about 25 mg/l at the end of the year, as observed in previous years.

Because the effects of algal growth in the oxidation ponds on the effluent ammonia and nitrate concentrations are variable form year to year, the measured RWCF effluent nitrate-N is the suggested TMDL accounting method for estimating the nitrification credits provided by the nitrification bio-towers. The benefits that will be achieved in the DWSC (i.e., increased minimum DO concentration) from the nitrification facility reduction in effluent ammonia concentrations will be calculated below in the third segment of the suggested TMDL accounting procedures.

Effects of Flow on the Combined (River Algae and RWCF) BOD Concentration

The SJR flow at Vernalis will govern the maximum concentration of algae at Mossdale, as previously described in the first segment of the suggested TMDL accounting procedures. The SJR flow downstream of the head of Old River will control the fraction of the river algae that will be transported to the DWSC and will also control the dilution of the Stockton RWCF effluent. There is a tradeoff between the benefits of flow from diluting the RWCF effluent and the impacts of flow from transporting more of the upstream river algae into the DWSC. The head of Old River barrier or gate could be used to control the flow and provide the best flow for the TMDL implementation program.

The proposed TMDL accounting procedures will properly calculate both of these effects (algae transport and RWCF dilution) from the DWSC flow. The effects of south Delta export pumping, that reduces the DWSC flow could be compensated with the head of Old River barrier (or gate). Estimating the flow that may provide the best overall TMDL benefit can be investigated with the TMDL accounting tool, for a range of RWCF effluent BOD and river algae BOD concentrations. If the Mossdale algae BOD concentration was high and the RWCF effluent BOD was relatively low, a lower DWSC flow might provide the greatest TMDL benefit. For most conditions, a minimum flow of about 200 cfs, to provide a dilution to about 20% of the RWCF effluent BOD concentration, may result in DO concentrations in the DWSC that would meet the DO objective.

The downstream DO profile and the minimum DO in the DWSC will be estimated in the third segment of the TMDL accounting procedures. The calculations of the minimum DO in the DWSC will match the measured DO at the RRI station only if the upstream river algae BOD, the transport to the DWSC, the dilution of the RWCF effluent and the combined inflow BOD and inflow DO concentrations are accurately estimated. Annual graphs of the TMDL daily accounting tool calculations of the DWSC DO concentrations in comparison with the daily minimum RRI data and the City of Stockton DO measurements will be used to show the ability of the accounting tool to estimate the DWSC DO and demonstrate the effects of TMDL implementation measures (i.e., upstream algae, DWSC flow, RWCF nitrification, Aeration Facility).

Segment 3—Estimating the Minimum DO in the DWSC

The third segment of the daily TMDL accounting procedures calculates the downstream DO-BOD balance in the DWSC, based on the inflow BOD, the inflow DO, the assumed DWSC reaeration rate, and the assumed BOD decay rate. The DO-BOD balance is based on the DWSC DO Model described in Appendix A of the 2008 Operations Report (ICF International 2010b). The Aeration Facility is proposed as a major TMDL implementation measure that can be included in the calculations of the third segment of the accounting procedures.

DO and BOD Balance in the DWSC

The downstream DO profile in the DWSC is controlled by the balance between the BOD decay (loss of DO) and the surface reaeration (source of DO). The Aeration Facility can add DO to the natural DWSC DO profile as tidal flows move back and forth past the diffuser, but the downstream reaeration will be reduced by this added DO (because the downstream DO deficit from saturation will be reduced). Many longitudinal DO profiles have been measured by the DWR *San Carlos* boat surveys and by the UOP boat surveys. The DWSC DO Model was developed to match the measured *San Carlos* DO profiles by specifying the DWSC flow, inflow DO, inflow BOD, and reaeration rate. The DWSC reaeration rate has been estimated to be about 20% per day.

The TMDL accounting procedures include a simplified DO balance that calculates the downstream BOD concentration, using the inflow BOD and inflow DO estimated in Segment 2 of the TMDL accounting tool and the specified BOD decay (assumed to be 10% per day). Therefore, both the reaeration rate (20% per day) and the BOD decay rate (10% per day) have been previously estimated for the DWSC and are assumed to be constant for all future conditions in the DWSC. The TMDL accounting tool calculates the daily DO and BOD balance for 5 days in the DWSC. Because the DO and BOD are assumed to be in equilibrium as the water moves downstream in the DWSC, the daily remaining BOD and DO deficit from saturation are determined by the initial DO and BOD. The inflow DO concentrations are assumed to be in equilibrium with BOD decay and reaeration for the river between Mossdale and the DWSC (Segment 2). The BOD decay rate was assumed to be 10% (same as in the DWSC), but the river reaeration rate was assumed to be 50% per day (higher than in the DWSC). The assumed DO saturation was 8 mg/l, corresponding to summer temperatures of about 20°C.

Table A-2 gives the daily BOD concentrations, DO concentrations, and the DO deficits (from DO saturation) calculated for 10 days in the DWSC with assumed inflow BOD concentrations of 5 mg/l, 10 mg/l, and 15 mg/l. The calculations indicate that the inflow DO for an assumed inflow BOD of 5 mg/l would be about 7.07 mg/l (DO deficit of 0.9 mg/l), and the minimum DO in the DWSC after 5 days would be about 6.38 mg/l. The inflow DO for an assumed inflow BOD of 10 mg/l would be about 6.15 mg/l (DO deficit of 1.9 mg/l), and the minimum DO in the DWSC after 5 days would be about 4.77 mg/l. The inflow DO for an assumed inflow BOD of 15 mg/l would be about 5.22 mg/l (DO deficit of 2.8 mg/l), and the minimum DO in the DWSC after 5 days would be about 3.15 mg/l. These are approximate values, assuming no other sources of BOD in the DWSC. With the BOD decay rate of 10% per day, about 40% of the BOD would be decayed after 5 days (60% remaining) and about 65% of the BOD would be decayed after 10 days (35% remaining). The inflow BOD of 5 mg/l would correspond to a BOD5 measurement of 2 mg/l. The inflow BOD of 10 mg/l would correspond to a BOD5 measurement of 4 mg/l. The inflow BOD of 15 mg/l would correspond to a BOD5 measurement of 6 mg/l. With the assumed BOD decay of 10% per day and the assumed reaeration rate of 20% per day, the minimum DO will always be calculated after 5 days. Therefore, a 5-day calculation of the DO-BOD balance will give the minimum DO expected in the DWSC.

The downstream position in the DWSC after 5 days (when the minimum DO is expected) depends on the net flow in the DWSC. This is a simple function of the geometry of the DWSC. Because there is about 2,000 af in each mile at low tide, the downstream movement would be about 1 mile per day for a flow of 1,000 cfs. Because the RRI station is 1.5 miles downstream from the SJR inflow at Channel Point (Dock 13), the SJR inflow would reach the RRI station in about 1.5 days with a flow of 1,000 cfs. If the flow was 500 cfs, the downstream movement would be 0.5 miles per day, and the SJR inflow would reach the RRI station after about 3 days. If the flow was 250 cfs, the downstream movement would be about 0.25 miles per day, and the SJR inflow would reach the RRI station after about 6 days.

Table A-2 indicates that the RRI station would measure the minimum DO in the DWSC for travel times of between 3 and 6 days, corresponding to flows of between about 250 cfs and 500 cfs. The minimum DO (after 5 days) would likely be measured upstream of RRI for lower flows and would likely be measured downstream of RRI for higher flows. Because of the tidal movement of water in the DWSC (of more than a mile each day), the RRI station will likely measure the minimum DO in the DWSC for a range of relatively low flows, when the inflow BOD would be relatively high and the minimum DO concentrations in the DWSC could be lower than the DO objective.

Table A-2. Calculated DWSC BOD and DO Concentrations for Inflow BOD of 5 mg/l 10 mg/ and 15 mg/l

Day	BOD (mg/l)	DO (mg/l)	DO Deficit (mg/l)
A. Inflow BOD of 5 mg/l			
0	5.0	7.07	0.9
1	4.5	6.76	1.2
2	4.1	6.56	1.4
3	3.6	6.44	1.6
4	3.3	6.39	1.6
5	3.0	6.38	1.6
6	2.7	6.41	1.6
7	2.4	6.46	1.5
8	2.2	6.53	1.5
9	1.9	6.61	1.4
10	1.7	6.69	1.3
B. Inflow BOD of 10 mg/l			
0	10.0	6.15	1.9
1	9.0	5.52	2.5
2	8.1	5.11	2.9
3	7.3	4.88	3.1
4	6.6	4.78	3.2
5	5.9	4.77	3.2
6	5.3	4.82	3.2
7	4.8	4.93	3.1
8	4.3	5.06	2.9
9	3.9	5.22	2.8
10	3.5	5.39	2.6
C. Inflow BOD of 15 mg/l			
0	15.0	5.22	2.8
1	13.5	4.28	3.7
2	12.2	3.67	4.3
3	10.9	3.32	4.7
4	9.8	3.16	4.8
5	8.9	3.15	4.9
6	8.0	3.23	4.8
7	7.2	3.39	4.6
8	6.5	3.59	4.4
9	5.8	3.83	4.2
10	5.2	4.08	3.9

Demonstration of DWSC Minimum DO Calculations

The accurate calculation of the minimum DO in the DWSC is the ultimate goal of the daily TMDL accounting tool. As described in the previous section, the DWSC minimum DO will occur after a travel time of about 5 days. A DO monitoring probe at the Navy Bridge (City R2a station) or Garwood Bridge (City R2 station and USGS tidal flow station) would be a good location for measuring the river inflow DO to the DWSC. Weekly measurements are collected at stations R1, R2, and R2a by the City of Stockton. These river data along with the RRI daily minimum DO concentrations will be used to confirm the daily estimates from the TMDL accounting procedures for recent years (2000–2010). Once the accuracy of the daily TMDL accounting tool is confirmed to the satisfaction of the CVRWQCB staff and stakeholders, it could be used to evaluate responsibility for periods of low DO and determine the benefits (i.e., increased DWSC DO concentrations) for nitrification and other BOD reduction measures, as well as to identify the benefits from increased flows.

Demonstration of Accounting Calculations for 2000

Figure 25a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2000. The measured flows are generally used in the TMDL accounting calculations, but the estimated flows (based on export pumping and periods when the head of Old River barrier is installed) are shown to confirm the measured patterns. DWSC flows of less than 500 cfs were measured in January, early July, and December 2000. These were the periods with lowest dilution of RWCF effluent.

Figure 25b shows the calculated inflow BOD concentrations for 2000. The BOD from upstream river algae (estimated from the daily DO range at Mossdale) that was calculated to enter the DWSC (estimated from the travel time and algae decay rate of 5% per day) is shown (green triangles). The maximum algae BOD during 2000 was about 10 mg/l from mid-July to mid-August, corresponding to the lowest SJR flows of about 2,000 cfs. The calculated RWCF BOD contributions (purple boxes) depend primarily on the ammonia-N concentrations and the river flow. The ammonia-N concentrations were lowest during the summer months (previously shown). Because the DWSC flows were relatively high most of the year, the RWCF BOD contributions were greatest in the winter and fall months with flows of less than 500 cfs. The maximum BOD calculated for the RWCF were 15–25 mg/l in January and in December.

Figure 25c shows the estimated inflow DO to the DWSC for 2000. The inflow DO was calculated from the saturated DO and the estimated BOD (green and red lines at the bottom of the graph, using the right scale) for the assumed BOD decay rate of 10% per day and the assumed river aeration rate of 50% per day. The minimum inflow DO estimated in 2000 was about 6 mg/l in July and August. The weekly DO measurements at station R2 (City of Stockton) indicate the minimum inflow DO concentrations were about 7 mg/l in 2000.

Figure 25d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2000. The daily minimum DO measured at the RRI station and the weekly DO measurements at stations R4, R5, and R6 are shown for comparison. The minimum estimated DO concentrations were about 1 mg/l in early January, because of the very high inflow BOD estimated during the low flow period. Although the minimum daily RRI DO concentration were 5–6 mg/l (DO saturation deficit of 6 mg/l), the accounting tool is apparently overestimating the effects of the high

BOD on the inflow DO and on the DWSC DO. Perhaps the assumed BOD decay rate of 10% per day should be reduced during the cool winter months. The daily DO estimates follow closely the measured DO concentration patterns for most of the year. The minimum estimated DO concentrations of about 4 mg/l in July and August were very close to the measured DO concentrations during this period. The estimated DO decline in December (caused by RWCF ammonia-N and low flows) was very close to the measured RRI DO concentrations. Considering the many uncertainties in the TMDL accounting methods, this first year of comparison provided a remarkable match of the estimated daily DO concentrations with the measured DO patterns in the DWSC.

Demonstration of Accounting Calculations for 2001

Figure 26a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2001. The estimated flows were used for 2001 because the Garwood measured flows were missing during the summer months. DWSC flows of less than 500 cfs were measured in January and February, early April, from mid-June to early October (head of Old River barrier installed), and in December 2001. These were the periods with lowest dilution of the RWCF effluent.

Figure 26b shows the calculated inflow BOD concentrations for 2001. The maximum estimated river algae BOD concentrations (green triangles) were about 10 mg/l in June and July, with about 5 mg/l estimated for July and August of 2001. The SJR flows at Vernalis were about 1,500 cfs during these four summer months. The calculated RWCF BOD contributions (purple boxes) depend primarily on the ammonia-N concentrations and the river flow. The ammonia-N concentrations were lowest during April–June and were about 10 mg/l in July-September (previously shown). The calculated RWCF BOD contributions were about 5–10 mg/l in January, February, July, and September, with the highest BOD of 10–15 mg/l calculated in August. The highest calculated combined inflow BOD concentrations were about 15–20 mg/l in July and August. This was the period with the lowest expected inflow DO and DWSC DO concentrations.

Figure 26c shows the estimated inflow DO to the DWSC for 2001. The inflow DO was calculated from the saturated DO and the estimated inflow BOD with the assumed BOD decay and reaeration rates. The minimum inflow DO estimated in 2001 was about 5 mg/l in July and August. The weekly DO measurements at station R2 (City of Stockton) generally confirm these estimated inflow DO concentrations for 2001.

Figure 26d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2001. The daily minimum DO measured at the RRI station and the weekly DO measurements at stations R4, R5, and R6 are shown for comparison. The minimum estimated DO concentrations were about 7–9 mg/l in January–April and matched the measured DO concentrations reasonably well. The estimated daily DO declined in late May and June as the river algae BOD increased, and the estimated DO of about 4 mg/l in June was similar to the DO measurements. The estimated DO was a minimum of 2–3 mg/l in July and early August, and then increased to about 5 mg/l in September and 8 mg/l in November as the estimated BOD was reduced. The estimated DO in December was about 9 mg/l, but the measured DO was only about 7 mg/l, suggesting that the estimated inflow BOD was not high enough. This was caused by using the estimated flows of about 500 cfs in December, while the measured flows were about 250 cfs. This difference indicates the importance of the DWSC flow estimates during relatively low flow periods for accurately estimating the dilution of the ammonia-N concentrations in the RWCF effluent. Considering the many uncertainties in the TMDL accounting methods, this second year of comparison provided a remarkable match of the estimated daily DO concentrations with the measured DO patterns in the DWSC.

Demonstration of Accounting Calculations for 2002

Figure 27a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2002. The measured Garwood flows (5-day moving average) were used for 2002. DWSC flows of less than 500 cfs were measured in mid-January through mid-April, from June through August, and in early December 2002. These were the periods with lowest dilution of the RWCF effluent.

Figure 27b shows the calculated inflow BOD concentrations for 2002. The maximum estimated river algae BOD concentrations were about 10 mg/l from mid-June to mid-September of 2002. The SJR flows at Vernalis were less than 1,500 cfs during these summer months. The calculated RWCF BOD contributions were greater than 10 mg/l in February and March, were about 5 mg/l from mid-August to mid-November, and were 10–25 mg/l in late November and early December (because of very low flows).

Figure 27c shows the estimated inflow DO to the DWSC for 2002. The inflow DO was calculated from the saturated DO and the estimated inflow BOD with the assumed BOD decay and reaeration rates. The minimum inflow DO estimated in 2002 was about 5–6 mg/l in June through September. The weekly DO measurements at station R2 (City of Stockton) and at R2a (new station at Burns Cut) suggest that the actual inflow DO was about 4–5 mg/l during these summer months. This suggests that the river algae BOD might have been higher than estimated in 2002.

Figure 27d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2002. The daily minimum DO measured at the RRI station and the weekly DO measurements at stations R4, R5, and R6 are shown for comparison. The minimum estimated DO concentrations were about 8–9 mg/l in January, whereas the measured DO was only 5–6 mg/l. The estimated DO concentrations in February–March were 4–7 mg/l, matching the measured DO very well. The higher estimated inflow and DWSC DO concentrations in April–May (because of the increased SJR flows and installation of the head of Old River barrier) matched the measured DO concentrations reasonably well. The estimated daily DO declined in late May and June as the river algae BOD increased, and the estimated DO of about 4 mg/l at the end of June was similar to the DO measurements. The estimated DO was 5 mg/l in July and early August, while the measured DO was 3–4 mg/l. The minimum estimated DO was about 3 mg/l from mid-August to mid-September, increased to 5 mg/l at the end of September, and was 7–8 mg/l at the end of October. The measured DO confirmed these DO estimates in September and October. The very low estimated DO at the end of November and early December (caused by low flows) was lower than the measured DO of about 3–4 mg/l. Nevertheless, the daily estimated minimum DWSC DO concentrations for 2002 were similar to the measured DO concentrations during almost all periods of the year.

Demonstration of Accounting Calculations for 2003

Figure 28a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2003. The measured Garwood flows (5-day moving average) were used for 2003. DWSC flows of less than 500 cfs were measured in January through mid-April, early June, July-mid-September, and mid-November through December 2003. These were the periods with lowest dilution of the RWCF effluent.

Figure 28b shows the calculated inflow BOD concentrations for 2003. The maximum estimated river algae BOD concentrations were about 10 mg/l from late May to early September. The SJR flows at Vernalis were about 1,500 cfs during these summer months. The calculated RWCF BOD contributions were about 10 mg/l in January, about 20–25 in early February (low flows), and about 10 mg/l in March. The calculated RWCF BOD was less than 5 mg/l during the VAMP flow period, but increased in late May (low flows) to about 10–20 mg/l, and increased again in mid-November and December to about 15–20 mg/l (low flows).

Figure 28c shows the estimated inflow DO to the DWSC for 2003. The inflow DO was calculated from the saturated DO and the estimated inflow BOD with the assumed BOD decay and reaeration rates. The minimum inflow DO estimated in 2003 was about 6 mg/l in February, about 4–5 mg/l in late May, and about 6 mg/l in mid-June through August. The weekly DO measurements at station R2 (City of Stockton) and at R2a (new station at Burns Cut) suggest that the lowest inflow DO was about 4–5 mg/l during July, and about 6–7 mg/l during most of the June–September period.

Figure 28d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2003. The minimum estimated DO concentrations were about 3 mg/l in early February and 5–6 mg/l in mid-February through March, whereas the measured DO was less than 2 mg/l in February and increased from 2 mg/l to 6 mg/l in March. The estimated DO concentrations decreased in late May to 2–3 mg/l, whereas the measured DO was 3–4 mg/l in early June. The estimated DO of 4–5 mg/l matched the measured DO in June–August, and both the estimated and measured DO increased to about 6 mg/l at the end of September, and were both about 8 mg/l at the end of October. The estimated DO was 5–6 mg/l at the end of November and early December, but decreased to 2–3 mg/l at the end of December. The measured DO at RRI was 6–7 mg/l in mid-November through December. The accounting procedures may be overestimating the decay of BOD in the winter months (should add temperature correction to the BOD decay rate). Nevertheless, the daily estimated minimum DWSC DO concentrations for 2003 were similar to the measured DO concentrations during most periods of the year.

Demonstration of Accounting Calculations for 2004

Figure 29a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2004. The measured Garwood flows (5-day moving average) were used for 2004. DWSC flows of less than 500 cfs were measured in January and February, June–September, and mid-November through December 2004. These were the periods with lowest dilution of RWCF effluent.

Figure 29b shows the calculated inflow BOD concentrations for 2004. The maximum estimated river algae BOD concentrations were about 10 mg/l from late May to late July. The SJR flows at Vernalis were about 1,500 cfs in June and just 1,000 cfs in July, August, and September. The calculated RWCF

BOD contributions were very high (10–25 mg/l) in January and February, about 10–15 in early June and early August, and very high (10–25 mg/l) again in mid-November through December because of low flows. The calculated RWCF BOD was less than 5 mg/l during the VAMP flow period and in October when DWSC flows were greater than 1,000 cfs. The combined BOD was greater than 15 mg/l during June, July, and August, as well as in the low flow periods of January–February and November–December.

Figure 29c shows the estimated inflow DO to the DWSC for 2004. The minimum inflow DO estimated in 2004 was less than 6 mg/l in late January and late November. The R2 and R2a measurements suggest that the inflow DO was not quite this low in these cooler months. The estimated inflow DO was 4–5 mg/l in the summer months, and the R2 and R2a measurements were even lower (3–4 mg/l) in July and August. The river DO can be substantially reduced by high BOD concentrations during summer (warm) low flow periods.

Figure 29d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2004. The minimum estimated DO concentrations were less than 1 mg/l in late January, about 3–4 mg/l in early February and 6–8 mg/l in March through May. The measured DO was 4–5 mg/l in late January and February, and was 7–8 mg/l in March–May. The estimated DO decreased in late May to a minimum of 1–3 mg/l in early June. The measured DO showed a decrease from about 7 mg/l to 3–4 mg/l in June. The estimated DO matched the measured DO quite well in July and August, with a minimum of about 2–3 mg/l from mid-July to mid-August. The estimated DO increased to 4–5 mg/l in September, while the measured DO remained at 2–3 mg/l. The river algae or the RWCF effluent BOD was apparently higher than calculated in September. The estimated DO increased in October from 5 to 8 mg/l, while the measured DO increased from 4 to 7 mg/l. The estimated DO was greatly reduced to less than 2 mg/l at the end of November and averaged about 3–4 mg/l in December. The measured DO was reduced to about 5 mg/l at the end of November and was very low (3–5 mg/l) in December. The calculations apparently should reduce the BOD decay rate in the winter months. Adjustments in these initial estimates of the river algae and RWCF BOD effects (to better match the measured DO) may provide a more accurate historical baseline for evaluating the effects of more flow and reduced ammonia on the DWSC DO concentrations.

Demonstration of Accounting Calculations for 2005

Figure 30a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2005. The measured Garwood flows (5-day moving average) were used for 2005. The SJR flows in 2005 were very high throughout the year, with a minimum flow of about 2,000 cfs in early September and mid-November. DWSC flows were about 1,000 cfs in August and were less than 500 cfs from mid-November to mid-December. Because of these high flows, the BOD concentrations are not expected to be high enough to cause low DO conditions in the DWSC.

Figure 30b shows the calculated inflow BOD concentrations for 2005. The maximum estimated river algae BOD concentrations were about 5–10 mg/l from mid-July to mid-September. The calculated RWCF BOD contributions were less than 5 mg/l until the low flow period of mid-November to mid-December. The combined BOD was about 10 mg/l during July and August, and was greater than 20 mg/l in the November–December low flow period. Figure 30c shows the estimated inflow DO to the DWSC for 2005. The minimum inflow DO estimated in 2005 was 6–7 mg/l in mid-July to mid-

September. The estimated inflow DO was 3–5 mg/l in the November-December period, while the measured DO at R2 and R2a was 6–8 mg/l.

Figure 30d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2005. The minimum estimated DO concentrations were 8–10 mg/l in the months of January–June because of the high flows and low BOD concentrations. The measured DO concentrations in January and February were lower (6–8 mg/l), suggesting that the inflow BOD was not accurately estimated. The estimated DO concentrations decreased in July from about 7 mg/l to a minimum of 4 mg/l and were 4–5 mg/l in August and early September, matching the measured DO relatively well. The estimated DO increased in September and October to about 8 mg/l. The measured DO was about 1 mg/l less than the estimated DO during this period. The estimated DO was much lower that the measured DO of 5–6 mg/l in December, again suggesting that a temperature modifier may be helpful for the winter months. A reduction in the DWSC DO was observed in December of 2005 (caused by high ammonia and low flow), but it was not as strong as estimated with the TMDL accounting calculations.

Demonstration of Accounting Calculations for 2006

Figure 31a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2006. The measured Garwood flows (5-day moving average) were used for 2006. The SJR flows in 2006 were very high throughout the year, higher than 2005, with a minimum flow of about 2,000 cfs in early December. DWSC flows were higher than 2,500 cfs until mid-July, and were a minimum of about 1,500 cfs from mid-July through August. Because of these high flows, the BOD concentrations are not expected to be high enough to cause low DO conditions in the DWSC.

Figure 31b shows the calculated inflow BOD concentrations for 2006. The maximum estimated river algae BOD concentrations were about 5–10 mg/l in late July and early September. The calculated RWCF BOD contributions were less than 5 mg/l until the low flow period of early December. The combined BOD was about 10 mg/l during late July, early September, and early December. Figure 31c shows the estimated inflow DO to the DWSC for 2006. The minimum inflow DO estimated in 2006 was about 7 mg/l in July. The estimated DO was within 1 mg/l of the saturated DO for most of the year. The measured DO generally confirmed the high inflow DO concentrations during this year with low BOD concentrations.

Figure 31d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2006. The minimum estimated DO concentrations were about 2 mg/l below the DO saturation for most of the year. The minimum estimated DO was about 5 mg/l in late July, corresponding to the period of highest estimated algae. The estimated DO increased from about 6 mg/l at the beginning of September to about 9 mg/l at the end of October. The measured DO concentrations were about 1 mg/l less than the estimated DO during this period. The estimated DO was reduced to about 7–8 mg/l in early December because of the low flow. The measured DO was similar (8–9 mg/l) in November and early December. The reduced BOD concentrations were accurately estimated and resulted in higher DO concentrations in the DWSC during both 2005 and 2006 with higher SJR and DWSC flows. Nevertheless, the Aeration Facility might have been operated for some periods in these high flow years. For example, measured DO concentrations were less than 5 mg/l in July and August and less than 6 mg/l in September 2005. Measured DO concentrations were slightly less than 5 mg/l in late July 2006.

Demonstration of Accounting Calculations for 2007

Figure 32a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2007. The measured Garwood flows (5-day moving average) were used for 2007. The SJR flows in 2007 were very low again, similar to flows in 2001–2004. The minimum SJR flows were about 1,000 cfs in July–September. The DWSC flows were less than 500 cfs in early April and from June through September, and again in mid-November through December. The DWSC flows were apparently about 0 cfs in July and August 2007, but a minimum flow of 160 cfs was specified to provide a minimum calculated dilution of the RWCF effluent (DWSC inflow was about 20% effluent).

Figure 32b shows the calculated inflow BOD concentrations for 2007. The estimated river algae BOD concentrations were about 10 mg/l in June. Higher algae concentrations were expected in July–September, corresponding to the low SJR flows of about 1,000 cfs. But the daily DO range at Mossdale did not indicate much algae photosynthesis during these low flow months. The calculated RWCF BOD contributions were less than 3 mg/l throughout the entire year, because the nitrification facility was operating, and the constructed wetlands and additional filters also reduced the CBOD concentrations.

A special study was performed by UOP scientists to determine the effects of the fall pulse flow and the head of Old River installation on downstream algae and BOD entering the DWSC and the DO profile in the DWSC. Boat surveys with sampling and water quality monitoring were conducted from Mossdale to Turner Cut weekly from September 19 through November 15, 2007 (ICF International 2010a). Patterns of algae biomass and BOD were generally decreasing slightly from Mossdale to the DWSC, during this fall periods with flows ranging from less than 250 cfs to 1,500 cfs. The patterns of algae growth, degradation, and zooplankton grazing that were measured with these boat surveys in this transition between Mossdale and the DWSC can only be approximated in the TMDL accounting procedures.

Figure 32c shows the estimated inflow DO to the DWSC for 2007. The minimum inflow DO estimated in 2007 was about 6 mg/l in mid-June corresponding to the highest algae BOD. But the measured DO from R2 and R2a stations indicated much lower inflow DO of about 5 mg/l in July and 6 mg/l in August. The measured DO concentrations suggest that the estimated algae BOD for July and August should have been much higher.

Figure 32d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2007. The minimum estimated DO concentrations were about 2 mg/l below the DO saturation for most of the year. The minimum estimated DO was about 5 mg/l in mid-June, corresponding to the highest algae BOD for 2007, and increased to 6–7 for July–September. However, the measured DO in late June was 3 mg/l, was 4–5 mg/l in July and August, and about 5–6 mg/l in September. The estimated DO was about 2 mg/l higher than the measured DO in these three months, indicating that the actual algae BOD should have been higher. Although the estimated RWCF BOD concentrations were much lower with the reduction of ammonia-N concentrations in 2007, the measured DO concentrations were less than 5 mg/l for June–August and less than 6 mg/l in September. Therefore, the Aeration Facility might have been operated for some periods in 2007. Because the DWSC flows were generally less than 250 cfs, one pump and U-tube operations might have been sufficient (4,000 lb/day) to increase the measured DO to the DO objective.

Demonstration of Accounting Calculations for 2008

Figure 33a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2008. The measured Garwood flows (5-day moving average) were used for 2008. The SJR flows in 2008 were about 2,000 cfs in the winter months and were reduced to about 1,000 cfs from mid-June through September. The DWSC flows were less than 500 cfs in parts of January and February, June–September, and for most of November and December 2008. A minimum flow of 160 cfs was again specified.

Figure 33b shows the calculated inflow BOD concentrations for 2008. The estimated river algae BOD concentrations were about 10 mg/l in June, July, and August (as was expected for similar low flows in 2007). The calculated RWCF BOD contributions were less than 2 mg/l throughout the entire year, because the nitrification facility was operating, and because the constructed wetlands and additional filters also reduced the CBOD concentrations.

Figure 33c shows the estimated inflow DO to the DWSC for 2008. The minimum inflow DO estimated in 2008 was about 7 mg/l in June–August corresponding to the highest algae BOD. But the measured DO from R2 and R2a stations indicated lower inflow DO of about 5–6 mg/l in July and 6 mg/l in August. The measured DO concentrations suggest that the estimated algae BOD for June–August should have been somewhat higher.

Figure 33d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2008. The minimum estimated DO concentrations were about 2 mg/l below the DO saturation for most of the year. The minimum estimated DO was about 5 mg/l in June–August, corresponding to the highest algae BOD for 2008, and increased from 6 to 8 mg/l in September. The measured DO in June was about 5–6 mg/l and was increased slightly in July and August. July and August were the first months of operational testing (about half-time) of the Aeration Facility, and the Aeration Facility operations increased the RRI DO data by 1–2 mg/l. The measured DO in early September was about 5 mg/l, and then increased to about 7 mg/l with the Aeration Facility operated for 10 days at the end of the month. The effects of the Aeration Facility are not yet included in the TMDL accounting calculations, so the estimated DO does not reflect periods of testing in 2008. The measured DO in June was generally just below 5 mg/l, so one pump operations may have been sufficient to meet the DO objective. Some Aeration Facility operations may also have been needed in July–September 2008 to meet the DO objectives. The Aeration Facility can generally increase the RRI DO by 1–2 mg/l.

Demonstration of Accounting Calculations for 2009

Figure 34a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2009. The measured Garwood flows (5-day moving average) were used for 2009, except for July and August when a minimum flow of 160 cfs was specified (measured flows were less than 0 cfs–reversed). The SJR flows in 2009 were extremely low, with only about 1,000 cfs in the winter months, a small peak flow of 2,500 cfs during the VAMP period, and a minimum of only 500 cfs at Vernalis in July and August. The DWSC flows were less than 500 cfs for most of the year, and apparently reversed in July and August.

Figure 34b shows the calculated inflow BOD concentrations for 2009. The estimated river algae BOD concentrations were greater than 5 mg/l in the low flow period of March and April, and were between 5 and 10 mg/l from June through September, with a peak of 15 mg/l in mid-July. The calculated RWCF BOD contributions were less than 2 mg/l throughout the entire year, because the nitrification facility was operating, and the constructed wetlands and additional filters also reduced the CBOD concentrations. River algae was the only substantial source of BOD entering the DWSC during 2009.

Figure 34c shows the estimated inflow DO to the DWSC for 2009. The minimum estimated DO was about 6 mg/l in mid-July corresponding to the highest algae biomass estimate. The measured DO at R2 and R2a was about 5 mg/l from mid-May through July, and was about 6 mg/l in August. These measured DO concentrations suggest that the river algae biomass was higher than estimated from the daily range of DO at Mossdale. A more reliable estimate of the river algae BOD may be required for more accurate estimates of the inflow BOD and corresponding inflow DO to the DWSC.

Figure 34d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2009. The minimum estimated DO concentrations were about 2 mg/l below the DO saturation in the winter and decreased to about 7 mg/l during the March–April period with increased river algae. The measured DO during this period was higher (8–9 mg/l), suggesting the increased river algae BOD did not actually reach the DWSC. The estimated DO decreased in May and was 5–6 mg/l in June. The minimum estimated DO was about 5 mg/l in July, but decreased to 3 mg/l during the peak algae biomass estimate. The estimated DO was 5–6 mg/l in August and September, and increased to about 1 mg/l below DO saturation in October-December. The measured DO was 5–6 mg/l from June to mid-September, and increased to 7 mg/l at the end of September. The measured DO was about 2 mg/l below DO saturation in October–December, with a peak DO of 9 mg/l measured during the late October pulse flow period. The estimated DO was generally within 1 mg/l of the measured DO for most of the year. Adjustments in the river algae BOD estimates would likely improve the estimated DWSC minimum DO concentrations.

The Aeration Facility was operated for testing in 2 weeks of September and 1 week of October 2009. Although the measured DO was about 5 mg/l for the summer months, one pump operations of the Aeration Facility might have been used to increase the DO to about 6 mg/l in June–September. As observed in most years, September temperatures are often high enough that saturated DO is still about 8 mg/l, and the measured DO concentrations are often between 5 mg/l and 6 mg/l. The Aeration Facility may have been needed to increase the September DO concentrations to 6 mg/l.

Demonstration of Accounting Calculations for 2010

Figure 35a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2010. The measured Garwood flows (5-day moving average) were used for 2010 (through September). The SJR flows at Vernalis in 2010 were moderate, with winter flows of about 2,500 cfs, spring flows of about 5,000 cfs, and minimum flows of less than 1,500 cfs from mid-July to mid-September. The DWSC flows were less than 500 cfs for a short period in early February and from mid-July to mid-September.

Figure 35b shows the calculated inflow BOD concentrations for 2010. The estimated river algae BOD concentrations were greater than 5 mg/l in the low flow period of late March, were greater than 10 mg/l in mid-July, but declined to about 5 mg/l in August and September. The calculated RWCF BOD contributions were less than 2 mg/l throughout the entire year, because the nitrification facility reduced the ammonia-N concentration to about 1 mg/l. The combined BOD was less than 5 mg./l for the entire year except for July and August.

Figure 35c shows the estimated inflow DO to the DWSC for 2010 (through August). The minimum estimated DO was only about 1 mg/l less than saturated DO except for the late March and July periods with higher river algae BOD estimates. The measured DO was also generally just 1–2 mg/l below DO saturation, until late July and early August when the measured DO at R2 and R2a was 4–5 mg/l. These low DO concentrations suggest that the estimated river algae BOD concentrations must have been higher than was estimated from the daily DO range at Mossdale. A more reliable estimate of the river algae BOD may be required for more accurate estimates of the inflow BOD and corresponding inflow DO to the DWSC.

Figure 35d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2010. The minimum estimated DO concentrations were about 2 mg/l below the DO saturation in the winter but decreased to about 7 mg/l during the late March period with increased river algae. The measured DO during February and early March was lower than the estimated DO, suggesting higher BOD concentrations than were estimated. The estimated DO decreased to 6 mg/l in late June, was a minimum of about 4 mg/l in mid-July, and increased from 5 to 6 mg/l in August. The measured DO was a minimum of 5 mg/l in late July, and was 5–6 mg/l in August. The estimated DO in the summer of 2010 was relatively high because of higher SJR flows in June (higher than 3,000 cfs) and relatively low algae biomass estimated in July and August. The estimated DO was generally within 1 mg/l of the measured DO for most of the year. Adjustments in the river algae BOD estimates would likely improve the estimated DWSC minimum DO concentrations.

The Aeration Facility was operated for testing for 10 days in August and 7 days in September of 2010. Although the measured DO was less than 5 mg/l on in late July, one pump operations of the Aeration Facility might have been used to increase the DO to about 6 mg/l from mid-July to mid-September. The summer DO concentrations in the DWSC during the past 4 years (2007–2010) have been only slightly less than 5 mg/l (DO objective) in June–August, and slightly less than 6 mg/l (DO objective) in September. This appears to be the direct result of the City of Stockton RWCF nitrification facility, which has reduced the effluent ammonia-N concentrations to about 1 mg/l. The minimum DO in the DWSC is now primarily controlled by the upstream river algae BOD, which is only high enough to cause low DO conditions in the summer months. Additional measurements of the river algae concentrations at Mossdale would allow more accurate estimates of the DWSC inflow BOD and the resulting minimum DO concentrations, and could be used to forecast periods when the Aeration Facility could be operated to increase the DWSC DO concentrations.

Conclusions and Recommendations

This appendix has reviewed portions of the SJR DO TMDL implementation program and described possible TMDL accounting procedures that could be used to track SJR and DWSC flows and water quality conditions that are directly related to the measured DWSC DO concentrations. This appendix is included in the *Stockton Deep Water Ship Channel Demonstration Dissolved Oxygen Aeration Facility Project Final Report* (ICF International 2010c) as a contribution toward the future SJR DO TMDL implementation plan to help meet the DO objective, using all available information about the SJR and DWSC water quality conditions and biochemical processes and influences. These suggested TMDL accounting procedures could be used as a framework for continued research to better understand some of the remaining uncertainties, and as a tool for integrating and interpreting water quality monitoring data from the SJR stations in DWSC stations. These accounting procedures incorporate the findings from the previous DWSC and upstream studies that were funded by CALFED and ERP grants.

The first section of this appendix reviewed the SJR DO TMDL implementation plan described in the 2005 Basin Plan Amendments, which discussed the need for quantitative daily accounting of the various effects on DO in the DWSC and for identification of proportional responsibilities for future low DO concentrations. Because the accuracy of the suggested TMDL accounting calculations has been demonstrated by matching the estimated minimum DO patterns with the measured DO concentrations for 2000–2010, these calculations can be used with confidence to estimate the effects of DWSC geometry, SJR and DWSC flows, and BOD concentrations from upstream algae and from the City of Stockton RWCF effluent.

The second section of this appendix described the framework and specific calculations for possible SJR DO TMDL accounting procedures that might be used for estimating the effects of SJR and DWSC flows, upstream river algae concentrations, and Stockton RWCF effluent concentrations on the combined inflow BOD to the DWSC and the resulting DO concentrations in the DWSC. The accounting procedures are described as three segments: Segment 1 provides an estimate of upstream river algae at Mossdale from several water quality monitoring records, Segment 2 provides an estimate of DWSC flows that control the fraction of river algae transported to the DWSC and the dilution of the Stockton RWCF effluent concentrations, and Segment 3 calculates the minimum DO in the DWSC as a function of inflow BOD (from river algae and RWCF effluent) that controls the inflow DO and the downstream DO-BOD balance in the DWSC.

These daily accounting procedures were demonstrated with a series of comparative graphs showing the estimated DO compared to the measured DO in the DWSC for 2000–2010. Because these years included a wide range of SJR flows and water quality conditions, the ability of the accounting procedures to accurately estimate the DWSC DO concentrations for each of these different years was generally confirmed. These TMDL accounting calculations could be used as a tool for understanding the causative factors for low DO in the DWSC and assigning proportional responsibilities for operating the Aeration Facility (or other implementation measures) that could increase the DWSC DO concentrations to meet the DO objective. If approved by RWQCB staff and stakeholders, this suggested accounting procedure could also provide a reporting framework to demonstrate compliance with the SJR DO TMDL implementation program.

The further development and approval of these proposed daily accounting procedures by the CVRWQCB and stakeholders will be necessary prior to their use as part of the SJR DO TMDL implementation program. The future operation of the Aeration Facility as part of the TMDL implementation plan to meet the DO objective is dependent on the adoption of a mechanism to regulate and fund its operation. The Aeration Facility is a promising method for reducing or eliminating periods of low DO concentrations (below the DO objective) in the DWSC, thus reducing or eliminating the need for upstream BOD load reductions or SJR flow management. Two major recommendations follow from the development and comparison of the daily accounting procedures for the historical 2000–2010 SJR and DWSC flows and water quality conditions.

- **Monitoring Strategy**. A future SJR DO TMDL monitoring strategy should be developed based on the existing measurements and previous special studies of the DWSC and the upstream river hydrology and water quality processes. A TMDL monitoring strategy would likely include water quality monitoring in the DWSC and at several upstream SJR stations. The future SJR DO TMDL monitoring strategy should be developed and approved by the CVRWQCB staff and stakeholders; accordingly, it is not discussed in this appendix. However, the proposed accounting procedures described herein may provide a useful template for specifying the most important monitoring locations and water quality variables that could be included in a future monitoring and reporting framework.
- **Operations Strategy**. A future operations strategy for the Aeration Facility should be developed by stakeholders to guide the effective and efficient operations as part of the SJR DO TMDL implementation plan. The accounting procedures described in this appendix demonstrate that the upstream SJR flow and water quality (algae) conditions as well as the DWSC flow and dilution of the RWCF are each important in determining the minimum DO in the DWSC, and may provide reliable forecasting of low-DO conditions. The Aeration Facility operations strategy could be developed by stakeholders based on a review of the DWSC DO conditions during recent years (2000–2010) and the evaluation of expected changes in DWSC DO from increased flows or reduced BOD concentrations. The monitoring strategy together with the operations strategy should identify periods when the Aeration Facility could be effectively used to increase the DO concentrations in the DWSC and reduce any future DO objective deficits. The operations strategy might include coordinated DWSC operations that would satisfy the existing aeration requirements for the Port of Stockton (for dredging permit) and the USACE (for channel deepening effects) as well as the SJR DO TMDL implementation requirements. The future operation of the Aeration Facility by a “stakeholder alliance” as part of the SJR DO TMDL implementation plan would require an agreement between the CVRWQCB and stakeholders for monitoring, daily accounting of flows and water quality, and funding allocation procedures.

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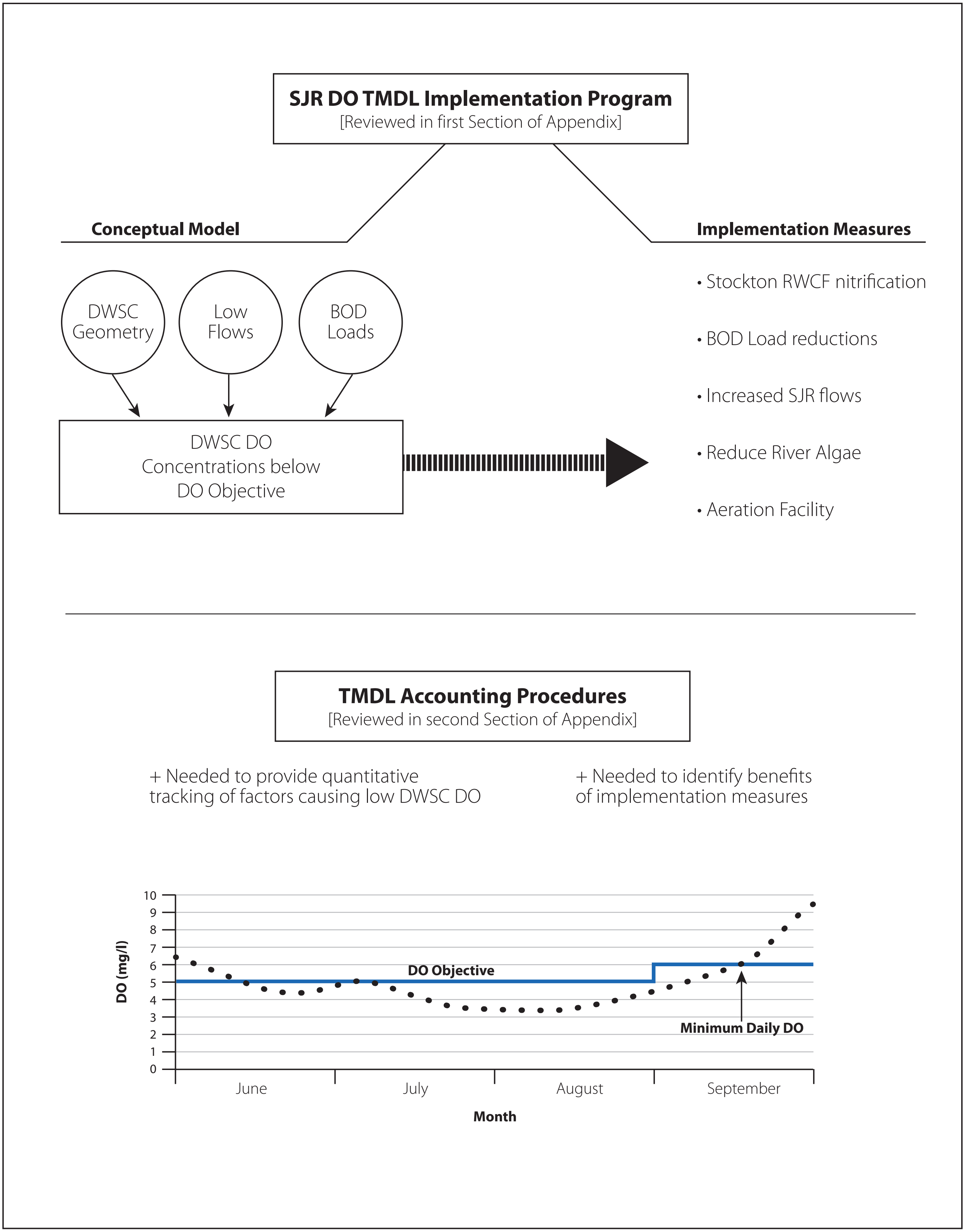

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Figure 1a
Diagram of the SJR DO TMDL Implementation Program

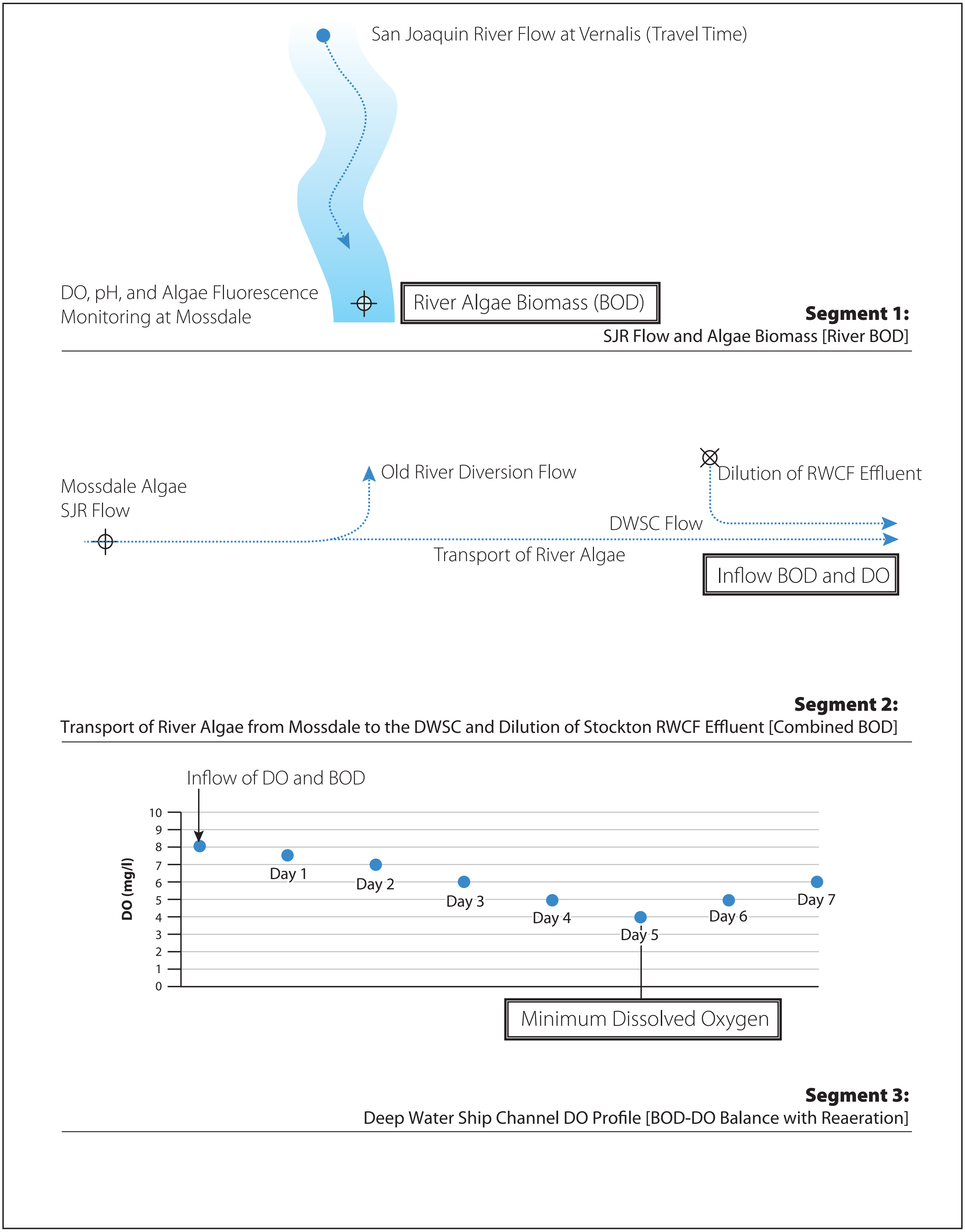

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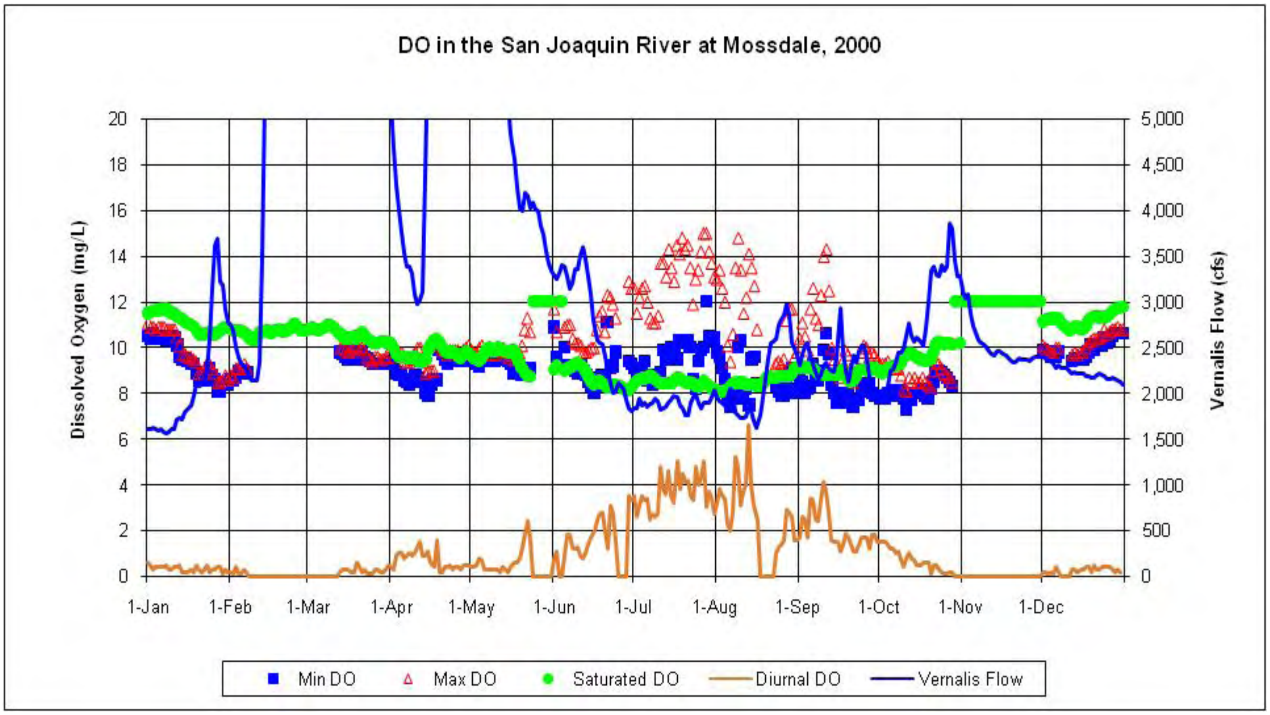
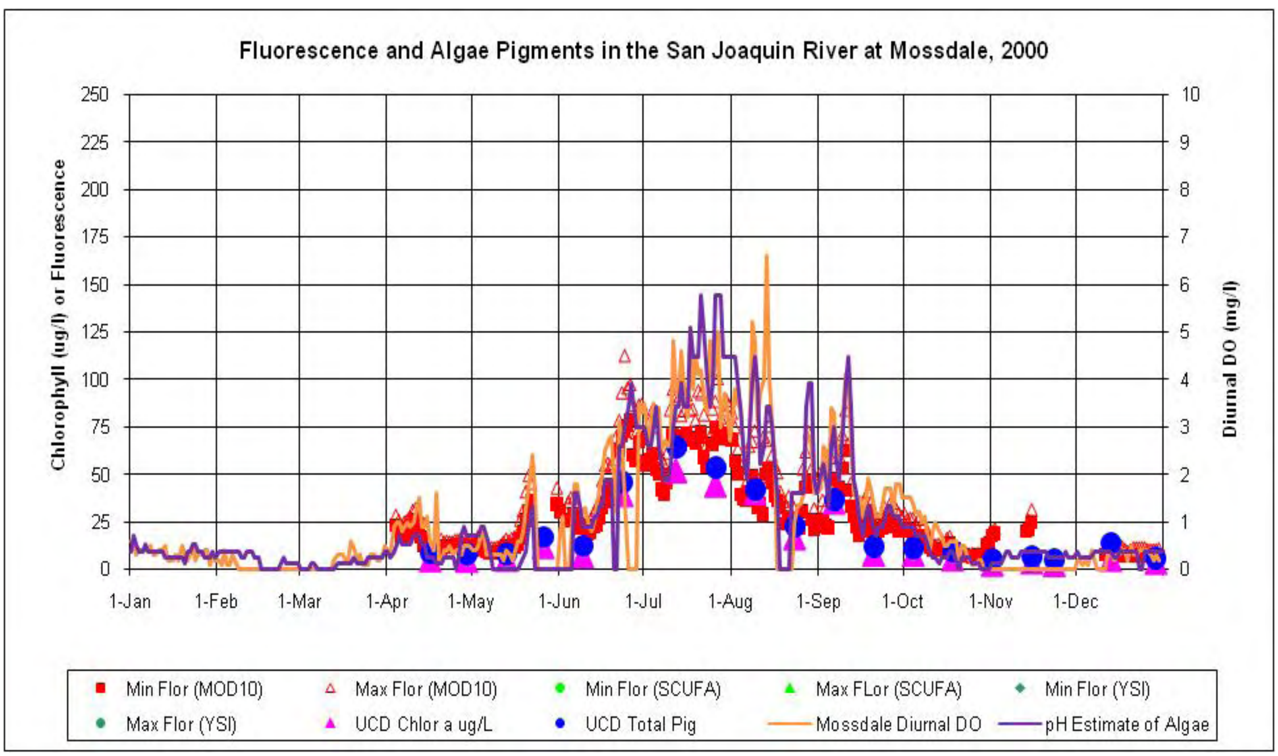
Figure 1b
Framework for the SJR DO TMDL Accounting Procedures

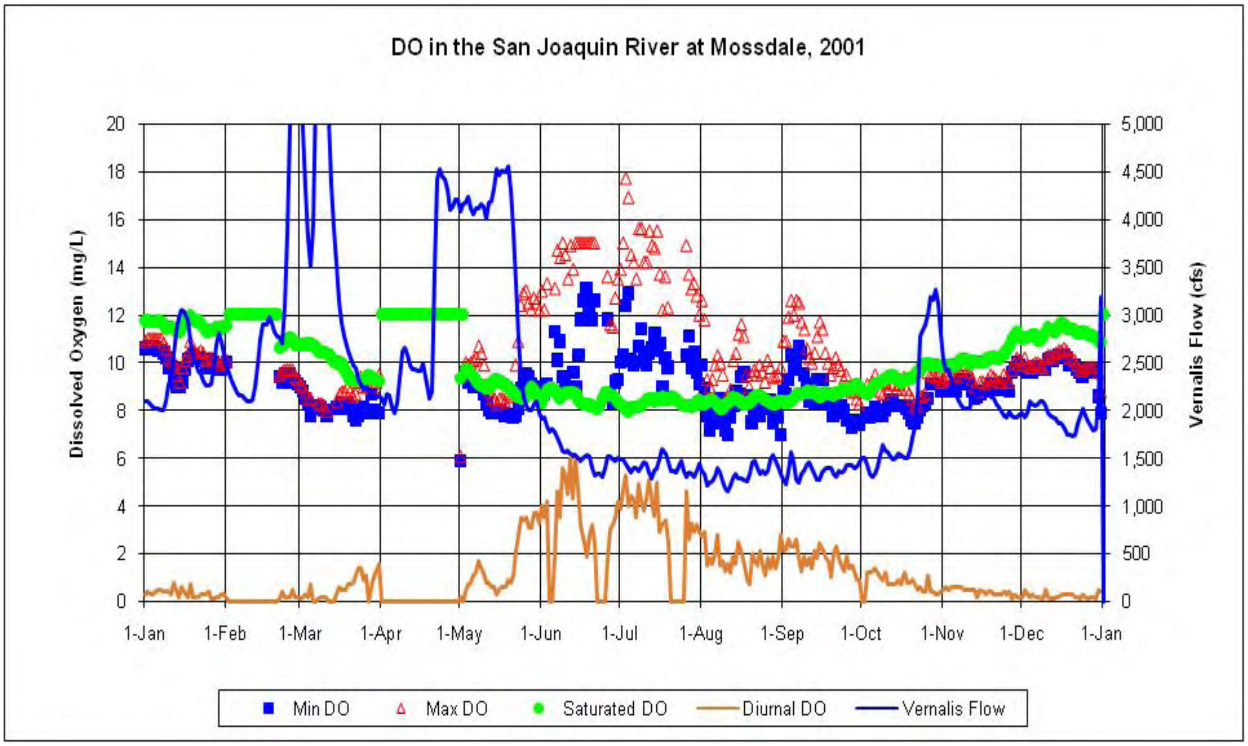


a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2000.

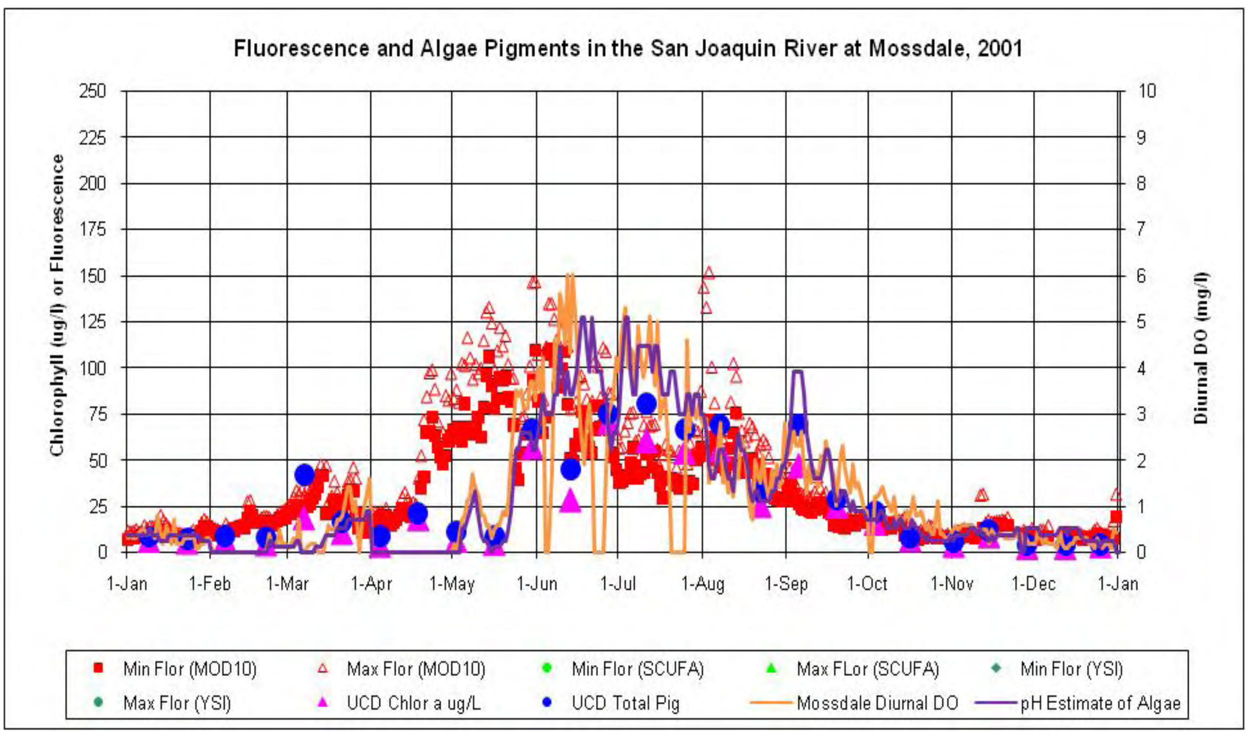


b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH, Measured Fluorescence, and Extracted Algae Pigment (UC Davis) Concentrations at Mossdale for 2000. (Turner Model 10 fluorescence multiplied by 0.5 to match UCD pigment).

Figure 2

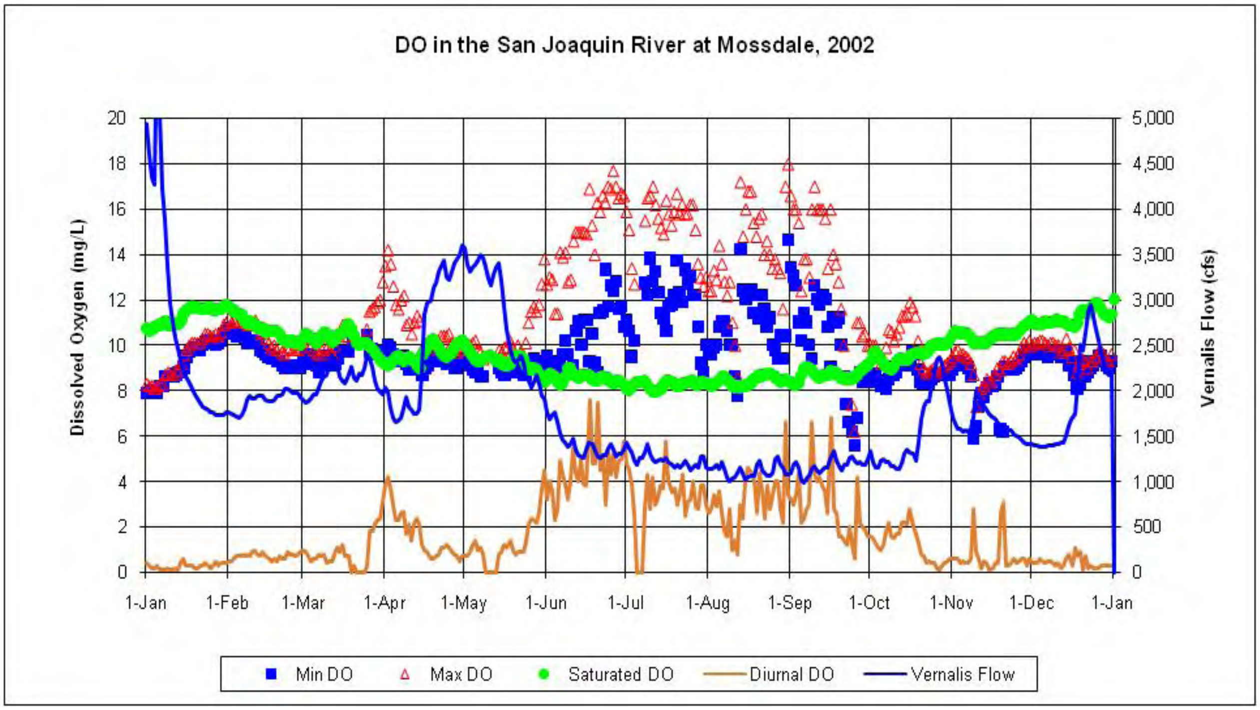


a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2001.

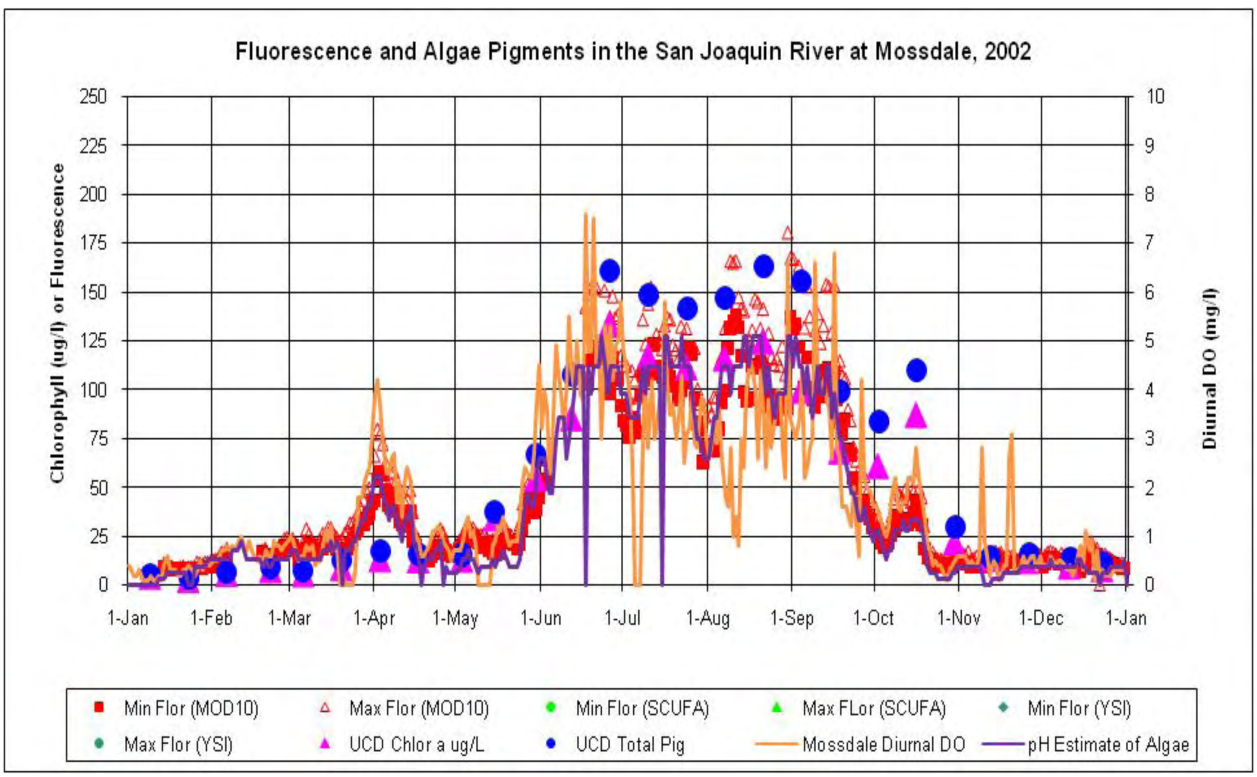


b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH, Measured Fluorescence, and Extracted Algae Pigment (UC Davis) Concentrations at Mossdale for 2001. (Turner Model 10 fluorescence multiplied by 0.5 to match UCD pigment).

Figure 3

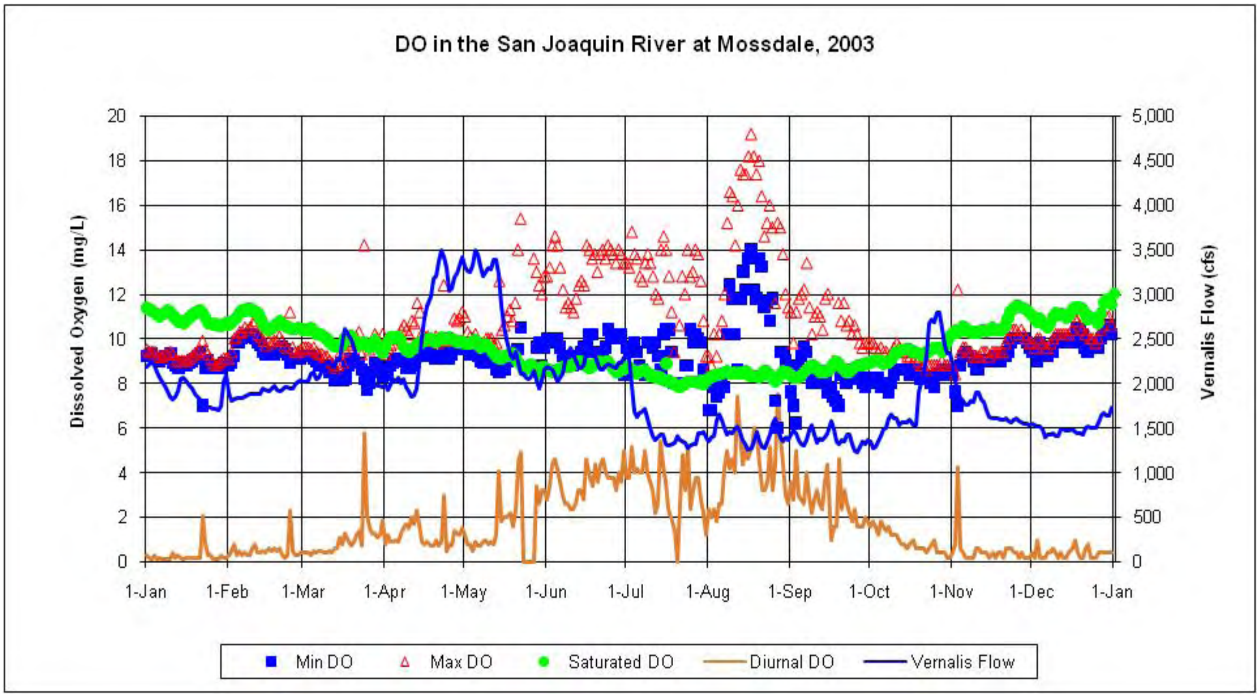


a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2002.

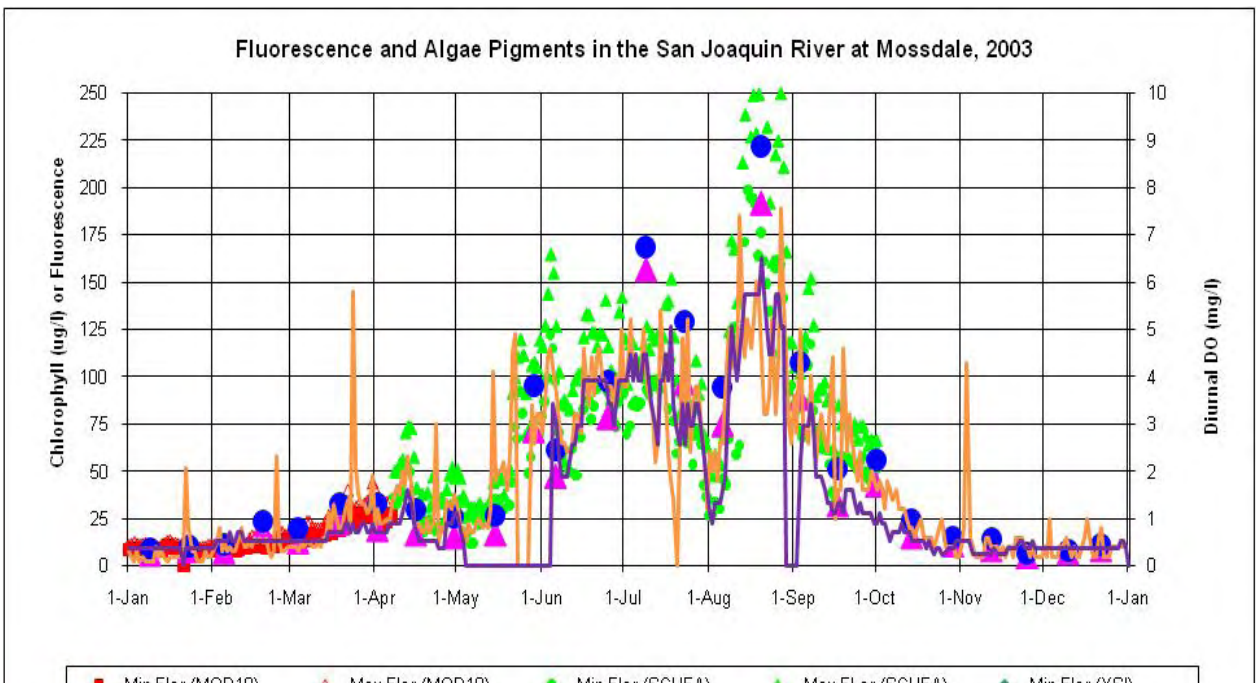


b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH, Measured Fluorescence, and Extracted Algae Pigment (UC Davis) Concentrations at Mossdale for 2002. (note: Turner Model 10 fluorescence multiplied by 0.5 to match UCD pigment).

Figure 4

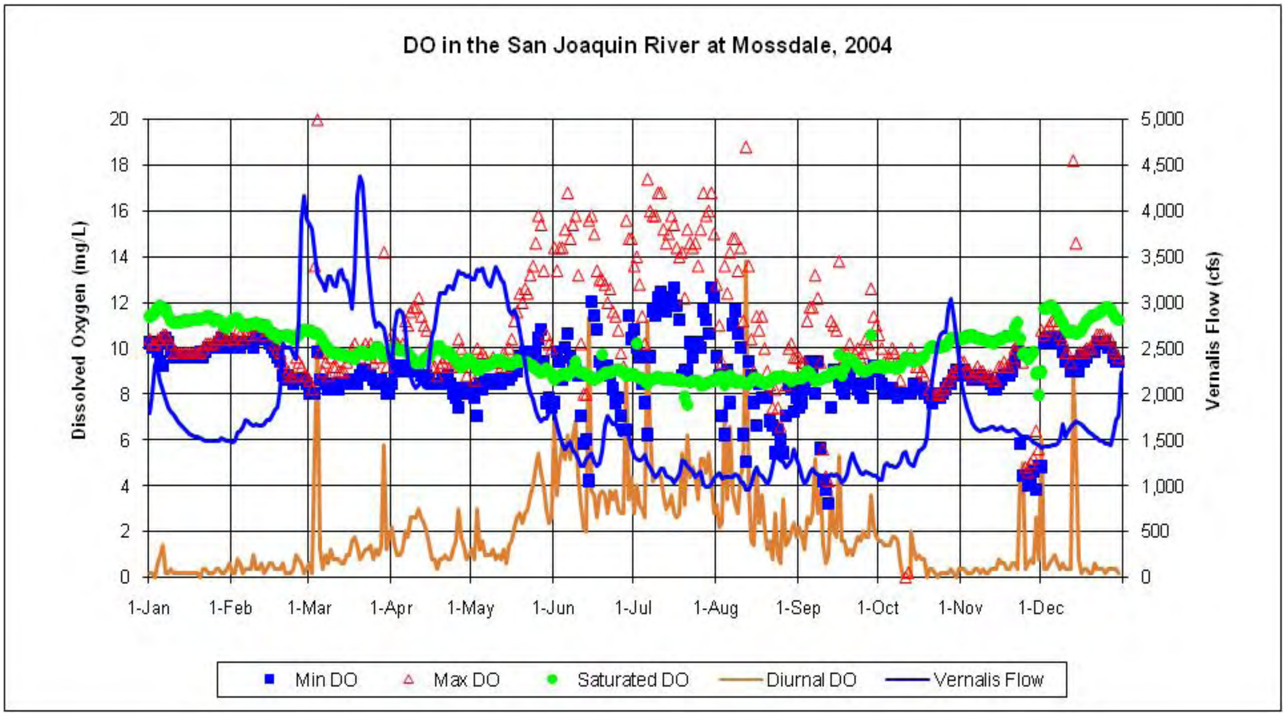


a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2003.

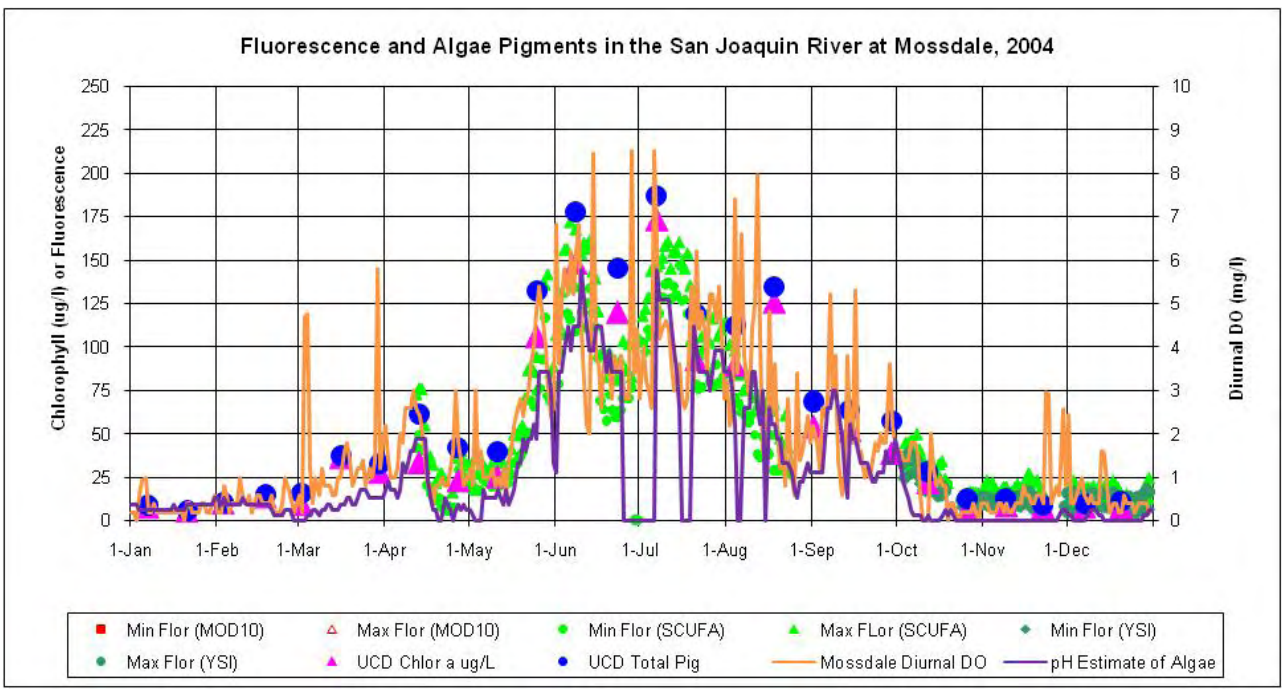


b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH, Measured Fluorescence, and Extracted Algae Pigment (UC Davis) Concentrations at Mossdale for 2003. (note: Turner SCUFA fluorescence multiplied by 2.5 to match UCD pigment).

Figure 5



a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2004.



b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH, Measured Fluorescence, and Extracted Algae Pigment (UC Davis) Concentrations at Mossdale for 2004. (note: Turner SCUFA fluorescence multiplied by 2.5 to match UCD pigment. YSI fluorescence (began in October) multiplied by 1.5 to match UCD pigment).

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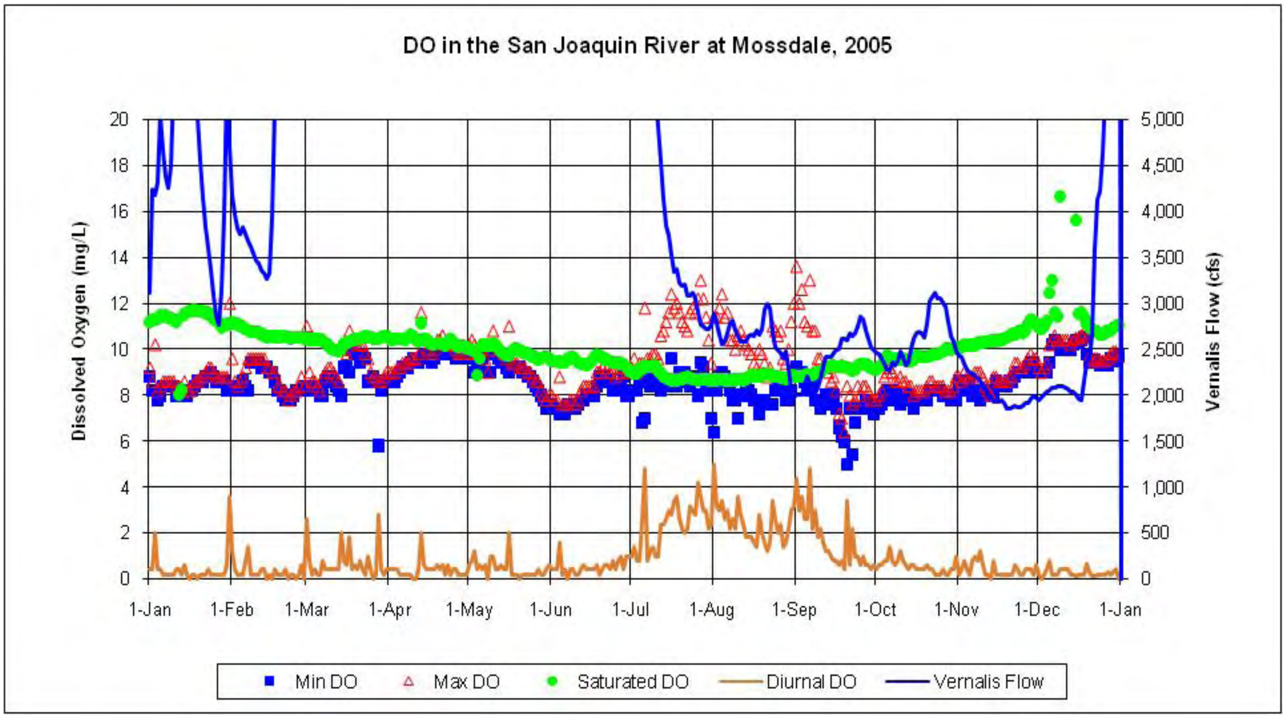
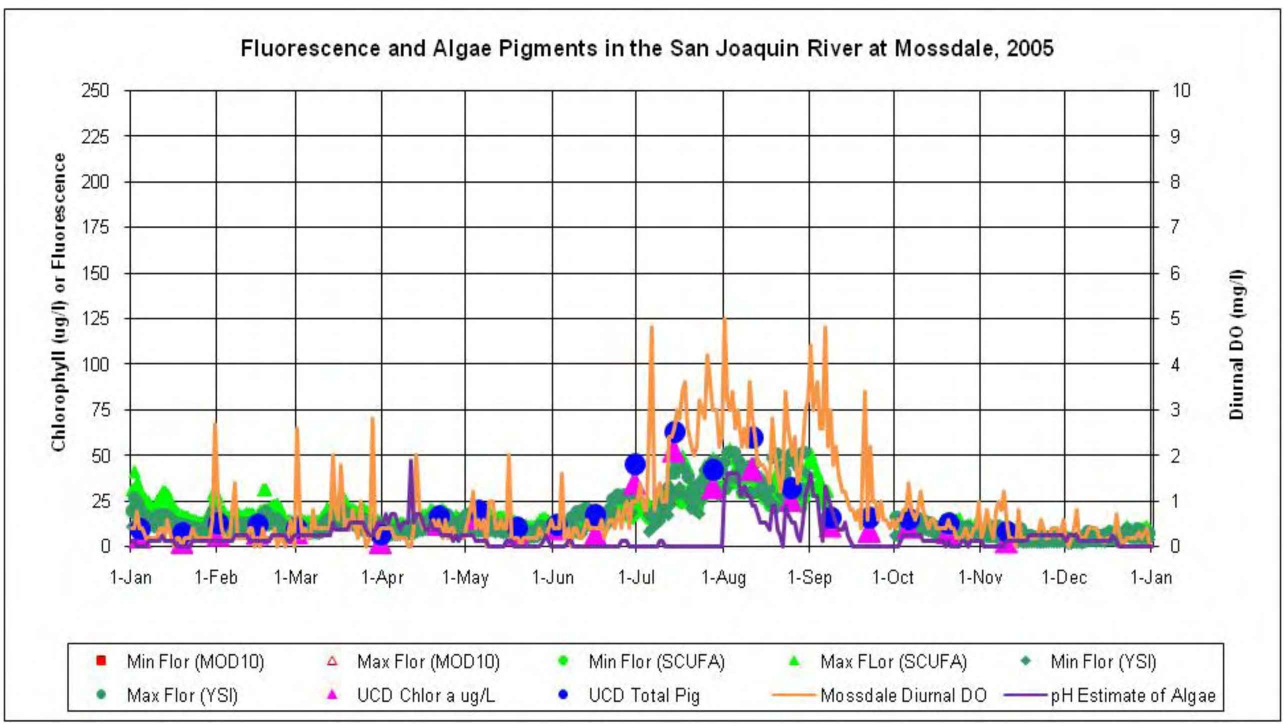
Figure 6



a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2005.



b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH, Measured Fluorescence, and Extracted Algae Pigment (UC D and UOP) Concentrations at Mossdale for 2005. (note: Turner SCUFA fluorescence multiplied by 2.5 to match UCD pigment [ends in September]. YSI fluorescence multiplied by 1.5 to match UCD pigment).

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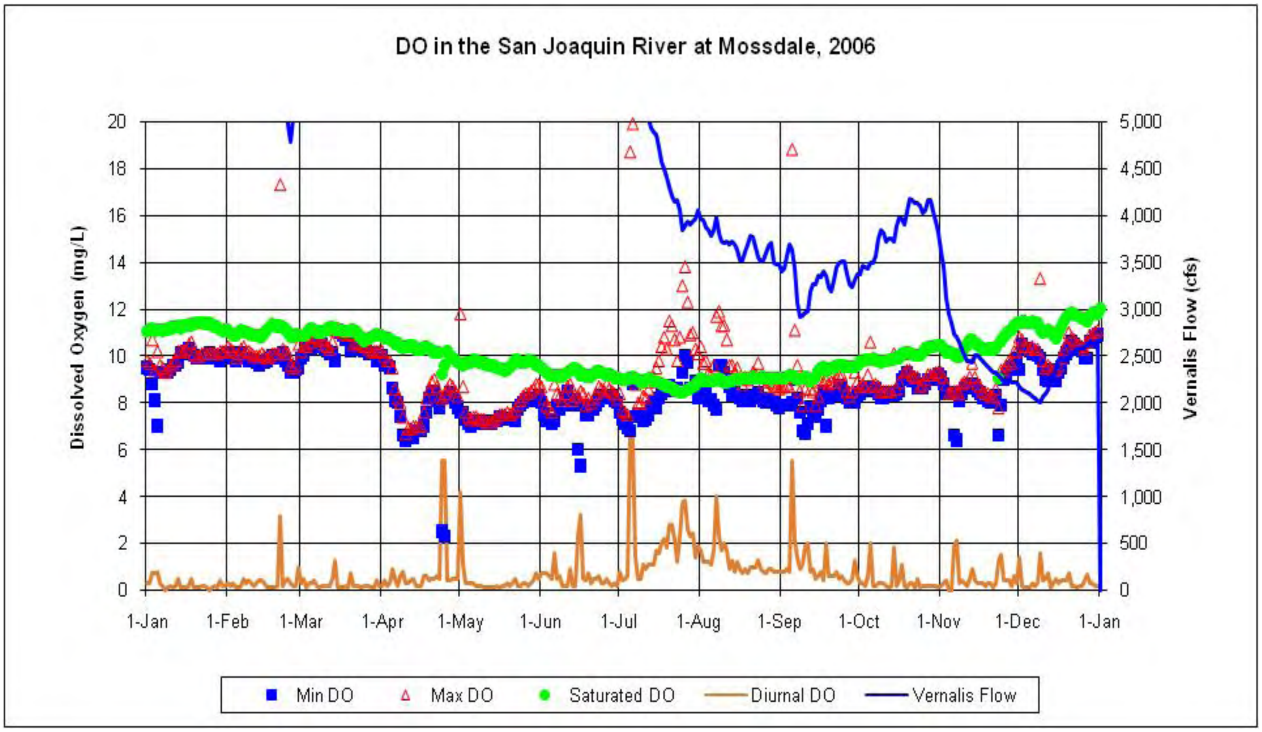
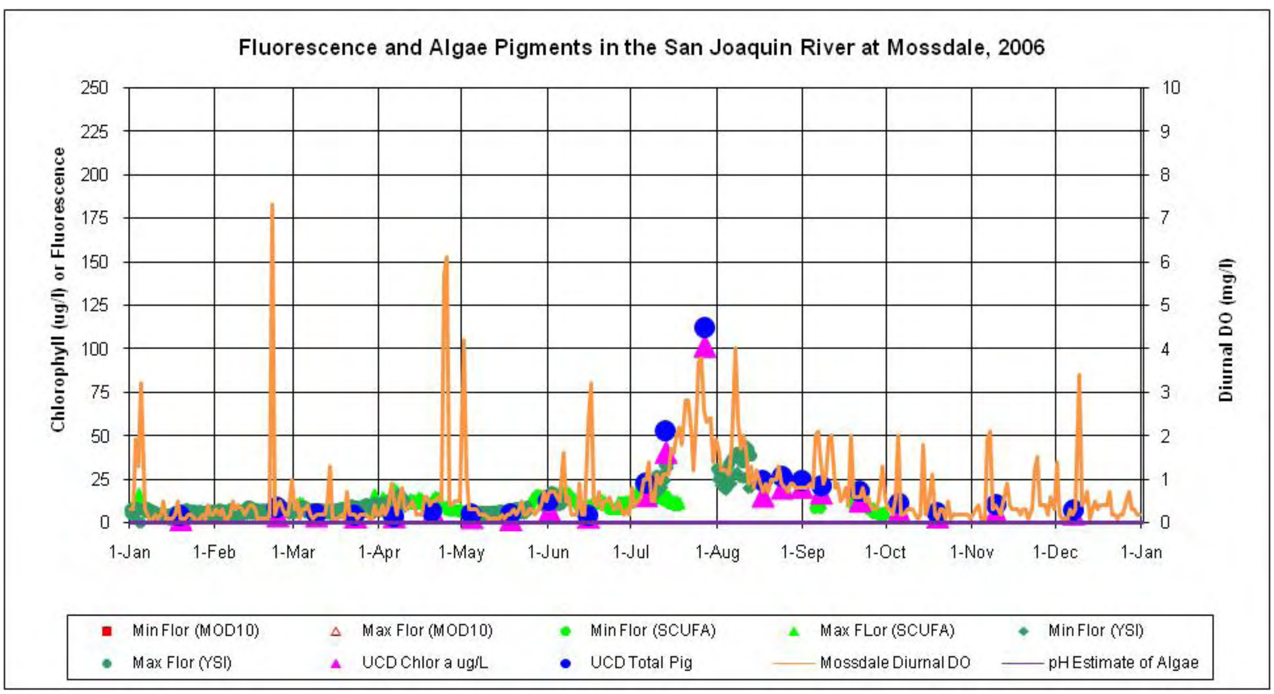
Figure 7



a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2006.



b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH (not shown), Measured Fluorescence (not shown), and Extracted Algae Pigment (UOP) Concentrations at Mossdale for 2006. (note: YSI fluorescence multiplied by 1.5 to match UCD pigment).

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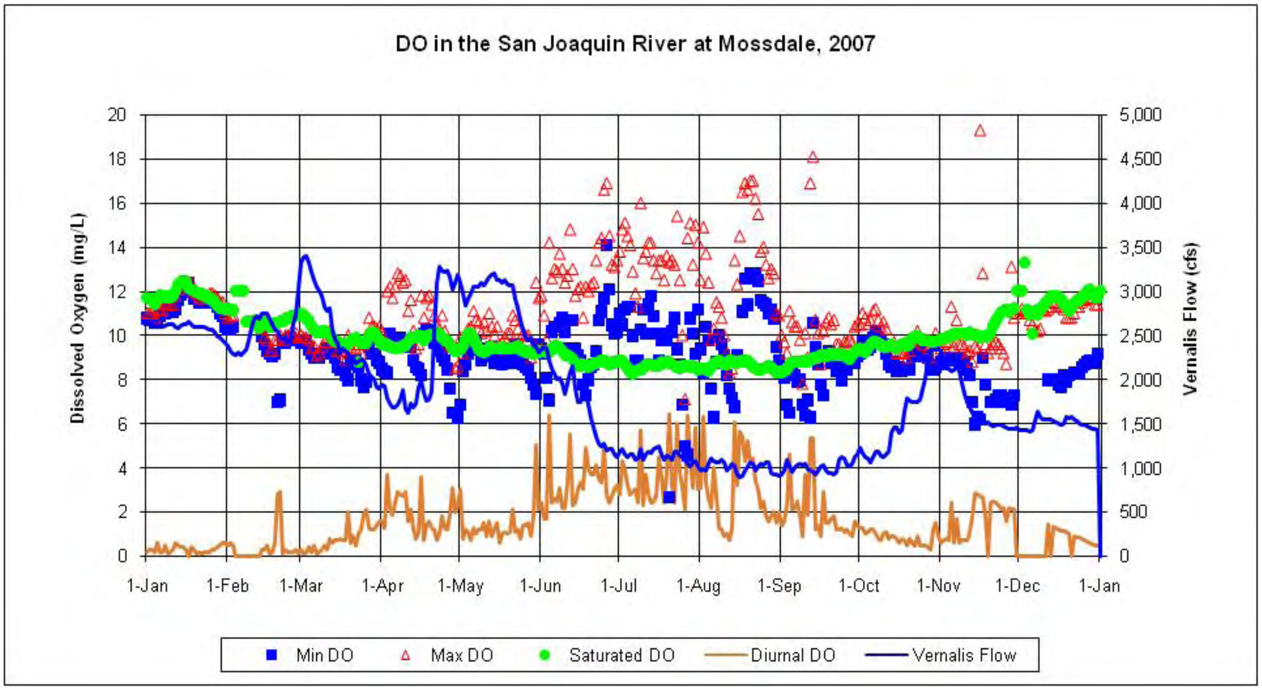
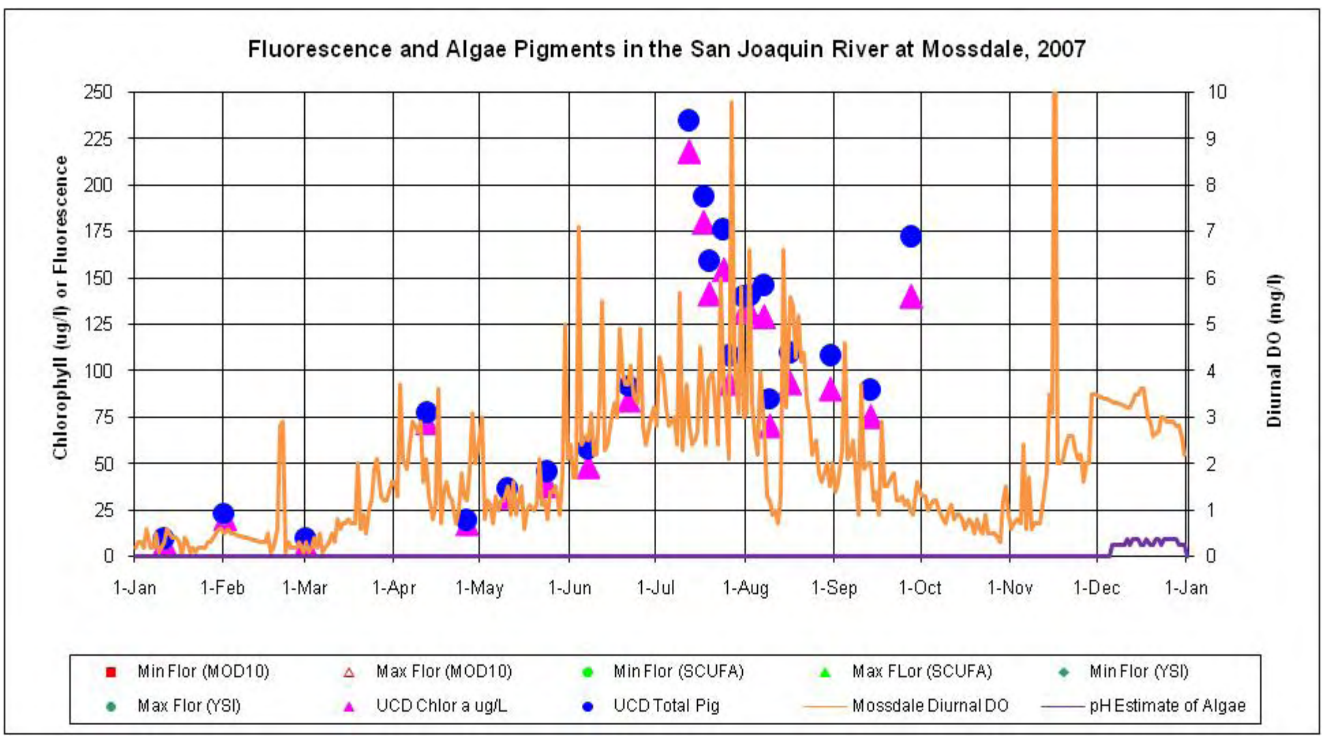
Figure 8



a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2007.



b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH(not shown), Measured Fluorescence (not shown), and Extracted Algae Pigment (UC Davis) Concentrations at Mossdale for 2007.

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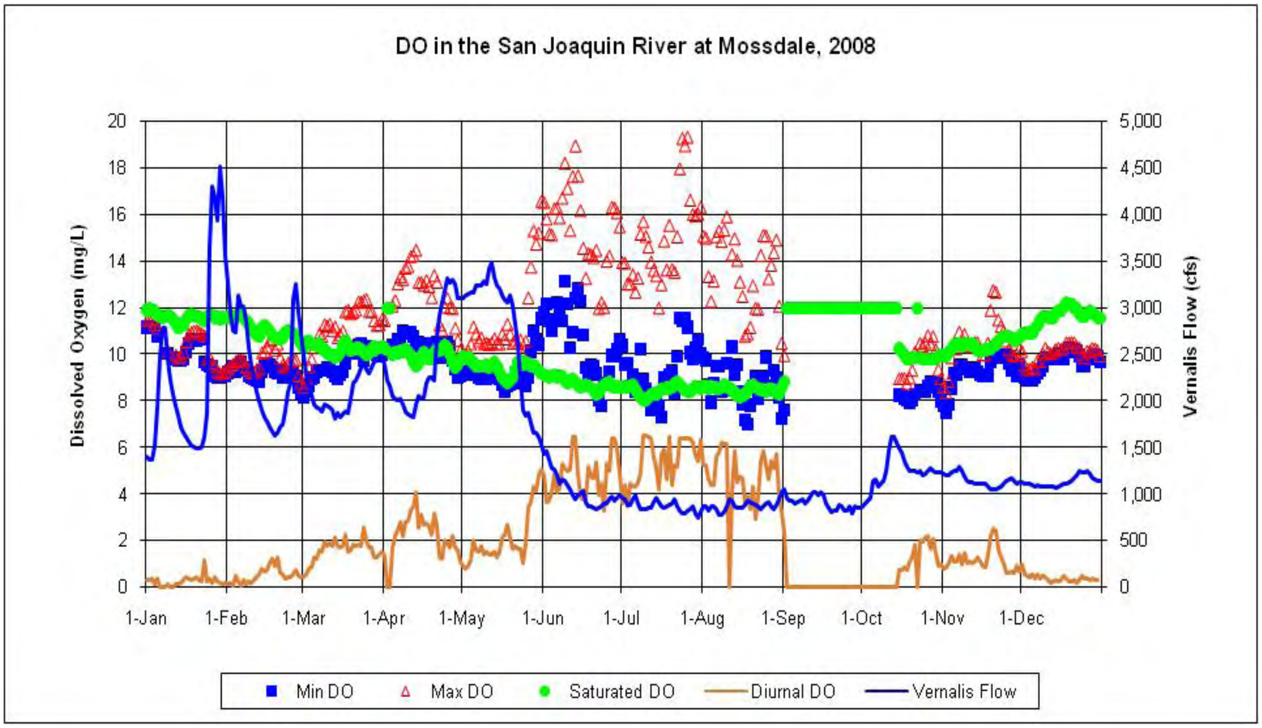
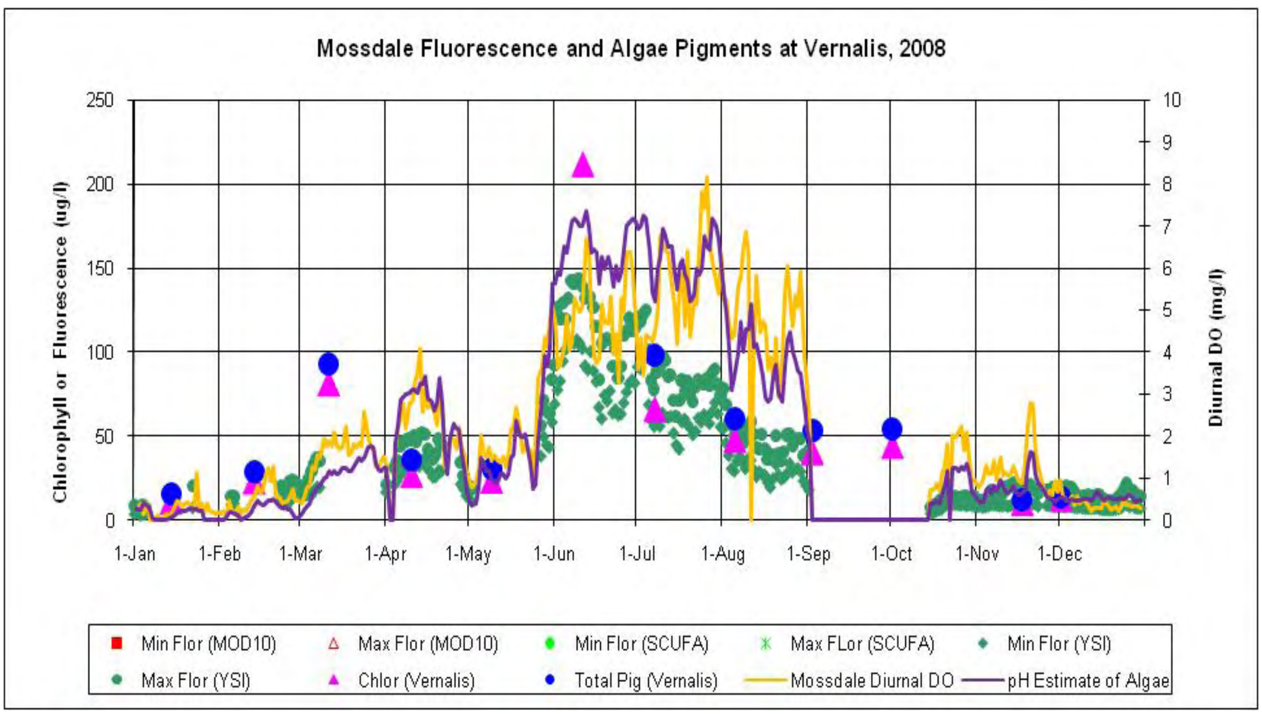
Figure 9



a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2008.



b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH, Measured Fluorescence, and Extracted Algae Pigment (DWR) Concentrations at Mossdale for 2008. (note: YSI fluorescence multiplied by 1.5 to match DWR algae pigment).

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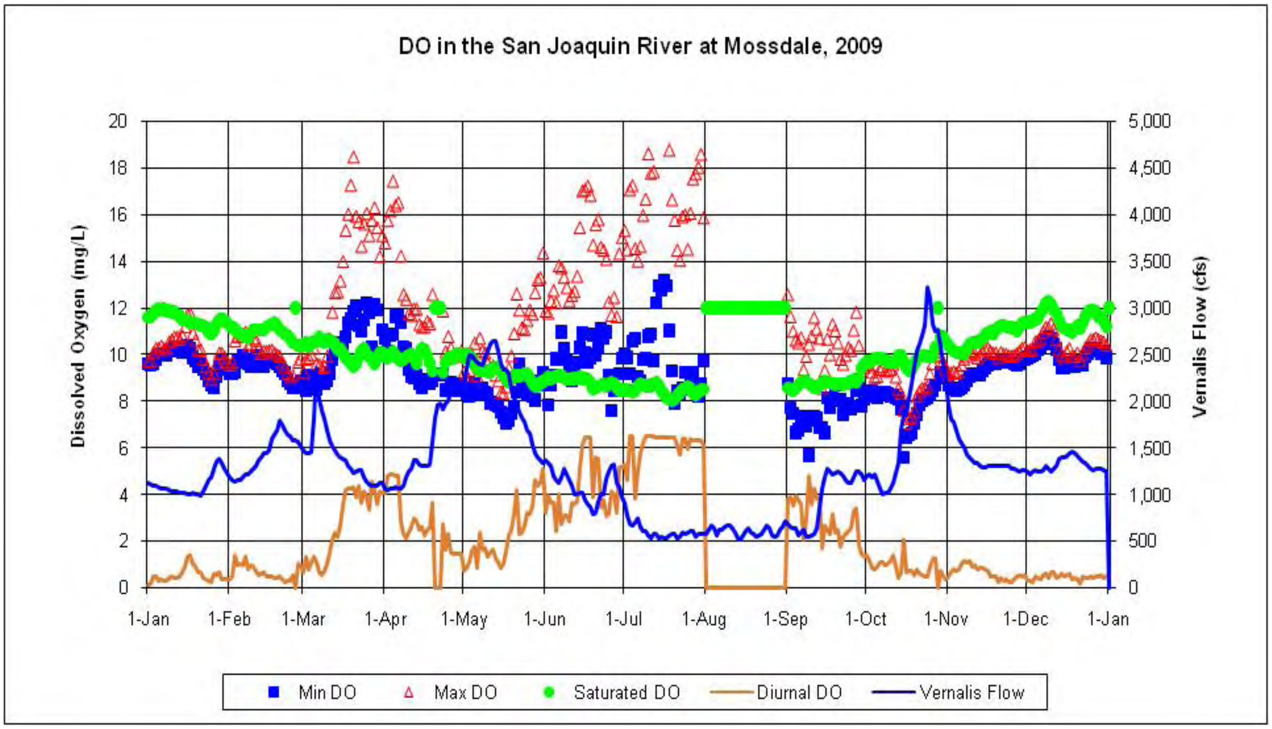
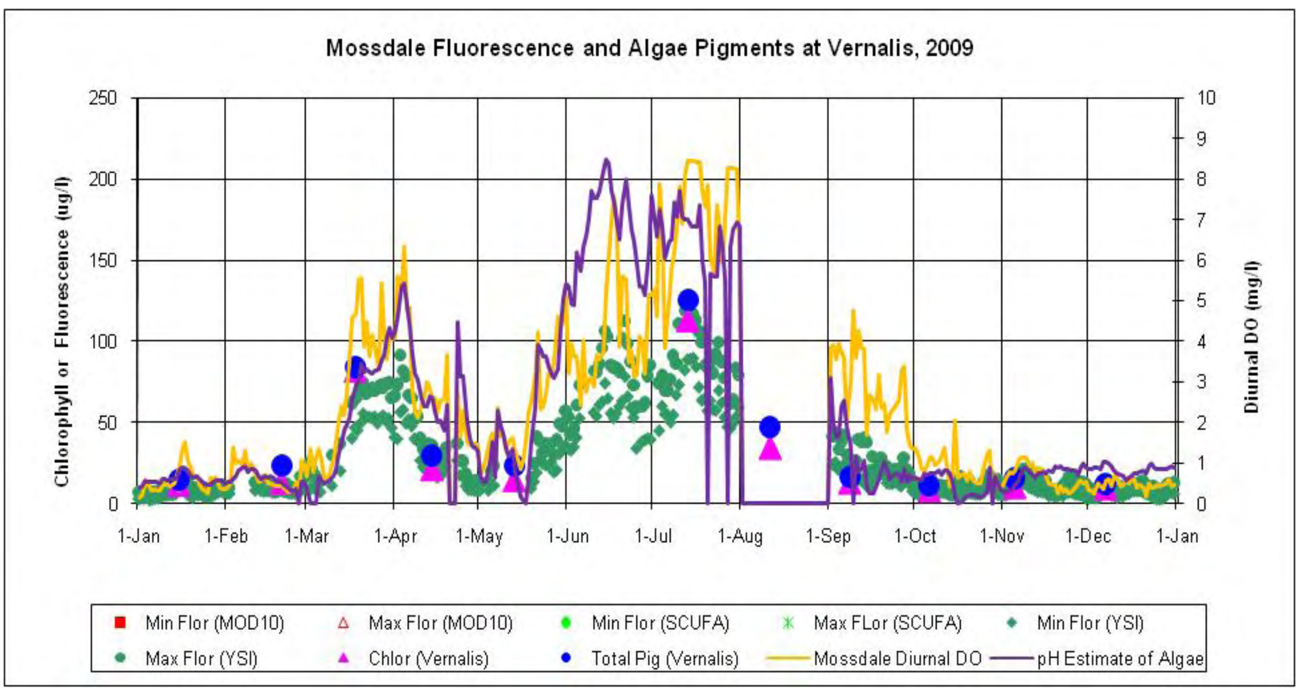
Figure 10

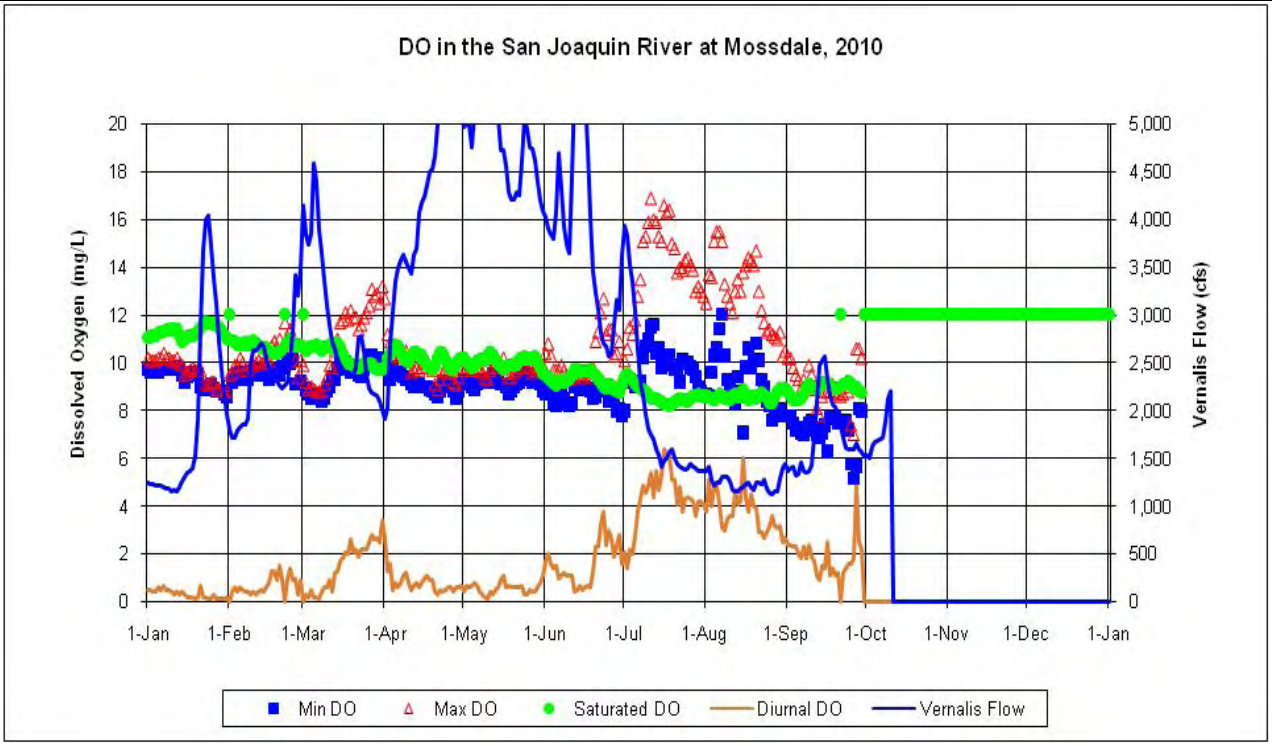


a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2009.

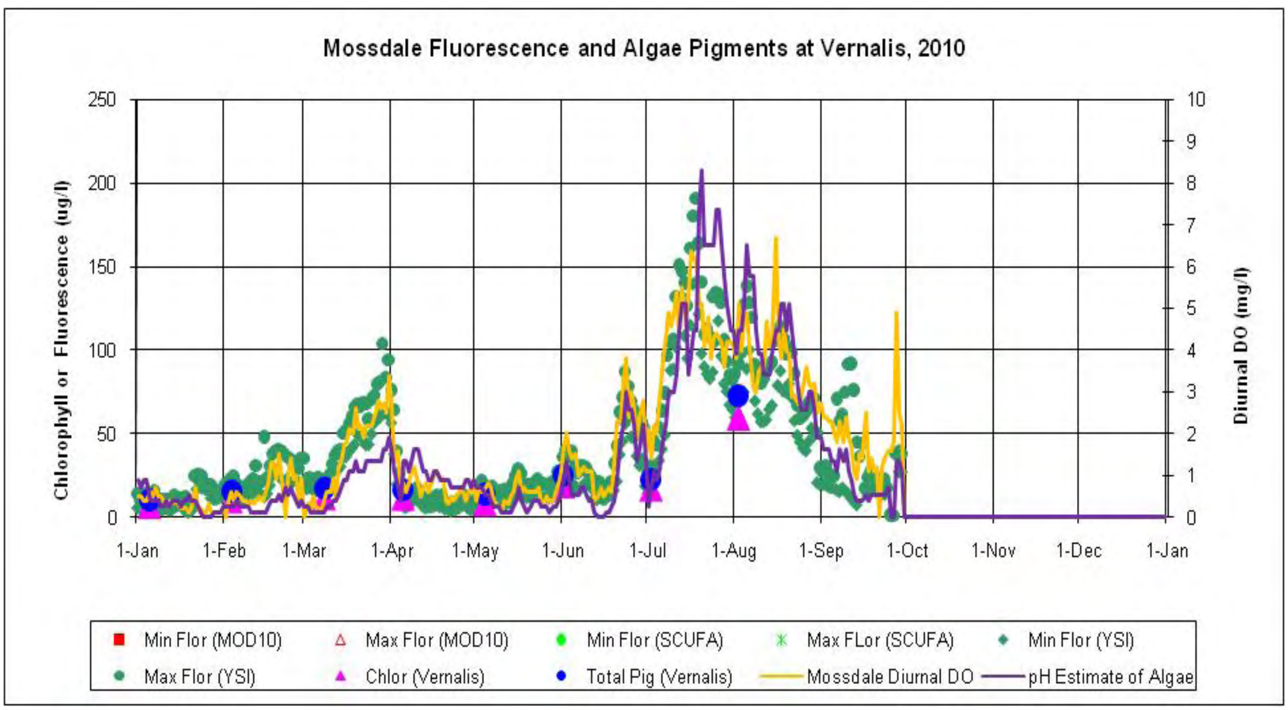


b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH, Measured Fluorescence, and Extracted Algae Pigment (DWR) Concentrations at Mossdale for 2009. (note: YSI fluorescence multiplied by 1.5 to match DWR algae pigment).

Figure 11

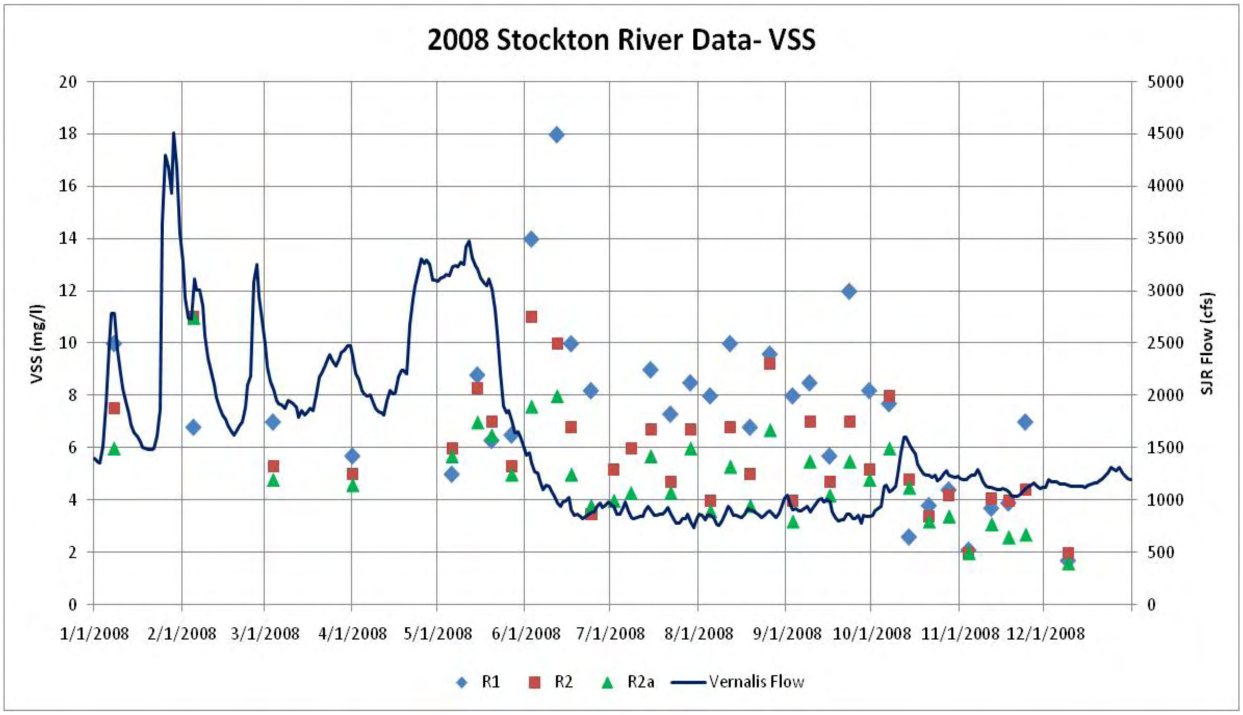


a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2010.

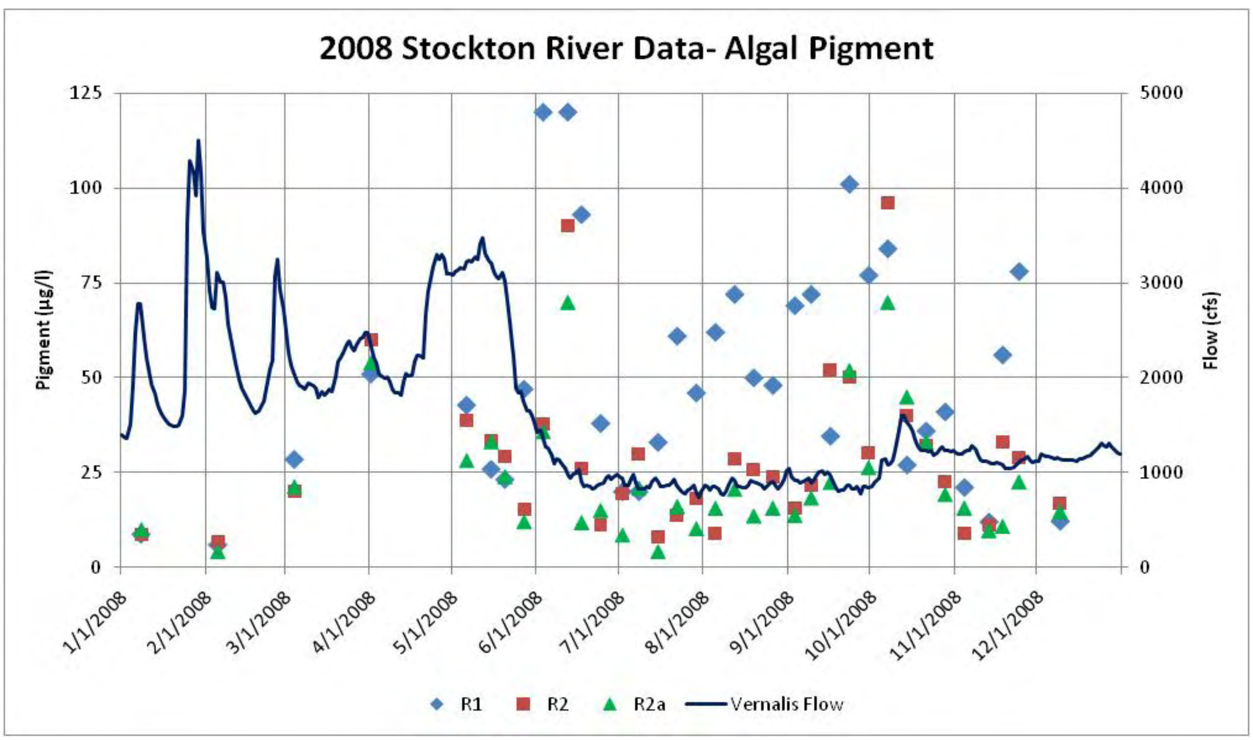


b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH, Measured Fluorescence, and Extracted Algae Pigment (DWR) Concentrations at Mossdale for 2010. (note: YSI fluorescence multiplied by 1.5 to match DWR algae pigment).

Figure 12

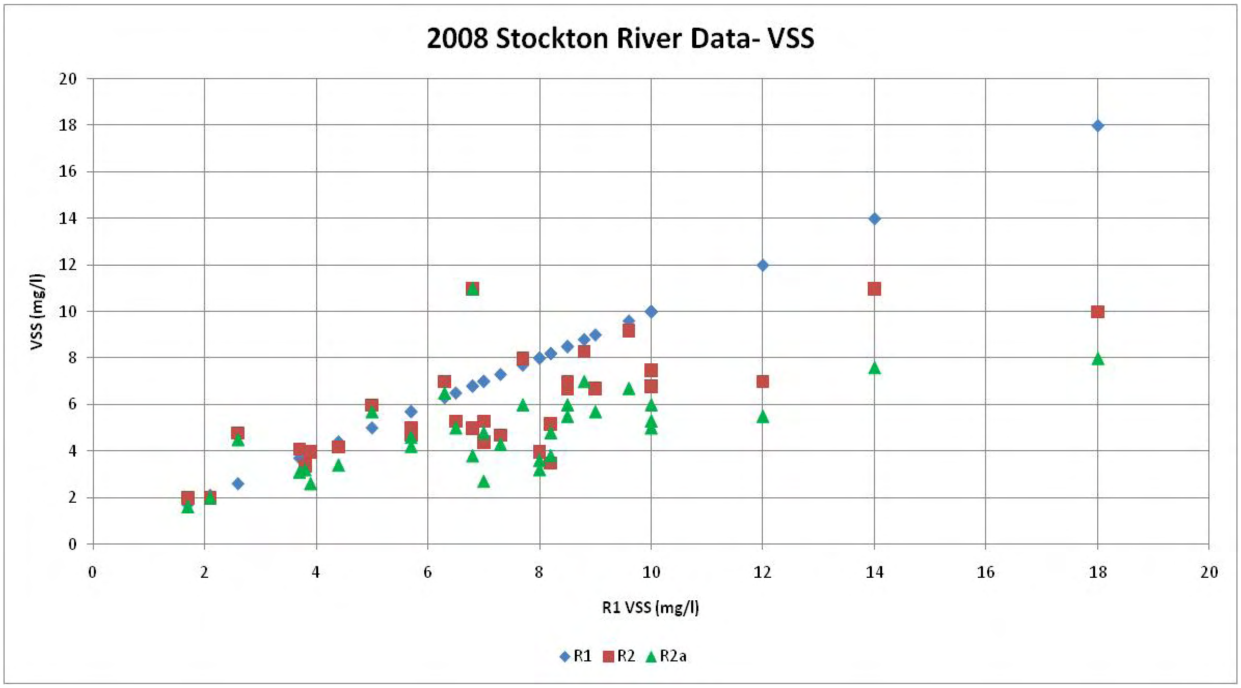


a) City of Stockton River Station Measurements of VSS at R1, R2, and R2a for 2008.

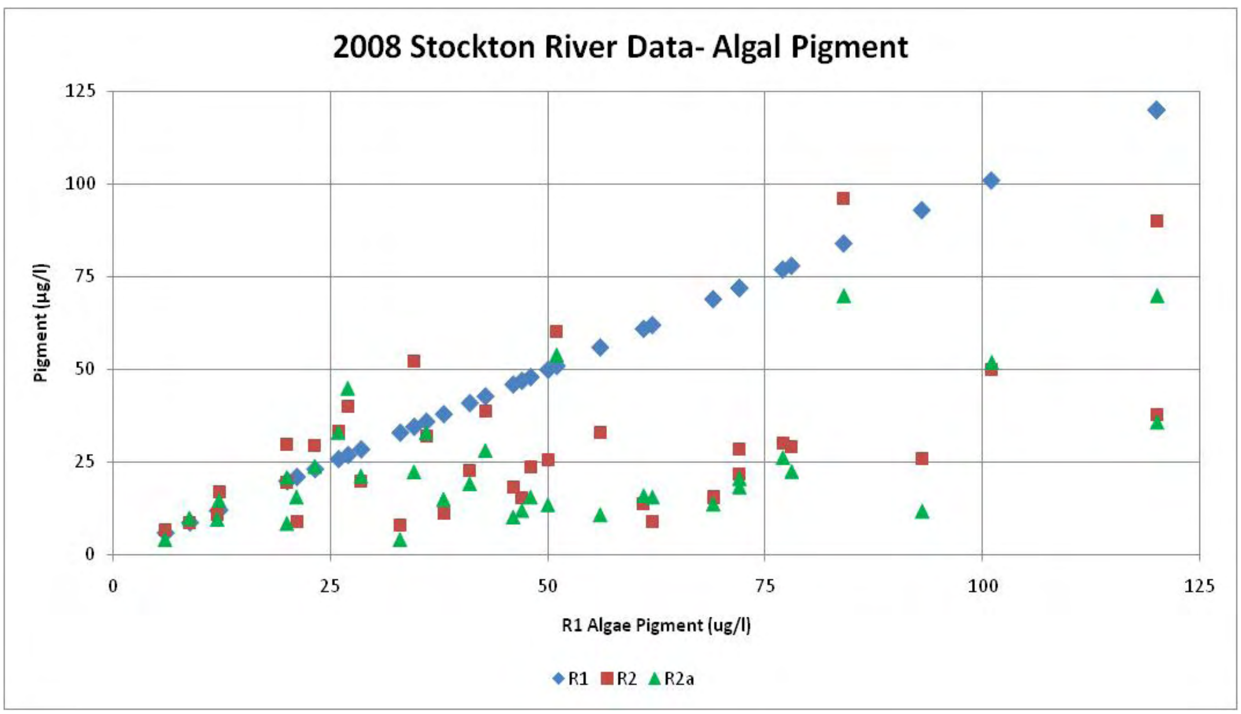


b) City of Stockton River Station Measurements of Algae Pigment (chlorophyll and phaeophytin)at R1, R2, and R2a for 2008. The San Joaquin River flow at Vernalis is shown for comparison.

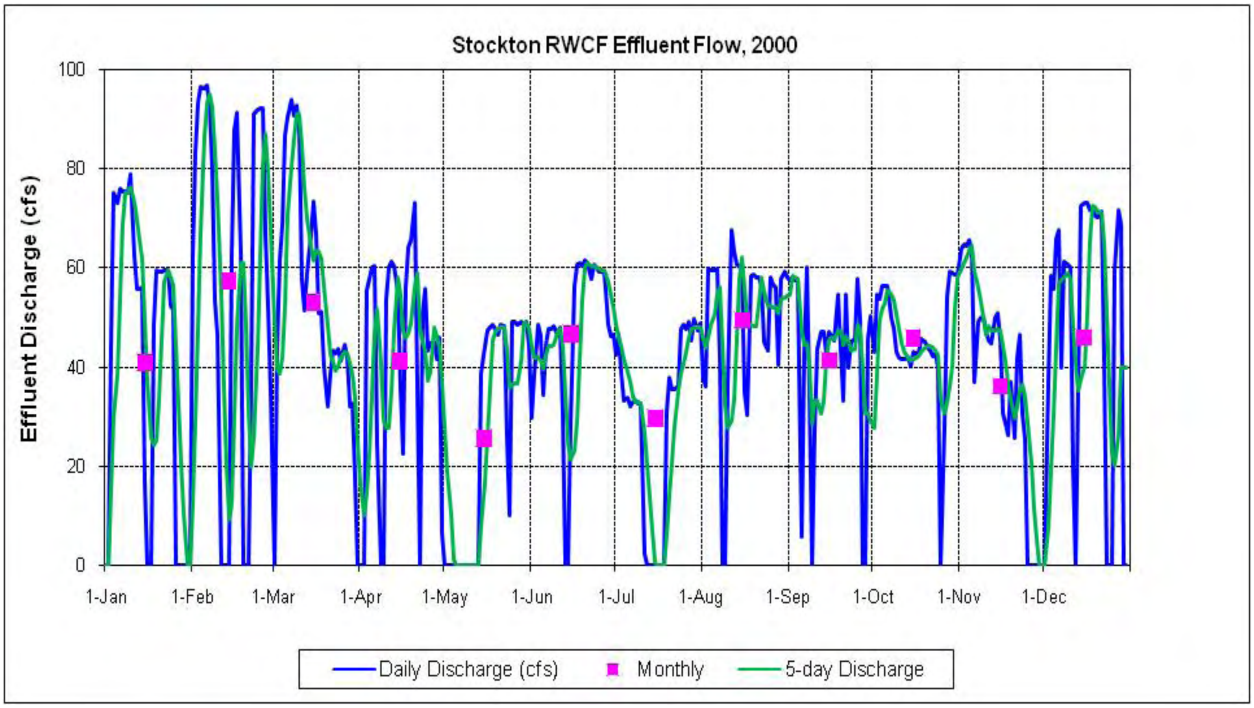
Figure 13



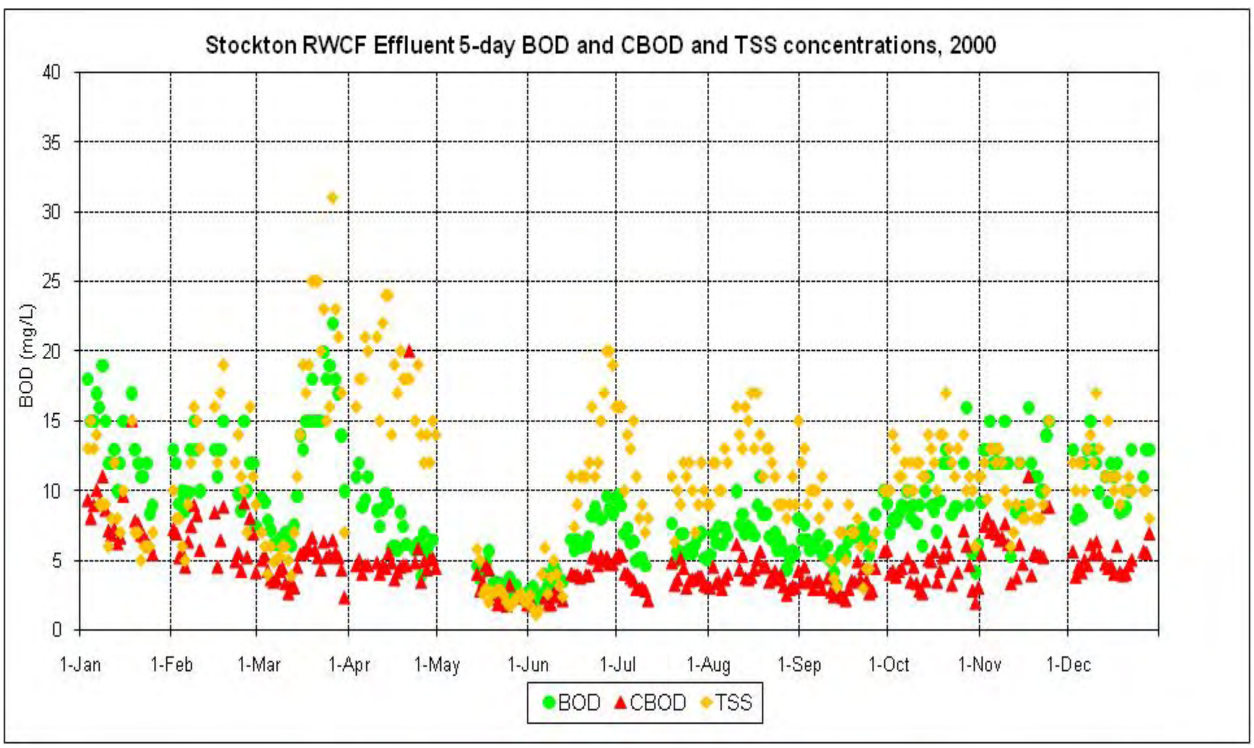
c) City of Stockton River Station Reduction of VSS from R1 to R2 and R2a for 2008.



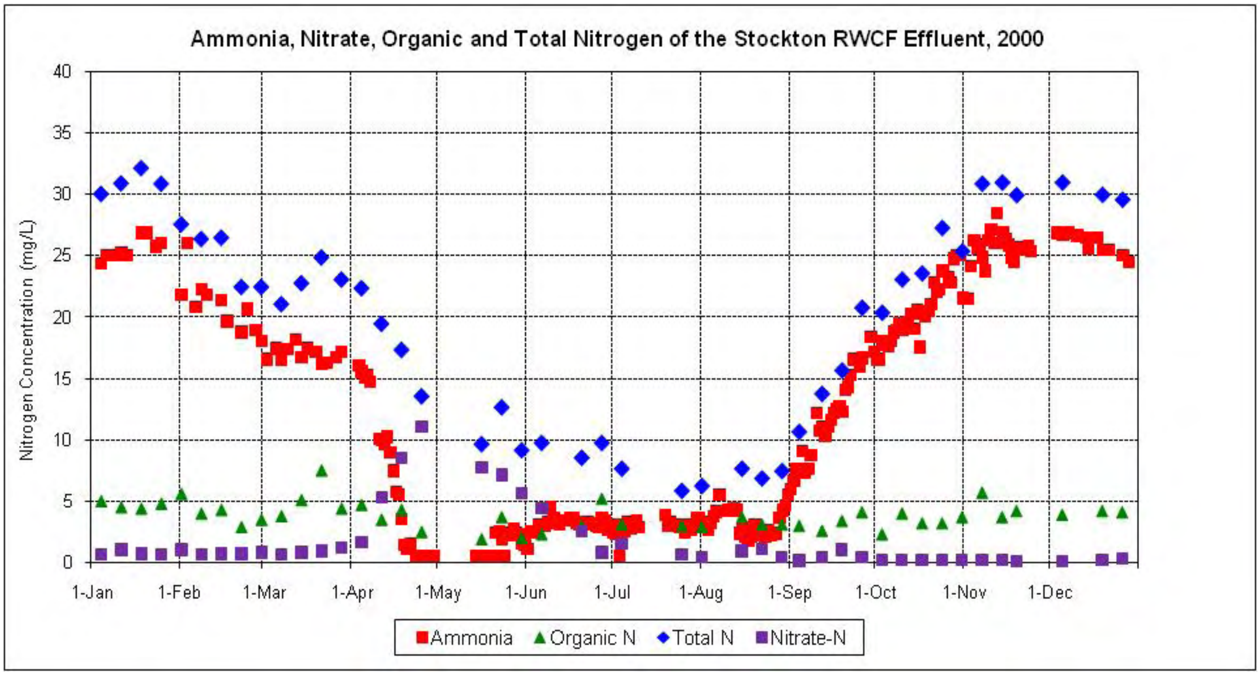
d) City of Stockton River Station Reduction of Algae Pigment from R1 to R2 and R2a for 2008.



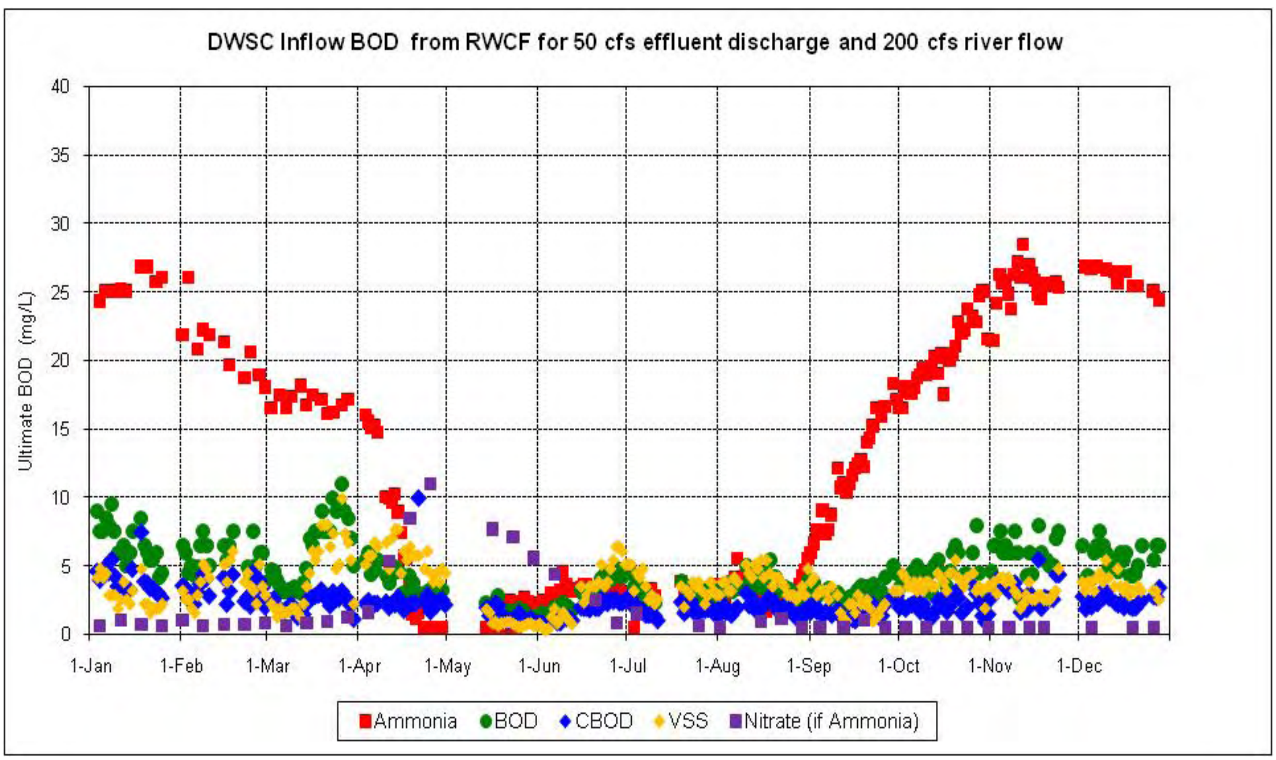
a) Stockton RWCF effluent daily discharge, 5-day moving average discharge and monthly average discharge (cfs) for 2000.



b) Daily measurements of 5-day BOD, 5-day CBOD and TSS concentrations (mg/l) for 2000.



c) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2000.



d) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2000.

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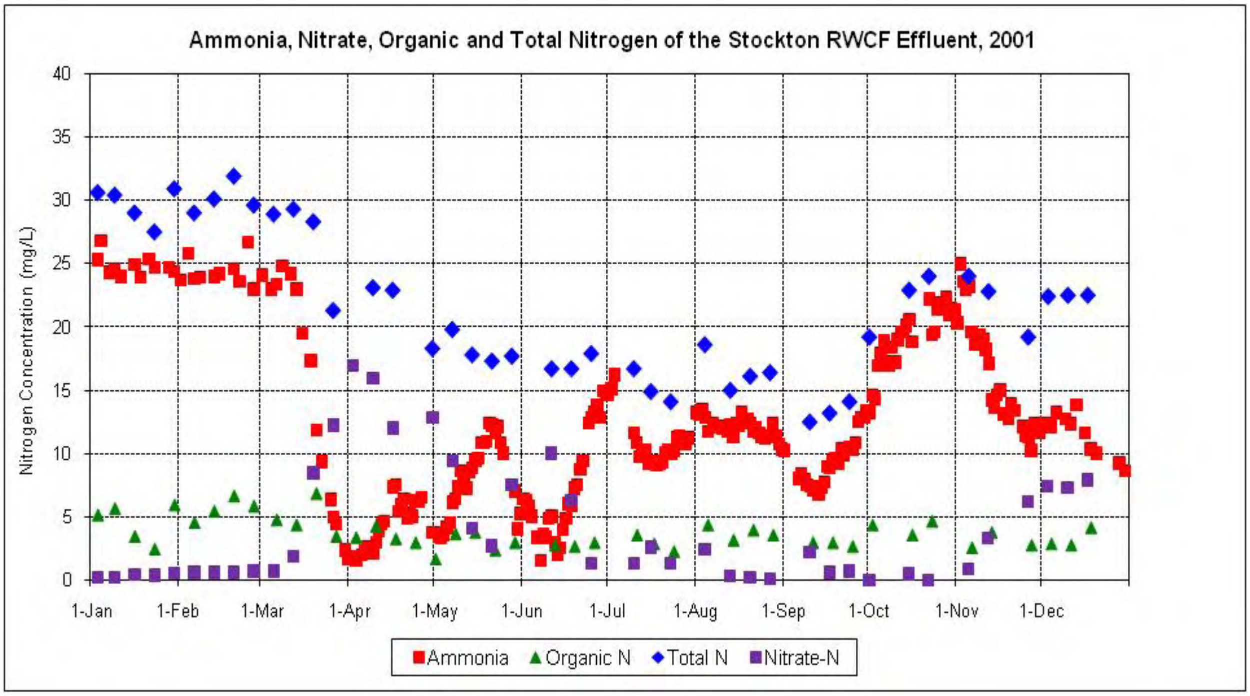
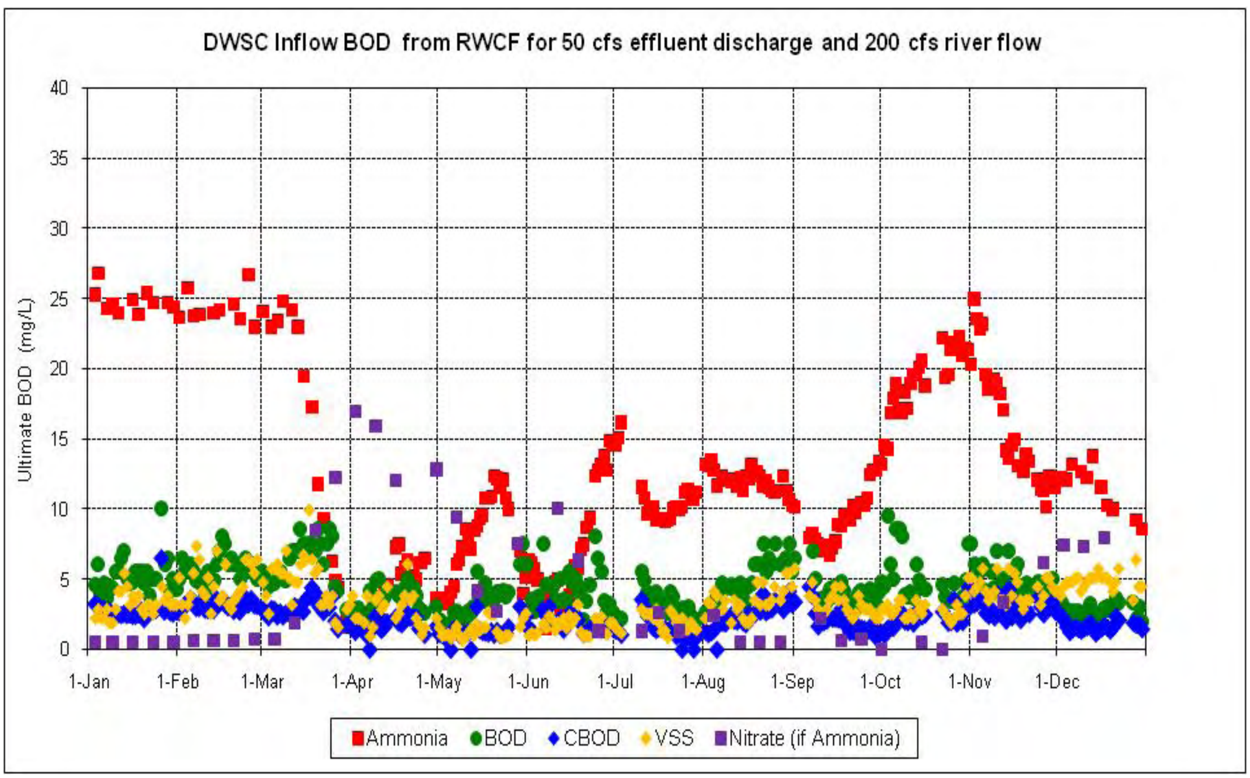
Figure 14
Continued

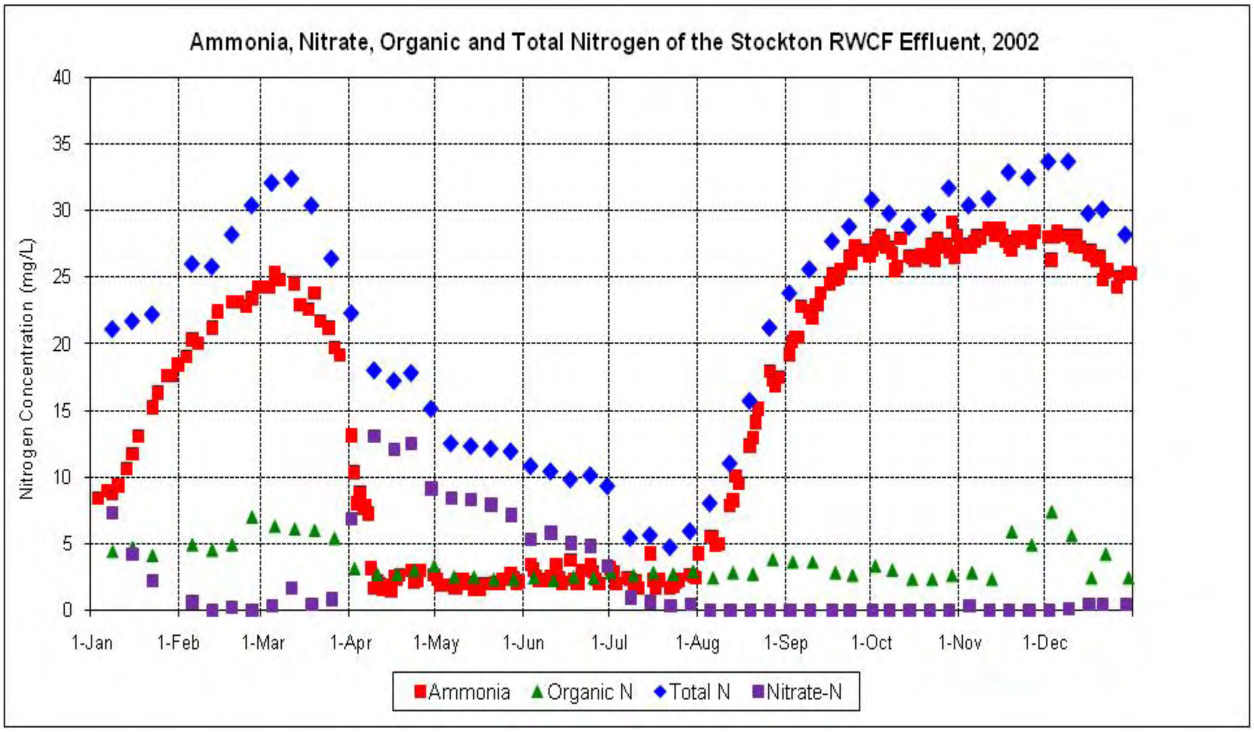


a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2001.

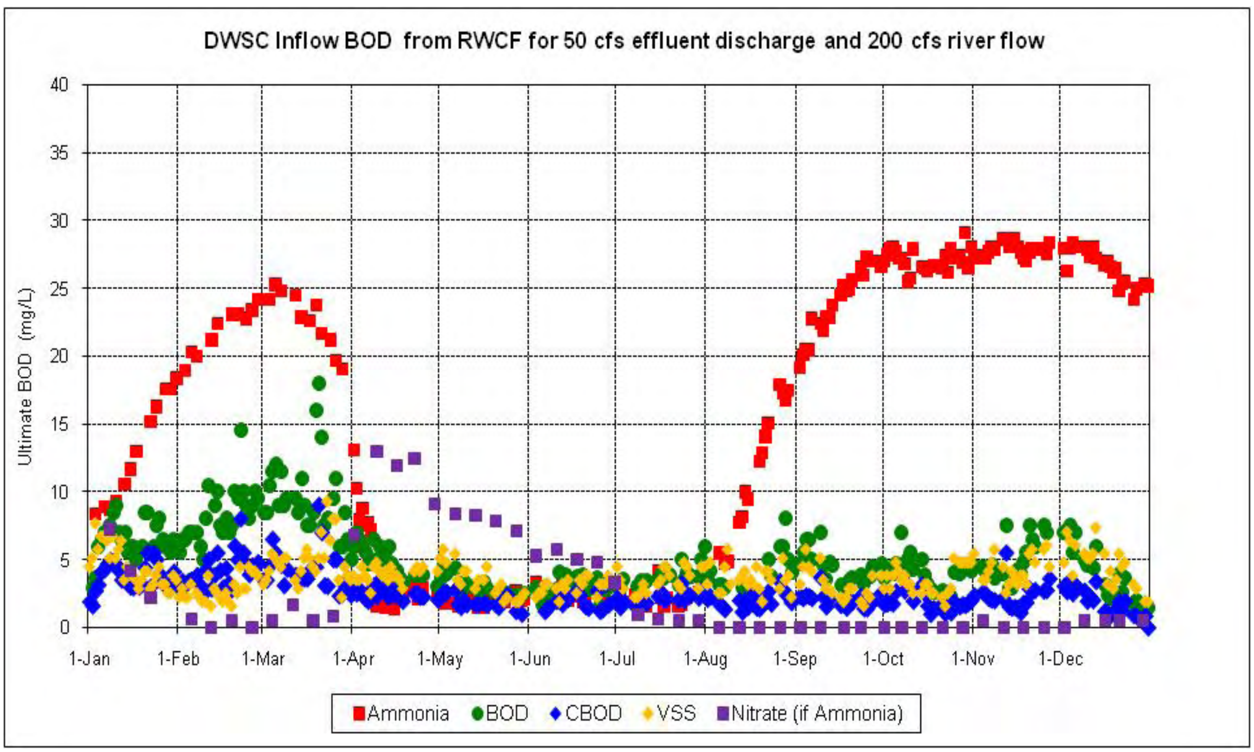


b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2001.

Figure 15



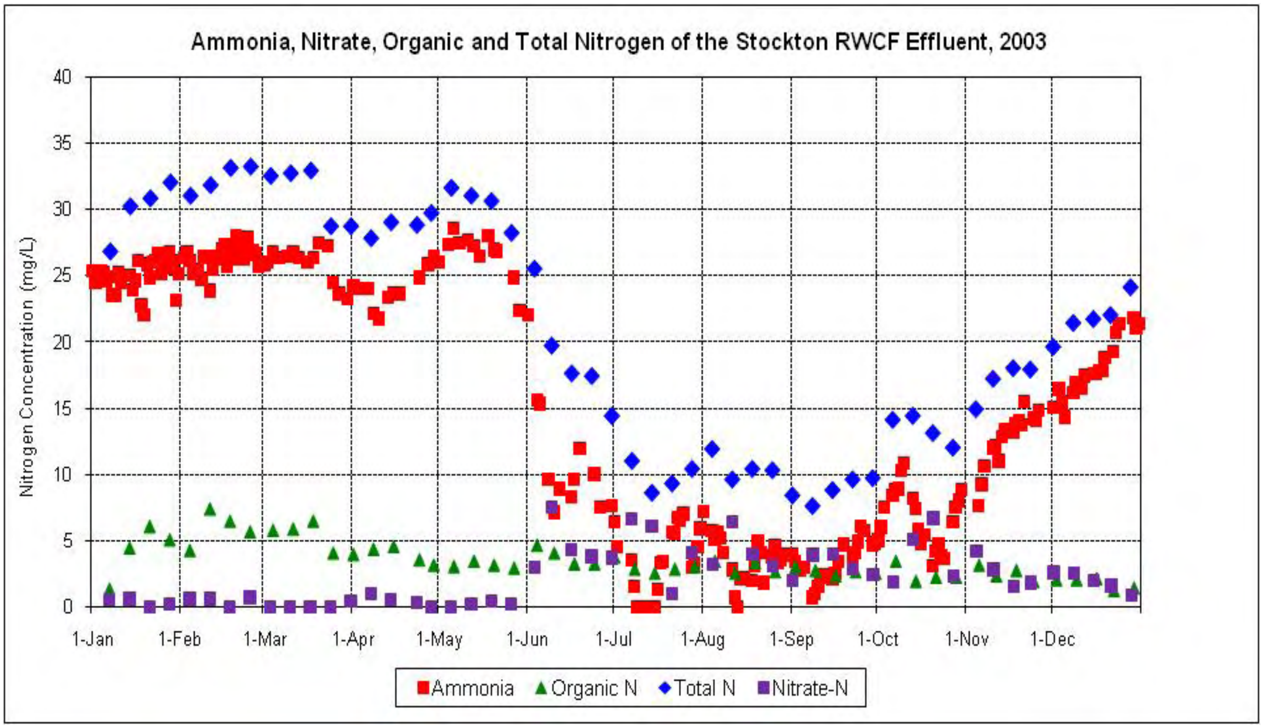
a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2002.



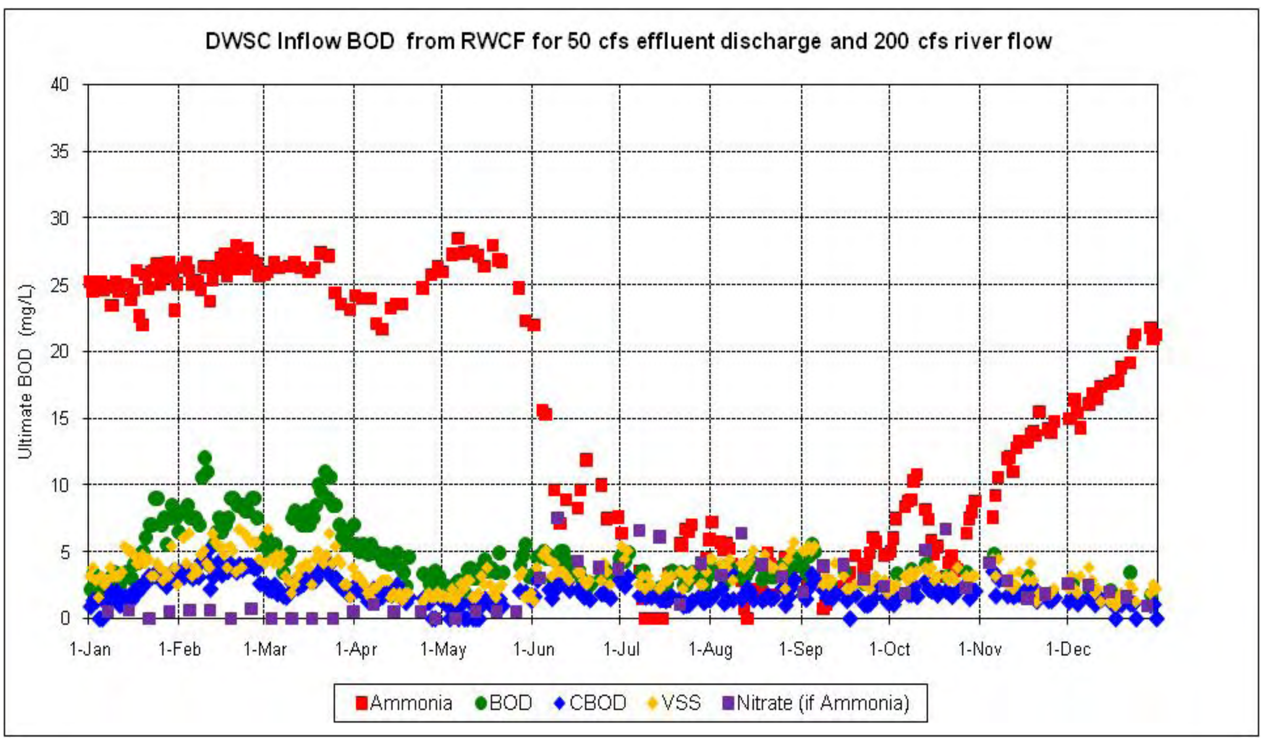
b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2002.

Figure 16

INTERNATIONAL

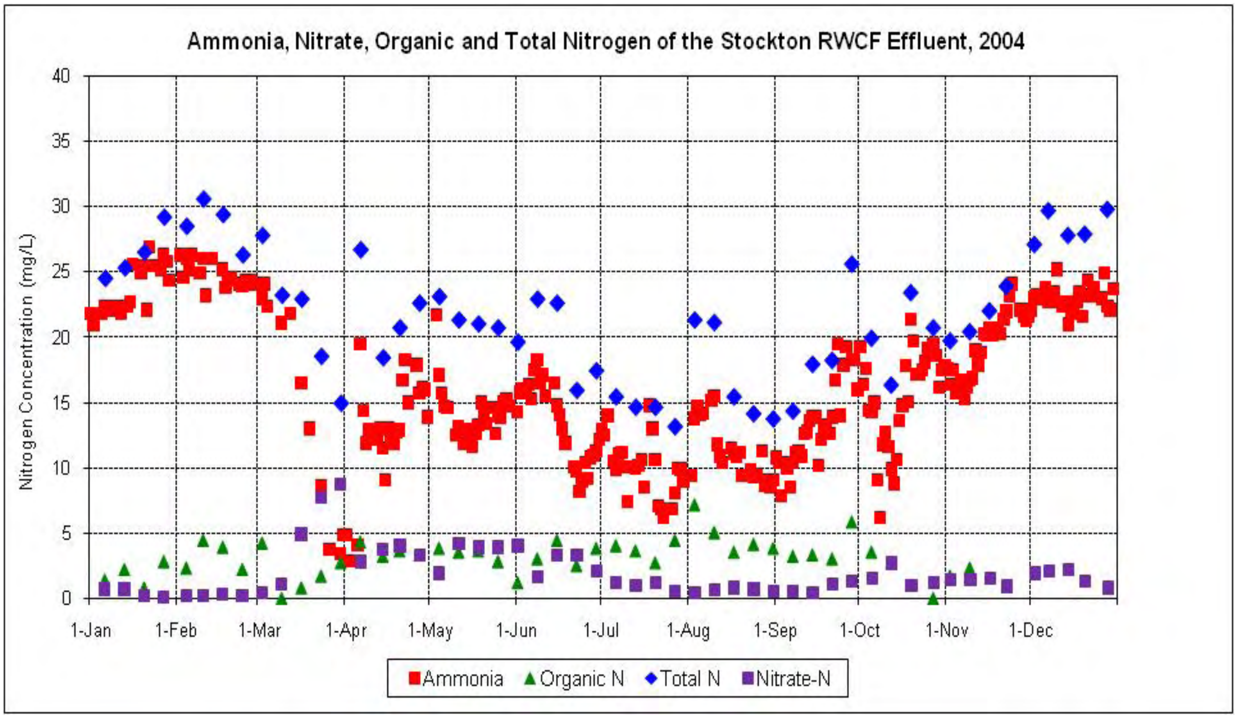


a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2003.

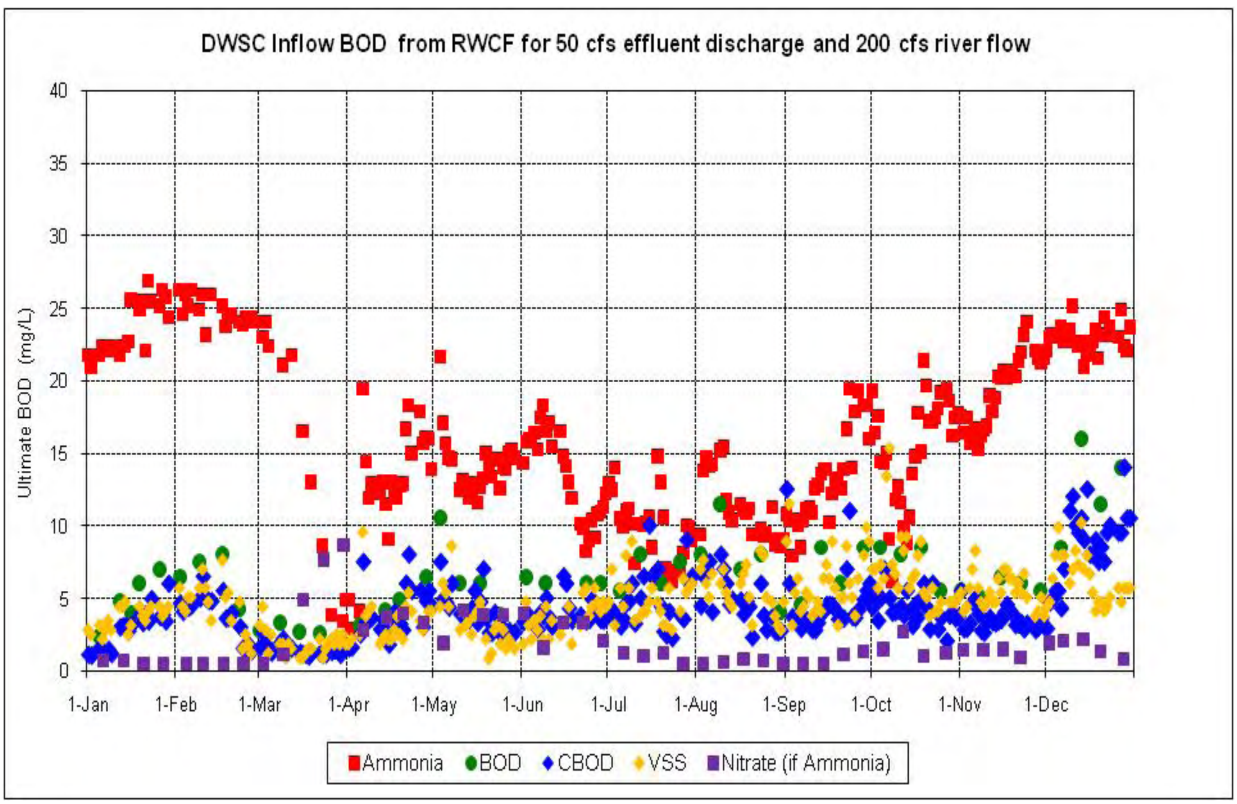


b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2003.

Figure 17

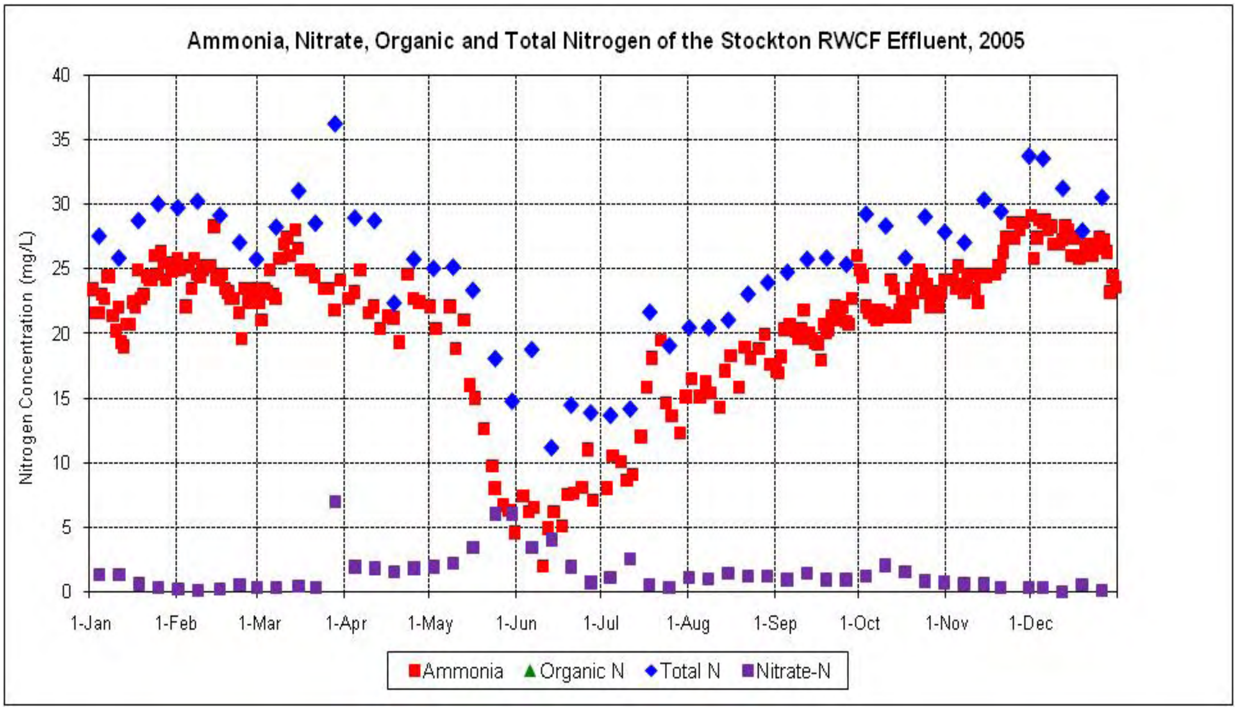


a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2004.

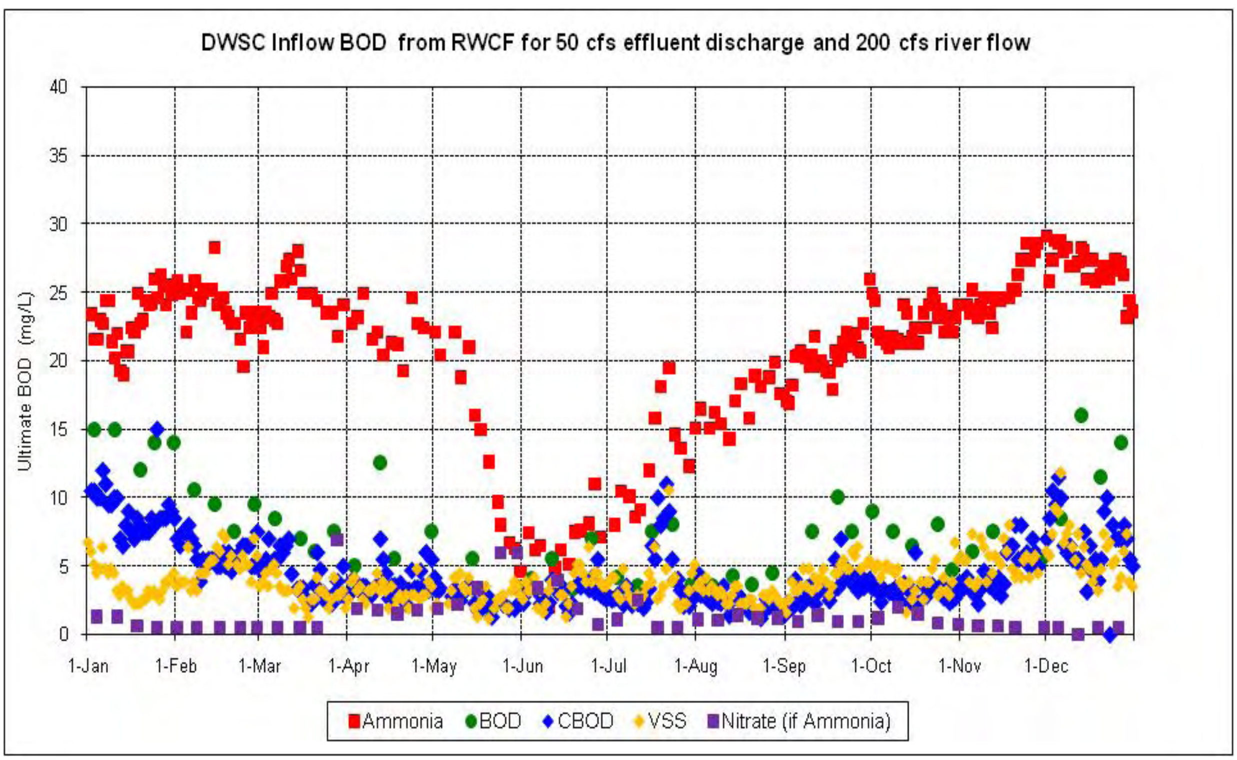


b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2004.

Figure 18

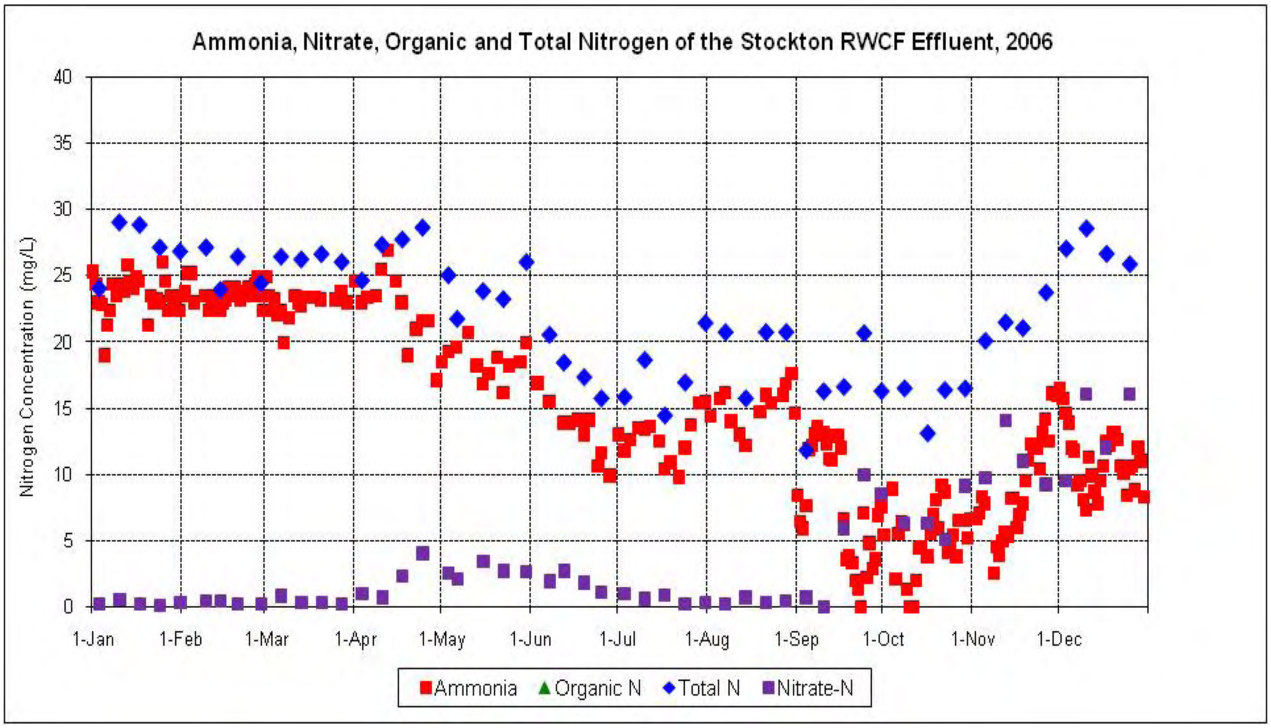


a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2005.

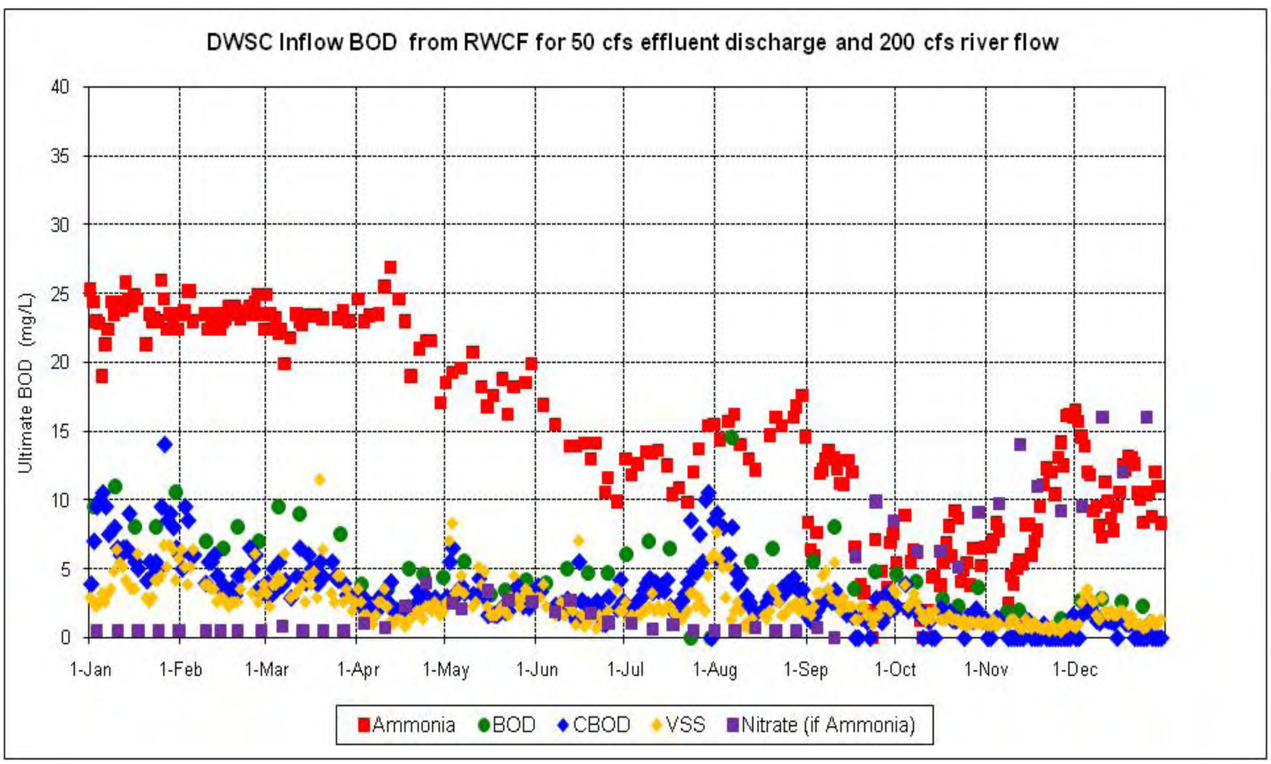


b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2005.

Figure 19



a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2006.



b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2006.

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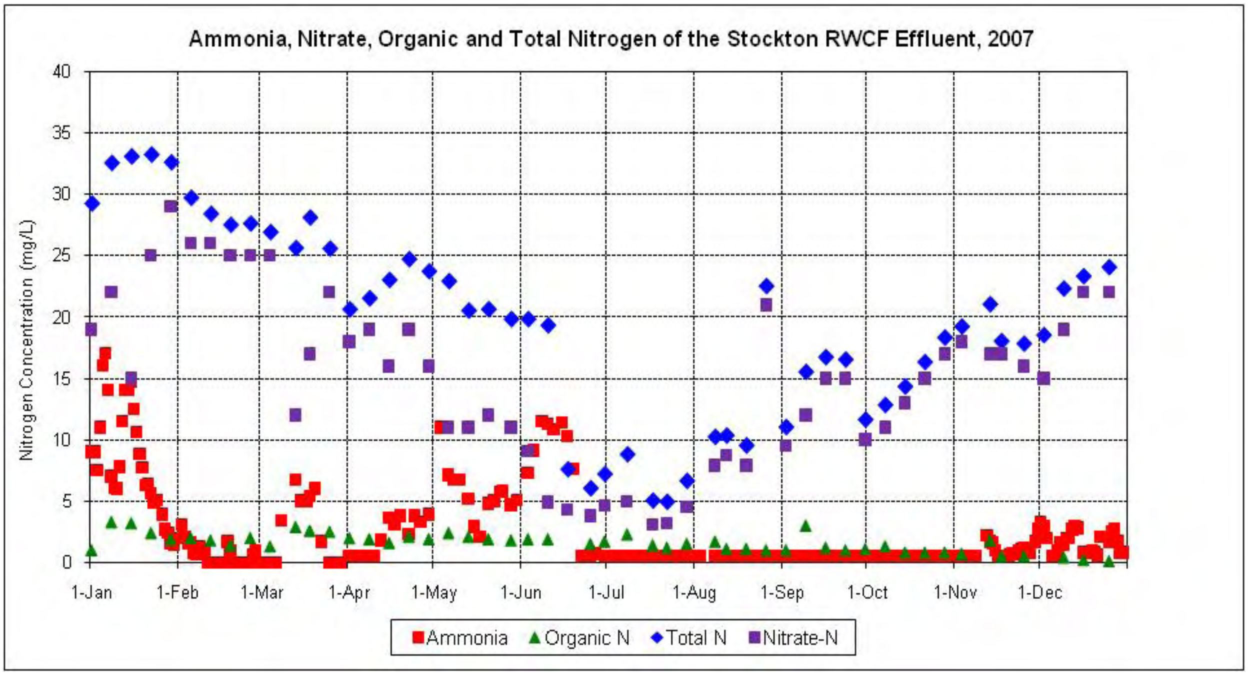
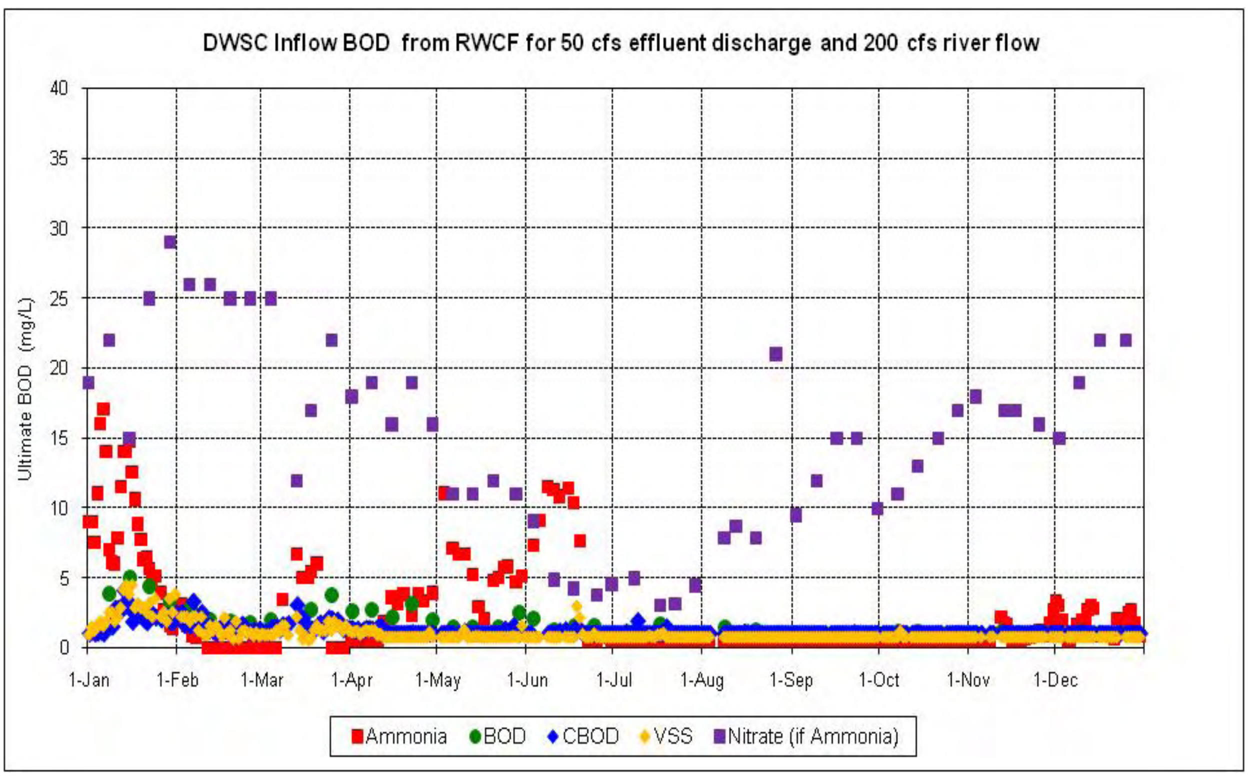
Figure 20



a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2007.



b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2007.

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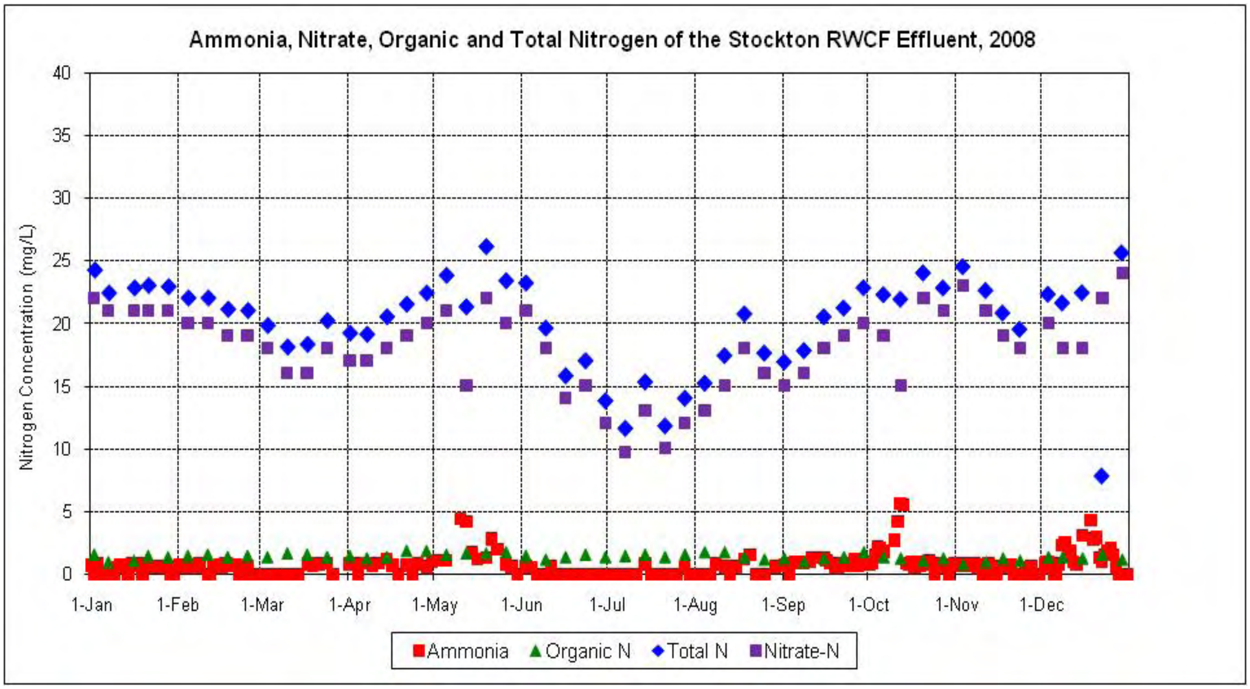
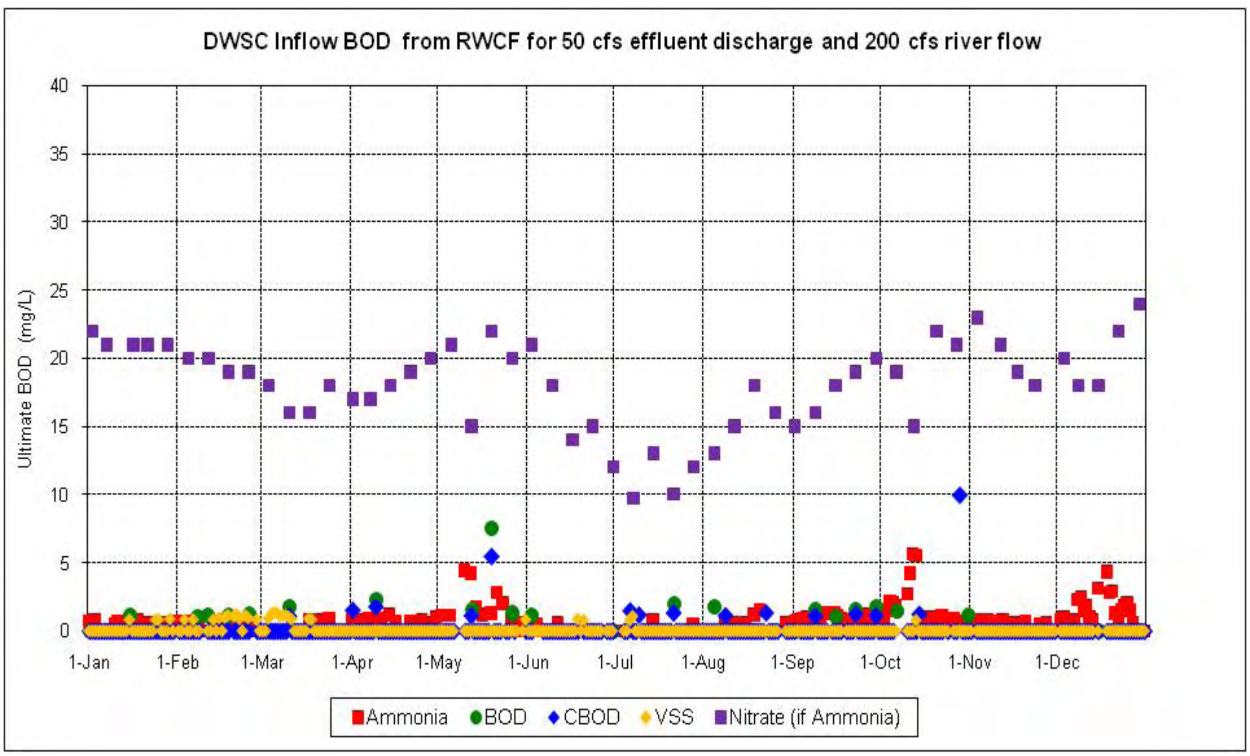
Figure 21



a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2008 [Most ammonia-N was <0.5 mg/l].



b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2008.

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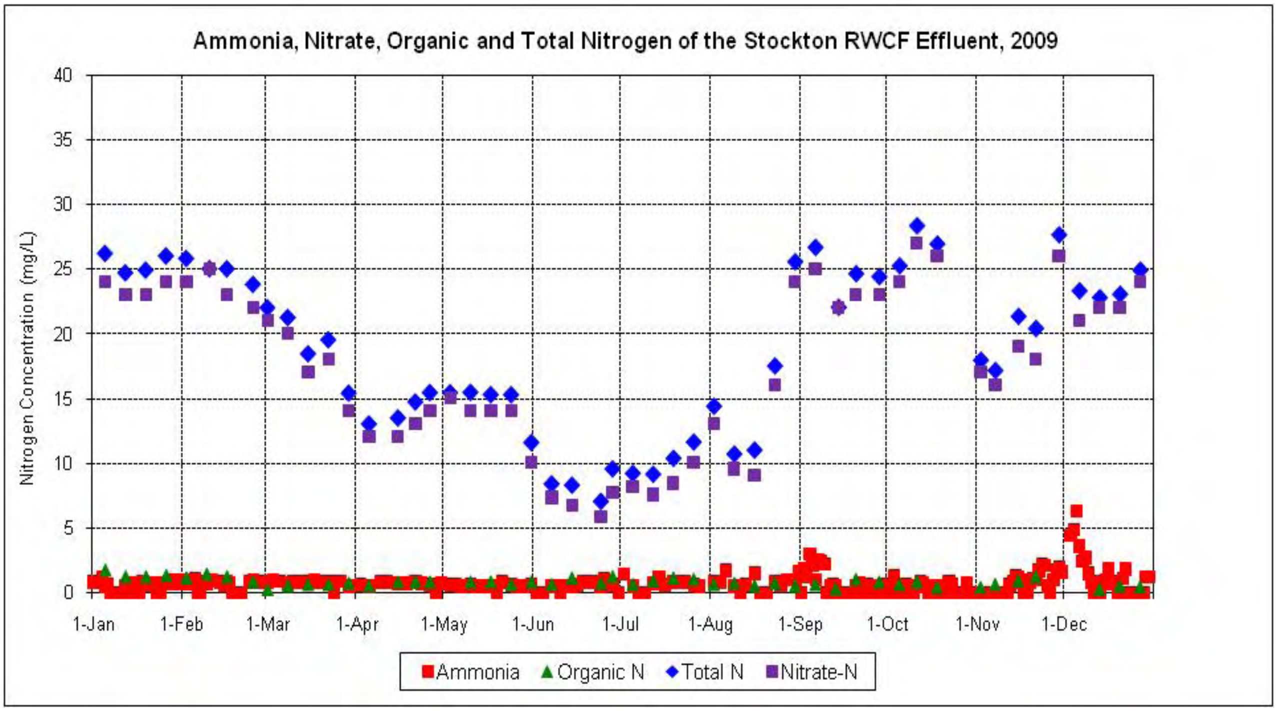
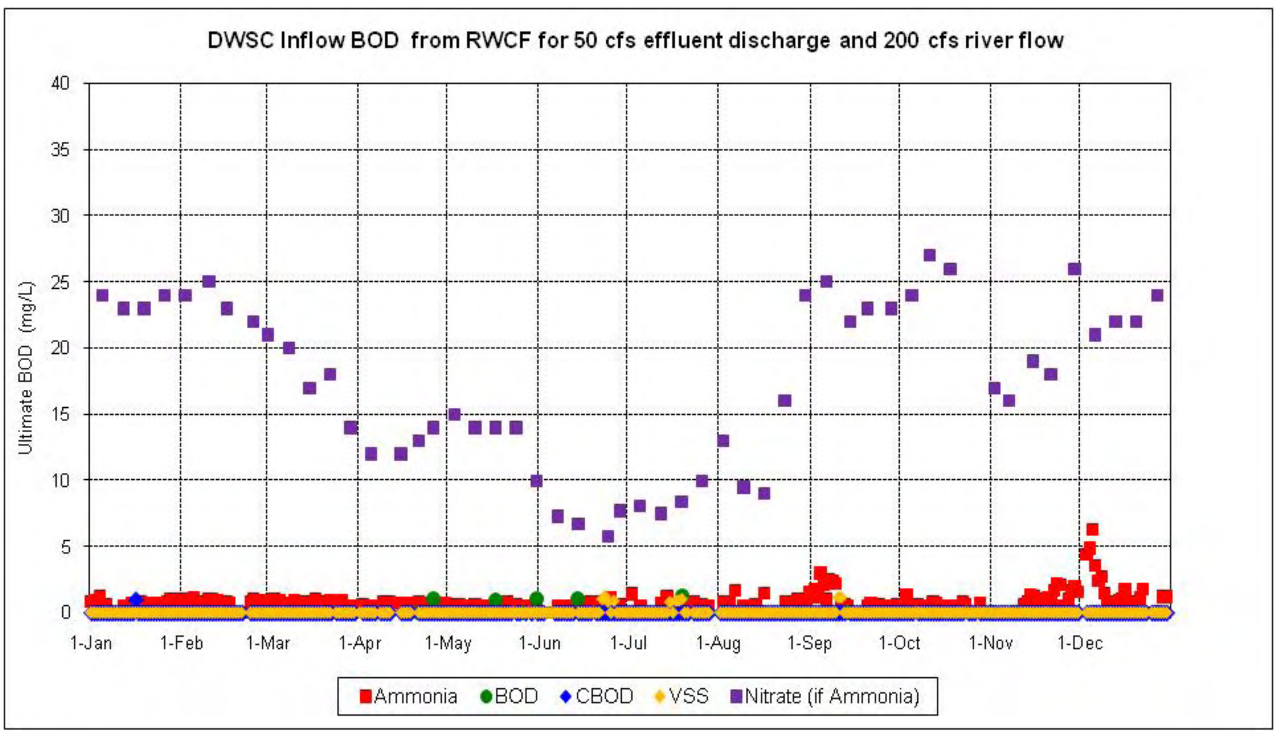
Figure 22



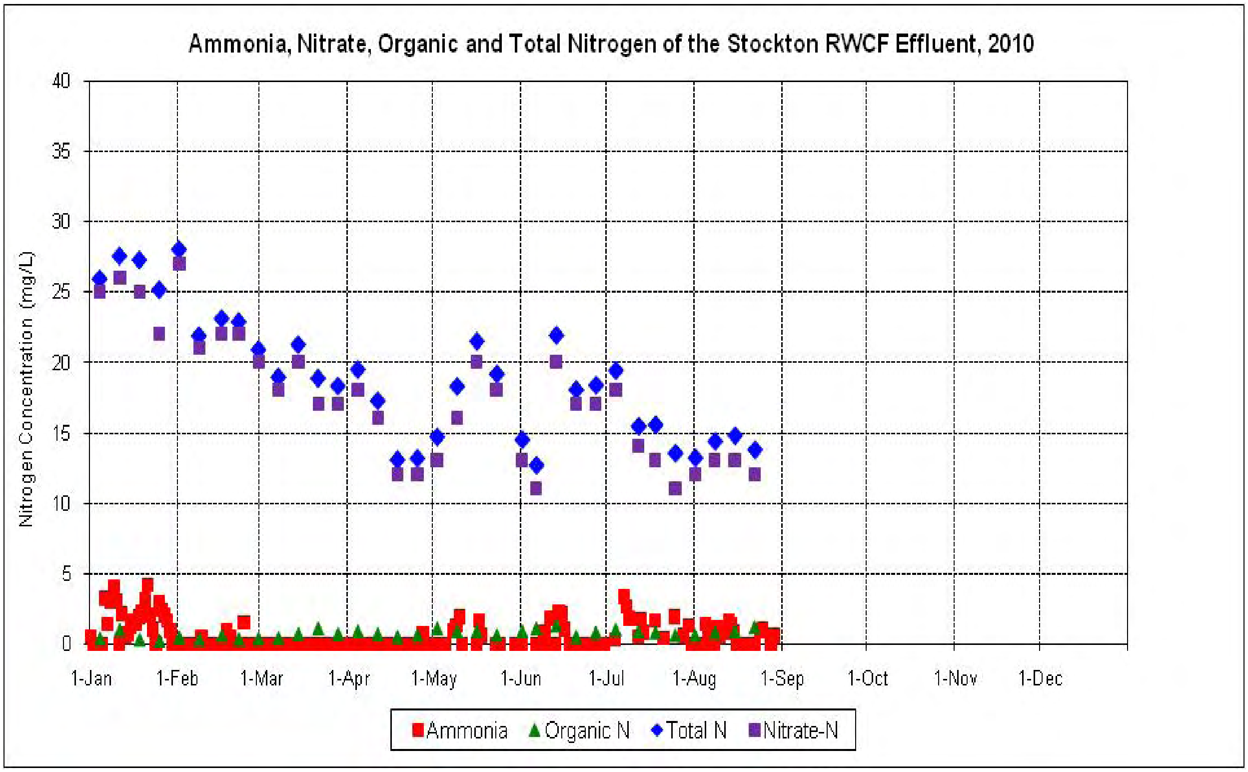
a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2009 [Most ammonia-N was <0.5 mg/l].



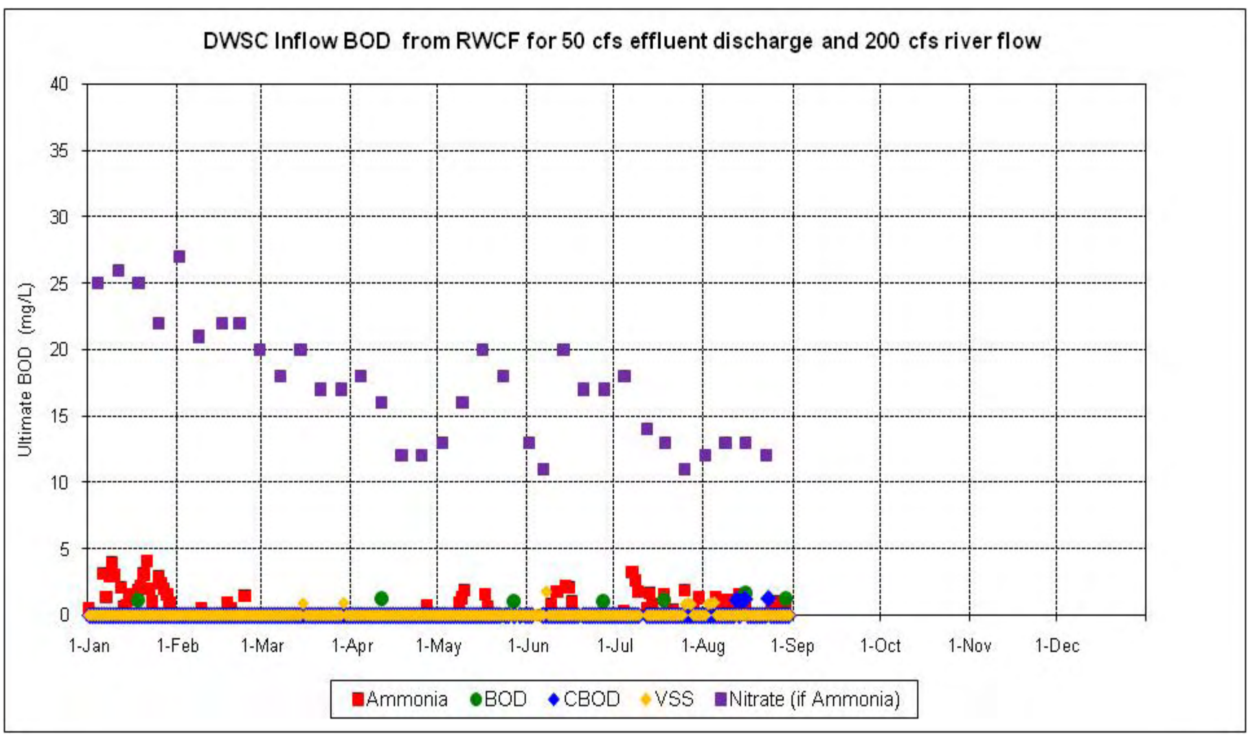
b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2009.

INTERNATIONAL

Figure 23



a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2010 [Most ammonia-N was <0.5 mg/l].



b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2010.

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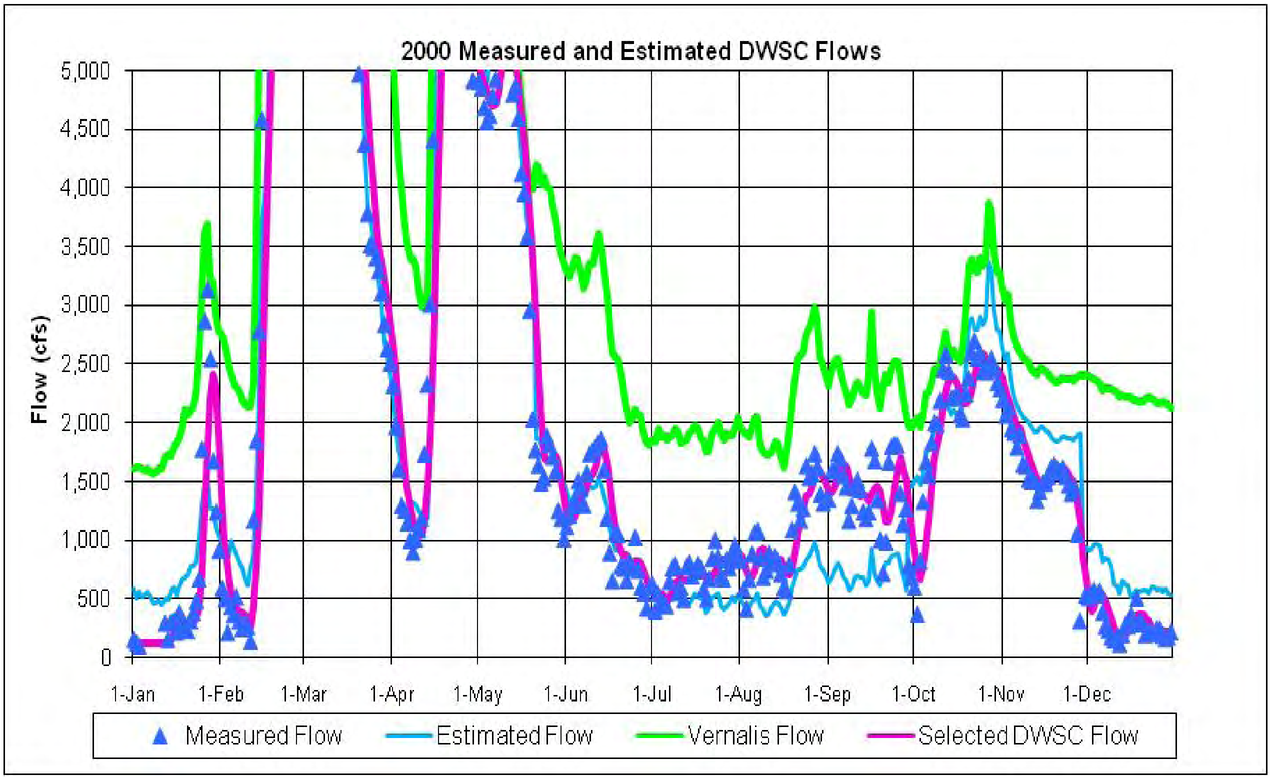
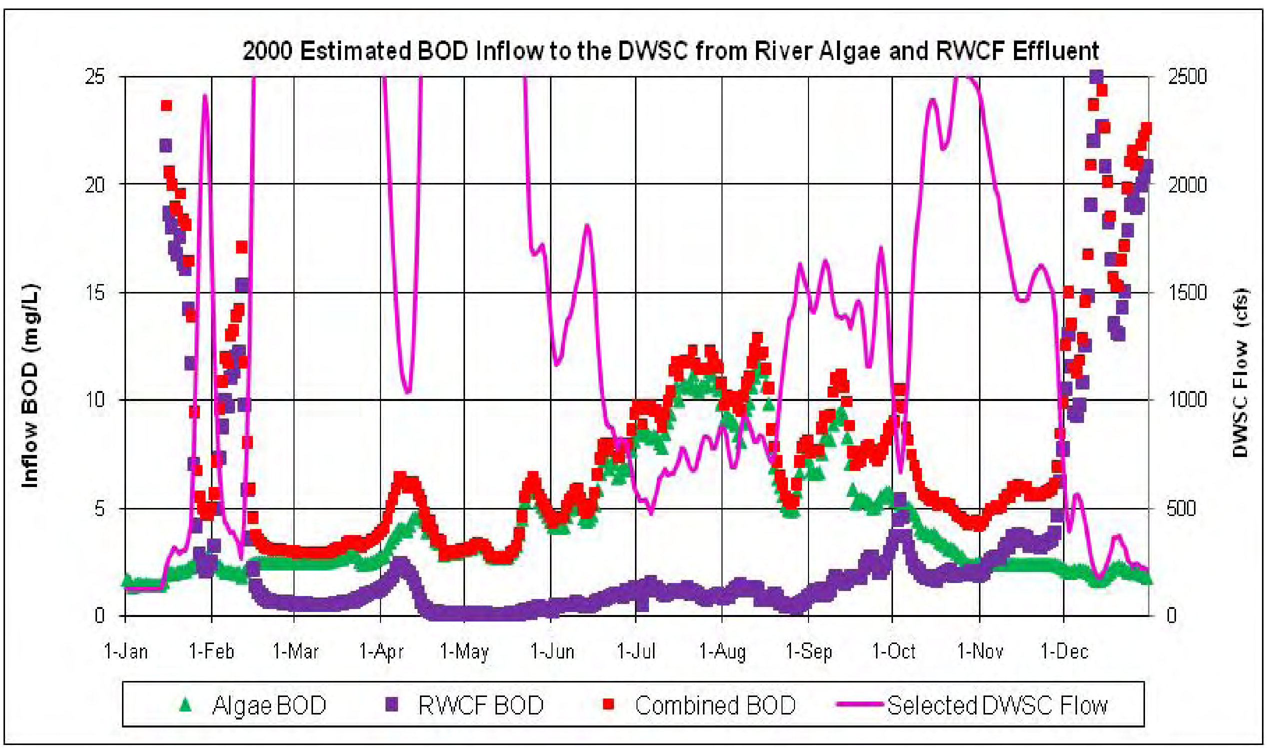
Figure 24



a) Daily Measured (Selected) and Estimated DWSC Flow with SJR Flows at Vernalis for 2000.



b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2000.

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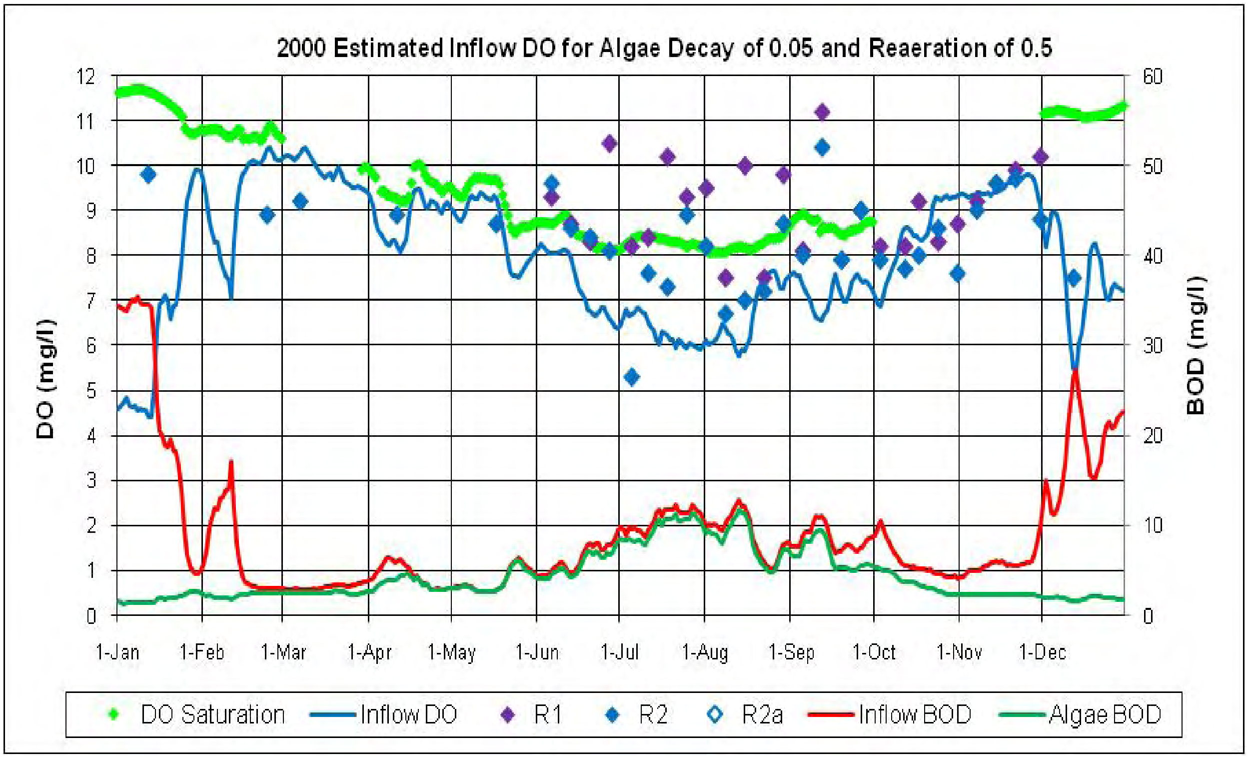
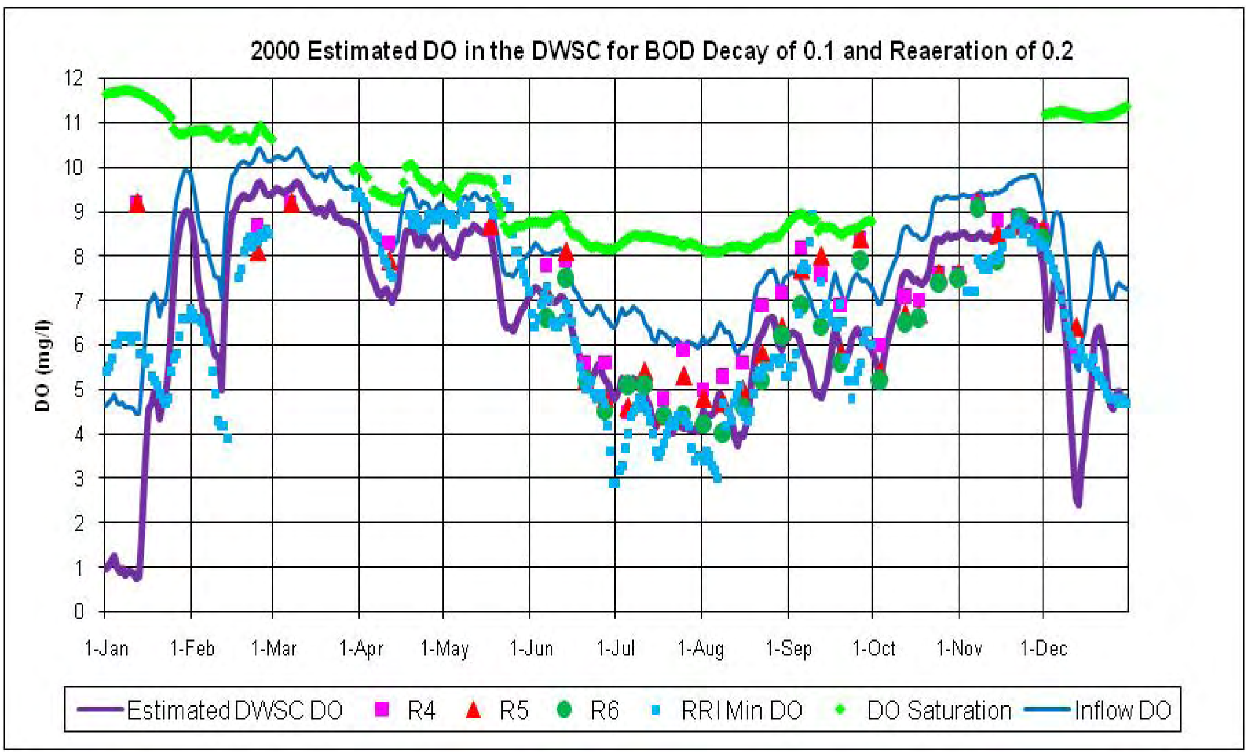
Figure 25



c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2000.



d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2000.

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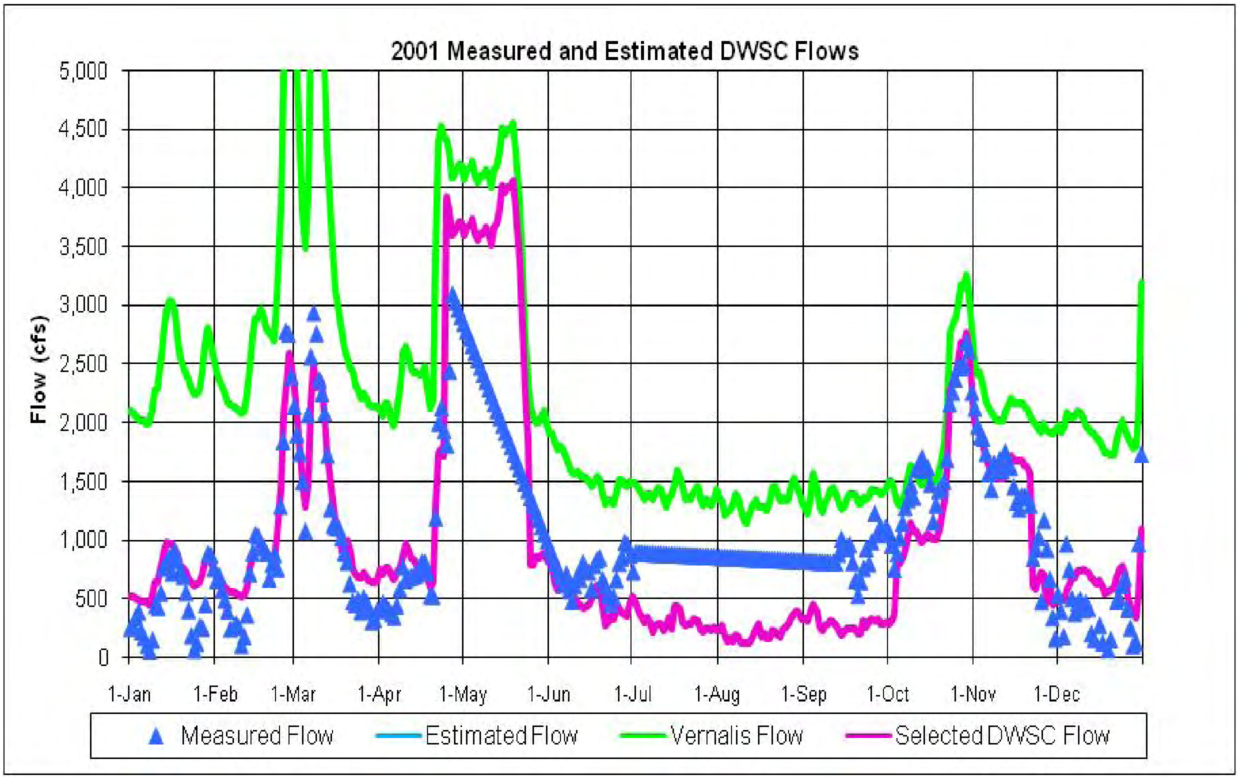
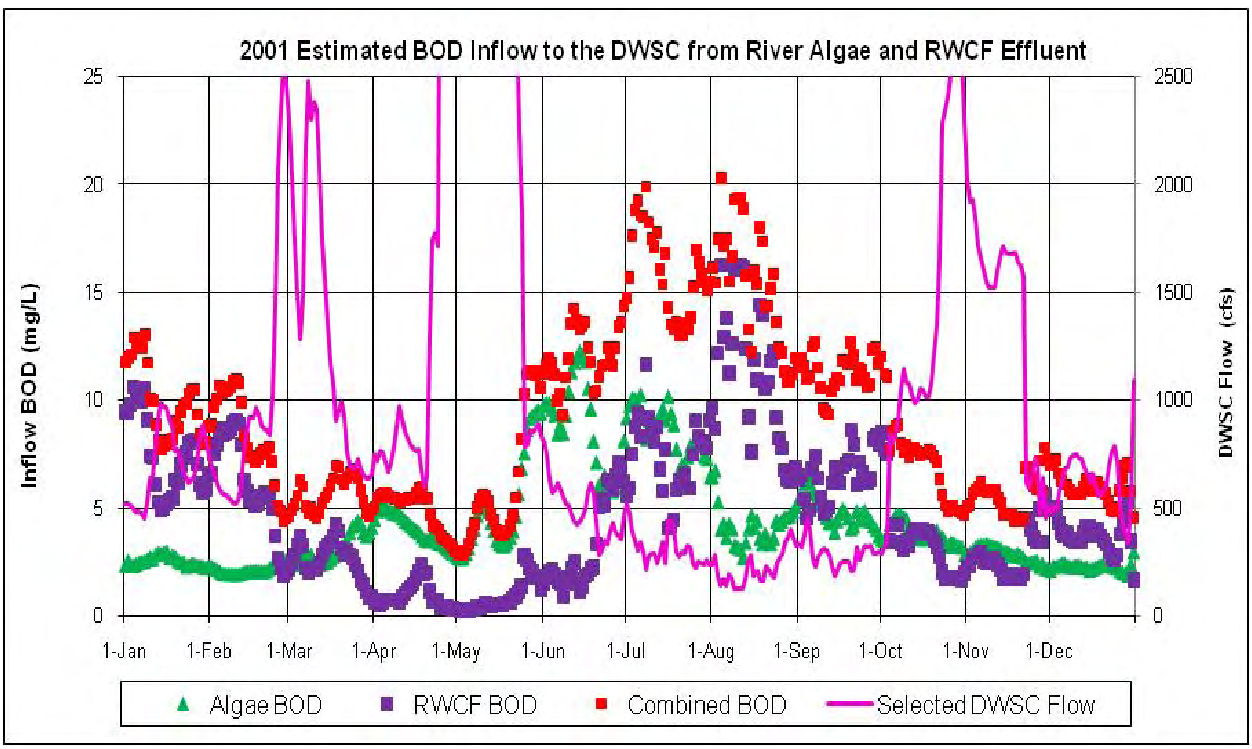
Figure 25
Continued



a) Daily Measured and Estimated (Selected) DWSC Flow with SJR Flows at Vernalis for 2001.



b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2001.

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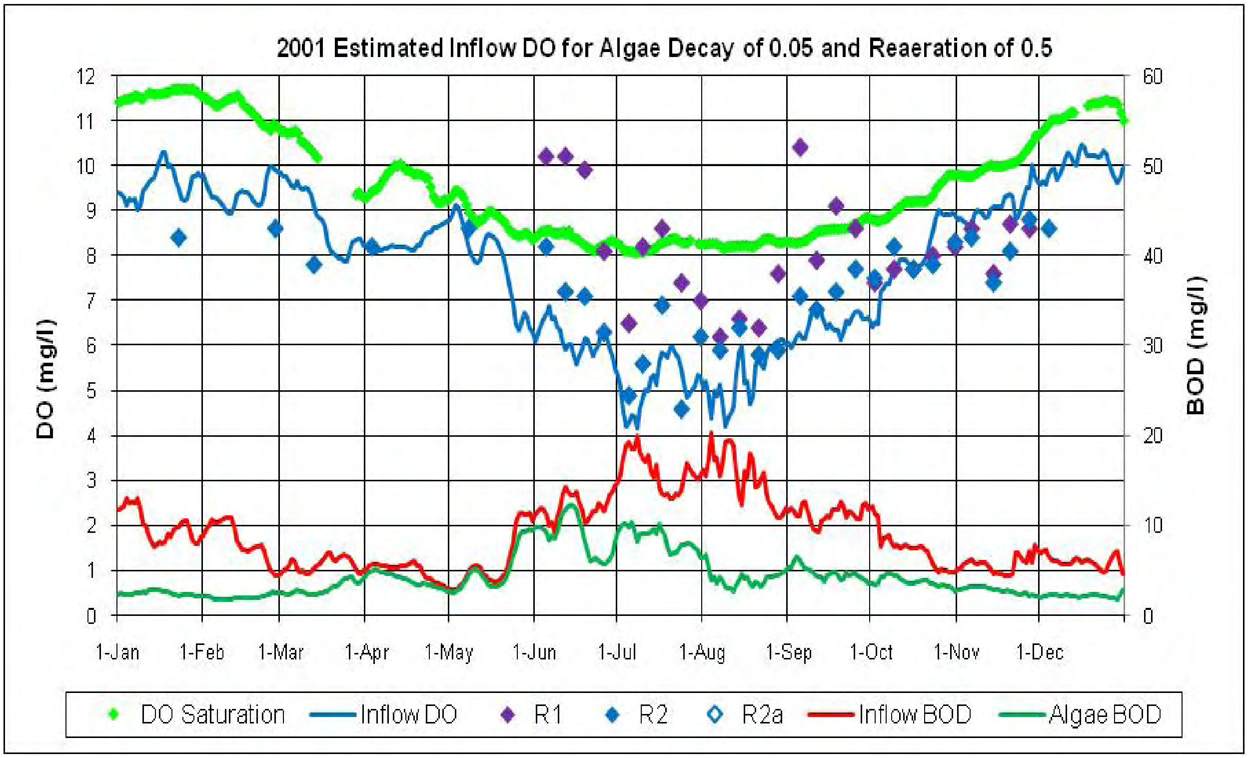
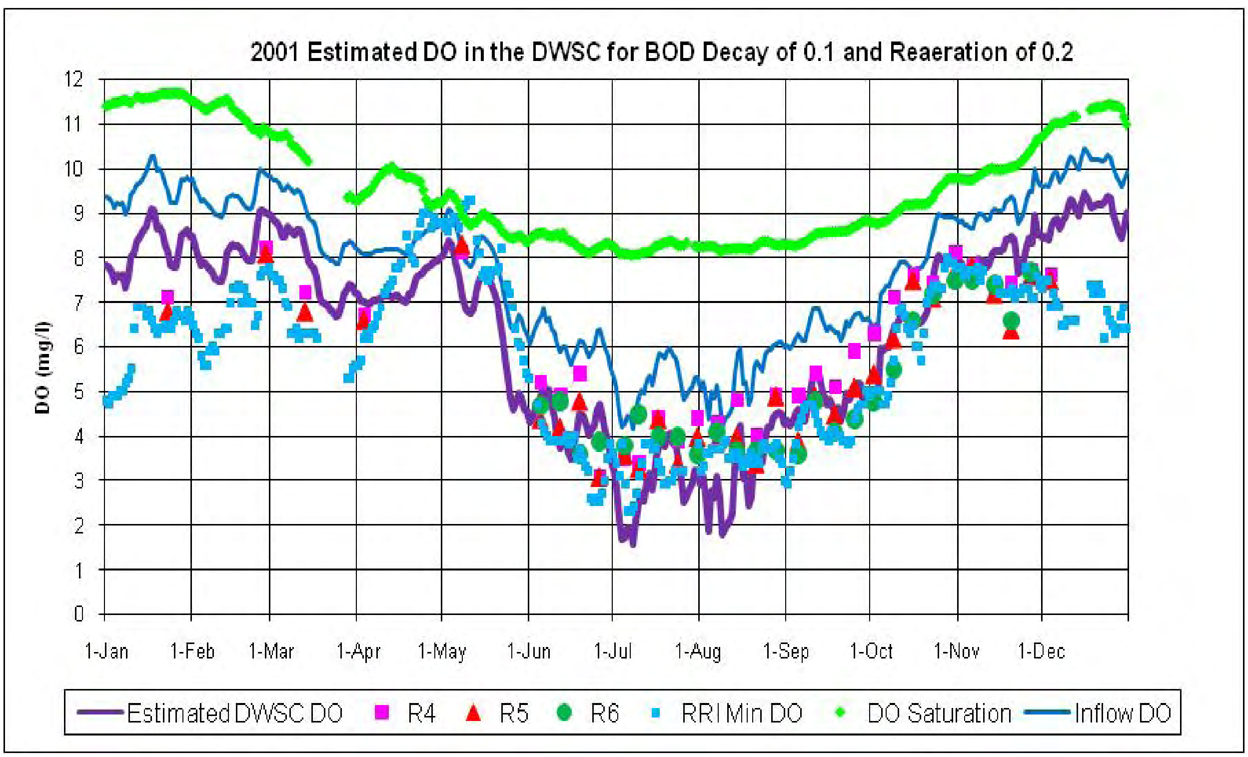
Figure 26

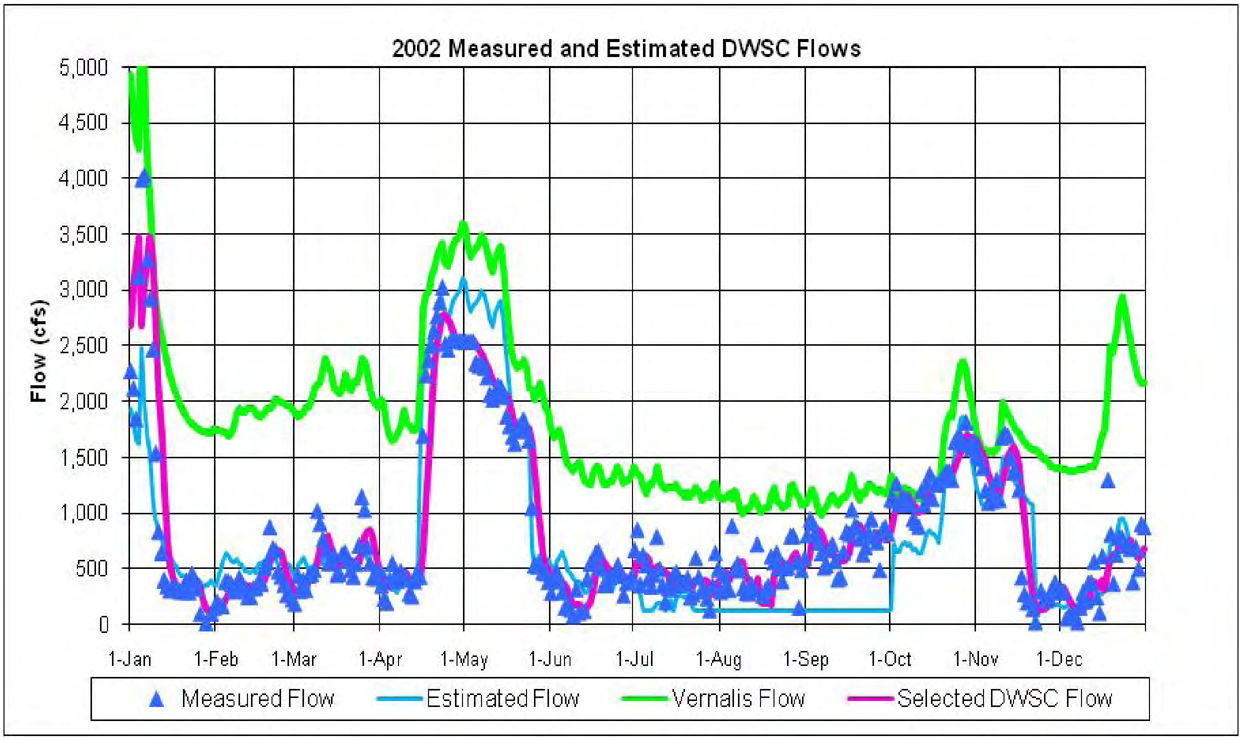


c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2001.

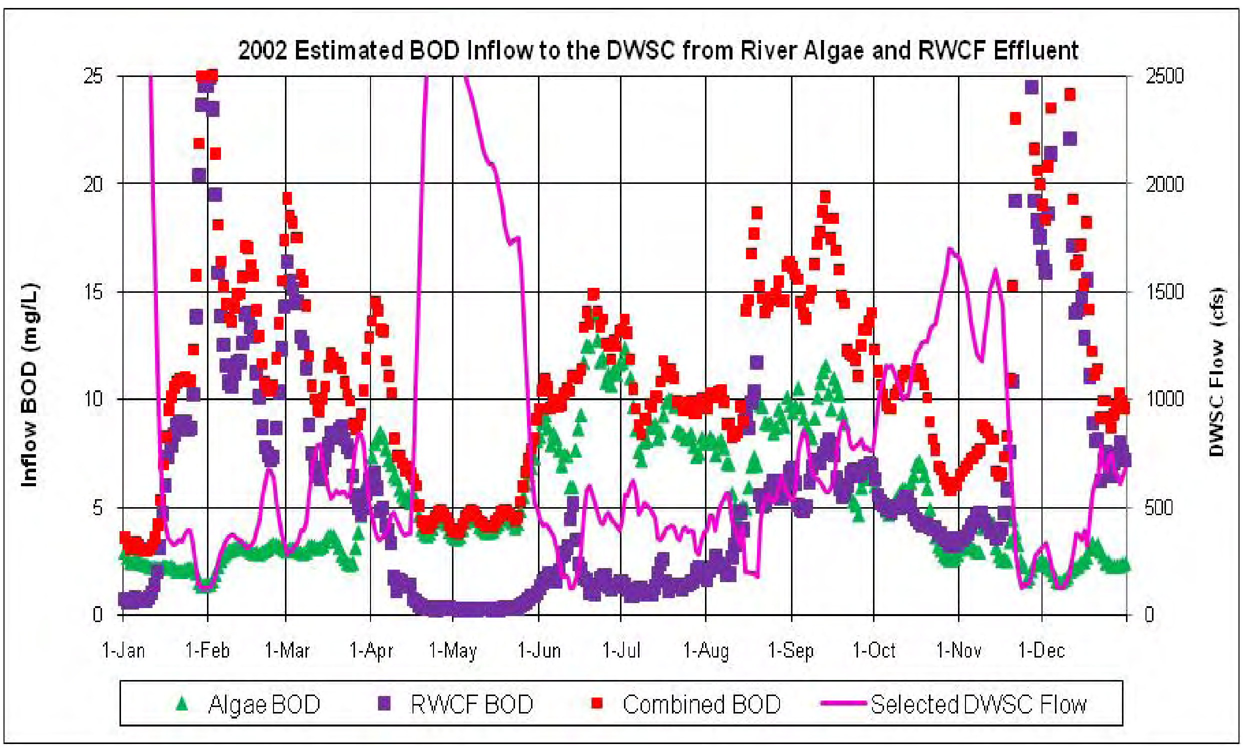


d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2001.

Figure 26
Continued

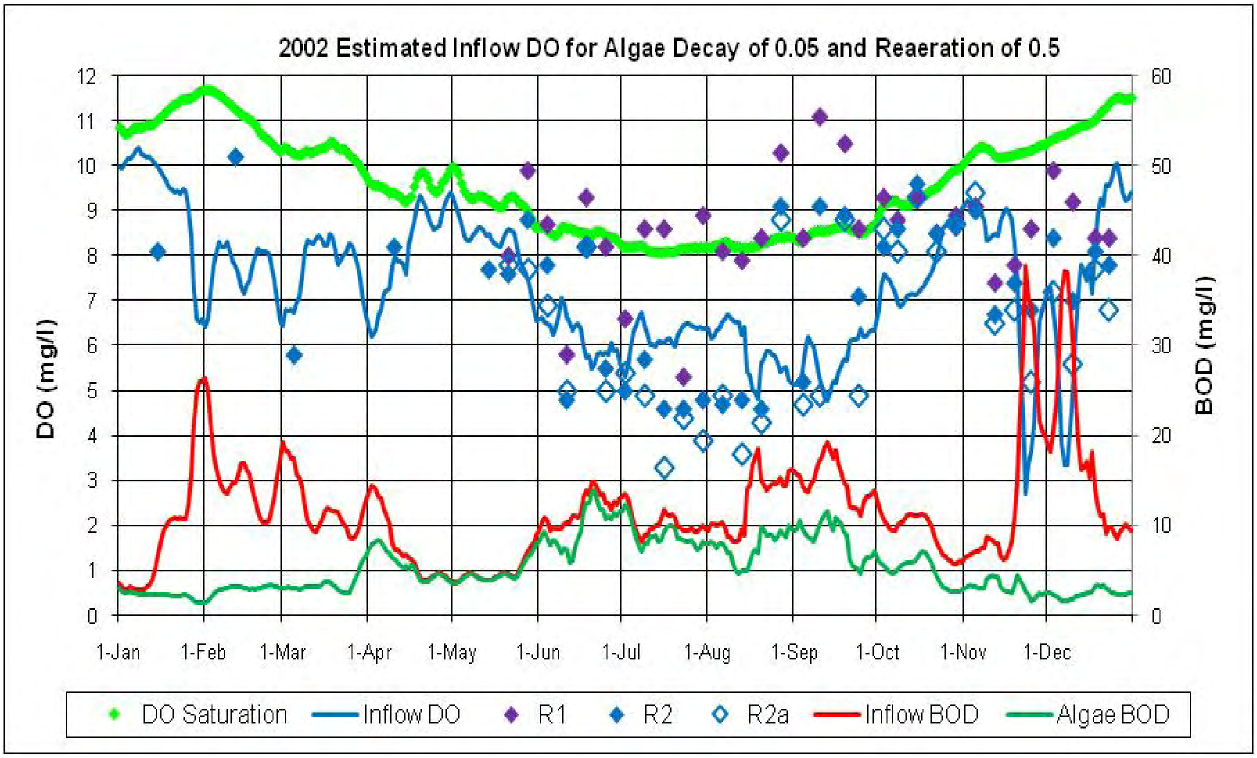


a) Daily Measured (Selected) and Estimated DWSC Flow with SJR Flows at Vernalis for 2002.

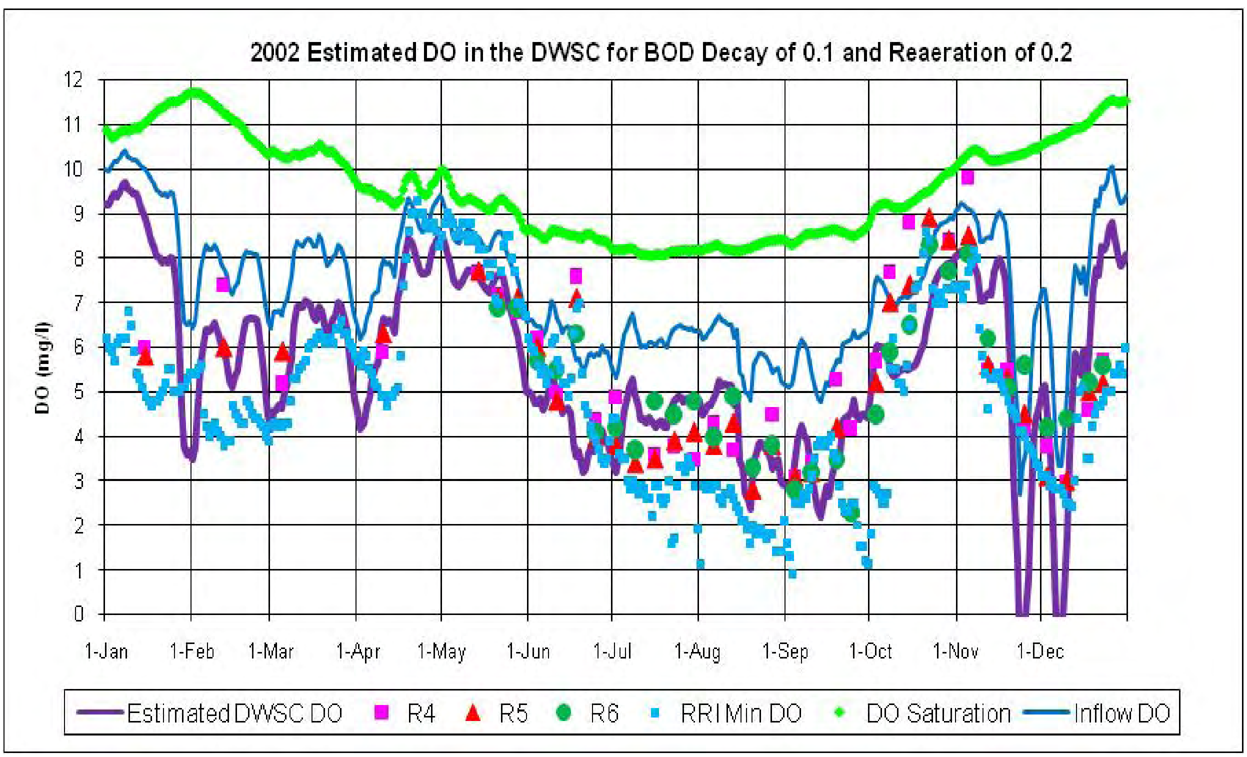


b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2002.

Figure 27



c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2002.



d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2002.

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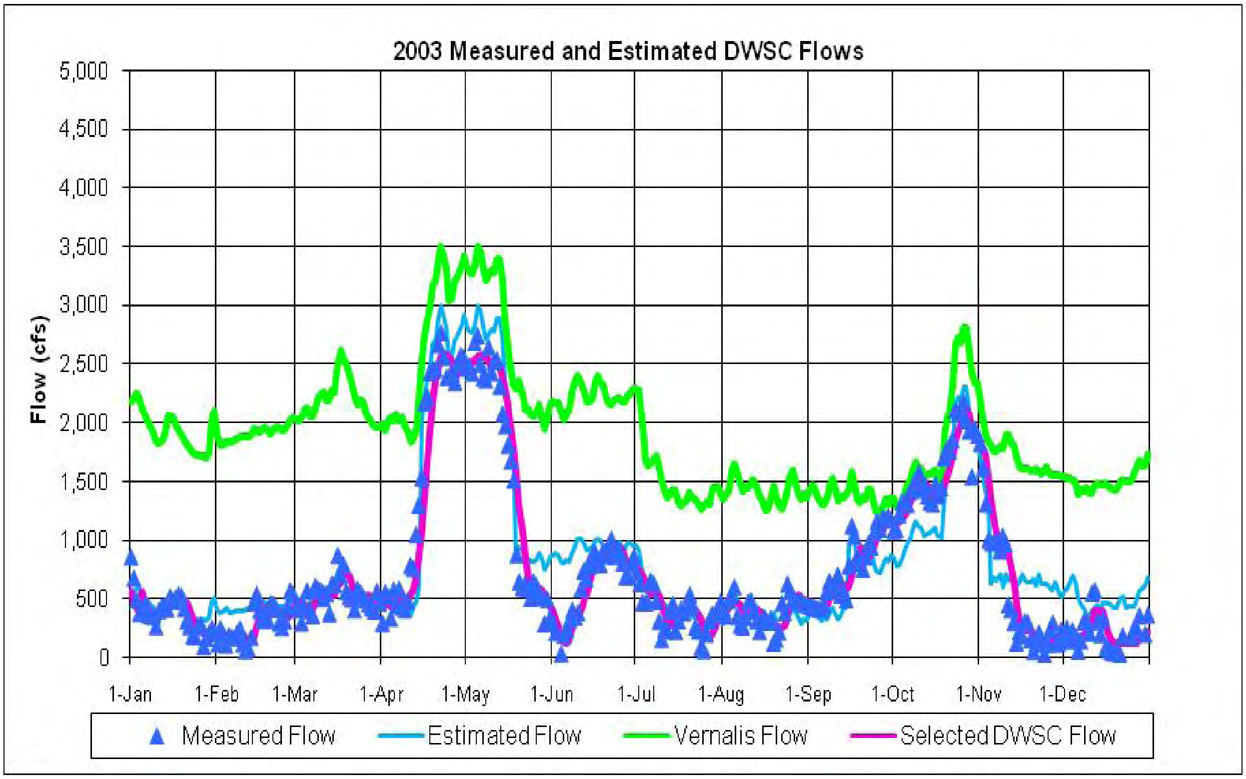
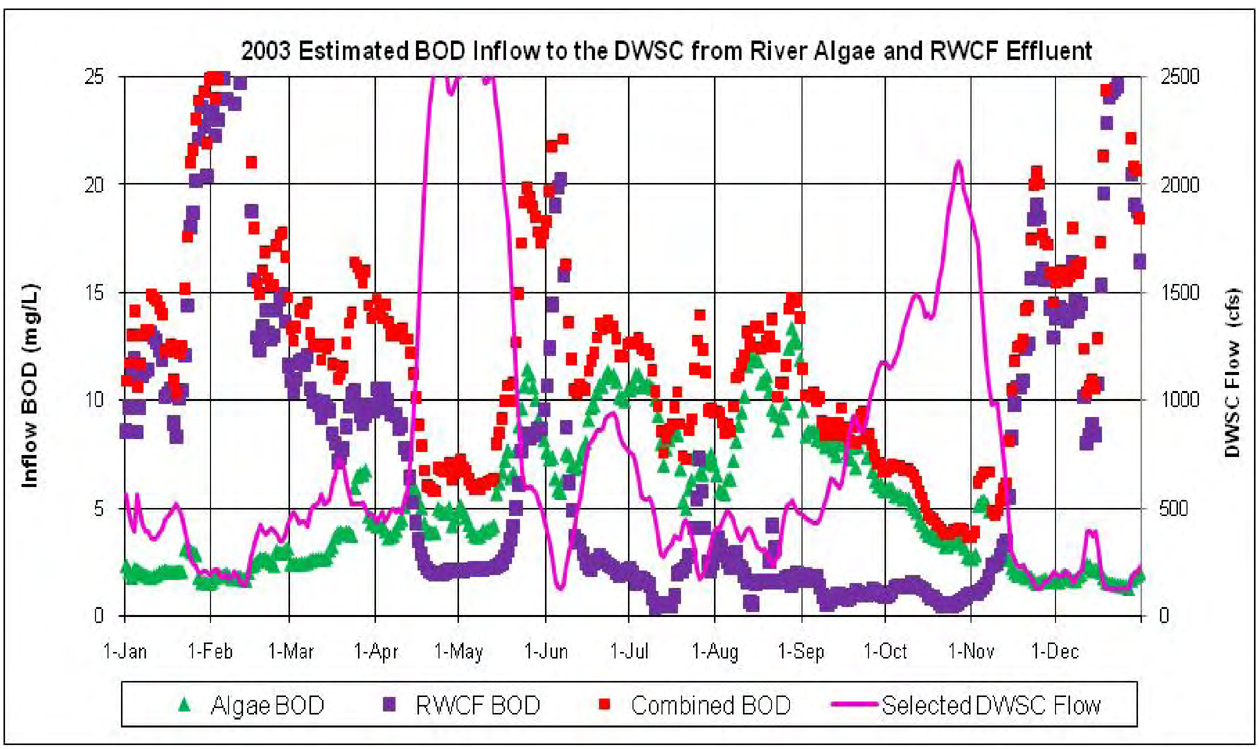
Figure 27
Continued



a) Daily Measured (Selected) and Estimated DWSC Flow with SJR Flows at Vernalis for 2003.



b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2003.

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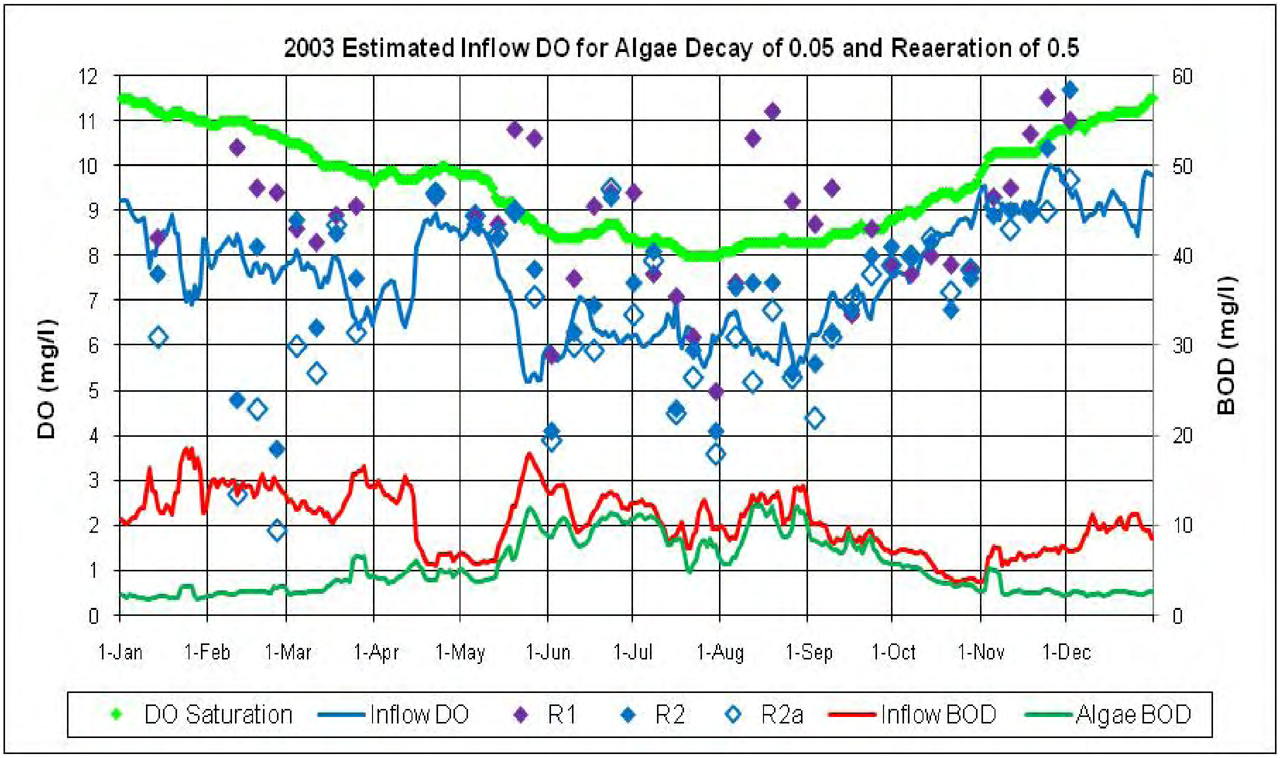
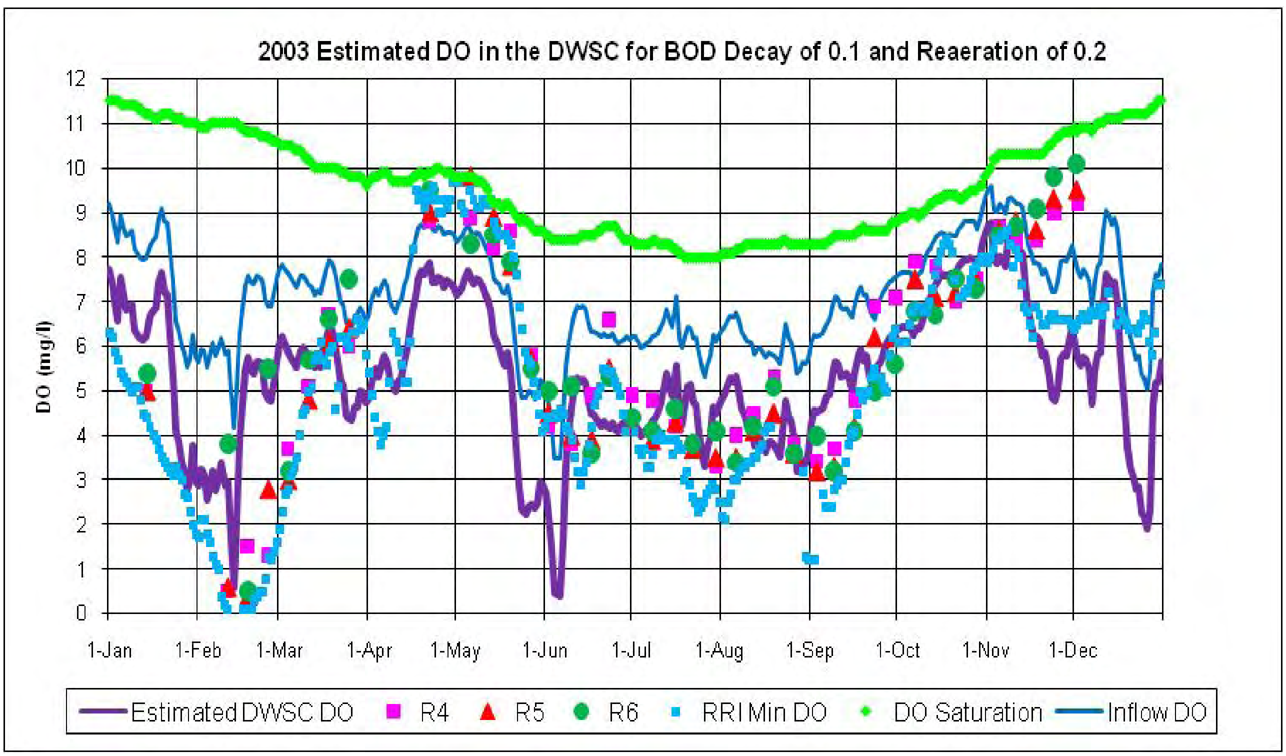
Figure 28

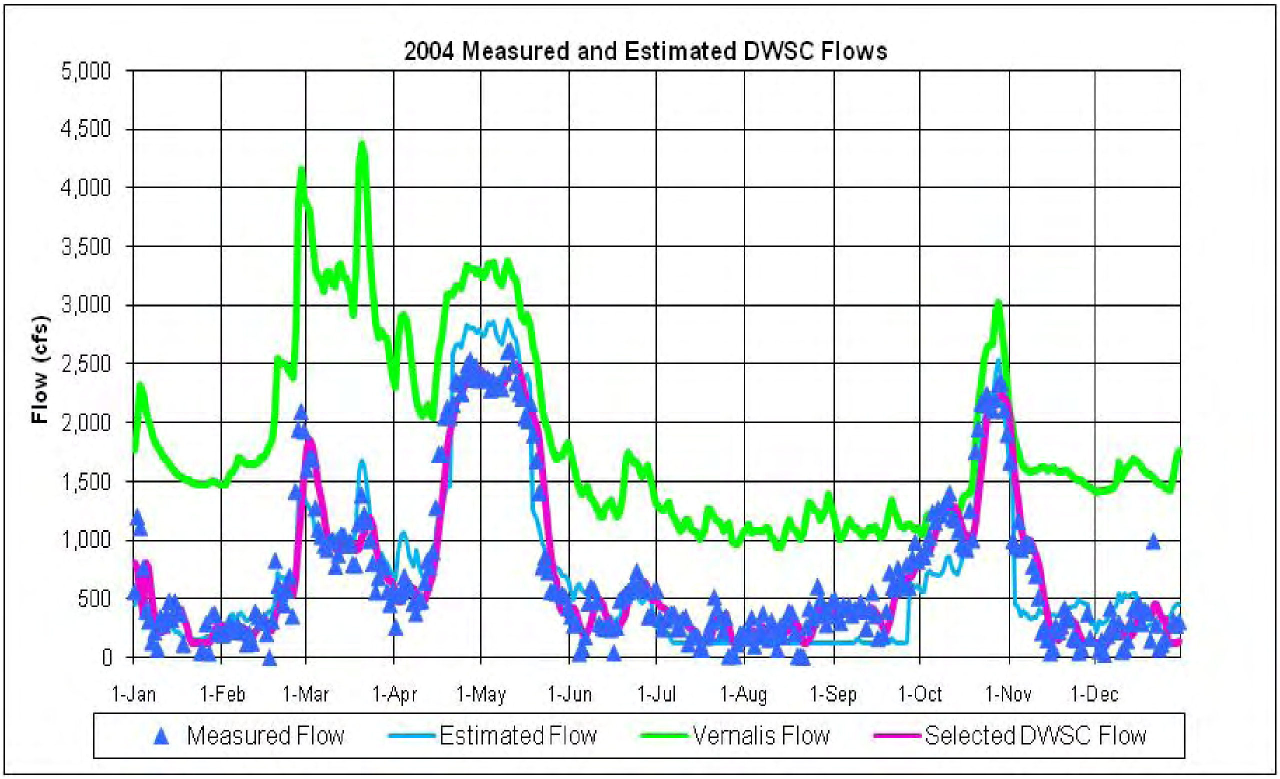


c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2003.

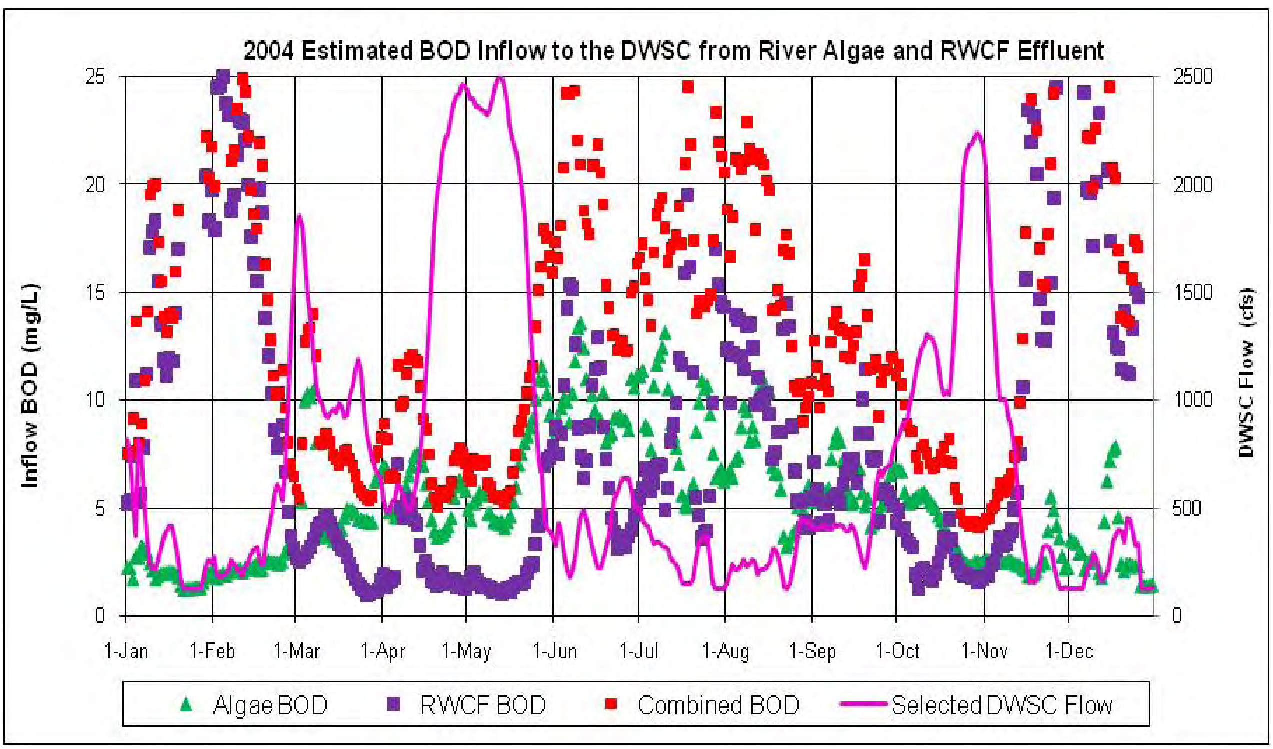


d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2003.

Figure 28
Continued

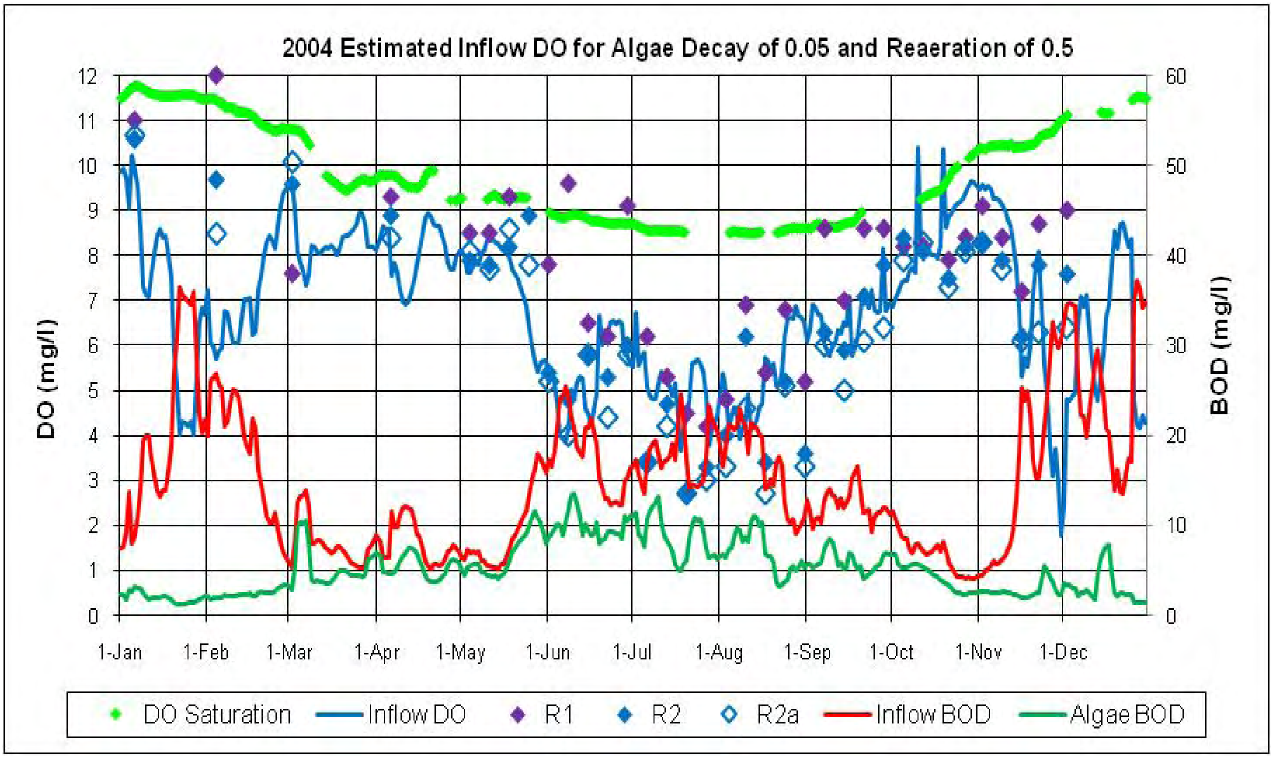


a) Daily Measured (Selected) and Estimated DWSC Flow with SJR Flows at Vernalis for 2004.



b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2004.

Figure 29



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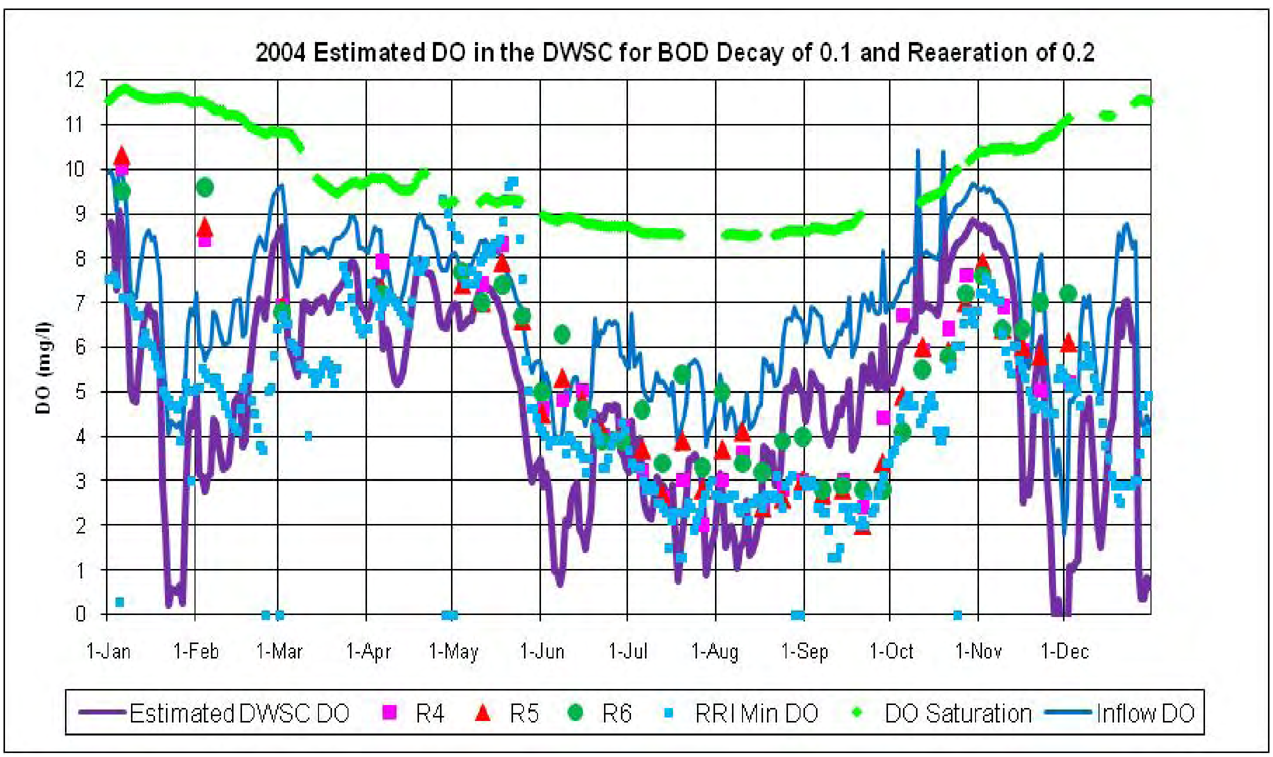

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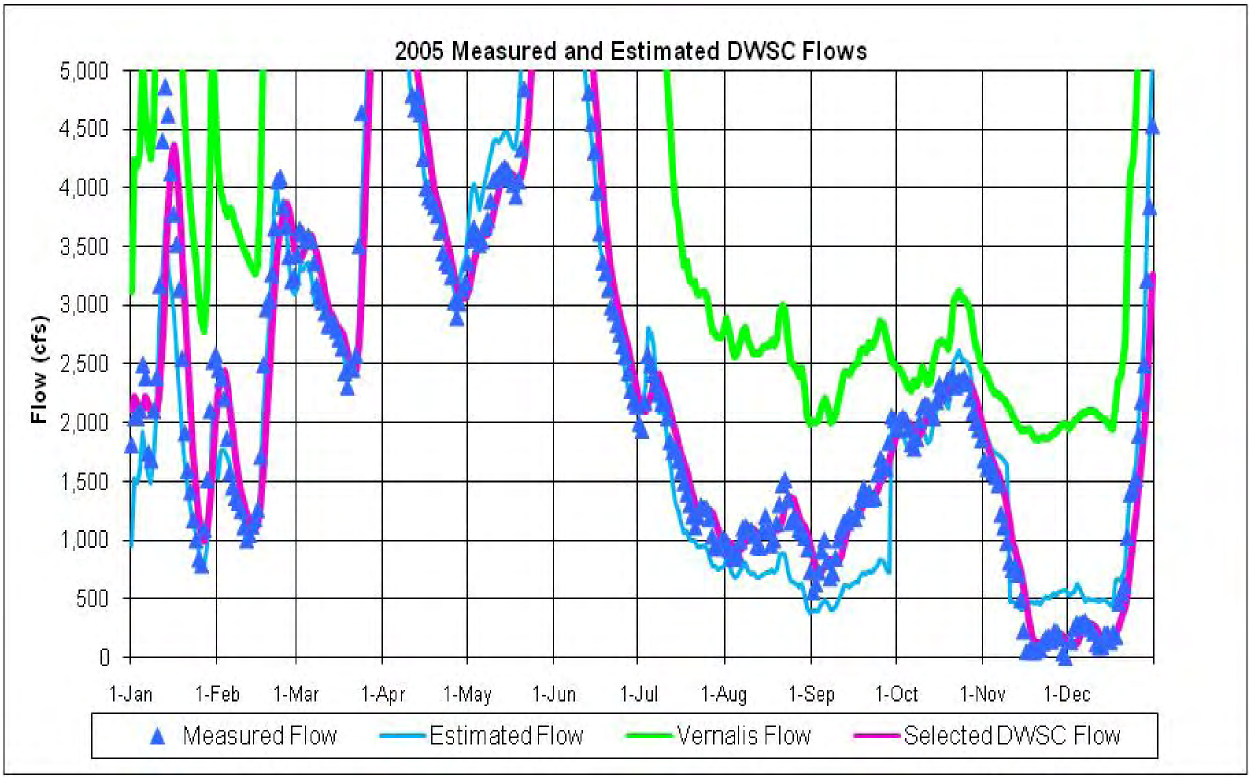
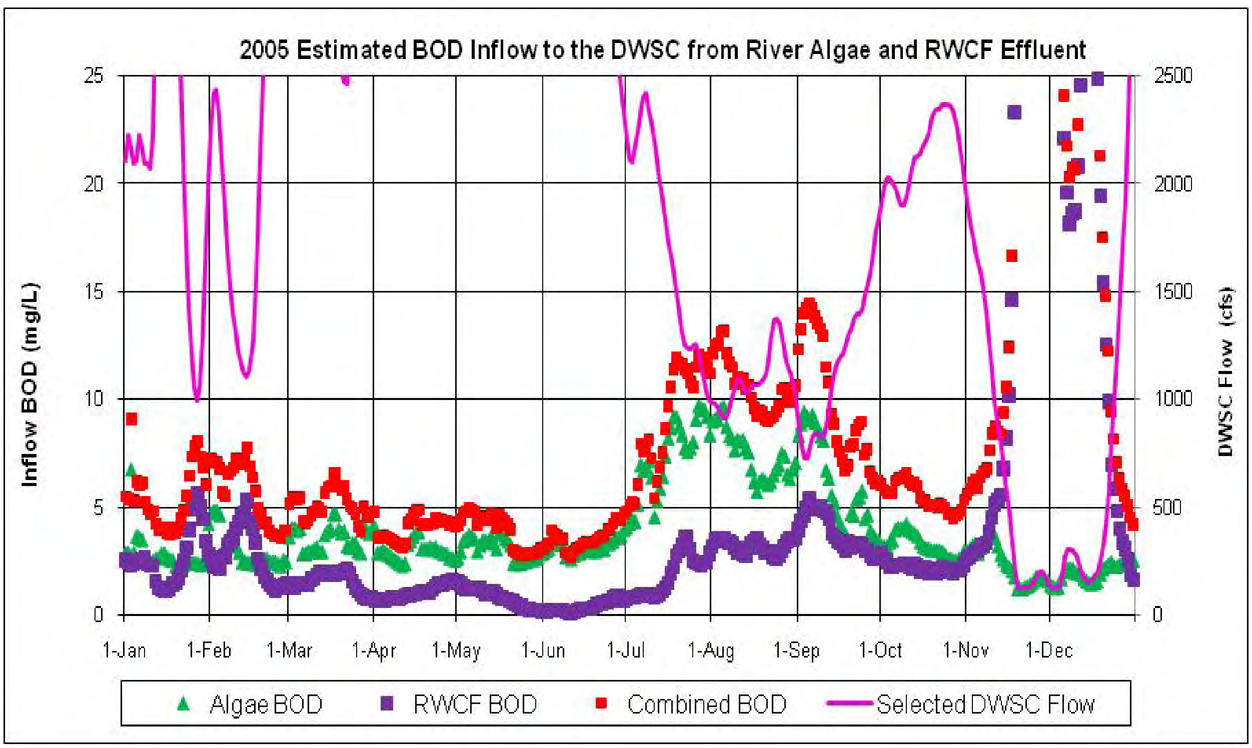
Figure 29
Continued



a) Daily Measured (Selected) and Estimated DWSC Flow with SJR Flows at Vernalis for 2005.



b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2005.

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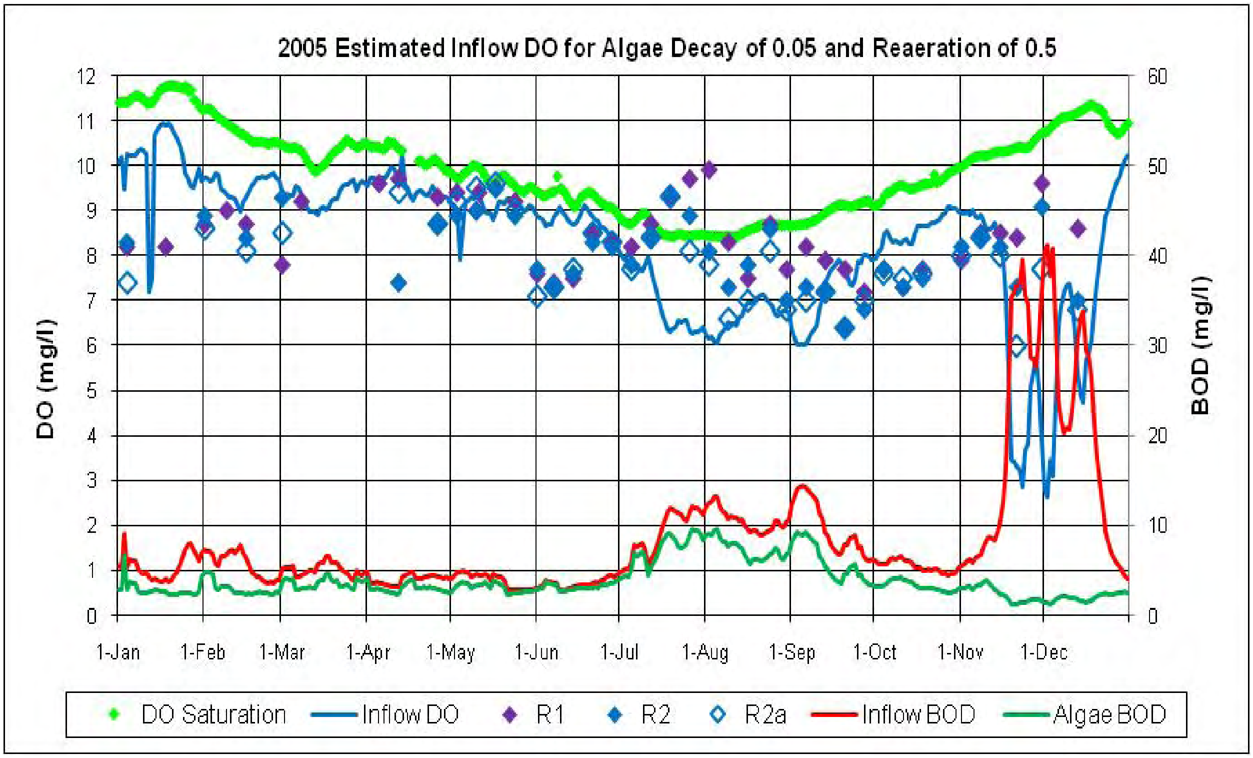
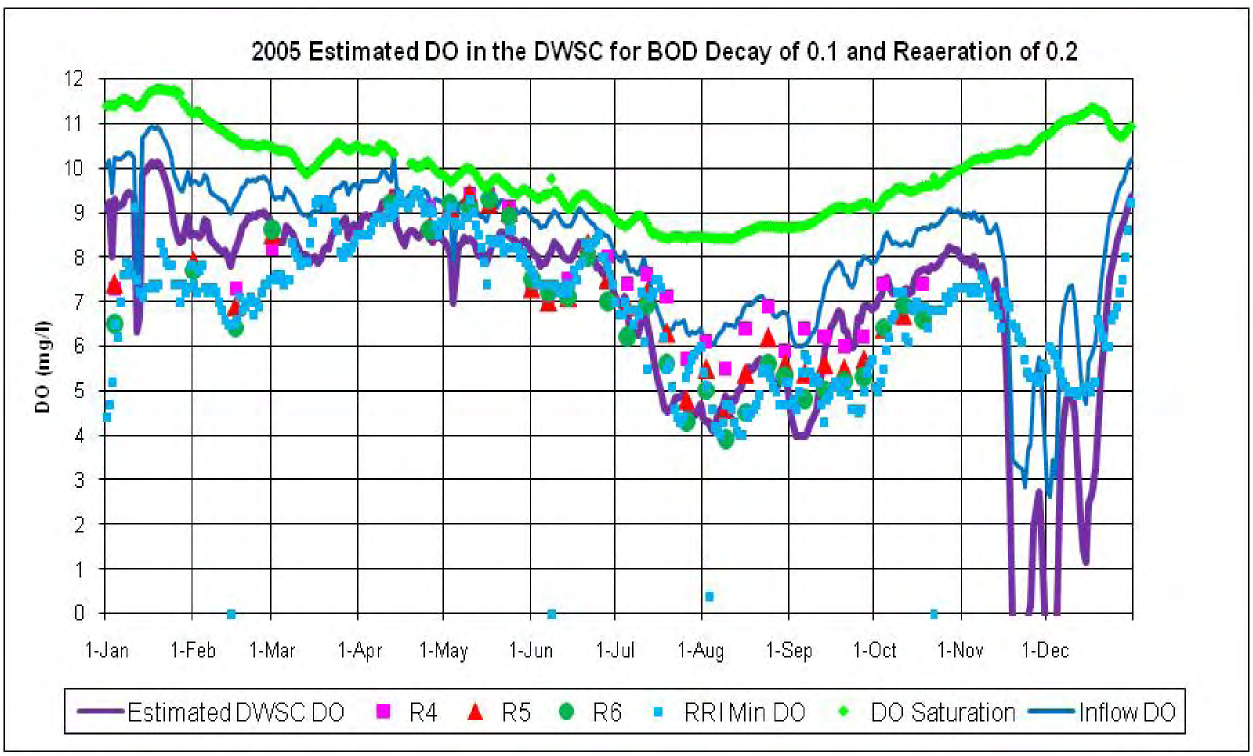
Figure 30

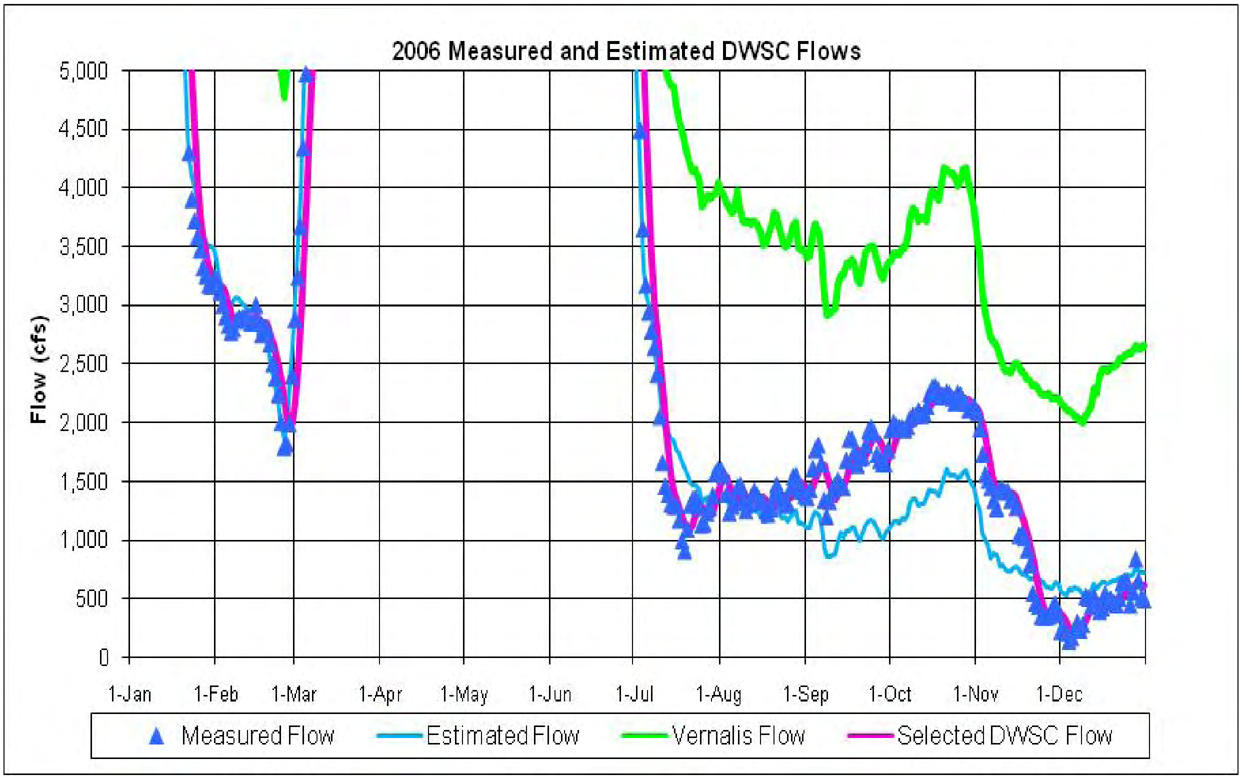


c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2005.

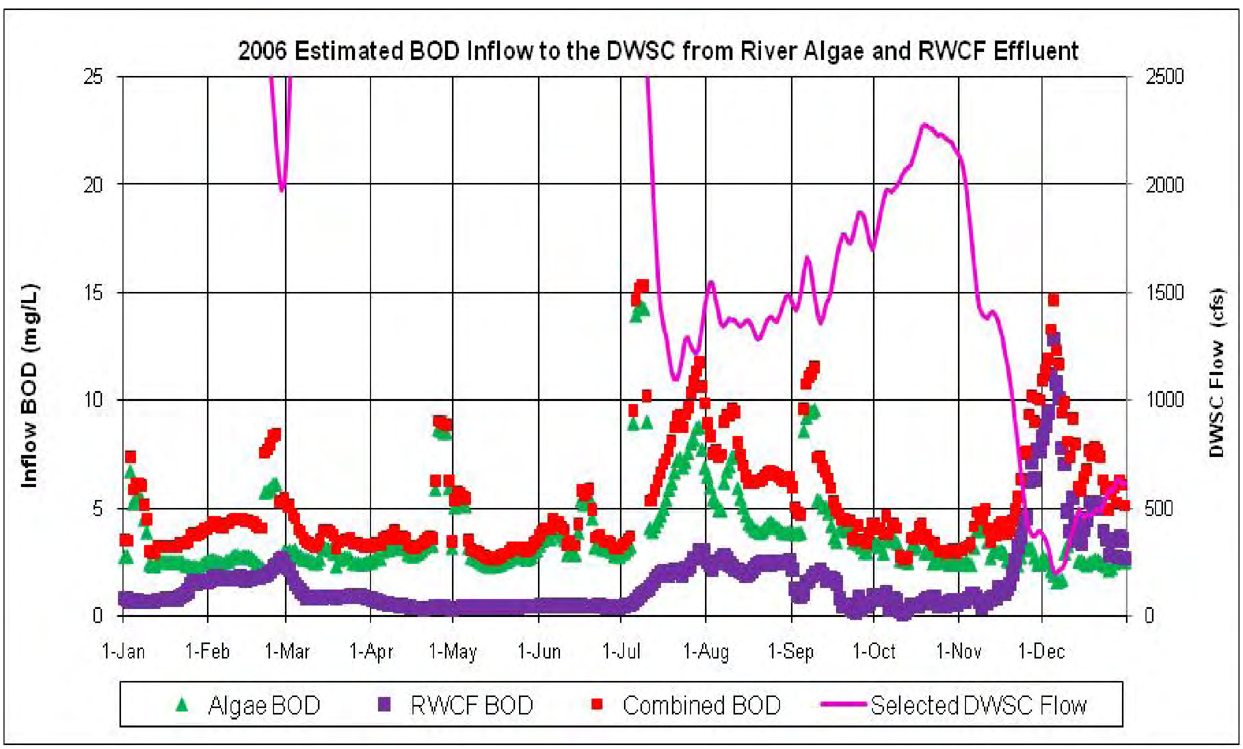


d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2005.

Figure 30
Continued

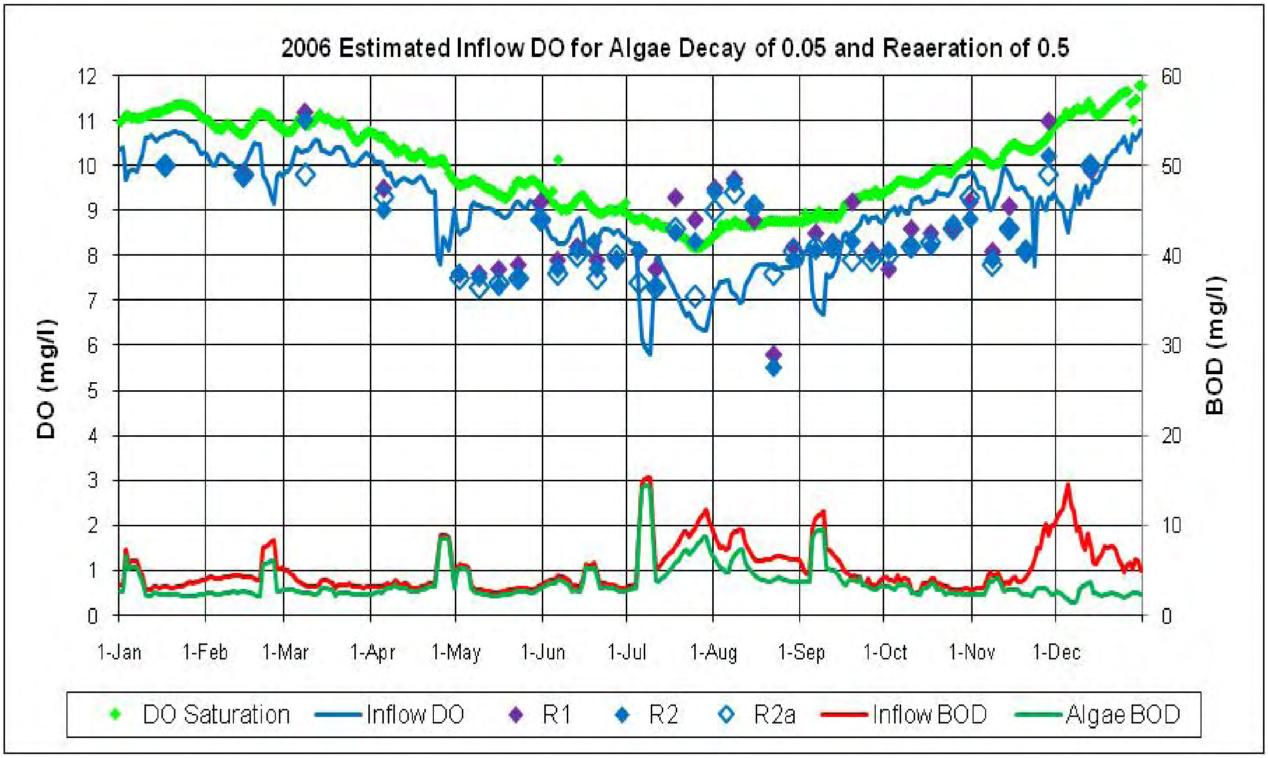


a) Daily Measured (Selected) and Estimated DWSC Flow with SJR Flows at Vernalis for 2006.

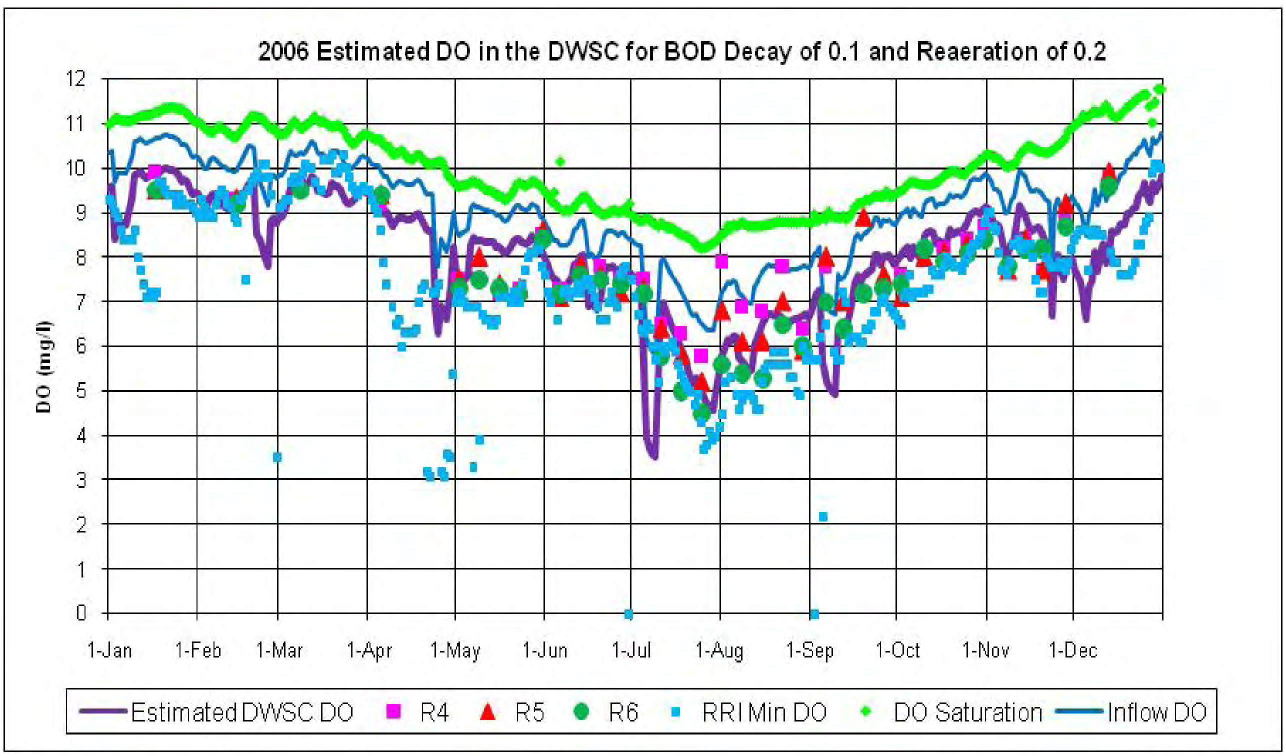


b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2006.

Figure 31



c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2006.



d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2006.

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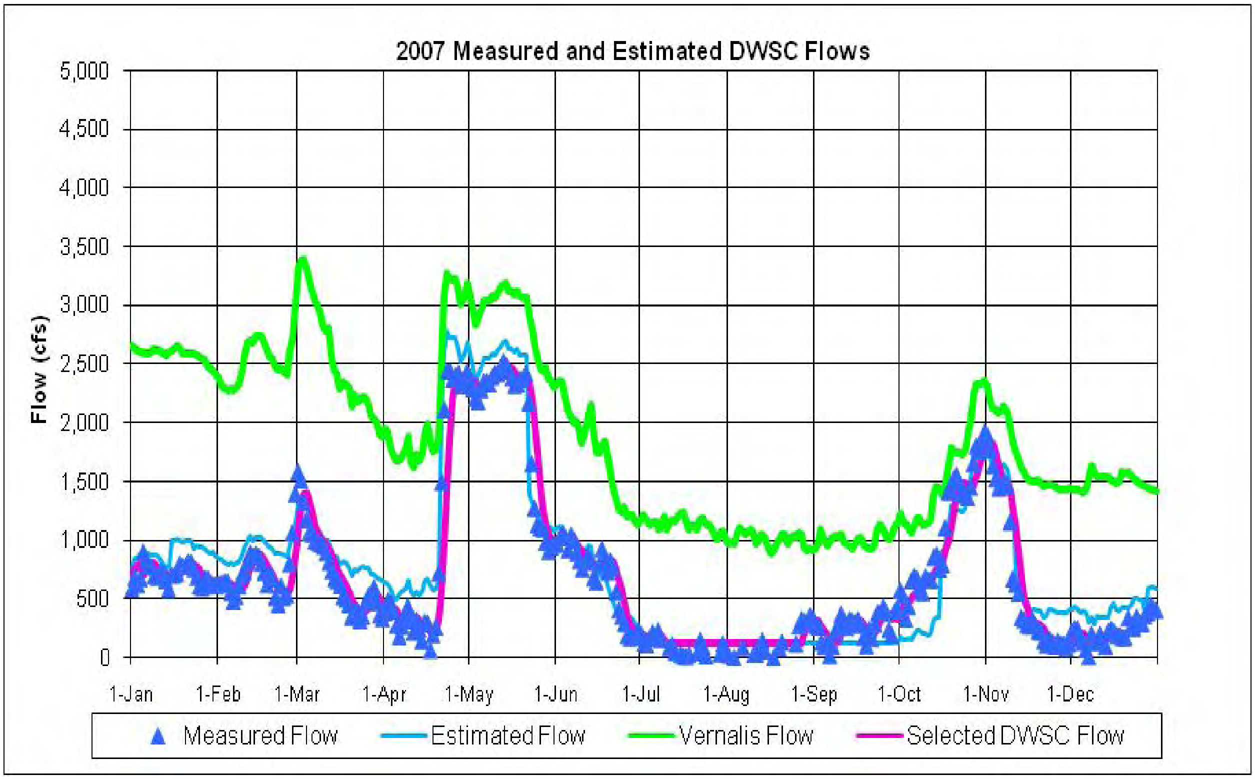
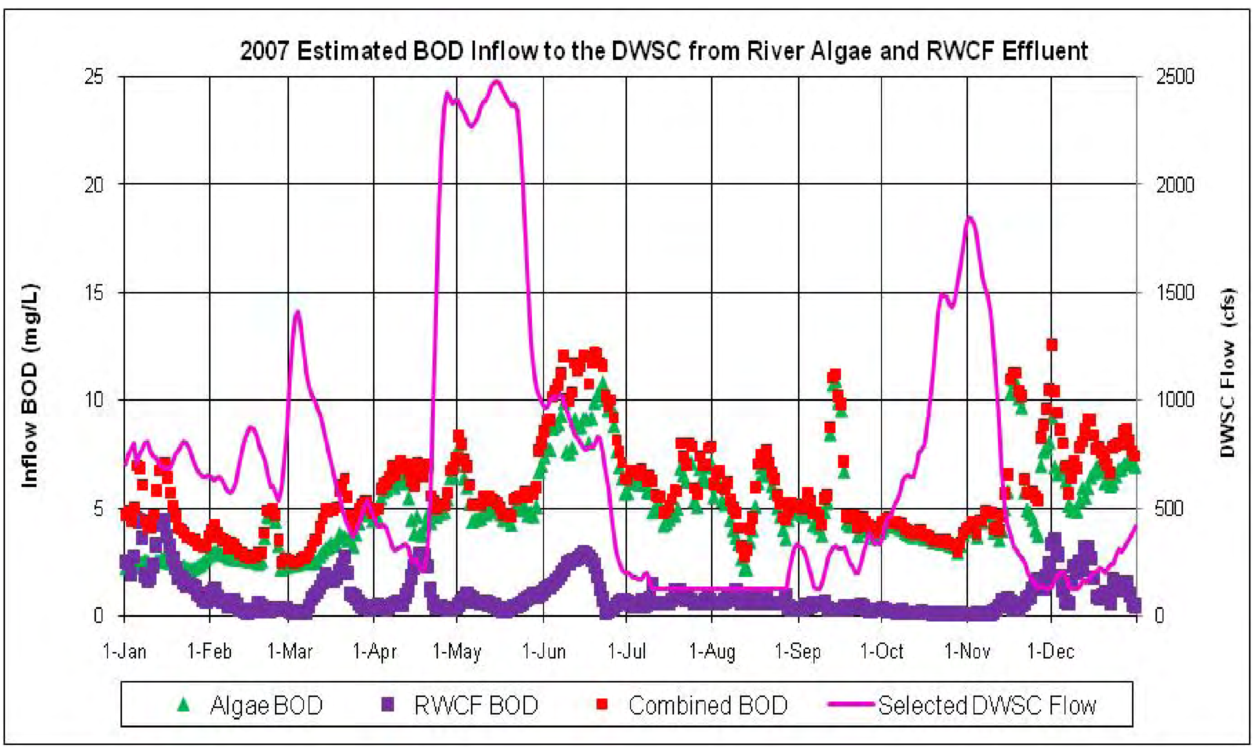
Figure 31
Continued



a) Daily Measured (Selected) and Estimated DWSC Flow with SJR Flows at Vernalis for 2007.



b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2007.

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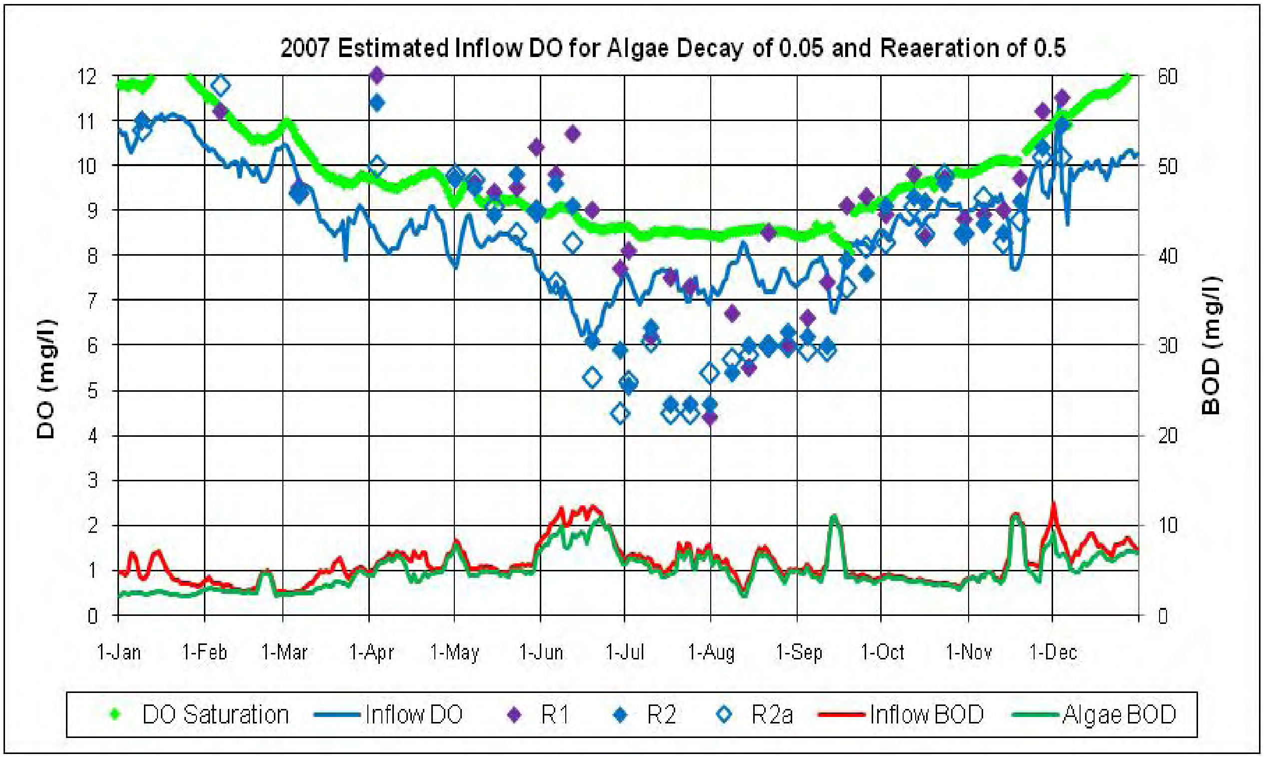
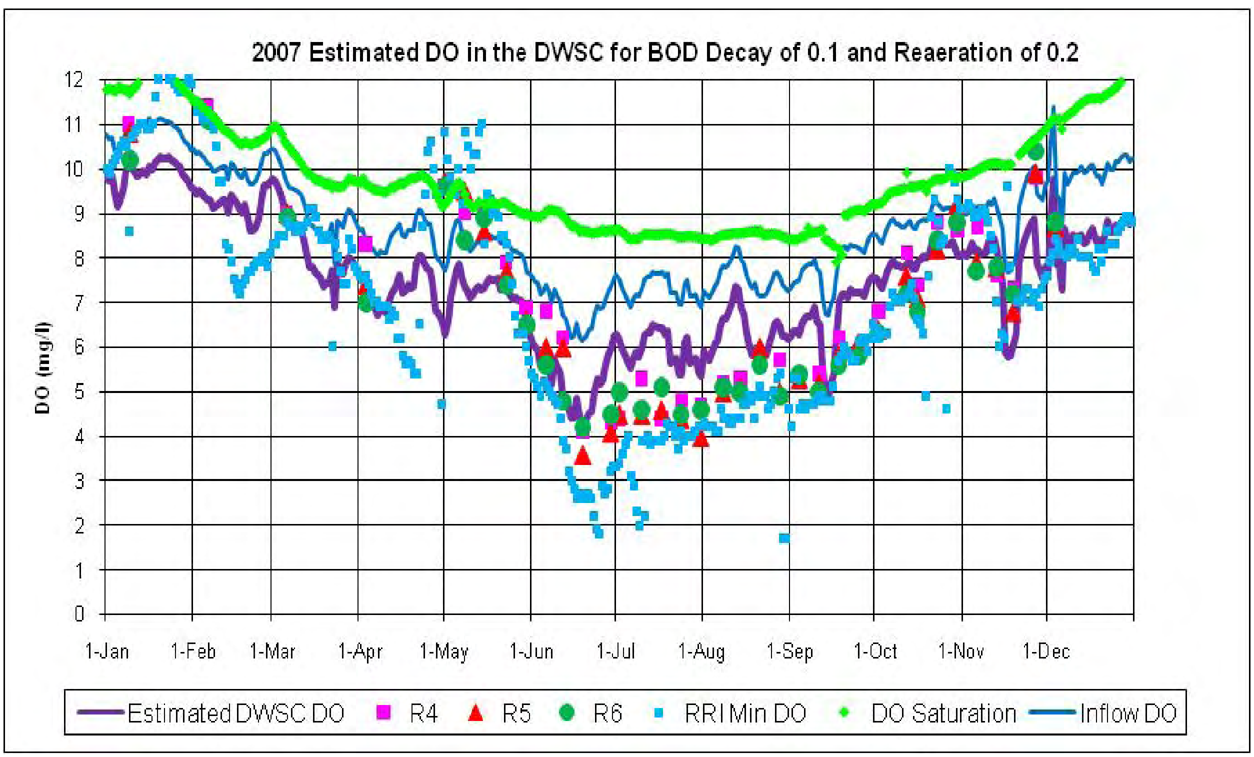
Figure 32



c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2007.



d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2007.

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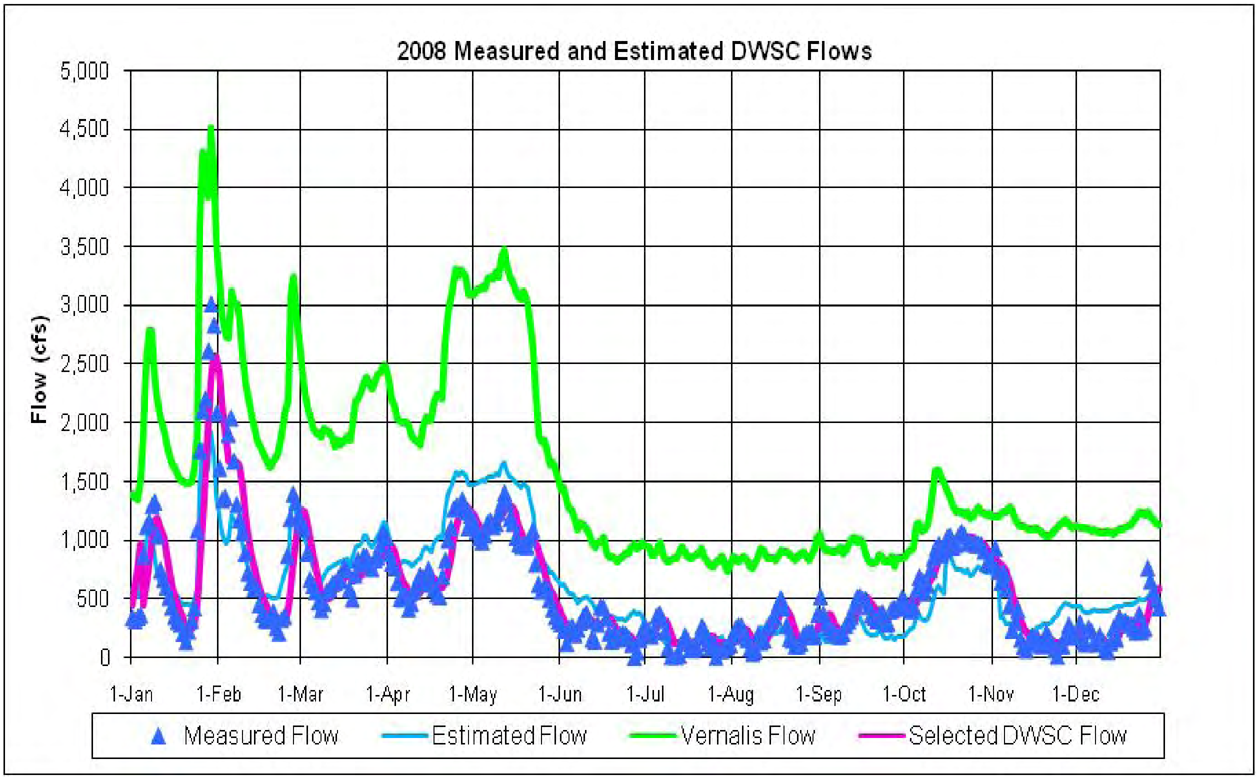
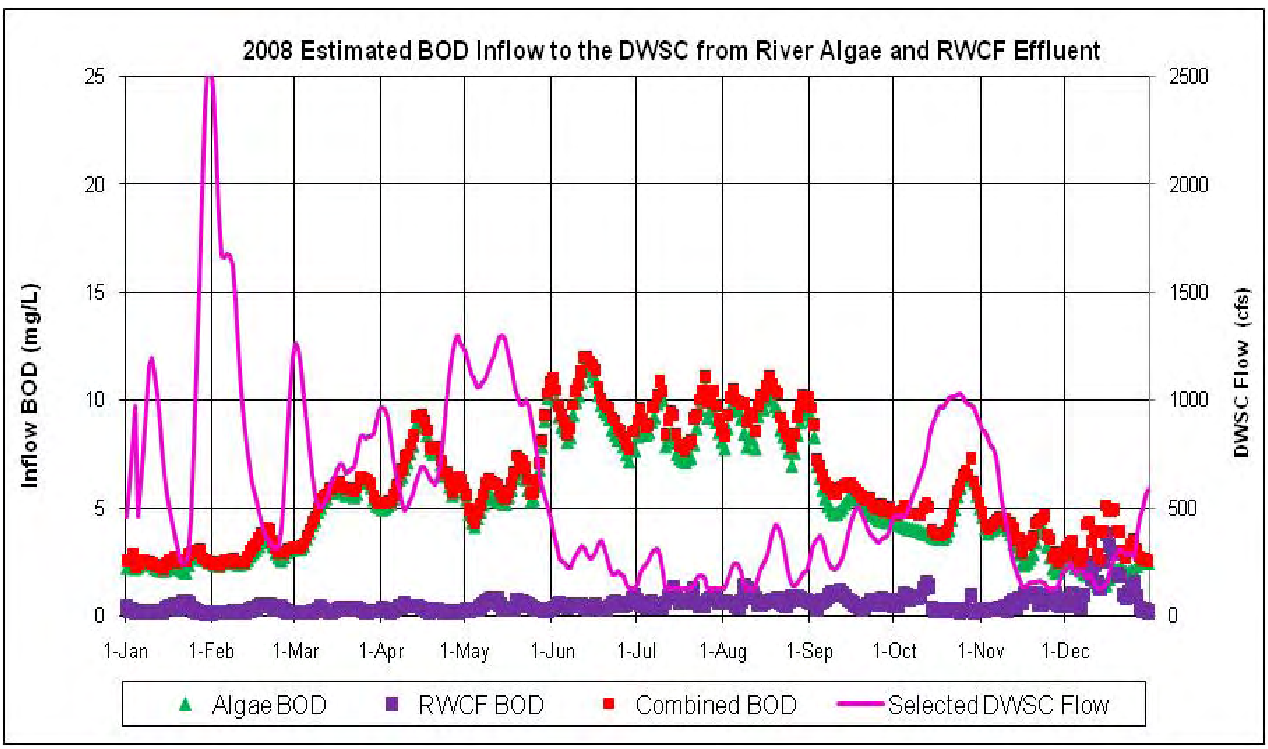
Figure 32
Continued



a) Daily Measured (Selected) and Estimated DWSC Flow with SJR Flows at Vernalis for 2008.



b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2008.

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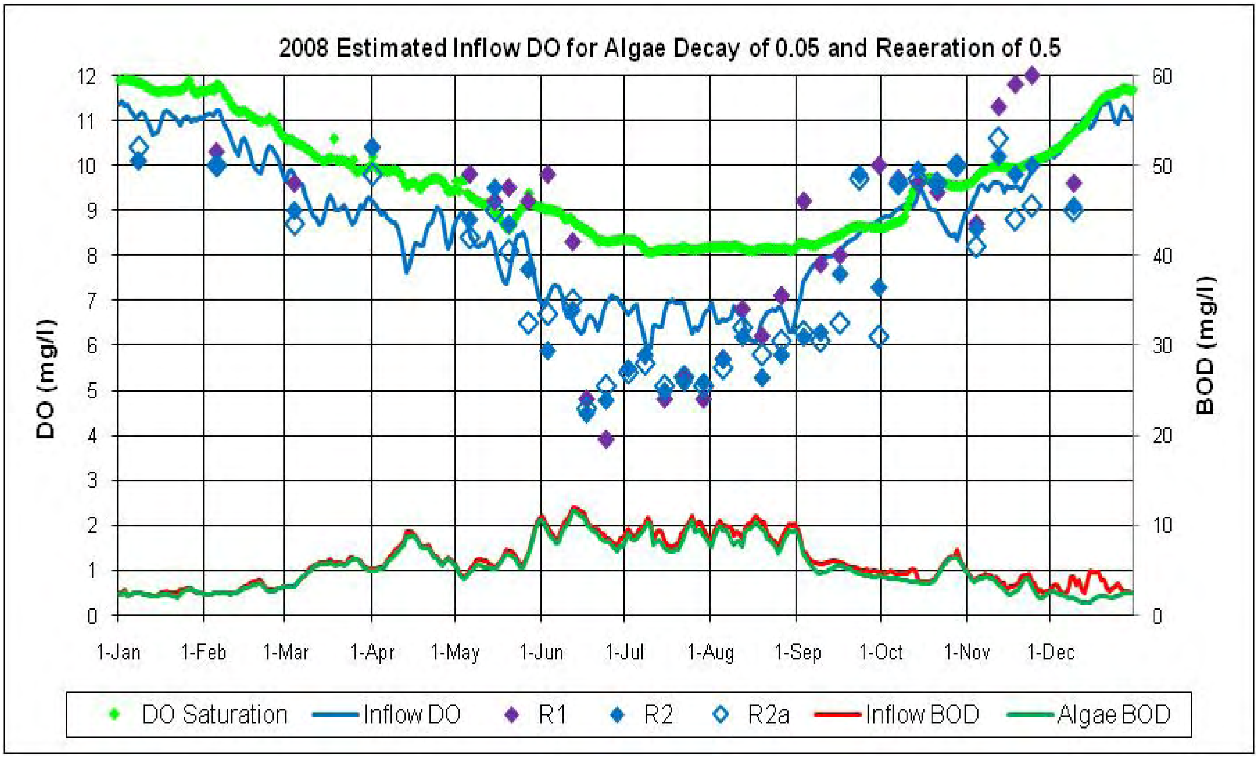
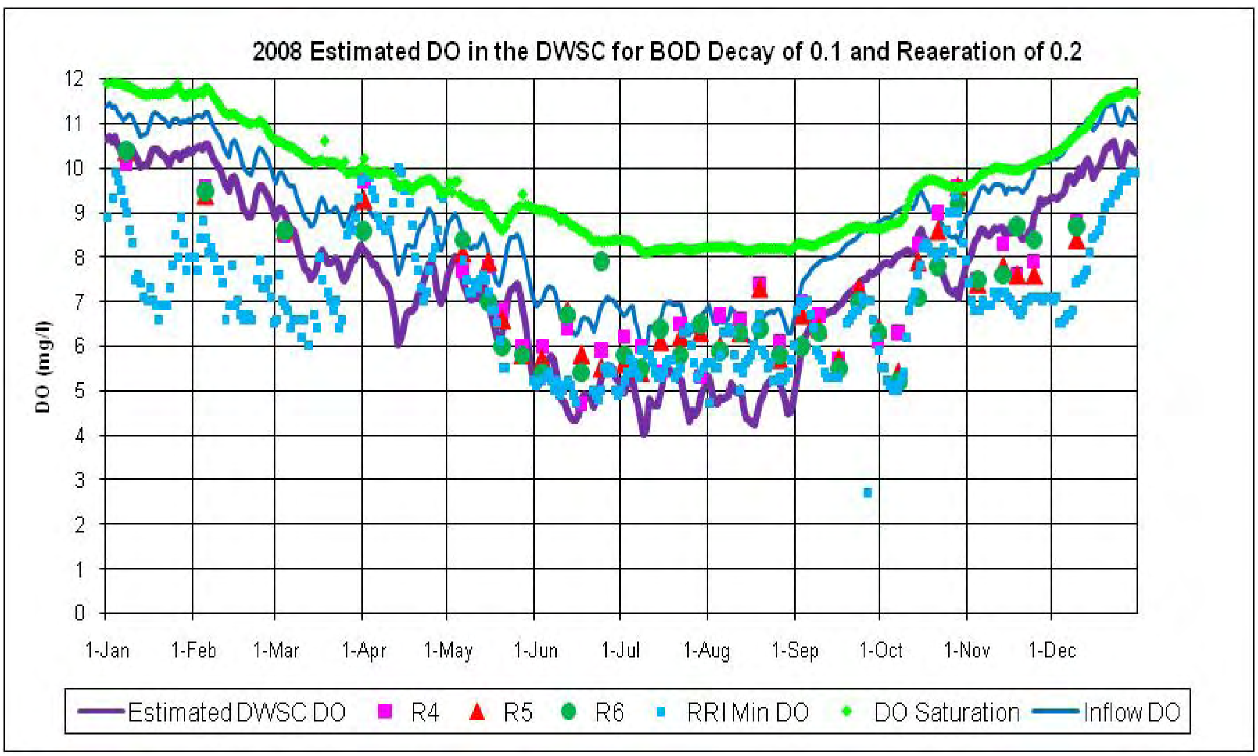
Figure 33



c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2008.



d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2008.

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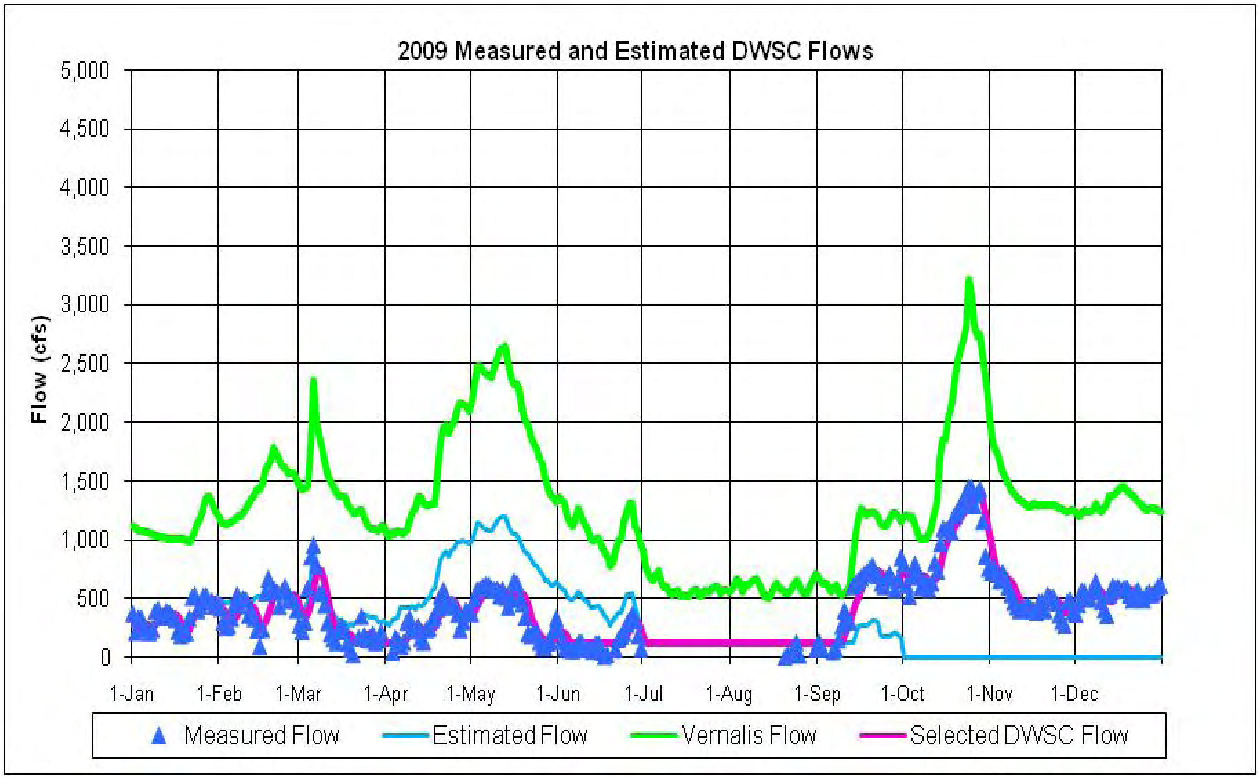
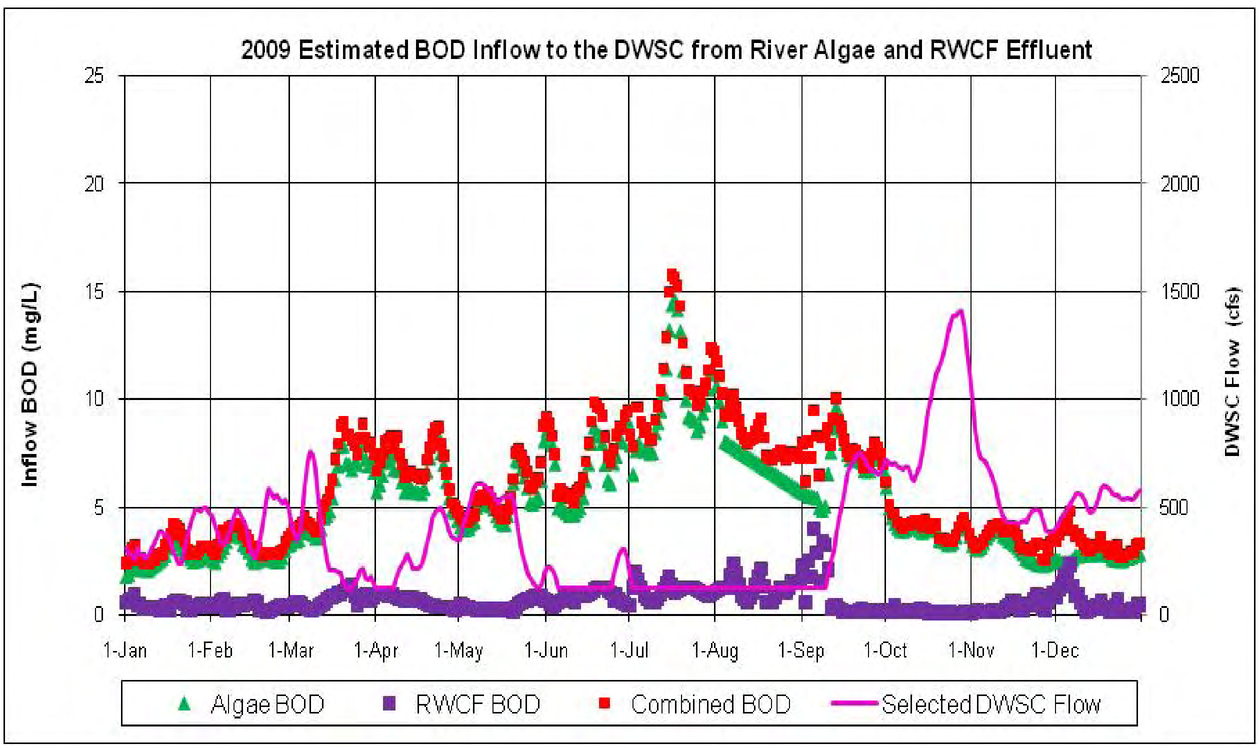
Figure 33
Continued

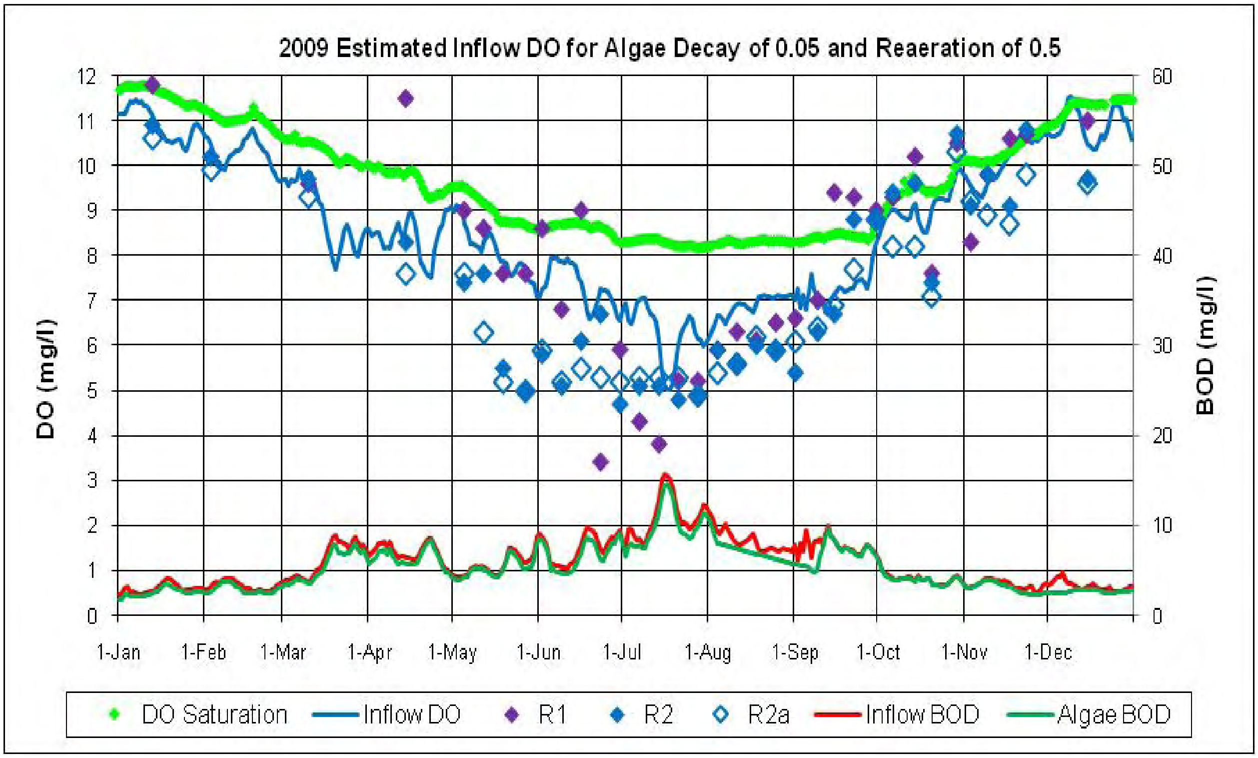


a) Daily Measured (Selected) and Estimated DWSC Flow with SJR Flows at Vernalis for 2009.

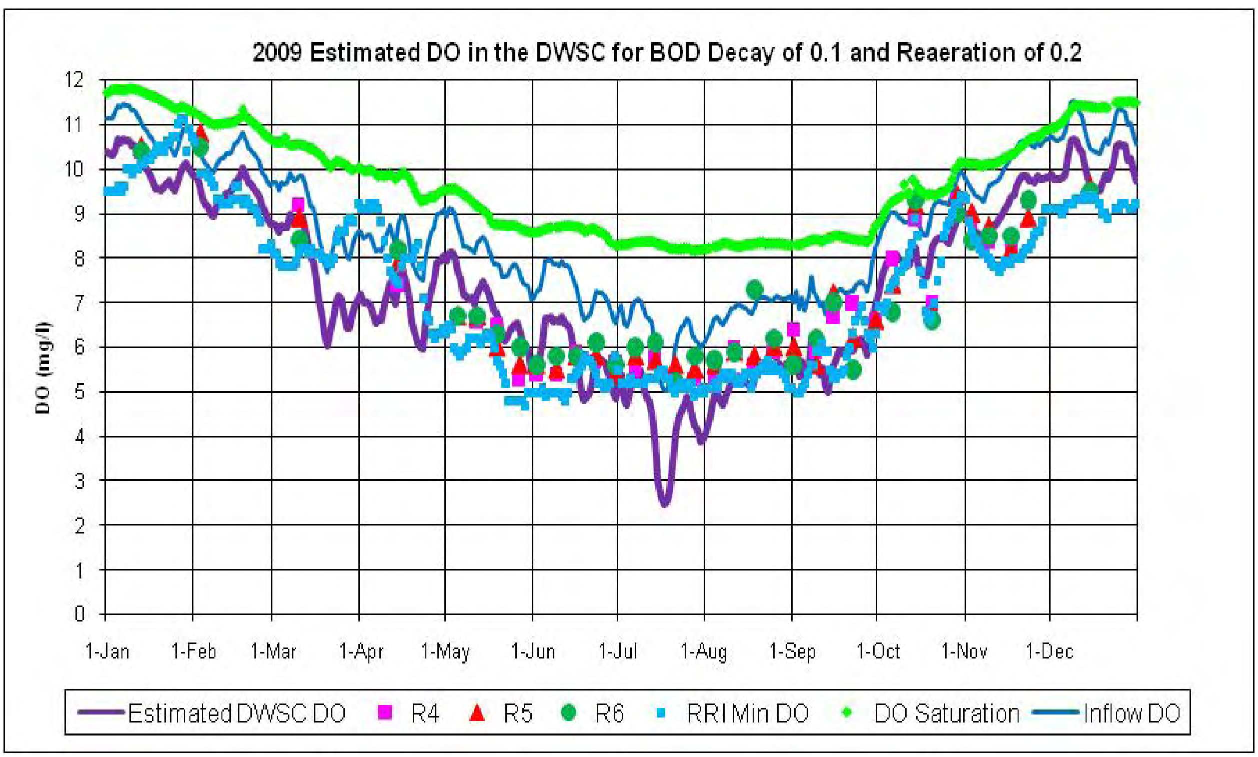


b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2009.

Figure 34

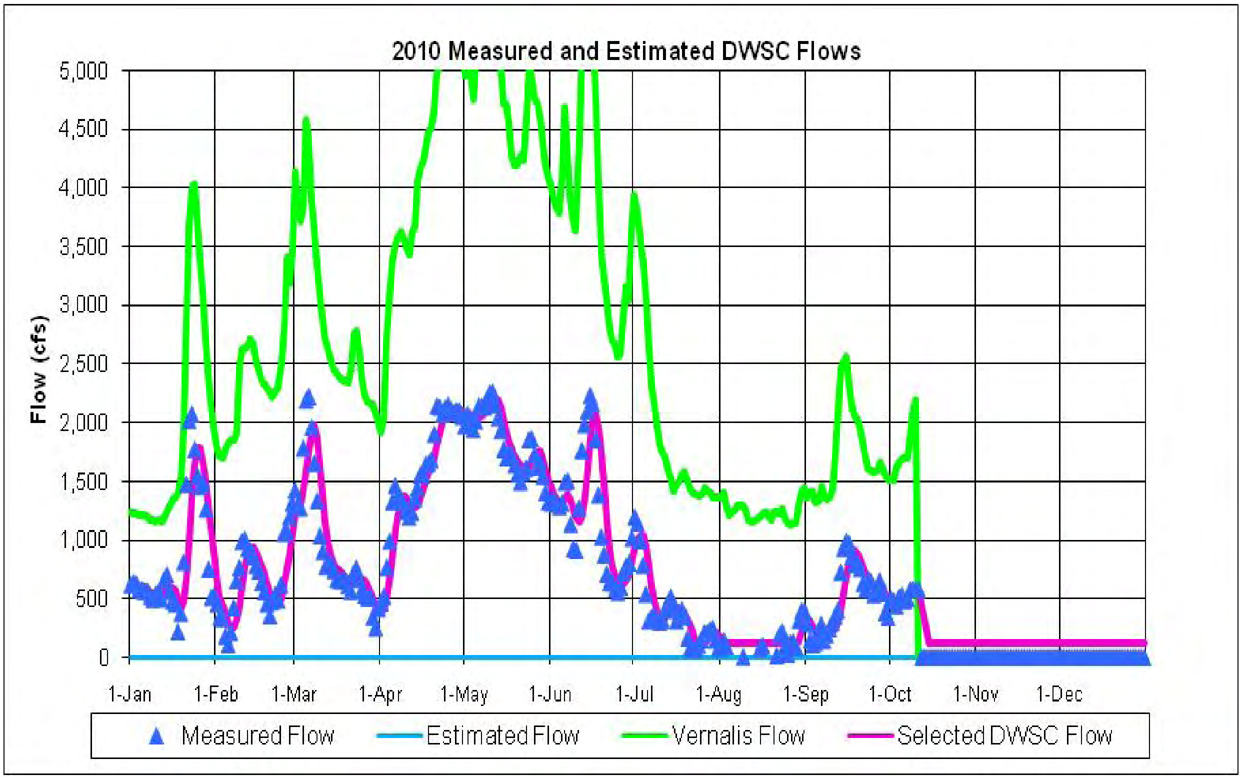


c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2009.

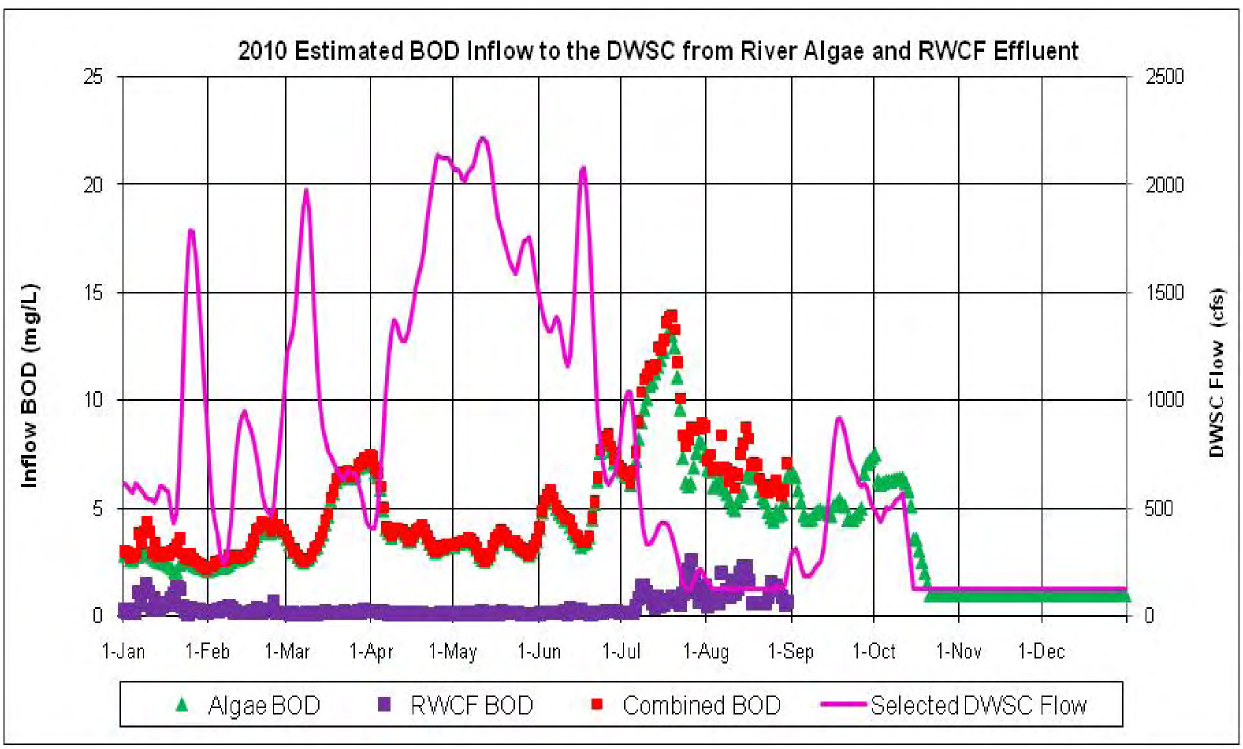


d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2009.

Figure 34
Continued



a) Daily Measured (Selected) and Estimated DWSC Flow with SJR Flows at Vernalis for 2010.



b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2010.

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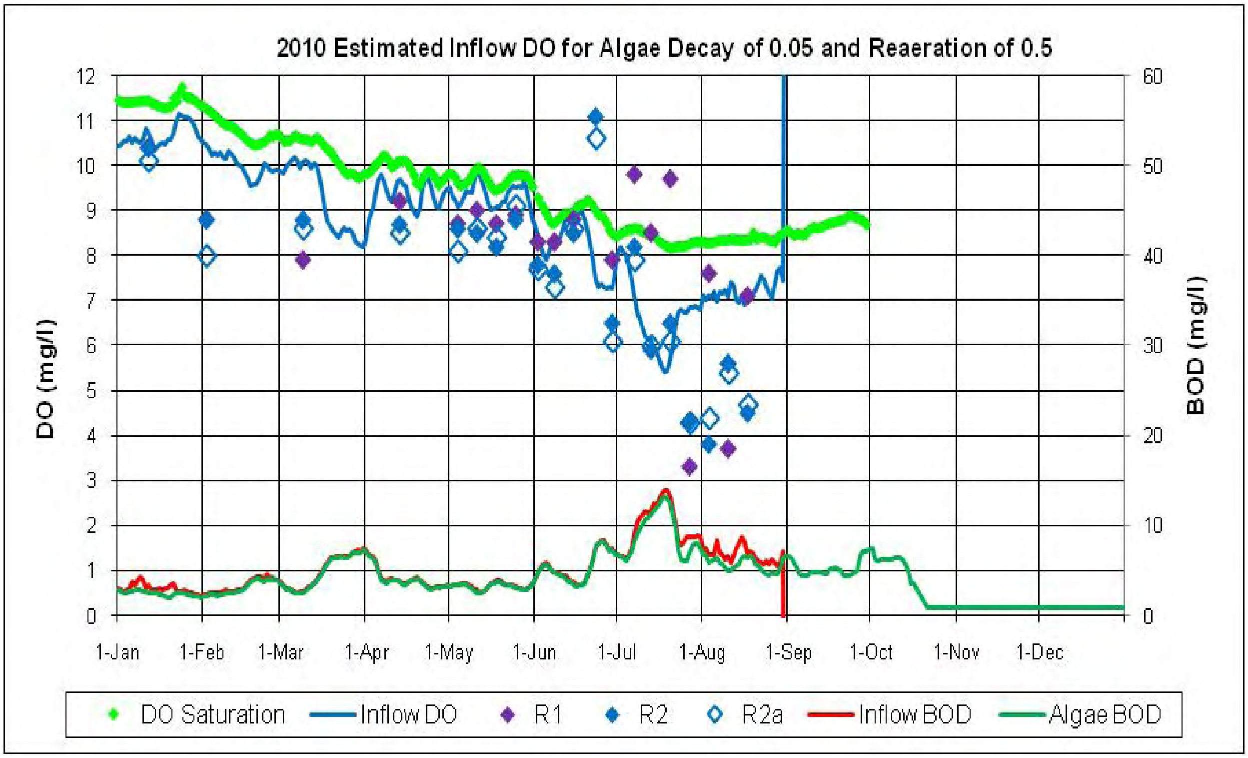
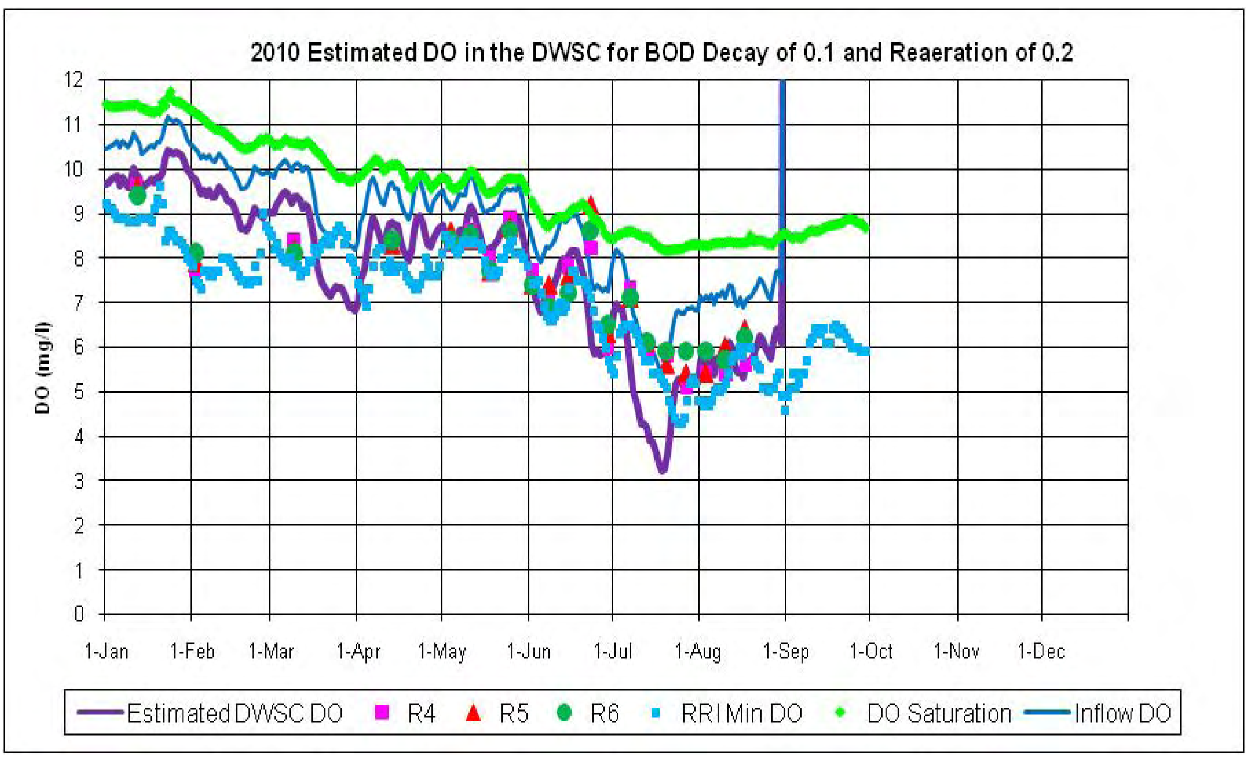
Figure 35



c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2010.



d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2010.

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Figure 35
Continued