Public Workshop (10/1-2/12)
Bay-Delta Workshop 2
Deadline: 9/14/12 by 12 noon

CONTRA COSTA WATER DISTRICT

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RECEIVED
9-14-12
SWRCB Clerk

By email to commentletters@waterboards.ca.gov and postal delivery

September 14, 2012

State Water Resources Control Board
1001 I Street
Sacramento, CA 95814

Subject: Comprehensive Review of the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary, Bay-Delta Workshop 2 – Bay-Delta Fishery Resources

Dear Chair Hoppin and Members of the State Water Resources Control Board:

Contra Costa Water District (CCWD) appreciates this opportunity to respond to the revised notice of public workshops and request for information for the Comprehensive Review and Update to the Bay-Delta plan dated August 16, 2012. Attached for your consideration is a document titled *Use of an Index for Old and Middle River Flow Objectives*, which builds on a concept that CCWD proposed in the 2010 proceedings on Delta flow criteria. CCWD is committed to working with you and your staff to further develop and implement the proposed concept in the Water Quality Control Plan update.

If you have any questions, please call me at (925) 688-8083, or call Deanna Sereno at (925) 688-8079.

Sincerely,

for Leah Orloff
Water Resources Manager

Attachment

cc: Les Grober, SWRCB
Diane Riddle, SWRCB
Karen Niiya, SWRCB
Richard Satkowski, SWRCB
Brock Bernstein, Workshops Facilitator

Use of an Index for Old and Middle River Flow Objectives

September 14, 2012

Contra Costa Water District
P.O. Box H2O
Concord, CA 94524

Submitted for:

State Water Resources Control Board
Comprehensive (Phase 2) Review and Update to the Bay-Delta Plan
Workshop 2: Bay-Delta Fishery Resources

Scheduled to Commence
October 1, 2012

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Table of Contents

1 Executive Summary

On April 14, 2010, Contra Costa Water District (CCWD) submitted a closing statement in the State Water Board's Informational Proceeding to Develop Flow Criteria for the Delta Ecosystem. At the request of Chair Hoppin, that statement included discussion of an approach for Old and Middle River (OMR) flow criteria that would both protect the public trust resources and allow efficient water supply operations through the use of an index to measure compliance with OMR objectives.

In Phase 2 of the Comprehensive Review and Update to the Bay-Delta Plan, the State Board may consider adoption of OMR flow objectives. This submittal for Workshop 2 of the Phase 2 process presents new analyses, developed since the 2010 Flow Criteria proceedings, to support the use of an index such as that discussed in CCWD's 2010 submittal for meeting any OMR flow objectives that may be set by the State Water Board.

The key points of this submittal, covered in Sections 2, 3, and 4 below, are as follows:

A. The "measured" value for OMR, which is used for compliance with current OMR objectives imposed by the fisheries agencies, is in fact an index, and one that includes significant sources of error.

B. The "measured" value is difficult to operate to, and lacks transparency.

C. Use of a simpler index to determine compliance with OMR objectives can:

   1. solve the operational and transparency problems, and

   2. provide a level of protection for listed fish species in the Delta equal to that of the "measured" values.

Section 2, entitled ""Measured" net flow in Old and Middle Rivers (OMR)" reviews the steps taken to calculate the United State Geologic Survey's net daily flows ("USGS OMR"), which are not directly measured quantities. Instead, they are calculated based on index velocities, mathematically filtered and daily averaged for each river, then summed and used to determine compliance with current OMR objectives. More than 30% of the time net combined daily OMR flows are missing from the official record; thus, scientific analysis based on USGS OMR typically relies on estimated values, with significant errors, to fill these data gaps. USGS OMR, commonly considered a "measured" value, is in fact an index of Delta hydrodynamics.

Section 3, entitled "Implementation and Transparency Issues" covers these sorts of issues in the use of the USGS data for measuring compliance with OMR requirements. USGS OMR values cannot be known in real time, since the mathematical filtering algorithm used imposes a delay of at least 35 hours, difficulties with the instruments or calculations often cause further delays, and permanent gaps in the data record are frequent. CVP and SWP operators have difficulty reliably operating to values that are not known in real time and are challenging to predict. Furthermore, compliance with OMR restrictions is not transparent in that neither regulators nor the public can ever know, in real time, whether the objectives are being met, and often can never determine with certainty whether the objectives had been met.

Section 4, entitled “Proposal for an Alternative Flow Index” presents an alternative hydrodynamic index for use in measuring compliance with OMR requirements that is based on information readily available in real time, that is both predictable and controllable by CVP and SWP operators, and that provides clear information regarding whether OMR requirements are being met. Analyses similar to those that support existing OMR requirements were performed for delta smelt, longfin smelt and steelhead, using both the alternative flow index and USGS OMR. (Analyses for Chinook salmon are underway but not yet complete.) These indicate that, for all three species considered, the relationships of salvage at the export pumps to the alternative flow index are very similar to the salvage/USGS OMR relationships, with the alternative flow index performing equivalently as a predictor of salvage.

2 "Measured" net flow in Old and Middle Rivers (OMR)

The values that are often referred to as "measured" net flow in Old and Middle Rivers (OMR) are not directly measured quantities. This section reviews the steps taken to calculate the values that are provided by the United State Geologic Survey (USGS) as tidally filtered daily flows. It is demonstrated that the "measured" net flow is an index that contains substantial error, including error induced from bad data and from periods when data are not available. An estimate of the error in the USGS calculation is presented, and will be compared with an alternative flow index in Section 4.1.

2.1 Calculation of "measured" OMR

Since 1987, the USGS has operated and maintained velocity meters in Old River on the west side of Bacon Island (station 11313405) and in Middle River on the east side of Bacon Island (station 11312676). The meters do not directly measure flow; they measure what the USGS terms an "index velocity", which is a measurement of velocity through a portion of each channel. Typically measurements of the index velocity are taken every 15 minutes. A measurement of the water level (i.e. stage) is also recorded at the same time. These are the actual measurements from which an estimate of net daily flow is calculated. The process used to estimate flow is reviewed briefly below to provide background for the error estimates in the following section.

To calculate flow, the USGS utilizes information collected during a limited number of site visits designed to calibrate the station. First, the geometry of the channel is surveyed to develop a relationship between the cross-sectional area and the water level. Second, velocity measurements are collected at many points along the channel cross section over a relatively short time period (typically about 12 or 13 hours) to capture tidal variability. The USGS incorporates the data collected during these field investigations to develop a calibration relationship called a "rating curve". Rating curves allow conversion of the index velocity to a mean channel velocity, which is then used to estimate flow by multiplying by the channel area. Channel area varies tidally with the water level, and is estimated based on stage measurements. (Ruhl and Simpson 2005) These calculations are all performed by the USGS to produce the 15-minute flow values reported to the USGS National Water Information System (NWIS) website.

Once the 15-minute flow is calculated at each station, the USGS applies a mathematical filter to remove the tidal fluctuations. For the Old River and Middle River stations, this is done with a Godin filter, which is a cascaded running mean filter and response function that smoothes the data twice using a 24-hour average and once using a 25-hour average. The USGS uses a centered filter that requires a minimum of 71 hours of continuous hourly data to generate a filtered estimate for one value at the center of that time period. Every filtered value is calculated using data from 35 hours before and 35 hours after that value. Finally, the filtered hourly data are averaged over 24 hours to determine a net daily value.

The USGS reports both the tidal (15-minute) data and the tidally filtered daily data on the NWIS website[1] in near real time, with tidal data updated every 15 minutes. However, since the filter method requires 35 hours of subsequent data to be collected before a value can be calculated, the

[1] http://waterdata.usgs.gov/nwis

most recent filtered data available at any time is generally 2-3 days old. It is these filtered values that are used to determine compliance under the current implementation of the OMR regulation.

The final step in the calculation of net flow in Old and Middle Rivers is to add the tidally filtered daily value for Old River and the tidally filtered daily value for Middle River, which is not done on the USGS website[2].

2.2 Error in Estimation of Missing Data

As with all field data collection programs, there are problems with instruments or information transfer that cause loss of data from the Old River and Middle River velocity meters at times. Due to the filtering technique described above, which relies on a 71-hour set of continuous data, small gaps in data time series can create large holes in the record of filtered values. For instance, if tidal data are missing, the filter leaves a gap of 35 hours spanning each side of the missing data. For a single missing data point, the gap is nearly 3 days. Calculating the daily average of tidally filtered values transforms the 3 day gap in the filtered data to a 4 day gap in the daily value, due to the loss of a single data point. Longer periods of data loss are fairly common in the official record, as shown in Figure 2-1.

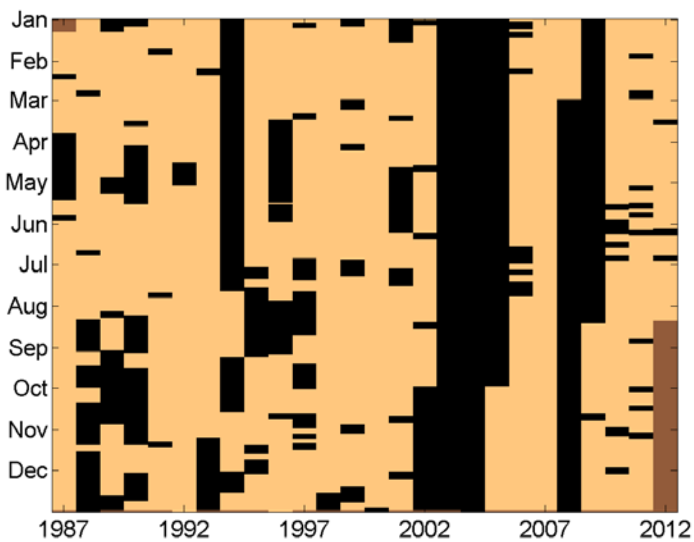

Figure 2-1: Data gaps in the official USGS tidally filtered daily Old River and Middle River data sets
Gaps in data exist throughout the USGS data record. While some gaps (colored in black) last only a few days, many gaps last weeks, months, and even years. [Data source: USGS tidally filtered flow from the NWIS website downloaded August 14, 2012]

The USGS NWIS website does not provide estimated values. USGS data are posted as provisional in near real time; USGS subsequently reviews the data and re-posts an approved data

[2] Due to the delay in posting of the USGS filtered values and the additional post-processing that is necessary to estimate OMR, DWR posts an estimated value of OMR on the California Data Exchange Center (CDEC) website at http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=omr. CDEC values are estimated and are not updated when data are quality controlled. The CDEC data set is discussed in Section 3.

set[3], replacing the provisional data. When a value is determined to be incorrect, either in real time or subsequently during the review process, it is simply removed from the website. Figure 2-1 shows when data are missing from the USGS NWIS website, and Table 2-1 lists the percentage of time when data are missing for either or both stations. As of August 2012, the USGS had reviewed (i.e. "approved") data through February 29, 2008. Data between March 1, 2008 and August 15, 2009 have been removed from the website, indicating a potential problem with that period. Provisional data are listed from August 15, 2009 through August 2012.

Table 2-1: Percent of time when data are missing from USGS stations at Old River and Middle River
From the time the sensors started operating in January 1987, a significant portion of the data has been invalid and is now missing values. Prior to analyses, the missing data must be estimated. [Data source: USGS tidally filtered flow from the NWIS website downloaded August 14, 2012]

	USGS "Approved" Data from January 11, 1987 to Feb 29, 2008	All USGS Data from January 11, 1987 to August 11, 2012
Old River	13%	17%
Middle River	21%	24%
Old River or Middle River, but not both	27%	23%
Old River and Middle River	4%	9%
Total time when OMR flow must be estimated	31%	32%

Most scientific analyses require a complete data set, so missing data has been estimated. The USGS developed a data set that incorporated estimates for missing data. This spreadsheet, originally developed in 2006 and updated in 2010, has become widely used in the scientific community. While the spreadsheet clearly indicates when data have been estimated, many scientists have not distinguished between estimated and measured values in their analysis; what is commonly referred to as the "measured" OMR flow data set comprises approximately 70% flows calculated from measured velocity indices and approximately 30% estimated values. The remainder of this section examines the amount of estimation error that has been introduced into the data set.

Typically, when the sensor in either Old River or Middle River is missing data, the tidally filtered daily flow is estimated based on the other river[4]. Figure 2-2 shows a scatter plot of the USGS approved tidally filtered daily flow at Middle River and Old River. The USGS developed piecewise quadratic relationships to estimate flow at one station based on flow at the other station, shown by the blue and red lines in Figure 2-2. The error in using these relationships is shown in Table 2-2. Similarly, Dr. Paul Hutton developed piecewise linear relationships for estimation of tidally filtered flow when one of the two flow values was available; the standard

[3] As of September 3, 2012, USGS-approved data are only available for the Old River station (11313405) and Middle River station (11312676) through February 29, 2008.
[4] Old River station and Middle River station are located approximately 3 miles apart as the bird flies, but 4 to 6.5 miles apart as the fish swims (through the connecting river channels).

error of estimation (SEE) for Hutton's estimation method is 298 cfs when Middle River is less than -4,000 cfs and 388 cfs when Middle River is greater than -4,000 cfs.

For the 23% of the time when tidally filtered flow in either Old River or Middle River is missing, the value is often estimated based on one of the above correlations.

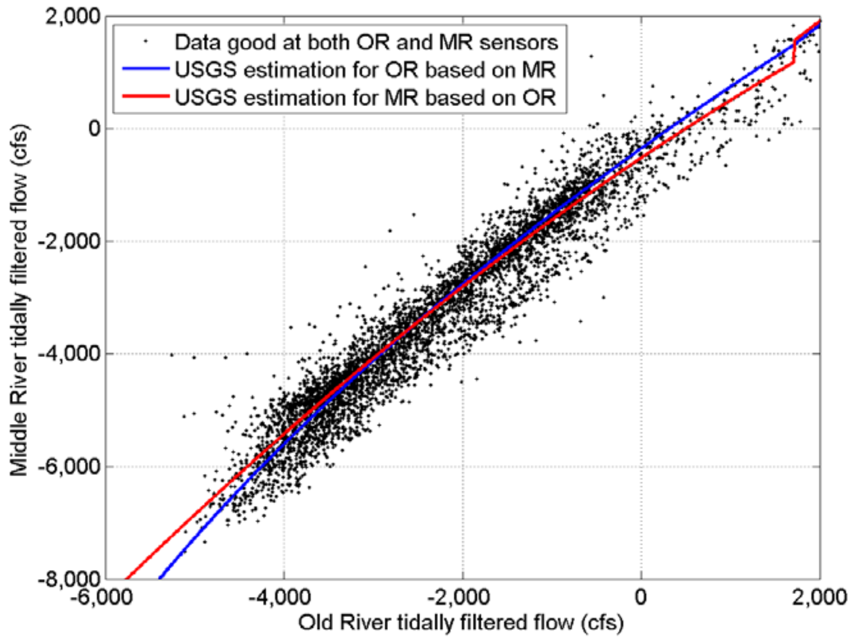

Figure 2-2: Relationship between tidally filtered flow in Old River (OR) and Middle River (MR). When tidally filtered flow from one of the stations is missing, it is common to estimate the value based on the known sensor. Substantial scatter exists in this relationship between the sensors, such that the prediction may be up to 2800 cfs from the actual value. [Data source: USGS tidally filtered flow from the NWIS website downloaded August 14, 2012.]

Table 2-2: Error in estimating flow at either Old River or Middle River
Use of the USGS estimation for tidally filtered daily average flow at either Old River or Middle River. The standard error of estimation (SSE) is a measure of the accuracy of predictions.

Estimation Method	SEE	Maximum Error
Old River based on Middle River	315 cfs	2,040 cfs
Middle River based on Old River	400 cfs	2,840 cfs

For the time periods when both the Old River and the Middle River sensors are missing data, multiple agencies have developed equations to estimate OMR based on other system variables. The California Department of Water Resources (DWR) and USGS developed estimates based on the total exports at the SWP and CVP facilities near Tracy, San Joaquin River flow at Vernalis, and the operation of a channel barrier at the head of Old River. The equation parameters and corresponding error estimates are listed in Table 2-3. Similarly, Paul Hutton developed a method to estimate Old and Middle River flows based on the above parameters as well as estimated net south Delta consumptive use and the position of the channel barrier in Grant Line Canal (Hutton 2008).

Table 2-3: Methods to estimate OMR based on Flow at Vernalis and Total Exports, with SEE
DWR and USGS independently developed methods to estimate OMR based on daily flow at Vernalis ($Q_{Vernalis}$) and Total Exports ($Q_{Exports}$) in the form Q_{OMR} (cfs) = A * $Q_{Vernalis}$ (cfs) + B * $Q_{Exports}$ (cfs) + C. The standard error of estimation (SEE) for these estimation methods ranges from 973 cfs to 1,295 cfs. SEE and maximum error for the DWR method is calculated based on the approved USGS OMR data set (as of August 2012). SEE for the USGS method is provided in Ruhl et al (2006), but the maximum error is not reported (NR).

Estimation Author	$Q_{Vernalis}$	Barriers	A	B	C	SEE	Maximum Error
DWR	All	All	0.58	-0.913	0	1,070 cfs	4,360 cfs
USGS	<10,000cfs	In	0	-0.8129	-365	973 cfs	NR
USGS	<10,000cfs	Out	0	-0.8738	1137	1,295 cfs	NR
USGS	≥10,000cfs	All	0.7094	-0.7094	-4619	1,090 cfs	NR

A secondary method to estimate OMR is a simple linear interpolation over the data gaps. The SEE for linear interpolation depends on the number of data points that are missing (Table 2-4). As discussed above, the shortest data gap in the tidally filtered daily values is 4 days (due to filter method). As shown in Figure 2-1, many data gaps are much longer than 4 days.

Table 2-4: Error of estimating tidally filtered daily OMR by linear interpolation over gaps in observed data
A viable method to fill small gaps in the tidally filtered daily average USGS values is to linearly interpolate over the data gap. However, the estimation error increases with the length of time that is missing data such that interpolating over more than 4 days can lead to significant maximum error in the estimate.

Length of Gap in Data (days)	SEE	Maximum Error
4	816 cfs	5,600 cfs
10	1,190 cfs	14,300 cfs
20	1,570 cfs	19,400 cfs

In summary, with data missing from the USGS sensors 32% of the time, the USGS OMR data that is typically used for analysis to determine and justify regulations on net flows in Old and Middle River incorporates error due to the necessity of estimating values. As described above, the standard error of estimation ranges from 300 to 1,300 cfs with a maximum error between 2,000 and 6,000 cfs. This error is simply part of what is often termed the “measured” OMR data set.

2.3 “Measured” OMR is itself an index

As discussed in Section 2.1, the values that are often colloquially referred to as “measured” OMR are calculated based on index velocities that are measured at two point locations in the

Delta. The 15-minute OMR flow values are calculated estimates of flow based on the localized measured velocities. USGS then filters and averages the flow values to describe a hydrodynamic parameter that is more useful for fish protection in the Delta than the actual measured values. This type of value is often referred to as an index because it indicates useful information about the system.

As discussed in Section 2.2, "measured" OMR is missing for a significant portion of the historical record, and the error of estimating the values is significant. However, even with the estimation error, the USGS OMR index has proven useful to deciphering complicated Delta hydrodynamics. OMR is hypothesized to reflect "the hydrodynamic influence of the water projects' diversions on the southern half of the Delta and thus the degree of entrainment risk for fishes in that region (Kimmerer 2008; Grimaldo et al. 2009)." (FWS 2011)

To explore the risk of entrainment under varying Delta hydrodynamics conditions, studies have utilized a particle tracking model (PTM), which simulates the transport and fate of neutrally buoyant particles in the Delta channels and estimates the probability that a parcel of water starting at one location will arrive at another location in a given time frame. The use of PTM for entrainment risk analysis and the modeling assumptions used for this report are discussed in Appendix A, Section A.2.

Results from hundreds of PTM simulations are summarized below to illustrate the extent to which OMR reflects Delta hydrodynamics. For these studies, particle releases were simulated with the PTM model at select fish survey locations within the Delta as shown in Figure 2-3. Particle movement was tracked throughout the simulation, and the total percentage of particles entrained at the SWP and CVP export facilities in the south Delta was determined for 28 day periods after each simulated particle release. In Figure 2-4, total percent entrainment is plotted against the average USGS OMR[5] during the simulation period to illustrate how well OMR predicts entrainment risk.

As expected, the entrainment risk is highly dependent on the starting location for the particles[6]. For instance, no more than 5% of the particles released near the confluence of the Sacramento and San Joaquin River were entrained during any of the simulations (panel A), yet nearly 90% of the particles released on the San Joaquin River near mouth of Old River were entrained during a few simulations (panel D).

The entrainment risk varies for different levels of average OMR flow, with considerable scatter in the results. For instance, for particles starting on the San Joaquin River near the mouth of Old River (panel D), at OMR equal to -3,000 cfs, entrainment varies from 8% to 24%, and at OMR equal to -5,000 cfs, entrainment varies from 4% to 64%. So while OMR clearly reflects some characteristics of Delta hydrodynamics, the value of OMR alone is not sufficient to predict particle movement, even in the idealized case of a numerical model.

[5] For the analyses presented in this section, "USGS OMR" includes both the calculated flows from the USGS NWIS website whenever available and estimates of the values using the USGS estimation methods for the periods when data is missing (see Section 2.2).

[6] Implementation of the current OMR regulations allows for consideration of the spatial distribution of delta smelt and longfin smelt to some extent; this is typically done currently through application of judgment of fishery experts in the adaptive management process. However, the regulations include a minimum value of OMR (-5,000 cfs) that cannot be exceeded regardless of spatial distribution.

The uncertainty between measured and modeled OMR is shown in Figure 2-5 for the historical period February 1990 through March 2012.

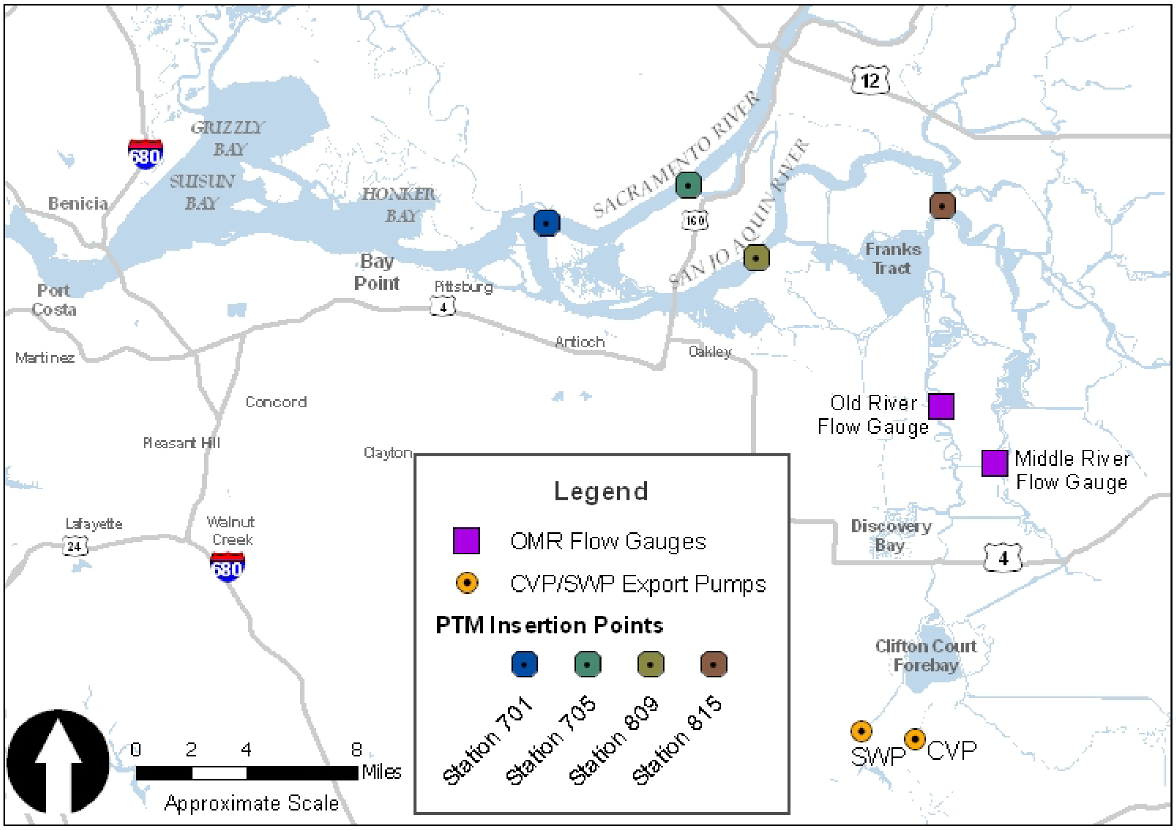

Figure 2-3: Map of PTM insertion locations

Particle tracking modeling is used to determine the movement of neutrally buoyant particles after release from specific locations within the Delta (Stations 701, 705, 809, and 815 shown in the map above). After release, particle movement is simulated with tidal hydrodynamics and the final particle fate (e.g. where the particle ends up after a defined amount of time) is determined.

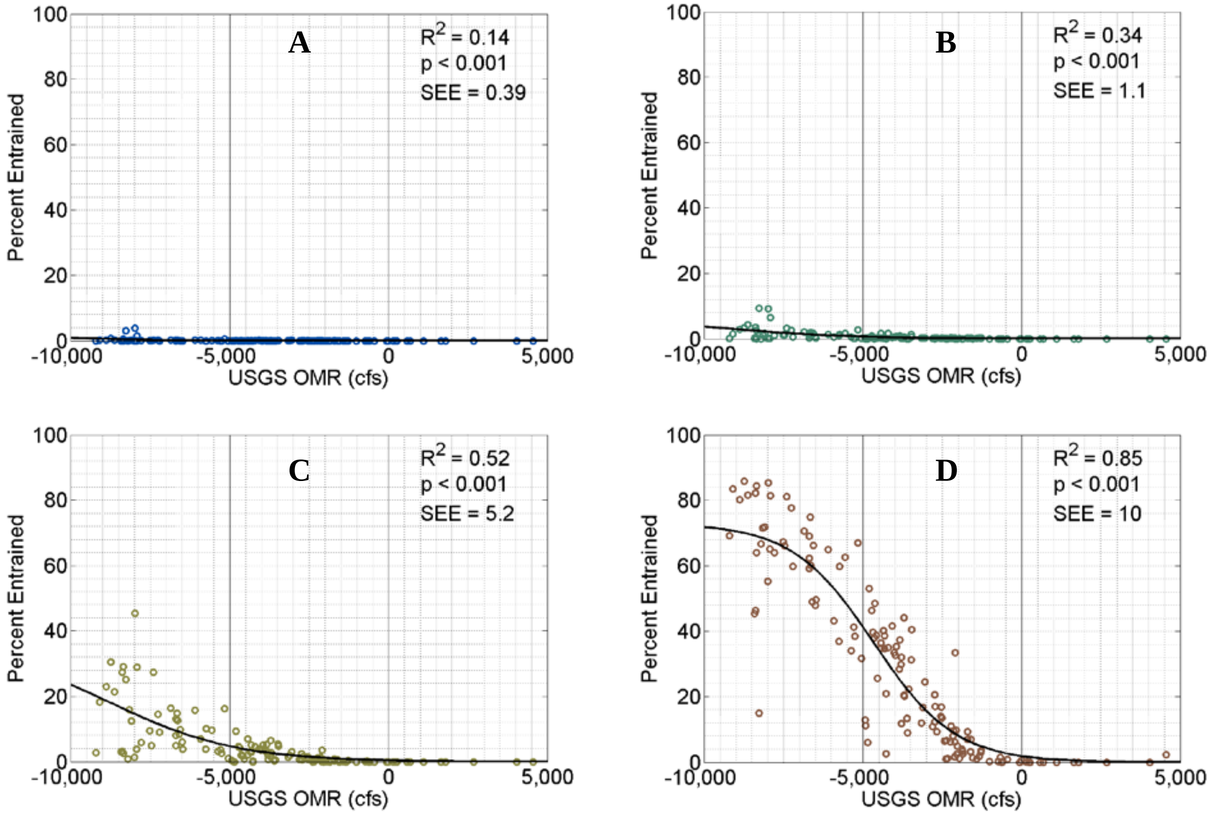

Figure 2-4: Entrainment of Particles as a function of OMR
Percent of particles entrained at the CVP and SWP export facilities in the south Delta depends on both the particle starting location and Delta hydrodynamics, indexed here by the average of the USGS OMR during the historical period that was simulated by the model. Particles were released at (A) the confluence of the Sacramento and San Joaquin Rivers (station 701), (B) the Sacramento River at Decker Island (station 705), (C) the San Joaquin River at Jersey Point (station 809), and (D) the San Joaquin River near mouth of Old River (station 815).

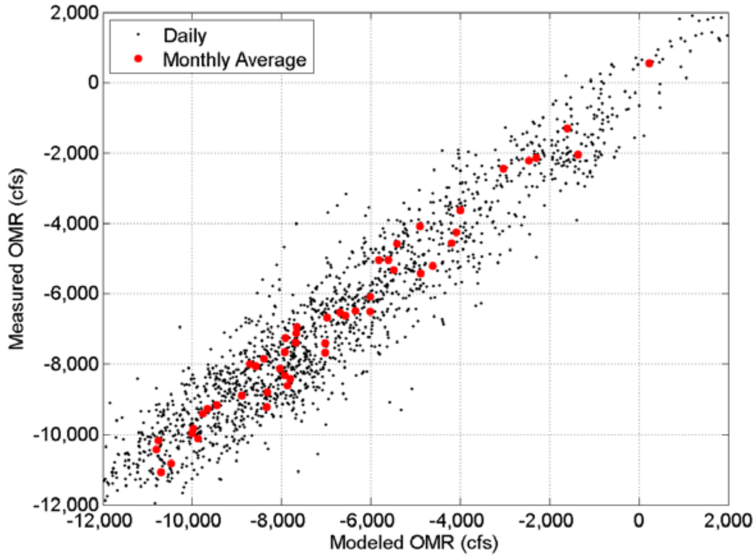

Figure 2-5: Comparison between "measured" OMR and the Modeled OMR as reported by DSM2
The DSM2 model outputs calculated values of flow in Old and Middle Rivers at the locations of the USGS stations. For historical boundary conditions, the DSM2 output (termed "modeled OMR") is an indicator of USGS OMR, with a SEE of 980 cfs for the daily values and SEE of 470 cfs for the monthly average. Modeled OMR will differ from USGS OMR due to inaccurate estimates of Delta consumptive use in the model, lack of effects of weather conditions in the model, or noise or other error in the "measured" values.

2.4 Conclusion

USGS OMR values are not directly measured quantities. Instead, they are calculated based on index velocities, mathematically filtered and daily averaged for each river, then summed and used to determine compliance with current OMR objectives. More than 30% of the time net combined daily OMR flows missing; scientific analysis based on USGS OMR typically relies on estimated values, with significant errors, to fill these data gaps. USGS OMR, commonly considered a "measured" value, is in fact an index of delta hydrodynamic conditions related to entrainment risk at the Banks and Jones Pumping Plants.

Issues that result from relying on USGS OMR for measuring compliance with OMR requirements are discussed in Section 3. An alternative flow index that avoids or resolves these issues is presented in Section 4, along with evidence that use of the proposed index provides a level of protection for listed fish species in the Delta that is equal to the protection provided by use of USGS OMR.

3 Implementation and Transparency Issues

OMR flow requirements are currently implemented under the Biological Opinions (BiOps) and incidental take permit for the operation of the Central Valley Project (CVP) and State Water Project (SWP)[7]. The values used to determine compliance are 14-day and 5-day averages of the USGS tidally filtered daily average values. Use of the USGS OMR data for compliance presents issues with implementation and transparency: CVP and SWP operators have difficulty reliably operating to the USGS values, and neither they, nor the public, can know, in real time, whether the objectives are being met.

3.1 Implementation Issues

Several factors make the current implementation of OMR difficult to use in practice:

3.1.1 Waiting time for results

USGS values for tidally filtered daily values of OMR flow are not available until at least 2 days after the fact, because the Godin filter used to process the data must be applied to flows that have not yet been measured; the daily average for Monday's OMR flow, for example, cannot be calculated until mid-day on Wednesday. Often difficulties with the instruments or calculations cause further delays.

Because of the delay, Project operators must make operational decisions based on their own estimated values for OMR. One such estimate is reported on the California Data Exchange Center (CDEC) website maintained by DWR[8]. Unfortunately, the CDEC data set incorporates errors from the USGS real-time data. The data are reviewed for such errors and corrected if possible during the USGS qa/qc process, which explains some of the differences in reported values between the CDEC and USGS data sets. However, by the time the qa/qc takes place, it is too late to make any operational adjustments.

3.1.2 Difficulty in predicting near-future OMR

Furthermore, the considerable variability in USGS OMR makes it difficult to predict, which complicates operational decisions and forecasting. Electrical power required to pump Delta water is typically scheduled 3 days in advance, and 5 or more days in advance over weekends or holidays. Compliance metrics that can be predicted 3 to 5 days in advance would greatly improve water operations planning, and could help improve power and water efficiency for the state.

Inflow on the San Joaquin River at Vernalis (SJR), combined CVP and SWP exports at Jones and Banks Pumping Plants, and the condition of the Head of Old River Barrier (HORB), are the dominant factors that drive OMR, but natural factors beyond the control of the Projects may act singly or together to affect OMR. Among these factors are sometimes unpredictable tidal action,

[7] Existing BiOps and permit include the 2008 U.S. Fish and Wildlife Service (FWS) and 2009 National Marine Fisheries Service (NMFS) BiOps for the coordinated operation of the SWP and CVP and the 2009 Department of Fish and Game (DFG) incidental take permit for longfin smelt for the SWP.

[8] http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=OMR

winds, variations in atmospheric pressure, and uncertainties regarding diversions, discharges, and seepage in the south Delta.

Figure 3-1 illustrates short term variability in the tidally filtered daily USGS OMR that remains unexplained in hindsight, and could not have been predicted. The plots show the daily deviation of flow values from the period average of flow values. The periods selected have relatively constant exports and SJR flow (small deviations from the period average) but OMR flow varies more significantly (larger deviations from the period average) up to +/- 1,500cfs. This indicates that, while SJR flow and exports are the primary drivers of OMR, there are other significant environmental influences on OMR as well. These unpredictable influences on OMR make water pumping operations difficult to plan with certainty in advance, and can force sudden actions in an attempt to avoid OMR violations when unexpected changes occur.

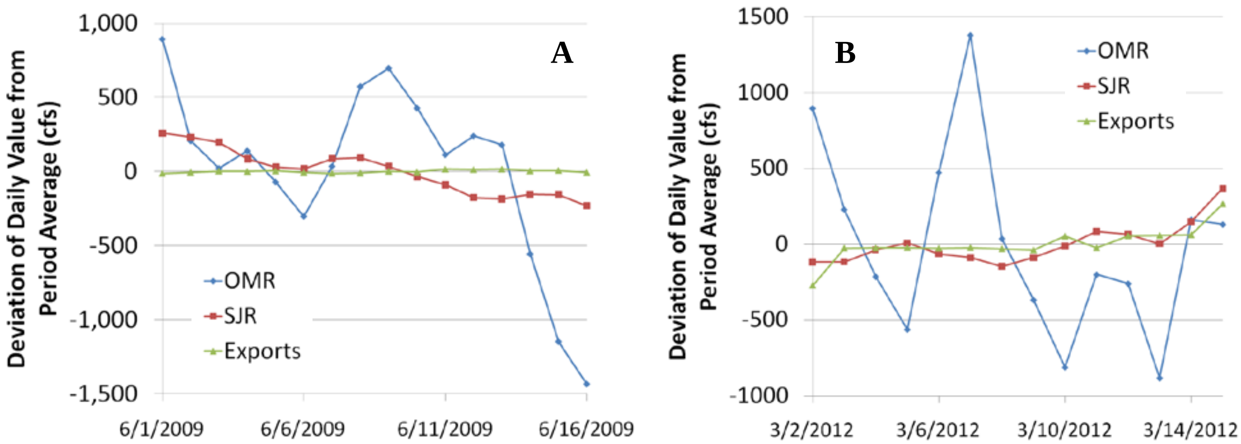

Figure 3-1: Unexplained variability in tidally filtered daily "measured" OMR
(A) June 1-16, 2009: Exports are essentially constant throughout the entire period, and Vernalis flow decreases slightly (by less than 500 cfs) and steadily over the period. OMR fluctuates by nearly 2,500 cfs, with the largest change occurring over the last few days of the period. (B) March 2-15, 2012: Exports and Vernalis flow are essentially constant, but OMR fluctuates.

3.1.3 Measurement errors cannot be avoided

Errors or lack of values in the posted USGS data add an additional level of difficulty for operators attempting to meet OMR requirements. The variability illustrated in panel A of Figure 3-1 may be due to instrument error. The data for June 2009 was downloaded as provisional data from the USGS NWIS website in June 2012. However, the June 2009 data has now (as of September 2012) been removed from the USGS NWIS website indicating that errors may have been found during the quality control process. Occasional errors are to be expected of any values originating in field measurements, and these comments are not intended as criticism of the USGS process. However, modifications to the current OMR regulation to reduce the reliance on such values would improve the implementation.

3.2 Transparency Issues

Because of the delay in calculating and posting the USGS OMR data, it is impossible to determine if the Projects are in compliance in real time. The regulators that set the OMR objectives, the Project operators and the general public cannot know whether objectives have been met on any given day until at least 2 days later. And because errors in the USGS data are sometimes corrected months or years after the fact (as discussed in Section 2.2 above), the determination of compliance may change.

Without knowing whether objectives are being met, the effectiveness of the adaptively managed objectives cannot be accurately assessed in real time. Adopting a compliance metric that could be easily calculated with readily available information would improve transparency.

3.3 Solution

As discussed in Section 2.3, USGS OMR flow is itself an index that reflects Delta hydrodynamics, which is used to measure compliance with OMR regulations for the protection of listed fish species. And as shown in Sections 3.1 and 3.2 above, the USGS OMR index is difficult to use in practice. An alternative hydrodynamic index, based on information that is readily available in real time and that is both predictable and controllable by CVP and SWP operators, would simplify implementation and improve transparency. Of course, such an index should be used only if it would provide a level of protection for Delta fish equal to that provided by operating to the USGS flows. An index that meets these requirements is proposed in Section 4.

4 Proposal for an Alternative Flow Index

As illustrated in Section 2.3, the OMR values reported by USGS are an index of Delta hydrodynamics. As discussed in Section 3, measuring compliance with current OMR requirements based on the USGS OMR creates operational difficulty and lacks transparency. This section presents an alternative flow index of Delta hydrodynamics for use in measuring compliance with OMR requirements that will improve implementation and transparency, and will provide an equal level of protection for listed fish species in the Delta as is provided by measuring compliance using USGS OMR.

4.1 Alternative Flow Index Definition

The largest drivers of net flow in Old and Middle Rivers are the total combined exports and the San Joaquin River inflow into the Delta. The alternative flow index proposed herein is defined as a function of total exports at Banks and Jones pumping plants ($Q_{Exports}$), the average San Joaquin River flow over the prior 3 days ($\overline{Q_{SJR}}$), and the condition of the channel barrier at the head of Old River (Head of Old River Barrier, HORB) (Equation 4-1). The flow index was calculated as the best fit linear relationships of these variables with USGS OMR[9].

If HORB is not installed: $Flow\ Index = 0.42 * \overline{Q_{SJR}} - 0.87 * Q_{Exports}$

If HORB is installed: $Flow\ Index = -0.79 * Q_{Exports}$

Equation 4-1

This alternative flow index is designed to address issues with implementability and transparency that are experienced under the current OMR requirements. To this end it makes use of measured flow values that are easily available in real time, and does not include other parameters that have an order of magnitude lower influence on hydrodynamics and/or require estimation; results presented below indicate that use of this simple index for measuring compliance with OMR requirements provides a level of protection for listed fish species commensurate with use of USGS OMR. The 3 day averaging of San Joaquin River flows was included to smooth short term variations and account for a short time lag of the influence on San Joaquin River inflow on interior Delta hydrodynamics.

Section 4.2 below shows a comparison of the alternative flow index with USGS OMR and examines how both the index and USGS OMR reflect Delta hydrodynamics using the particle tracking model. Section 4.3 examines both the index and USGS OMR as predictors of fish salvage.

[9] To ensure the flow index is acceptable during time periods of interest, the calibration period was limited to time periods with Delta hydrodynamics similar to the regulated period. For instance, the Jones Tract levee breach period (June – Dec 2004) was excluded from the calibration period due to the unique hydrodynamics present during the breach and pump out (Hutton 2008). Similarly, the 1997 winter storms were excluded due to the extensive flooding on the San Joaquin River (USGS 2006, Hutton 2008). Furthermore, only values from December through June with negative tidally filtered daily USGS OMR that have been approved by the USGS were used to calibrate the flow index.

4.2 Comparison of Alternative Flow Index with USGS OMR

The alternative flow index is strongly correlated with USGS OMR, as shown in Figure 4-1. The scatter between values can be as much as ± 2,000 cfs and the SSE is 810 cfs, which is similar to the error for the methods used to estimate missing values of USGS OMR discussed in Section 2.2. Hence, the alternative flow index does not induce error greater than that generated when creating an index from measured values. The scatter in itself is not a cause for concern, since the purpose of the flow index is not to emulate USGS OMR values. Instead, the purpose of the flow index is to reflect Delta hydrodynamics in a way that is useful for fish protection. The utility of the alternative index is demonstrated in the following materials.

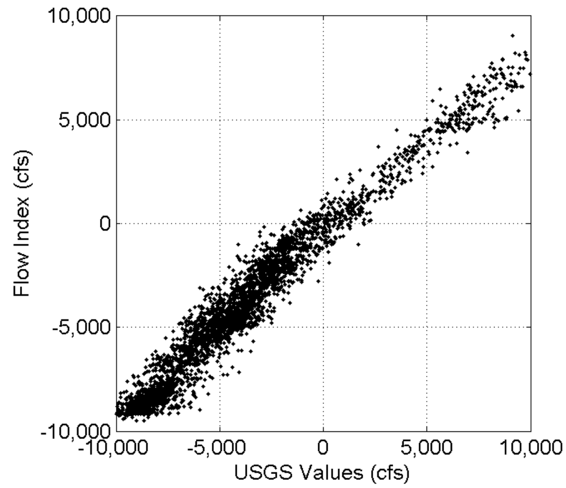

Figure 4-1: Comparison between USGS OMR and the Flow Index

The alternative flow index shows a strong correlation with USGS OMR during periods of negative net flow. As USGS OMR increases above +2,000 cfs, the flow index generally under-predicts USGS OMR values. The difference in positive net flows is not a focus of this discussion because the typical regulatory values for net OMR flow are less than zero.

To evaluate how well the alternative flow index reflects Delta hydrodynamics, we return to the PTM example provided in Section 2.3. Figure 4-2 shows the percent of particles entrained at the export facilities as a function of two indices: the first index (left column: panels A1, B1, C1, and D1) is the average USGS OMR[10] during the simulation period. The second index (right column: panels A2, B2, C2, and D2) is the alternative flow index defined in Equation 4-1. Particle entrainment is used here as an indicator of hydrodynamic conditions that predict fish salvage at the export pumps. The use of PTM for entrainment risk analysis and the modeling assumptions used for this report are discussed in Appendix A, Section A.2.

[10] For the analyses presented in this section, "USGS OMR" includes both the calculated flows from the USGS website whenever available and estimates of the values using the USGS estimation methods for the periods when data is missing (see Section 2.2).

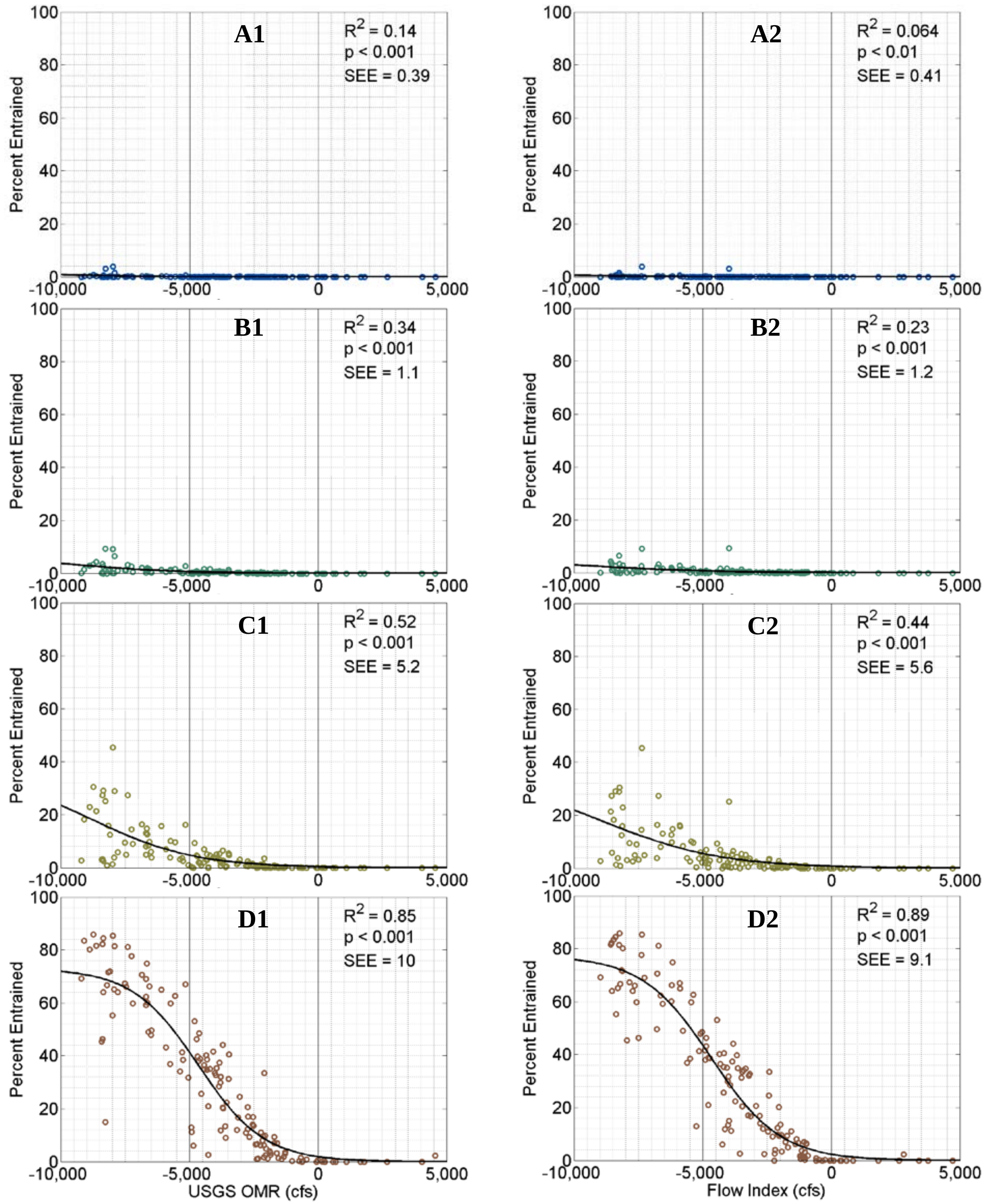

Figure 4-2: Entrainment of Particles as a function of Modeled OMR and the Flow Index

Percent of particles entrained at the CVP and SWP export facilities can be represented by the USGS OMR (panels A1, B1, C1, and D1) and the alternative flow index (panels A2, B2, C2, and D2). Particles were released at (A) the confluence of the Sacramento and San Joaquin Rivers (station 701), (B) the Sacramento River at Decker Island (station 705), (C) the San Joaquin River at Jersey Point (station 809), and (D) the San Joaquin River near mouth of Old River (station 815). See Figure 2-3 for a map of these locations.

Entrainment of particles released at the San Joaquin River near the mouth of Old River shows a strong response to both the recommended alternative index values (panel D2) and the USGS OMR values (panel D1). As particle release points move farther from the export pumps the entrainment response decreases, until there is almost no response during the 28 day simulation period for particles released at the confluence of the Sacramento and San Joaquin Rivers. The correlations and SEEs for the relationships between entrainment and the alternative index are similar to those for the relationships between entrainment and USGS OMR; R^2 is slightly higher for the alternative index for the particle release point with the strongest entrainment response, and slightly lower for the alternative index for other particle release points. Any conclusions or operational recommendations drawn from these relationships would not be materially different, whether USGS OMR or the alternative flow index was used.

4.3 Fish Protection with the Alternative Index

To evaluate whether the alternative flow index is useful for protection of listed fish species in the Delta, analyses similar to those in the existing BiOps, ITP, and technical workgroup presentations were performed for both the alternative flow index and USGS OMR. As new analyses are developed to support hydrodynamic indices for the remanded BiOps or in other venues, they can be similarly used to evaluate the alternative flow index, and to refine it as indicated.

Analyses are presented below for delta smelt, longfin smelt, and steelhead; analyses for Chinook salmon are underway but not yet complete. For all three species considered here, the relationships of salvage at the export pumps to the alternative flow index are very similar to the relationship of salvage to the USGS OMR flow index[11], with the alternative flow index performing slightly better as a predictor of salvage.

4.3.1 Delta Smelt

Both the daily (Figure 4-3) and seasonal (Figure 4-4) normalized salvage of adult delta smelt are plotted against USGS OMR and against the alternative flow index. For the daily salvage, visual inspection of the plots shows similar distributions for the two indices. The seasonal salvage plots also indicate the equivalence of the two indices, and have similar values of R^2 and SEE for both log-log and linear data fits.

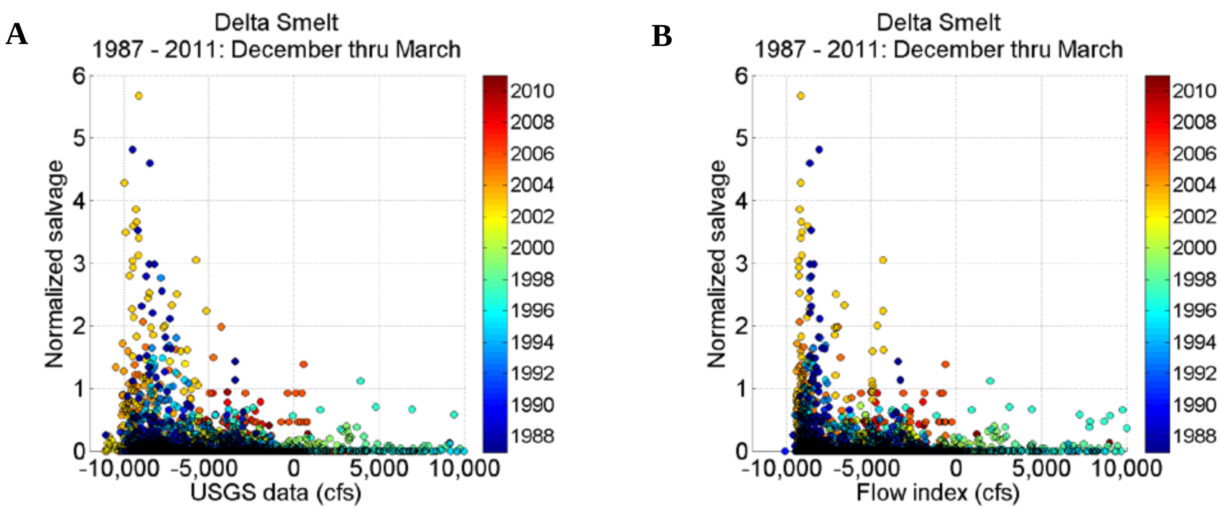

Figure 4-3: Daily salvage of adult delta smelt normalized by the prior FMWT index
Daily salvage of delta smelt from December through March of 1987-2011 is normalized by an annual population index (i.e. the Fall Midwater Trawl (FMWT) index) for each year and plotted against (A) the USGS OMR flow and (B) the alternative flow index. Data points are colored by the water year.

[11] For the analyses presented in this section, "USGS OMR" includes both the calculated flows from the USGS website whenever available and estimates of the values using the USGS estimation methods for the periods when data is missing (see Section 2.2).

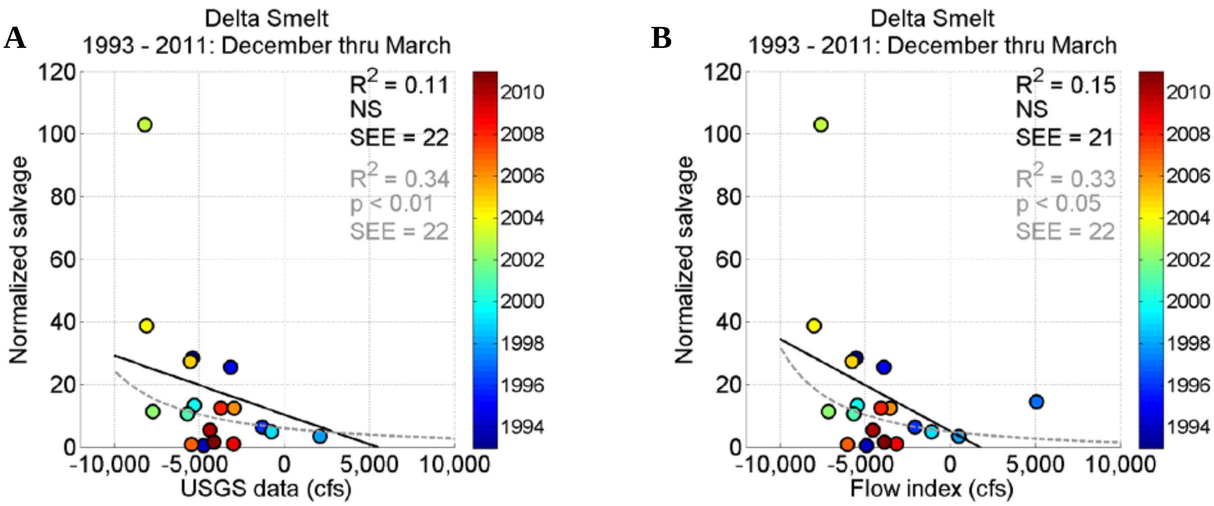

Figure 4-4: Seasonal (December through March) salvage of adult delta smelt normalized by previous FMWT index

Daily data from Figure 4-3 are summarized seasonally in this figure by showing the total salvage for December through March, normalized by the annual FMWT index, plotted against (A) the average USGS OMR during the period, or (B) the average alternative flow index during the period. Linear (black line) and log-log (grey dashed line) least squares fits are shown with the statistical parameters listed in the upper right corner of each plot. NS = not statistically significant ($p>0.05$)

USFWS, following the work of Deriso (2011), have developed analyses of delta smelt salvage that include Delta turbidity conditions in addition to south Delta hydrodynamic conditions. This work appears to show a relationship between normalized salvage of adult delta smelt, turbidity conditions measured at Clifton Court Forebay, and OMR net flow conditions, as illustrated in Figure 4-5. 4-5(A) is reproduced from the USFWS draft BiOp (2011), in which USGS OMR values are used. Figure 4-5(B) shows the relationship between adult delta smelt salvage, turbidity and the alternative flow index. By inspection, the alternative flow index is equally useful in describing the Delta hydrodynamic conditions that contribute to salvage of adult delta smelt. In fact, the vertical scatter may be slightly reduced in Figure 4-5(B).

Figure 4-5(C) is also reproduced from the 2011 USFWS draft BiOp. This figure presents the same relationship between turbidity, OMR net flows and adult delta smelt salvage, with salvage data points sorted into bins of magnitude relative to the previous Fall Midwater Trawl abundance index. Figure 4-5(D) presents the same relationship using the alternative flow index. Again, the alternative flow index appears to provide an equivalent utility in predicting adult delta smelt salvage, as compared to USGS OMR.

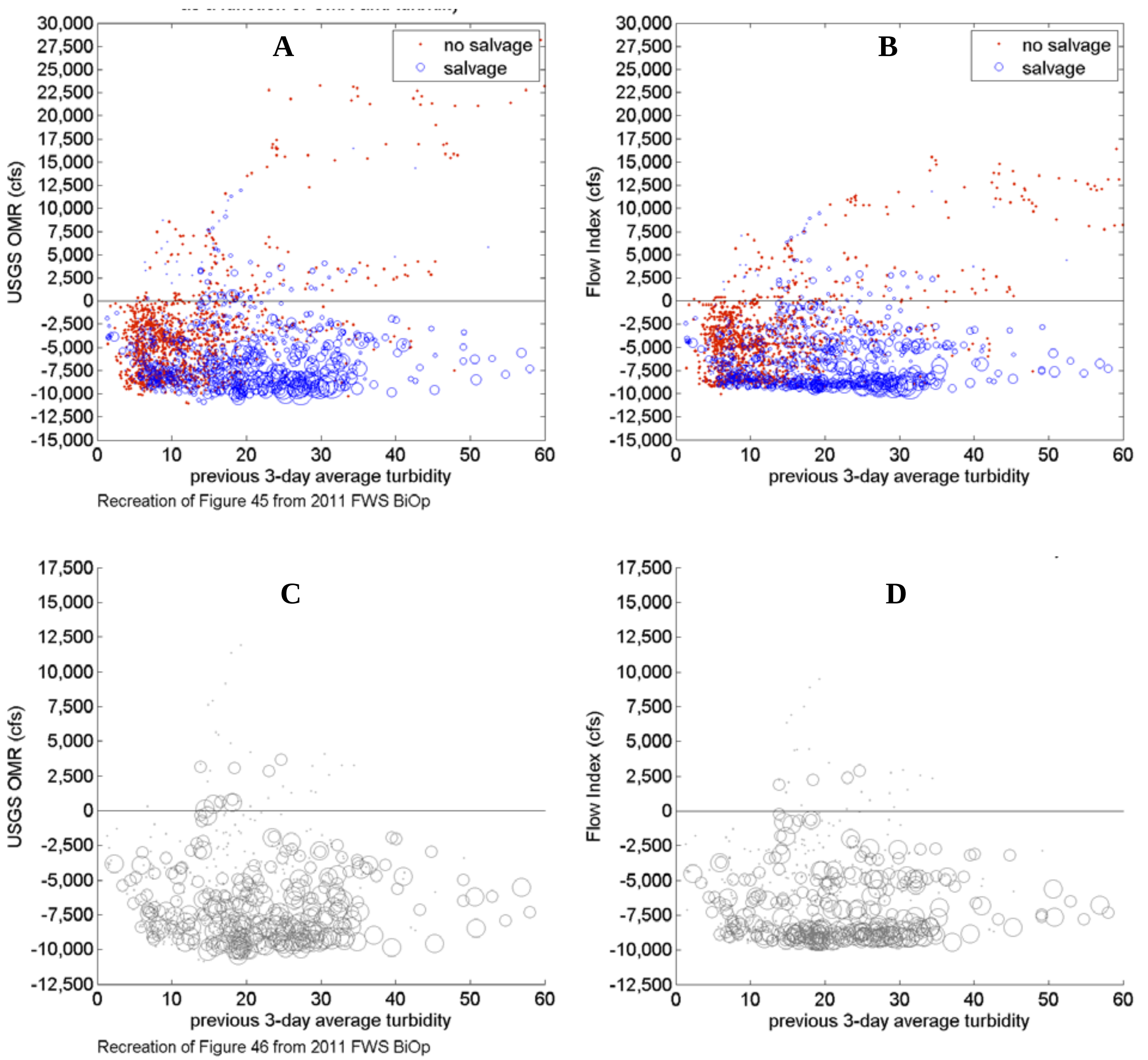

Figure 4-5: Normalized salvage of delta smelt as a function of turbidity and OMR
Panels A and B show normalized salvage (size of bubble) as a function of 3-day average turbidity at Clifton Court Forebay and either USGS OMR (Panel A) or the alternative flow index (Panel B). Panels C and D show normalized salvage (classified into 3 bubble sizes) as a function of 3-day average turbidity at Clifton Court Forebay and either USGS OMR (Panel C) or the alternative flow index (Panel D). [Data source: Panels A and C are recreated from the USFWS 2011 BiOp using data provided by USFWS]

In Figure 4-6, a familiar plot format is used to illustrate the data relating turbidity, south Delta hydrodynamics and adult delta smelt salvage. These data are the same presented in Figure 4-5. Here, turbidity is represented by the color of the data points, as indicated by the color bar on the right side of the plot. Figure 4-6(A) shows USGS OMR versus normalized salvage, and Figure 4-6(B) shows the alternative flow index versus normalized salvage. A comparison of these plots illustrates the similar utility of the USGS OMR index and the alternative flow index.

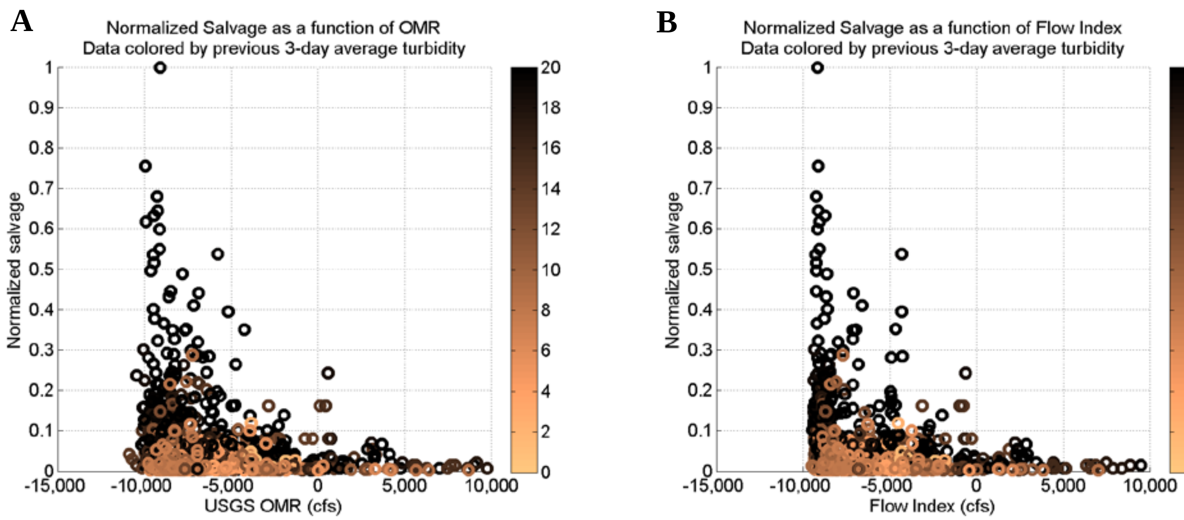

Figure 4-6: Normalized salvage of delta smelt as a function of OMR and turbidity
Panels A and B recast the same data that was shown in Figure 4-5panels A and B into a format similar to Figure 4-3. The difference between Figure 4-3 and Figure 4-6 is that the y-scale here was "normalized" by dividing the normalized salvage in Figure 4-3 by the maximum normalized daily salvage. The data points are now colored by turbidity instead of water year. [Data source: provided by USFWS]

4.3.2 Longfin smelt

Longfin smelt salvage was examined in the same way as delta smelt salvage: both the daily (Figure 4-7) and seasonal (Figure 4-8) salvage of adult longfin smelt is plotted against USGS OMR and against the alternative flow index. For longfin smelt, the plots were done for salvage normalized by prior FMWT, and also for salvage that has not been normalized, since there has been some concern that normalizing the longfin smelt numbers may obscure the true response of salvage to Delta hydrodynamics.

Results for longfin smelt are similar to those for delta smelt: each comparison shows, either visually or through statistics (values for R^2 and SEE), that the alternative flow index is an equally good predictor of salvage at the export pumps as is USGS OMR. Note that correlations for longfin smelt salvage may not be statistically significant without the incorporation of other variables, so conclusions regarding the relationship between salvage and any flow indices should be judged accordingly. However, the USGS OMR and the alternative flow index are both presented to allow comparison of these indices.

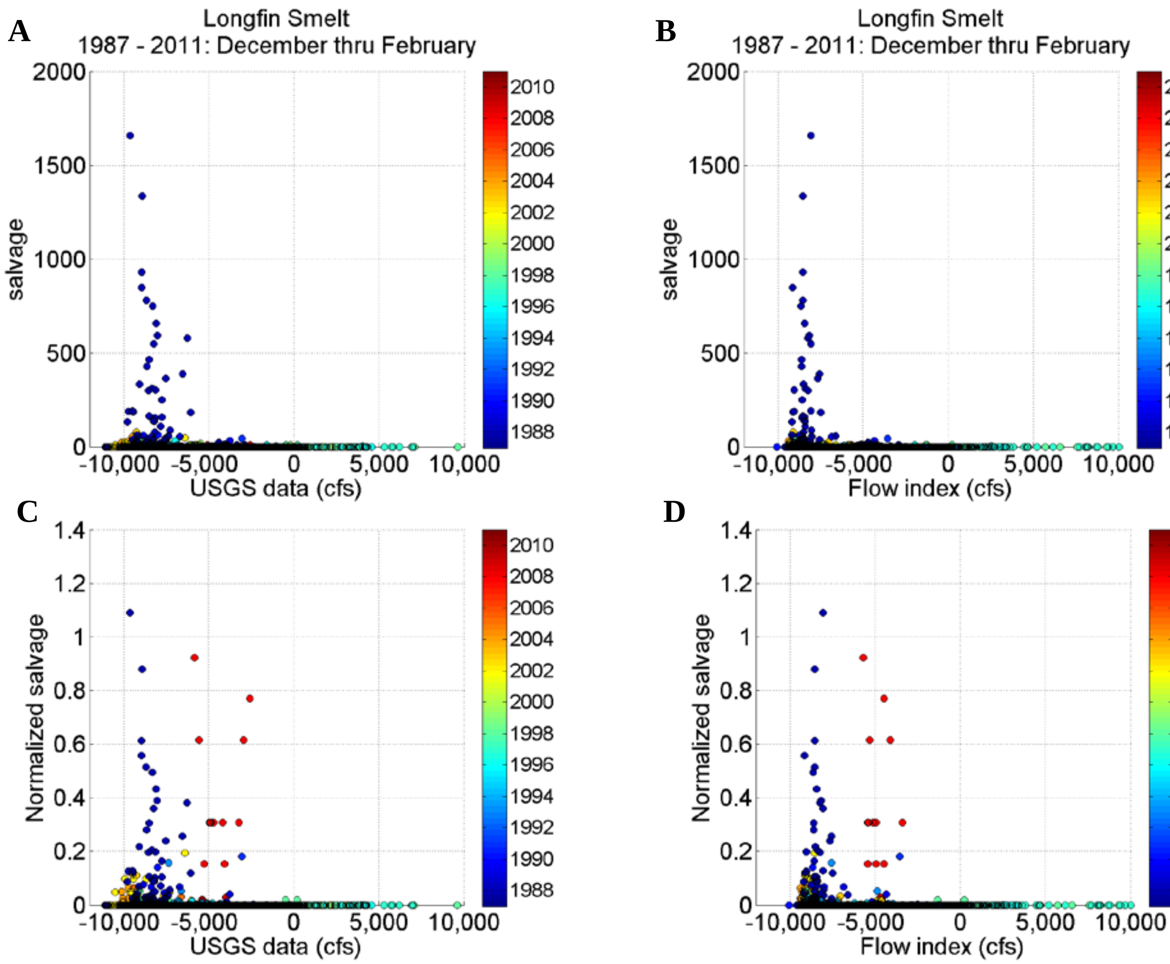

Figure 4-7: Daily salvage of longfin smelt December through February
Daily salvage of longfin smelt from December through February of 1987-2011 is normalized by an annual population index (i.e. the Fall Midwater Trawl (FMWT) index) for each year and plotted against (A) the USGS OMR flow and (B) the alternative flow index. Data points are colored by the water year.

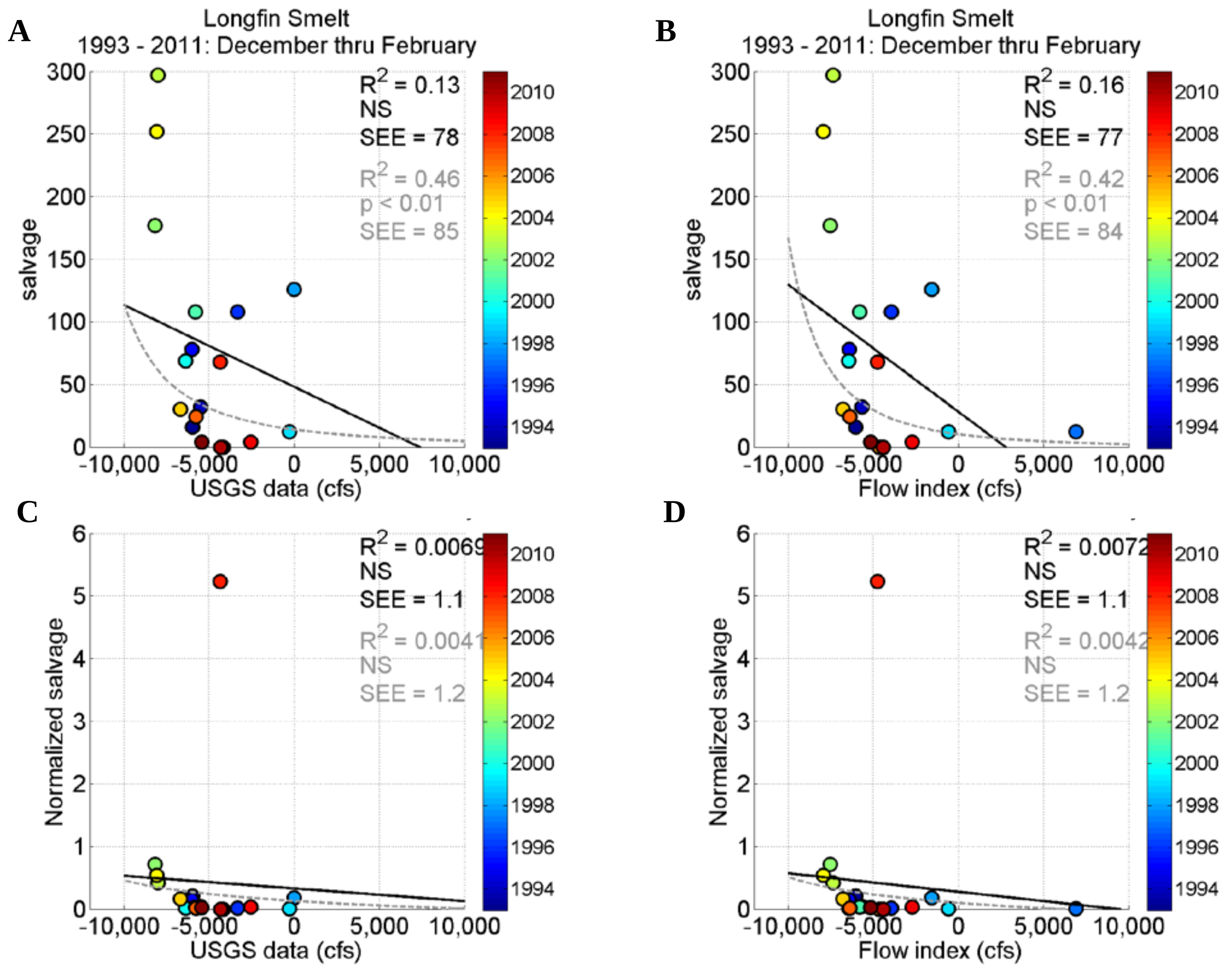

Figure 4-8: Annual total salvage of adult longfin smelt normalized by previous FMWT index
Daily data from Figure 4-7 are summarized seasonally in this figure by showing the total salvage for December through February normalized by the annual FMWT index plotted against (A) the average USGS OMR during the period, or (B) the average alternative flow index during the period. Linear (black line) and log-log (grey dashed line) least squares fits are shown with the statistical parameters listed in the upper right corner of each plot. NS = not statistically significant (p>0.05). Note that only the statistically significant relationship is the log-log function form in panels A and B.

4.3.3 Steelhead

Following technical analyses presented to the IEP steelhead project work team (Grimaldo 2012), Figure 4-9 shows steelhead salvage at the export pumps plotted against the alternative flow index and against USGS OMR. The top set of plots shows total steelhead salvage, which cannot be normalized because no population estimates are available. The bottom set shows salvage of steelhead with clipped adipose fins, normalized by total hatchery release[12].

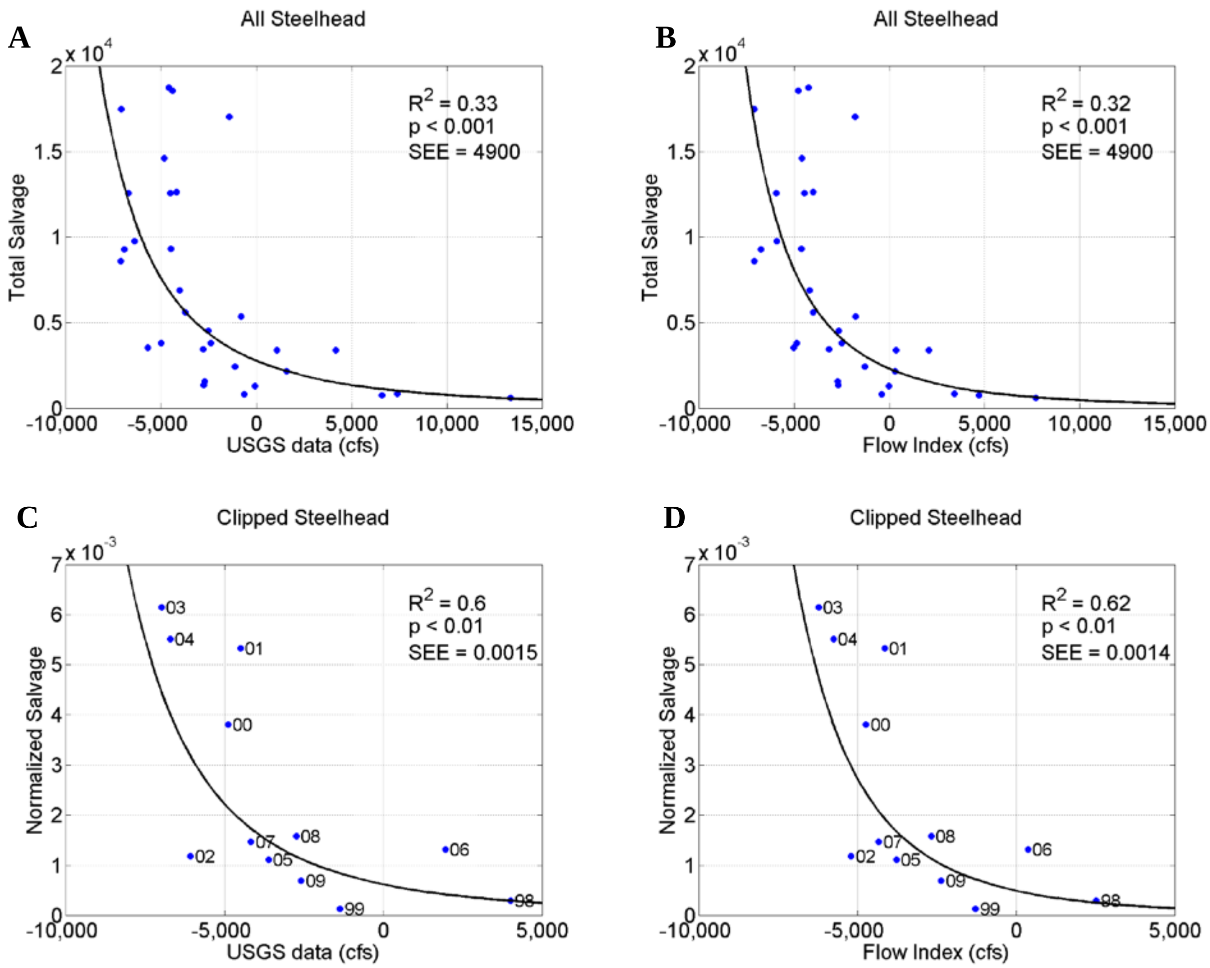

Figure 4-9: Seasonal Steelhead salvage as a function of OMR flow

Panels A and B show the seasonal (December through June) salvage of all steelhead for all steelhead 1981-2009 as a function of either (A) USGS OMR or (B) the alternative flow index. The total steelhead salvage cannot be normalized because no population estimation is available for wild steelhead. Panels C and D show the seasonal (December through June) salvage of steelhead with clipped adipose fins normalized by the total hatchery release for 1998 through 2009 as a function of either (C) USGS OMR or (D) the alternative flow index.

[12] Daily salvage data and annual hatchery releases were provided by Lenny Grimaldo, Bureau of Reclamation, Bay-Delta Office. The analysis was recreated here for comparison with the alternative flow index.

For both total steelhead salvage and hatchery steelhead salvage, results follow the same pattern as those for delta smelt and longfin smelt: salvage response to the alternative flow index is very similar to salvage response to USGS OMR.

It has been demonstrated herein that reliance on field measurements to obtain an index of south Delta hydrodynamics has significant issues with data error and data loss. Reliance on tidally filtered field data also creates issues with operational implementation and regulatory transparency. These include the inability to accurately forecast the index value, delay in knowing if regulations are met, and changes in the index values in the QA/QC process that occur well after the timeframe for compliance, or operational changes to meet compliance. The alternative flow index presented here resolves the above issues and provides relationships to fish salvage data that are as good as the currently used USGS OMR index.

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Appendix A Conceptual Model regarding influence of Old and Middle Rivers

Net flow in Old and Middle Rivers is sometimes perceived to "pull" fish and constituents into the south Delta towards, and ultimately into, the export pumps. However, net flow is a mathematical construct, and nothing actually moves with net flow. Tidal currents in the Bay and a significant part of the Delta dominate transport in the region. Net flow may be an indicator of system dynamics, but when considering the effects of flow on fish, it seems important to understand the actual flow conditions, and how they differ from averages such as net flow.

A.1 Tidal Dynamics

The Bay-Delta estuary is strongly tidal. Only when net velocities are a significant fraction of the tidal velocity do they start to influence hydrodynamics in a strong way.

A.1.1 Spatial and Temporal Variability

Strong tidal influence extends into the Delta along the mainstems of both the Sacramento and San Joaquin Rivers (Figure A-1). Velocity reaches a maximum positive value twice a day during ebb tide, with movement towards the Bay, and minimum negative value twice a day during flood tide. Peak maximum and minimum velocity is typically an order of magnitude greater than the filtered (or "net") velocity.

With tidal velocity peaking around 3 feet per second (ft/s) near the western edge of the Delta (panel A), an item drifting in the water column could move around 8-10 miles on one phase of the tide. Of course, as the item drifts, it will be subject to local velocity at the new location (i.e. the tidal influence changes with location); thus, looking at a single location (e.g. panel A) presents a limited perspective of the regional hydrodynamics and does not capture the movement of a floating item as it reacts to local velocities at different locations (i.e. spatial variability).

During the period illustrated in Figure A-1, Sacramento River inflow near Sacramento was around 10,000 cubic feet per second (cfs) in December, with a peak near 55,000 cfs in January (a moderate winter storm pulse). The winter pulse is most evident at station C, upstream of Rio Vista (panel C), where this flood pulse eliminates the flood tide from late January through late February. Downstream on the Sacramento River along Sherman Island (panel B), and near the western edge of the Delta (panel A), the winter pulse is evident in the filtered (i.e. "net") velocity; however the instantaneous velocity still shows a very strong tidal signal on both ebb and flood tide.

During this same time period, there is a similar, although much smaller, pulse of San Joaquin River inflow at Vernalis, which is approximately 1,200 cfs in December and peaks near 4,500 cfs in January. On the lower San Joaquin River (panels D and E), filtered velocity remains near zero for the entire period, without any evidence of the observed pulse. On Old River, near the flow gauges currently used for compliance of the Old and Middle River net flow regulations, net velocity is slightly negative, but the instantaneous velocity still shows strong tidal variability in both flood and ebb tides.

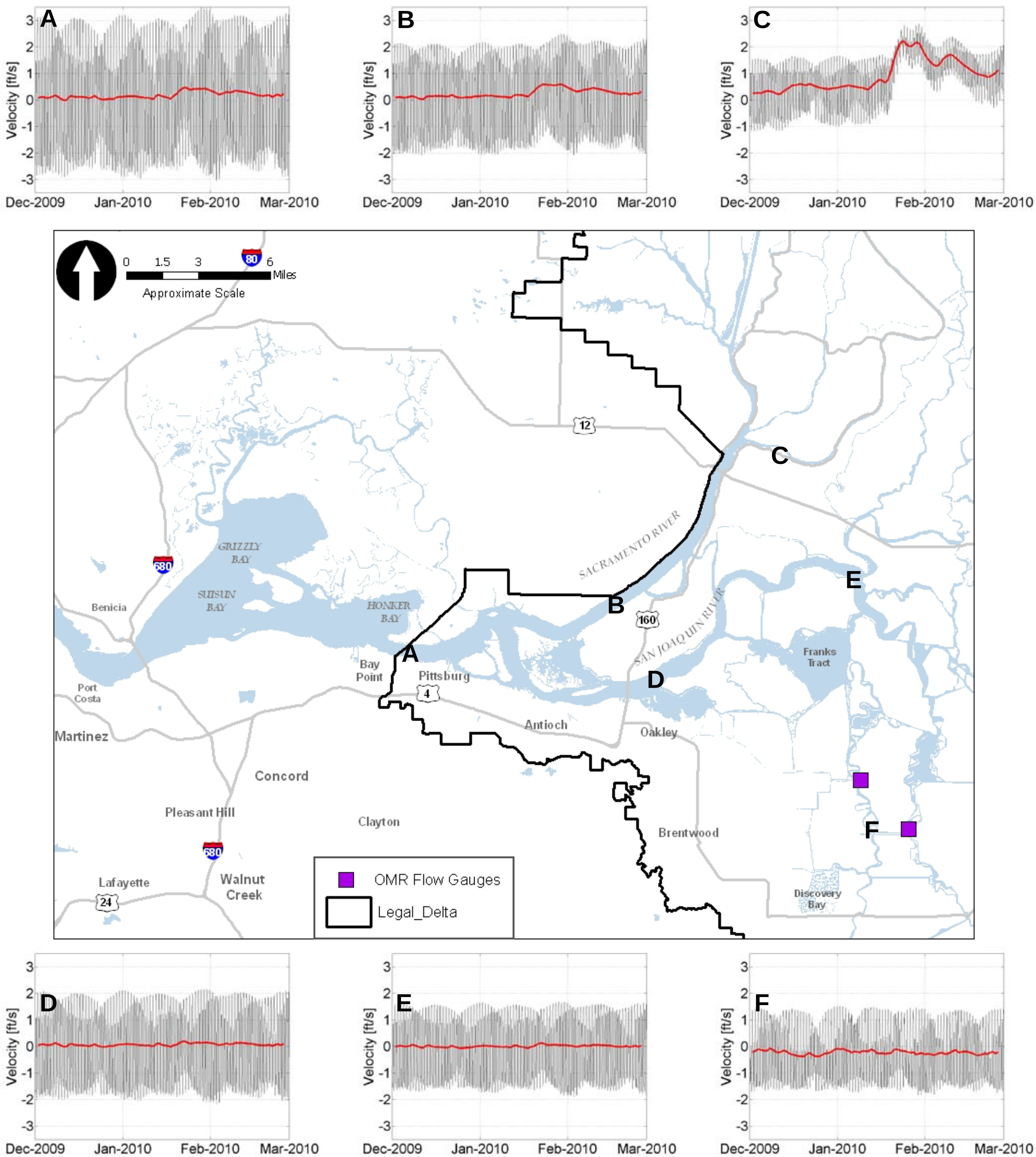


Figure A-1: Tidal velocities at specific locations within the Delta

Strong tidal influence extends into the Delta along the mainstems of both the Sacramento and San Joaquin Rivers. Panels A-F illustrate tidal and filtered (i.e. "net") velocity at the corresponding locations in the map. With tidal velocity peaking around 3 feet per second (ft/s) near the western edge of the Delta (subplot A), an item drifting in the water column could move around 8-10 miles on one phase of the tide. [Data source: DSM2 simulation using historical inputs from December 2009 to March 2010]

A.1.2 Loss of Ebb Tide

As shown in the prior section, instantaneous tidal velocity in the Delta is typically much greater than filtered (or "net") velocity. However, tidal flows can be altered. During periods of low San Joaquin River inflow, export pumping can shift the tidal signal in the southern Delta. As shown later in this section, the effect of the exports in this case is to reduce the ebb tide and enhance the flood tide. Peak tidal velocity can still be a factor.

The following discussion is condensed from a technical memorandum from Greg Gartrell to the NRC Committee on Sustainable Water and Environmental Management in the California Bay-Delta, dated January 20, 2010. It demonstrates the important factors in transport in the south Delta and how tidal and net flows interact.

Figure A-2 shows Delta flows[13] with the ebb and flood flows generally of the same magnitude in opposite directions. The average net flow is much smaller than any flow affecting the fish at a given moment.

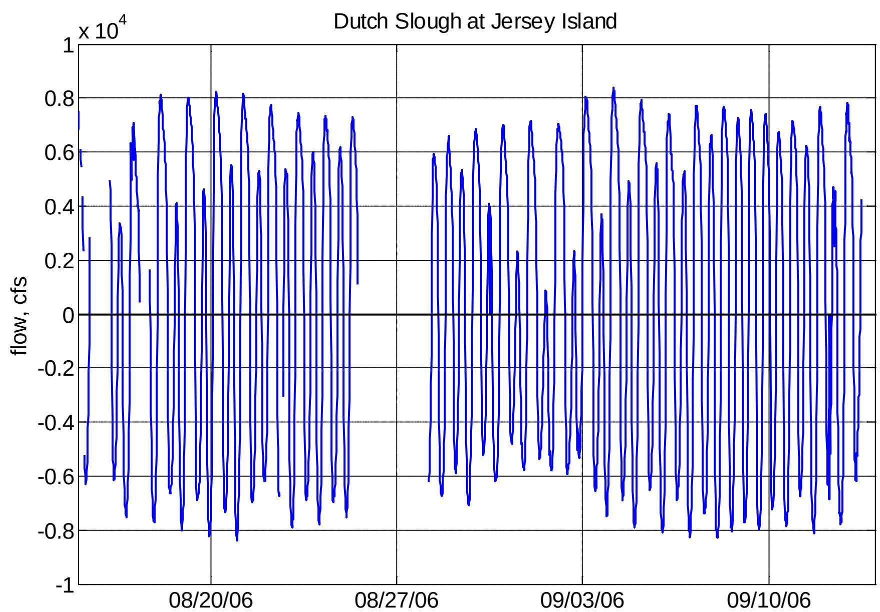


Figure A-2: Tidal flow in the Delta with flood and ebb flows nearly balanced. Tidal flow measured at Dutch Slough at Jersey Island. Note that the y-scale shows values from $-1x10^4$ to $1x10^4$ cubic feet per second (-10,000 to 10,000 cfs).

Figure A-3 shows tidal flows with a stronger flood than ebb. An aquatic organism at this location has a chance to move in the opposite direction from the flood flow (and opposite the average) if it uses the tides correctly (i.e., if it gets into the high velocity part of the channel on

[13] Data are from the California Data Exchange Center (http://cdec.water.ca.gov). Data shown in Figures A-2, A-3 and A-4 are for the period August 15 to September 14, 2006.

the ebb, and stays near the channel sides on the flood[14]). On the other hand, an organism in the high velocity part of the channel on the flood tide will move a long way south in one excursion, much farther than the net flow would have them move.

The point of this discussion is not to ignore net flows, but rather to caution against over-reliance on averaging that simplifies key dynamics into oblivion. Tidal flows are responsible for salinity intrusion and moving organisms around. Net flows alter the tides, sometimes substantially, but often not. Both must be considered carefully as is seen in the next discussion.

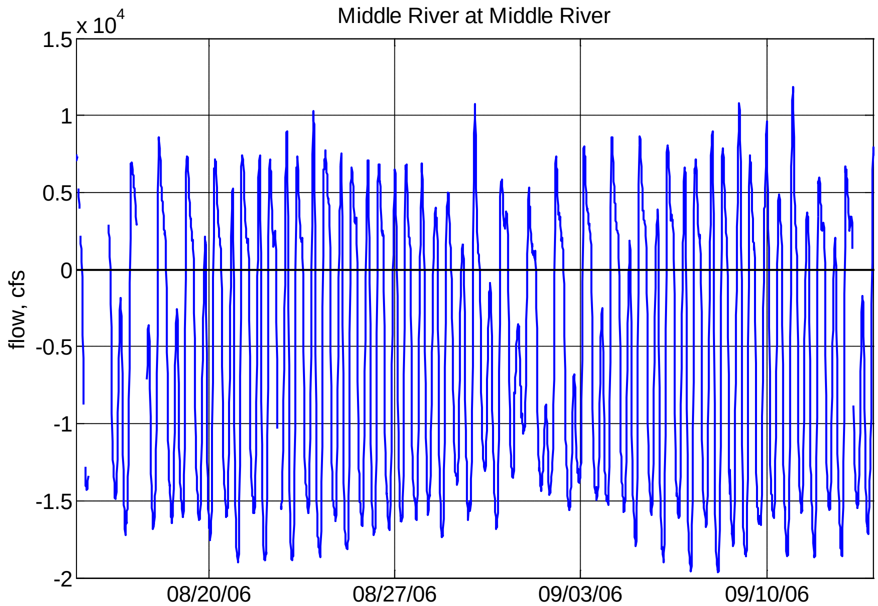


Figure A-3: Tidal flow with a strong flood tide compared to ebb
Tidal flow measured at Middle River at Middle River (west of Bacon Island). Note that the y-scale shows values from $-2x10^4$ to $1.5x10^4$ cubic feet per second (-20,000 to 15,000 cfs).

Figure A-4 shows an example where tidal flows are dominated by net flows. In this case, the tidal signal is still evident, but the net flow is so strong it has eliminated any ebb flow during certain periods. In this case, flow is essentially unidirectional, with varying velocity over the day.

[14] Data from fish surveys and special studies provide evidence of such behavior. For instance, juvenile salmon clearly have the ability to pick the right tide based on cues, or they could not get from north of Rio Vista to Chipps Island in just a few days.

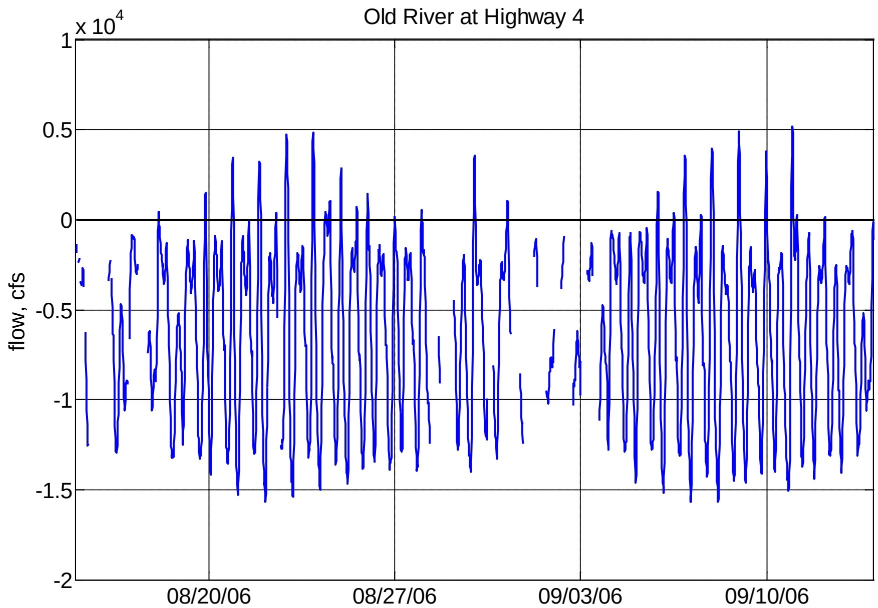


Figure A-4: Tidal flow when the ebb tide is entirely lost for substantial periods over the neap-spring tidal cycle.
Tidal flow measured at Old River near Highway 4. Note that the y-scale shows values from $-2x10^4$ to $1x10^4$ cubic feet per second (-20,000 to 10,000 cfs).

Figures A-2, A-3 and A-4 are measurements from the same time period. However, they all show different responses, and this is important. An aquatic organism moving in the channel does not experience the flows as represented in these figures: these are Eulerian representation and an organism experiences the velocities in its own Lagrangian system (i.e., the velocities as it moves). That Lagrangian excursion can be large (tidal movements are on the order of 4 to 5 miles). Consequently, if an organism starts at a location where there is still a substantial ebb tide but moves up the river on the flood tide and ends up in a location where the ebb has been substantially lost, it will not "slosh back" as the tides change: the velocities become unidirectional at some point along its path. It can be shown the threshold level for significant (Lagrangian) motion ending in salvage is when the alternative flow index reaches about 6,000 cfs (see technical memorandum from Greg Gartrell to the NRC Committee on Sustainable Water and Environmental Management in the California Bay-Delta, dated January 20, 2010). Note that it is not necessary for the ebb tide to be substantially lost at each point in the river, but for the excursion of a particle to reach a point where the ebb tide is substantially lost.

A.2 Particle Tracking as a Tool

PTM uses velocity, flow, and water elevation information from DSM2-Hydro to simulate the movement of virtual particles in the Delta on a 15-minute time-step throughout the simulation period. If a particle leaves the Delta system by way of an export or diversion or through any other model boundary, this information is recorded for later analysis and termed the "fate" of the particle. Additionally, the percentage of particles remaining within channels in each geographic region is tabulated and analyzed.

Use of PTM for fishery analysis has gained popularity over the last decade; however, the PTM tool has a number of limitations in application to fishery analysis. Chiefly, since the particles simulated in the model are neutrally buoyant (and therefore have no swimming behavior or other independent movement), results of these analyses are most relevant to the planktonic early larval stages of various organisms that do not move independently in the water column. The particles are not considered to reflect movements of juvenile or adult fish within the Delta, or of larvae that are able to move independently in the water column (for example, by varying their buoyancy). Recognizing these limitations, PTM is used in this report as an indicator of Delta hydrodynamics and potential risk for entrainment.

To evaluate hydrologic and operational variability, particle releases were simulated at the start of each month from January 1990 through March 2012, using historical Delta inflows and tides as inputs for the DSM2 model.

One thousand particles were released over a period of 25 hours (to encompass a full tidal cycle). Particle movement was tracked for 120 days; particle location is reported at 28 days and classified as flux past a specific location, potential entrainment at water intakes, or the percent remaining in channels in specific regions of the Delta and Suisun Bay and Marsh.

Appendix B OMR Compliance 2009-2012

The following plots are provided to illustrate the difficulties in operating the CVP and SWP exports to meet regulations set with the USGS OMR index. Each figure in this Appendix includes time series of the USGS tidally filtered daily average flow in Old and Middle Rivers (labeled as “Daily), running averages of the daily values (labeled as “5 Day Average” in the top subplot and “14 Day Average” in the bottom subplot), and the regulatory limit (labeled as “5 Day Control” in the top subplot and “14 Day Control” in the bottom subplot). The data are plotted in terms of negative cubic feet per second (-cfs); in these plots, compliance with the OMR regulation is indicated when the running average values (solid lines) are below the control values (dashed lines). However, the control values are not applicable until the control has been in effect for the averaging period (i.e. the 5-day control does not apply until the 5th day after the decision is made to set the control value).

The plots below also show data drop-outs, periods when meeting the regulatory requirement was missed and periods when it was met by large margins; discussions with operators indicate that the inability to predict outside factors leads them to use large “safety factors” at times, which make operation unnecessarily inefficient.

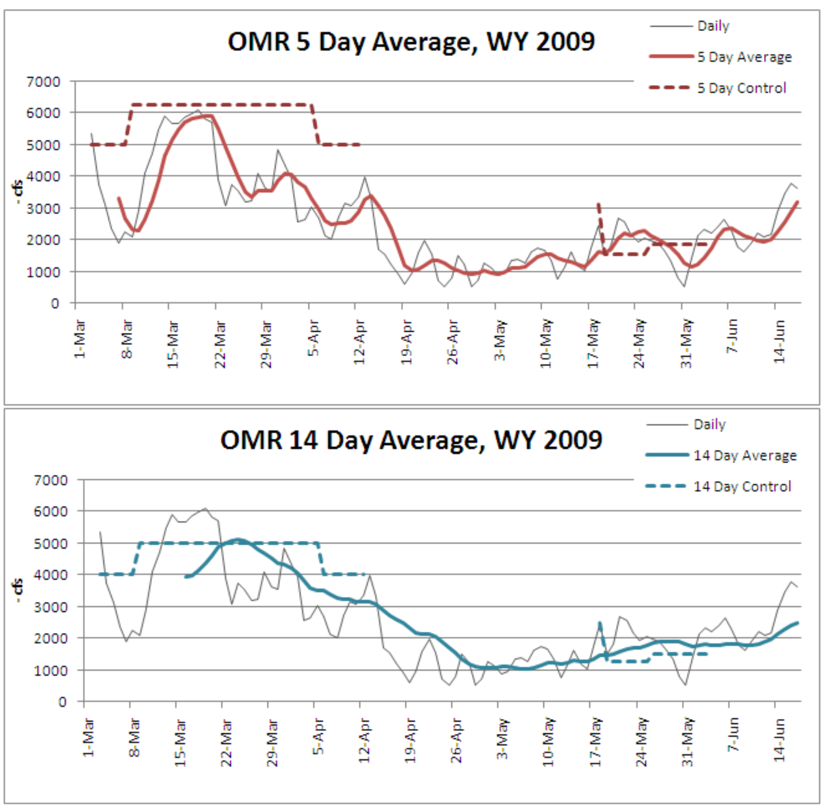


Figure B-1: Time series of measured OMR and Regulatory Controls for WY 2009

OMR Measurements from USGS stream flow data for Old River (station 11313405) and Middle River (station 11312676), tidally filtered by USGS. OMR Control values are provided in USFWS Determinations and note from the smelt working group (SWG) and the Delta Operations for Salmon and Sturgeon (DOSS) Group.

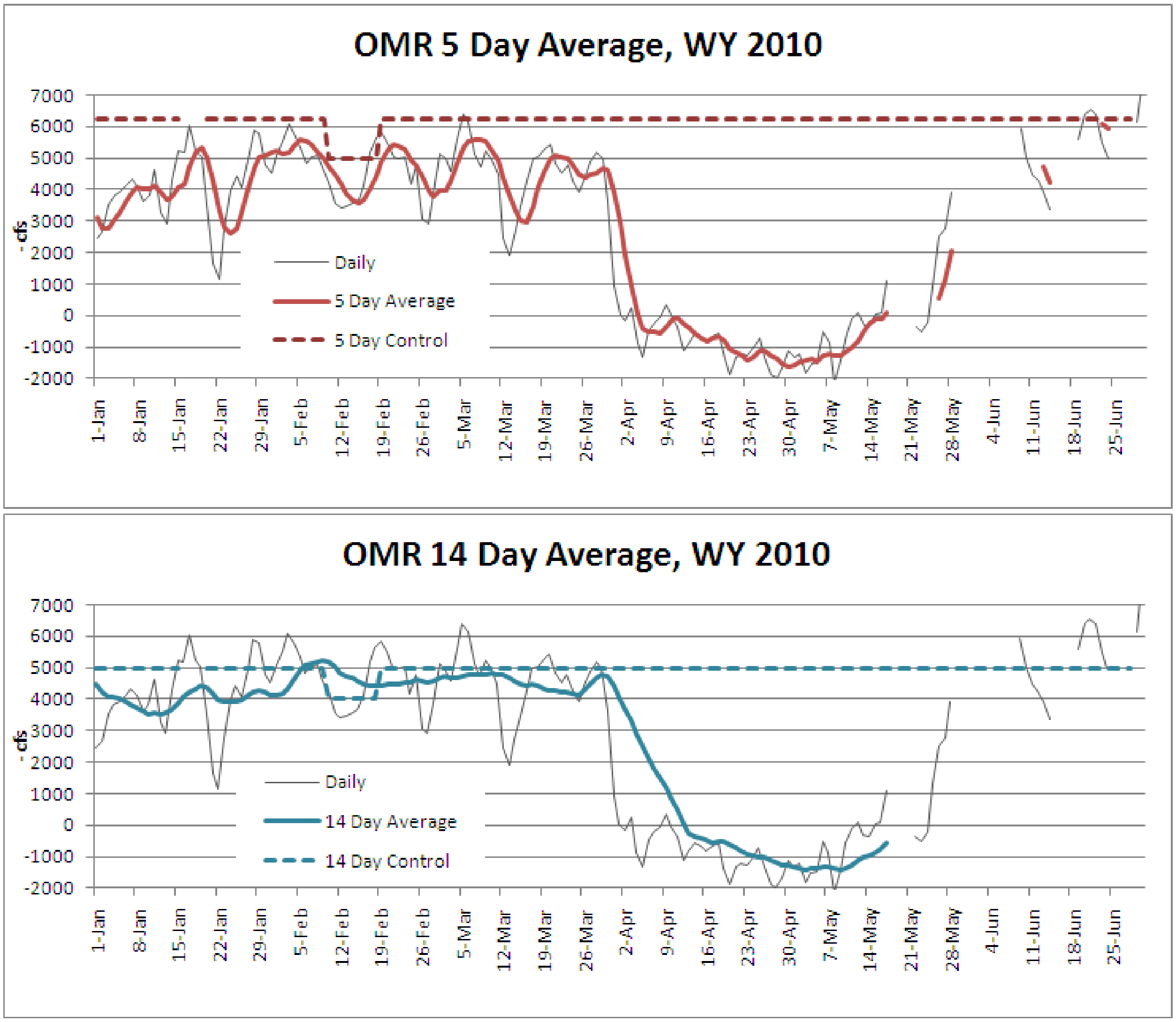
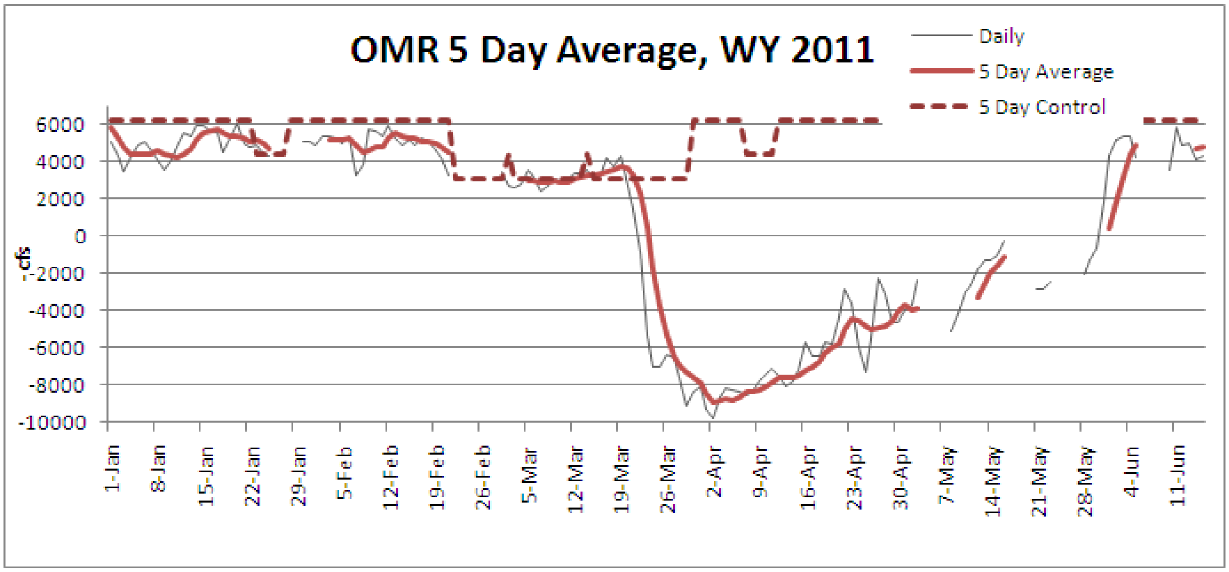


Figure B-2: Time series of measured OMR and Regulatory Controls for WY 2010

OMR Measurements from USGS stream flow data for Old River (station 11313405) and Middle River (station 11312676), tidally filtered by USGS. OMR Control values are from materials for the 2010 OCAP Integrated Annual Review Workshop.



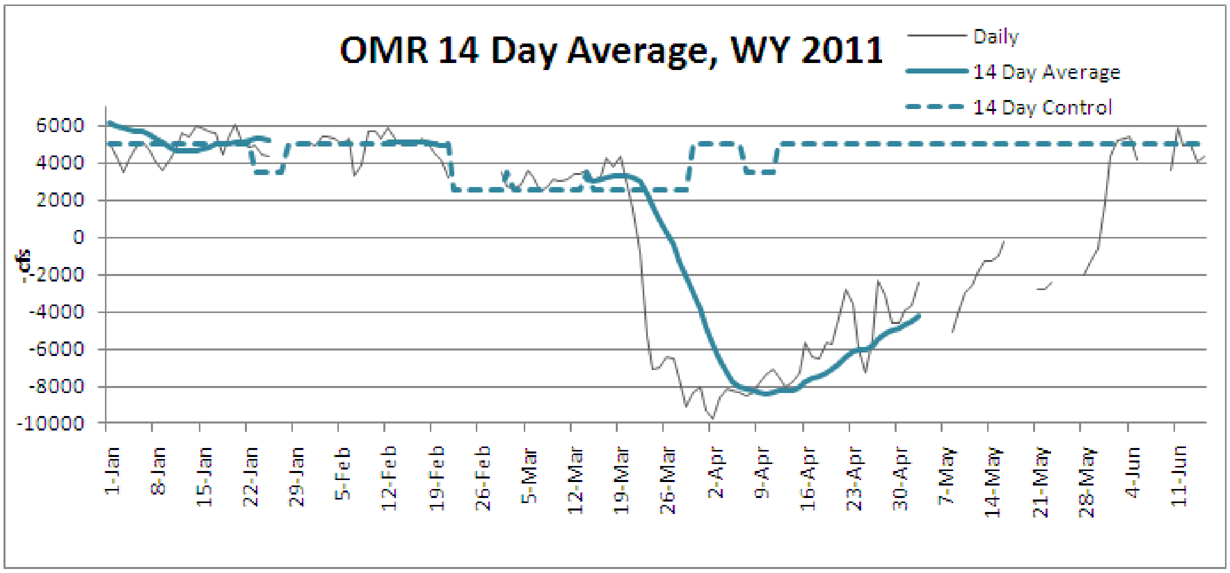


Figure B-3: Time series of measured OMR and Regulatory Controls for WY 2011
OMR Measurements from USGS stream flow data for Old River (station 11313405) and Middle River (station 11312676), tidally filtered by USGS. OMR Control values are from materials for the 2011 OCAP Integrated Annual Review Workshop.

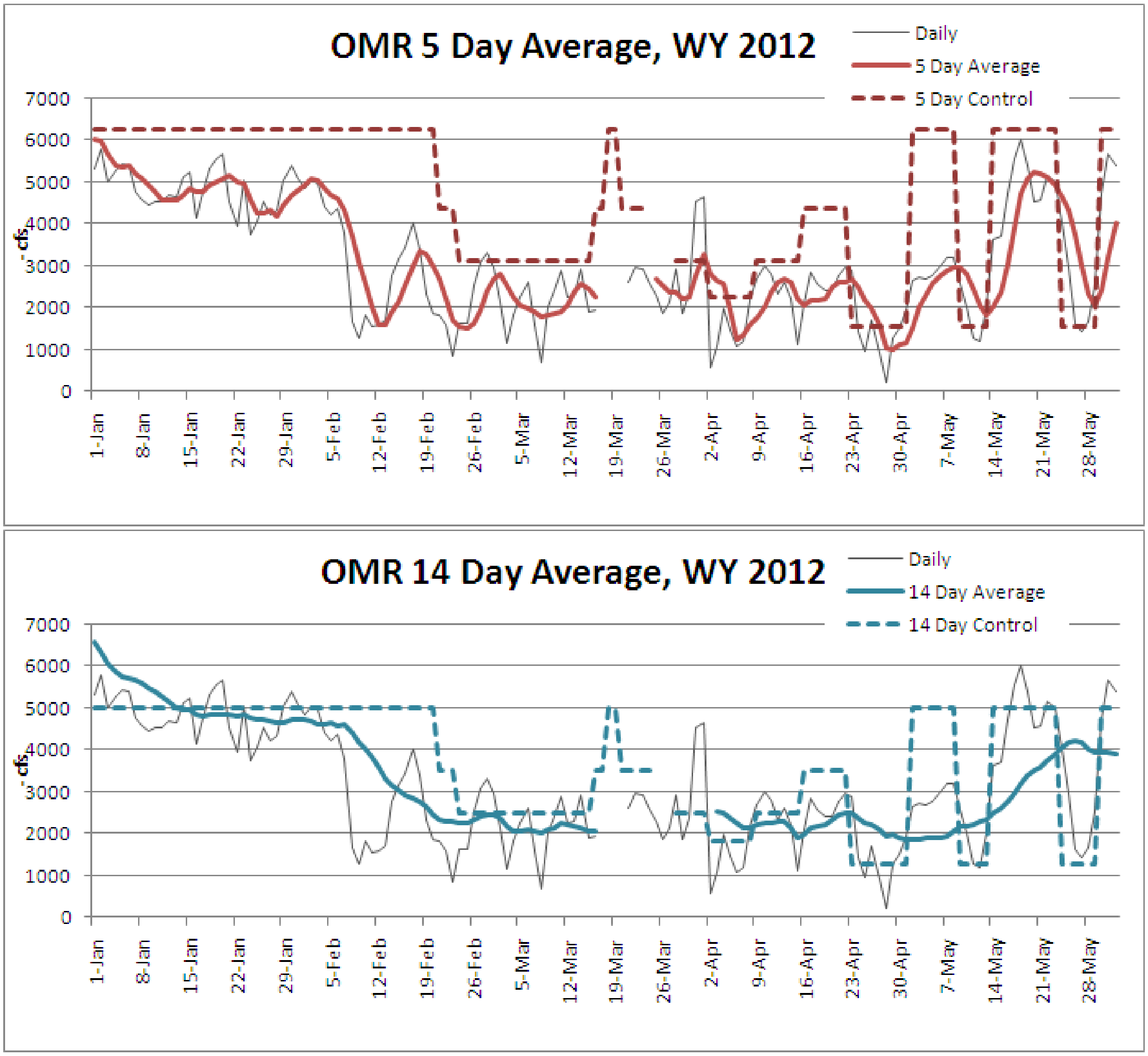


Figure B-4: Time series of measured OMR and Regulatory Controls for WY 2012

OMR Measurements from USGS stream flow data for Old River (station 11313405) and Middle River (station 11312676), tidally filtered by USGS. OMR Control values are provided in USFWS Determinations and note from the smelt working group (SWG) and the Delta Operations for Salmon and Sturgeon (DOSS) Group.