A Model to Estimate Combined Old & Middle River Flows

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Executive Summary

Introduction

The abundances of Delta smelt (*Hypomesus transpacificus*) and other pelagic fish species have declined dramatically over the last several years. These population declines are thought to be influenced by chemical pesticide exposure, food-web alterations, and water project entrainment. Studies are ongoing by the Interagency Ecological Program and others to define and understand the nature of these population declines (Armor and Sommer 2006). One such study found a correlation between Delta smelt salvage at the CVP-SWP export pumps and combined Old and Middle River flows near Bacon Island (Smith et.al. 2006). This correlation was a motivating factor to limit upstream (reverse) flows in Old and Middle Rivers (NRDC vs. Kempthorne 2007).

The current configuration of the Delta relies on Old and Middle Rivers to convey water from the Sacramento River to the CVP-SWP export pumps, a pathway that results in reverse flows. Since regulation of these reverse flows can have significant impacts on water project operations, accurate methods are needed to forecast Old and Middle River (OMR) flows.

This report reviews the hydraulics of OMR flows, evaluates the performance and limitations of existing empirical models to predict OMR flow, and documents the development of a new model of OMR flow. The new model was designed as a long-term planning tool that can be incorporated into CALSIM; however, the model also has applicability to short-term operations planning.

Hydraulics of OMR Flow

The USGS gauges tidal flows in Old and Middle Rivers at Bacon Island. Several hydraulic forces determine the volume and direction of flows at these locations. These hydraulic forces, as described in Section 2, may contribute to downstream (positive) flow or may contribute to upstream (reverse) flow. See Figure ES-1.

Performance of Existing Empirical Models of OMR Flow

Currently available empirical OMR flow models can produce widely different estimates. These differences motivated an effort to evaluate the performance and limitations of existing models and to explore methods of addressing these limitations. See Section 3 for details on the evaluation of existing models.

New Empirical Model of OMR Flow

The new empirical OMR flow model presented in Sections 4 through 6, herein referred to as the MWD model, is founded on a simple control volume or water balance. The model is calibrated with data generated by DWR's Delta Simulation Model (DSM2) and validated with field observations. Many, but not all, of the water balance terms are routinely measured or are estimated though currently available methods. Statistical methods were used to estimate unknown water balance terms.

Water Balance. If the influence of tides is ignored, the following south Delta water balance can be defined to describe OMR flow in term of other riverine flows and diversions:

OMR flow = San Joaquin River flow @ Vernalis
+ Indian Slough flow @ Old River
– San Joaquin River flow downstream of HOR
– Clifton Court Forebay diversions
– Jones Pumping Plant diversions
– CCWD Old River Intake diversions
– South Delta net channel depletion

Indian Slough flow is defined in the above water balance to be positive when flowing upstream (east) into Old River. The assumed sign convention is opposite that used in the DSM2 model. Indian Slough is tidally influenced, so net flows may be positive or negative. Net channel depletion is defined to be positive when depletions exceed accretions. Net channel depletions may be negative in the winter when local precipitation and drainage returns are greater than channel diversions. Table ES-1 summarizes the water balance by month for the period 1998-2006. CCWD's Old River diversion became operational in late 1997; therefore, data prior to 1998 were excluded from the table.

Estimating Unknown Water Balance Terms. The above water balance provides a foundation for the MWD model. Since most of the water balance terms are measured in the field or estimated through currently available methods, these terms are defined as independent variables in the MWD model. Two key water balance terms, Indian Slough flow at Old River and San Joaquin River flow downstream of the head of Old River (HOR), are not measured in the field or estimated through currently available methods. Therefore, regression equations were developed with DSM2 data to predict these terms. Table ES-2 summarizes regression equations and statistics for predicting San Joaquin River flow downstream of HOR. The final MWD model form and coefficients are summarized in Table ES-3.

Model Uncertainty. Model uncertainty was quantified by computing safety factors or "buffers" needed to avoid exceeding an OMR flow objective with 95% confidence. These buffers are summarized in Table ES-4 and key observations are highlighted below:

- Longer flow averaging periods can be forecasted with greater certainty, and therefore can rely on smaller buffers to meet OMR flow objectives. Buffers required to meet 7-day averaged flow objectives are approximately twice as large as buffers required to meet 14-day averaged flow objectives.
- Three-day forecasts can be estimated with greater certainty than 5-day forecasts, and therefore can rely on smaller buffers. Buffers required for a 5-day forecast are approximately 50% greater than those required for a 3-day forecast.

The current OMR flow objective is generally specified as a 7-day average; therefore, buffers for 7-day averaged flows are most applicable for short-term forecasting. Buffers for 14-day averaged flows serve as reasonable proxies for long-term planning studies. The 7-day buffers are overly conservative, given that much of the 7-day uncertainty is due to tidal effects that can be anticipated by operations planners.

Findings and Conclusions

Model Development & Application. The following findings and conclusions relate to MWD model development and application:

- The model, which was formulated as a water balance and calibrated with DSM2 data, provides (1) superior validation to observed data and (2) more robust sensitivity to key hydrologic variables. The model should be adopted as a planning tool for predicting OMR flow. Model performance as a short-term forecasting tool could be enhanced by including a tidal influence term.
- Clifton Court Forebay diversion is a better measure than Banks Pumping in predicting OMR flow. This consideration is important for short-term forecasting. For long term planning, the distinction is less important.

Potential Control Measures. The following findings and conclusions relate to potential measures to control OMR flow:

- Comparison of model estimates with observed OMR flows was used to develop planning "buffers" to account for estimate uncertainty.
    - Longer flow averaging periods can be forecasted with greater certainty, and therefore can rely on smaller buffers to meet OMR flow objectives. Buffers required to meet 7-day averaged flow objectives are approximately twice as large as buffers required to meet 14-day averaged flow objectives. The 7-day buffers are overly conservative, given that much of the 7-day uncertainty is due to tidal effects that can be anticipated by operations planners.
    - 3-day forecasts can be estimated with greater certainty than 5-day forecasts, and therefore can rely on smaller buffers. Buffers required for a 5-day forecast are approximately 50% greater than those required for a 3-day forecast.
- The only south Delta agricultural barrier that has a significant impact on OMR flow is the Grant Line Canal. This finding seems reasonable given that the Grant Line Canal barrier provides the greatest flow restriction. Therefore, any future Delta smelt protections should focus on operation of this barrier.
- Water savings will result from delaying or prohibiting installation of HOR and Grant Line Canal barriers. Studies are needed to determine if delayed installation would require export curtailments to meet south Delta water levels.
- Measures that increase San Joaquin River flows at Vernalis would be effective in controlling OMR flow. Such measures would be even more effective if the Paradise

Cut weir operation was modified to allow more San Joaquin River water into the south Delta.

References

Armor, C.S., and T.R. Sommer (2006). Pelagic Organism Decline 2005-2006: Overview of Program and Progress, 4th Biennial CALFED Science Conference 2006, October 23-25, 2006, Sacramento Convention Center.

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Table ES-1
Monthly Average South Delta Water Balance (cfs): 1998-2006

Month	Old & Middle Rivers	San Joaquin River @ Vernalis	Indian Slough @ Old River	South Delta Net Channel Depletions	San Joaquin River d/s HOR	Clifton Court Forebay Diversions	Jones Pumping Plant Diversions	CCWD Diversions @ Old River	Water Balance [1]	Difference (9) – (1)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Jan	-5850	4034	377	185	-1554	-5125	-3642	-98	-5824	26
Feb	-4275	6307	268	356	-2520	-4560	-3895	-139	-4183	92
Mar	-3043	8288	181	41	-3589	-4311	-3598	-99	-3085	-43
Apr	-718	8681	-14	-163	-3856	-2932	-2238	-144	-665	53
May	1271	8873	-193	-392	-4574	-1116	-1205	-116	1276	5
Jun	-2361	7503	6	-719	-3396	-2700	-2894	-191	-2392	-31
Jul	-7496	4785	294	-926	-2120	-5209	-4209	-154	-7539	-43
Aug	-9298	2621	440	-671	-1168	-6082	-4326	-135	-9320	-23
Sep	-8962	2368	476	-383	-1105	-5918	-4291	-118	-8971	-10
Oct	-7403	2633	414	-252	-1434	-4455	-4220	-94	-7407	-4
Nov	-6639	2490	388	-184	-1284	-4099	-3912	-74	-6675	-36
Dec	-5927	2246	359	-103	-741	-4378	-3266	-35	-5917	10

[1] Sum of Columns (2) thru (8)

Table ES-2
Regression Analysis Results:
Statistical Model of San Joaquin River Flow Downstream of Head of Old River

$$Q_{SJR\ d/s\ HOR}\ (cfs) = A * Q_{Vernalis}\ (cfs) + B * Q_{South\ Delta\ Diversions}\ (cfs) + C$$

HORB	GLC Barrier	Vernalis (cfs)	N	A	B	C	R2	SEE (cfs)	Comments
Out	Out	< 16,000	7167	0.499	-0.0312	-161	0.996	112	
Out	Out	16000-28000	622	0.276	0	3128	0.991	84	Weir allows flow in Paradise Cut
Out	Out	> 28000	214	0.327	0	1677	0.983	180	Weir allows flow in Paradise Cut, but at a lower rate
Out	In	All	2055	0.554	-0.0168	-45	0.918	127	
In (Spring)	Out/In	All	586	0.916	0	-146	0.978	219	
In (Fall)	Out/In	All	1251	0.747	-0.0109	-24	0.961	109	

N= number of observations; R2=coefficient of determination; SEE=standard error of estimate

Table ES-3
MWD OMR Flow Model Coefficients

$$Q_{OMR}\text{ (cfs)} = A * Q_{Vernalis} + B * Q_{South\ Delta\ Diversions} + C$$

Where: $Q_{South\ Delta\ Diversions} = Q_{CCF} + Q_{Jones} + Q_{CCWD} + Q_{South\ Delta\ NCD}$

HORB	GLC Barrier	Vernalis (cfs)	A	B	C
Out	Out	< 16,000	0.471	-0.911	83
Out	Out	16,000-28,000	0.681	-0.940	-3008
Out	Out	> 28,000	0.633	-0.940	-1644
Out	In	All	0.419	-0.924	-26
In (Spring)	Out/In	All	0.079	-0.940	69
In (Fall)	Out/In	All	0.238	-0.930	-51

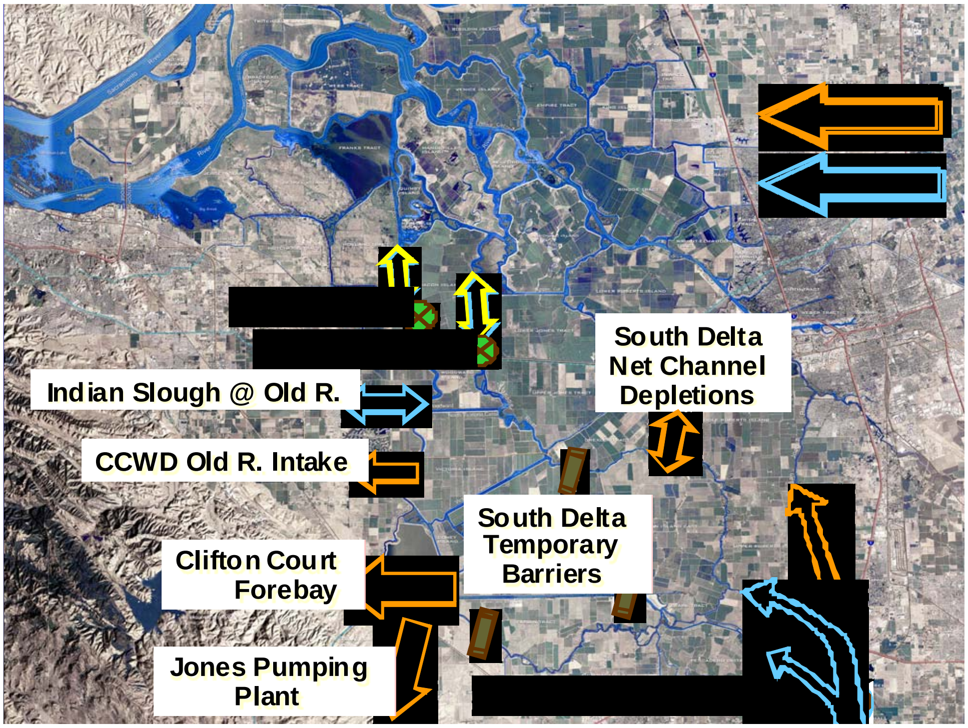
Table ES-4
OMR Flow Buffers with 95% Confidence (cfs)

Month	14-Day Averaged OMR Flow			7-Day Averaged OMR Flow		
	3-Day Forecast	5-Day Forecast	≥ 14 Day Forecast	3-Day Forecast	5-Day Forecast	≥ 7 Day Forecast
Dec	300	450	700	600	850	1000
Jan	250	350	450	500	700	800
Feb	250	350	500	500	700	850
Mar	200	300	300	350	550	600
Apr	300	450	700	600	900	1050
May	300	450	850	600	950	1200
Jun	250	350	700	450	650	850
12 Months	300	400	750	550	850	1000

Notes on USGS Observed Data Used to Develop Buffers:
1) 24-hour averages were computed from raw 15-minute data
2) 24-hour data were filled based on correlations between Old and Middle Rivers
3) The period Jan 1, 1990 thru Sep 30, 2006 were used to develop buffers except as noted below:
    a. Events when OMR flow was > 0 cfs were excluded from buffer calculations
    b. The period Jun 1, 2004 thru Dec 31, 2004 were excluded from buffer calculations (Jones Tract levee failure)

Other Note:
1) ≥14 Day and ≥7 Day forecasts assume no knowledge of antecedent conditions.

Figure ES-1
Hydraulic Forces Contributing to OMR Flow



Several hydraulic forces determine the volume and direction of flows in Old and Middle Rivers. These forces may contribute to downstream (positive) flow or may contribute to upstream (reverse) flow.

Section 1
Introduction

The abundances of Delta smelt (*Hypomesus transpacificus*) and other pelagic fish species have declined dramatically over the last several years. These population declines are thought to be influenced by chemical pesticide exposure, food-web alterations, and water project entrainment. Studies are ongoing by the Interagency Ecological Program and others to define and understand the nature of these population declines (Armor and Sommer 2006). One such study found a correlation between Delta smelt salvage at the CVP-SWP export pumps and combined Old and Middle River flows near Bacon Island (Smith et.al. 2006). This correlation was a motivating factor to limit upstream (reverse) flows in Old and Middle Rivers (NRDC vs. Kempthorne 2007).

The current configuration of the Delta relies on Old and Middle Rivers to convey water from the Sacramento River to the CVP-SWP export pumps, a pathway that results in reverse flows. Since regulation of these reverse flows can have significant impacts on water project operations, accurate methods are needed to forecast Old and Middle River (OMR) flows.

This report reviews the hydraulics of OMR flows, evaluates the performance and limitations of existing empirical models to predict OMR flow, and documents the development of a new model of OMR flow. The new model was designed as a long-term planning tool that can be incorporated into CALSIM; however, the model also has applicability to short-term operations planning.

References

Armor, C.S., and T.R. Sommer (2006). Pelagic Organism Decline 2005-2006: Overview of Program and Progress, 4th Biennial CALFED Science Conference 2006, October 23-25, 2006, Sacramento Convention Center.

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Section 2
Background

This section identifies hydraulic forces that determine OMR flows and discusses relative influences and control of these hydraulic forces. This section also provides a brief introduction to existing models of OMR flow.

Hydraulics of OMR Flow

The USGS gauges tidal flows in Old and Middle Rivers at Bacon Island. Several hydraulic forces determine the volume and direction of flows at these locations. These hydraulic forces, as described below, may contribute to downstream (positive) flow or may contribute to upstream (reverse) flow. See Figure 2-1.

San Joaquin River Inflows to Old and Middle Rivers. The San Joaquin River provides downstream flow to Old and Middle Rivers at the confluence of the San Joaquin and Old Rivers; this location is typically referred to as the Head of Old River (HOR). Under high flow conditions, the San Joaquin River also provides downstream flow through Paradise Cut. San Joaquin River flows upstream of the Delta are influenced by several factors, including reservoir releases along the Stanislaus River (New Melones), the Tuolumne River (New Don Pedro) and the Merced River (McClure). Total contributions from the San Joaquin River to Old and Middle Rivers are strongly influenced by physical structures such as an overflow rock weir at Paradise Cut and seasonal installation of a fish barrier at the Head of Old River. Total contributions from the San Joaquin River are also influenced (but to a lesser degree) by south Delta water levels, which are in turn influenced by seasonal installation of agricultural barriers, tides, and water diversions from the south Delta. Typically 60 to 80% of the San Joaquin River flow volume diverts into Old River and contributes to downstream OMR flows when the fish barrier at the HOR is not installed. The remaining volume flows past Stockton through the main stem of the San Joaquin River.

Water Diversions from the South Delta. Net flow in Old and Middle Rivers is upstream when south Delta water diversions exceed contributions from the San Joaquin River. South Delta water diversions include the SWP Clifton Court Forebay Intake, the CVP Jones Pumping Plant, the CCWD Los Vaqueros Intake on Old River, and local agricultural diversions. All south Delta water diversions contribute equally, on a per unit basis, to OMR reverse flows.

Indian Slough hydraulically bypasses the Old River gauging station at Bacon Island. Under high flow conditions, this bypass results in unmeasured net downstream flow at Old River. Under low flow conditions, this bypass results in unmeasured net upstream flow at Old River. The practical implication of Indian Slough is that, under low flow conditions, south Delta water diversions have less than a 1-to-1 effect on gauged OMR reverse flows. If this bypass did not exist, a 1-to-1 effect would exist (ignoring the influence of south Delta water diversions on the HOR flow split), i.e. an additional 100 cfs south Delta diversion would result in 100 cfs of additional reverse flow measured in Old and Middle Rivers.

Tides. The tide is another hydraulic force that determines the volume and direction of flows in Old and Middle Rivers. Flood and ebb tides influence flows within a day; spring and neap tides influence flows within a month. Numerical filtering of OMR flow data can remove much, but not necessarily all, of the influence associated with tides.

Relative Influence of Hydraulic Forces That Determine OMR Flows

In relative terms, south Delta water diversions have the largest influence on OMR flows. San Joaquin River inflows have a large, but smaller, influence on these flows. As discussed above, numerical filtering (e.g. 14-day averages) reduces the influence of tides on OMR flows.

Table 2-1 shows that, of the primary south Delta water diversions, the Clifton Court Forebay and Jones diversions are the largest and have been of similar magnitude in recent years. CCWD and local agricultural diversions are smaller; however, agricultural diversions can be significant during the irrigation season. The table also shows that San Joaquin River inflow is a large hydraulic force in determining OMR flows.

Control of Hydraulic Forces That Determine OMR Flows

Given the above discussion, reverse flows on Old and Middle Rivers may be effectively controlled through manipulation of water diversions and San Joaquin River inflows. Both the CVP and SWP play major roles in manipulating these hydraulic forces. In fact, the CVP plays an even greater role than the SWP.

While the SWP and CVP have similar control of reverse flows on Old and Middle Rivers through their respective operations of Clifton Court Forebay and Jones Pumping Plant, the CVP plays a much greater role in controlling San Joaquin River inflows to the south Delta. Both projects participate in operation of the HOR barrier, a structure that influences inflow to the south Delta (see above discussion). However, the CVP has additional control of inflow through its operation of New Melones and Millerton Reservoirs.

Existing Empirical Models of OMR Flow

Although physics-based models have been available for several years to predict OMR flows, empirical models were developed as easy to use and understand alternatives. The utility of such models is even greater now that water project operations are controlled by OMR flow objectives.

DWR developed several regression equations to estimate daily OMR flow (DWR 1986). The empirical model currently used by DWR relates OMR flow to (1) combined SWP-

CVP exports and (2) San Joaquin River flow at Vernalis. SWP export data represent flows at Clifton Court Forebay intake rather than pumping at Banks Pumping Plant.

USGS also developed a set of regression equations to fill missing OMR flow data (Ruhl et.al. 2006). In addition to combined SWP-CVP exports and San Joaquin River flow at Vernalis, this empirical model also relates OMR flow to south Delta temporary barrier installation. However, the model does not distinguish between installation of the HOR barrier (HORB) and installation of the three agricultural barriers.

The empirical OMR flow models developed by DWR and USGS have been used by the author and others to assess water supply impacts of proposed Delta smelt protective actions. The DWR empirical model has also been used in recent months for water project operations planning. The author has noted that these models can produce widely different impact estimates, depending on hydrology and operations.

Physics-based hydrodynamic models, such as DWR's Delta Simulation Model (DSM2), the Fischer Delta Model (FDM), and the Resources Management Associates (RMA) Delta Model, necessarily provide high-frequency estimates of flow in Old and Middle Rivers. Of the existing hydrodynamic models, this report focuses on DSM2 in subsequent evaluation of performance and limitations.

Proposal to Develop New Empirical Model

The differences noted above motivated an effort to evaluate the performance and limitations of existing empirical models of OMR flow, and to explore methods of addressing these limitations. While this effort has a special focus on developing a new planning model that can be used within CALSIM and other long-term analyses, its results may also benefit operations planning.

References

DWR (1986). New Flow Equations for the San Joaquin River at Stockton and for Old and Middle Rivers, Office Memorandum from Jim Snow to Richard Jones, April 17.

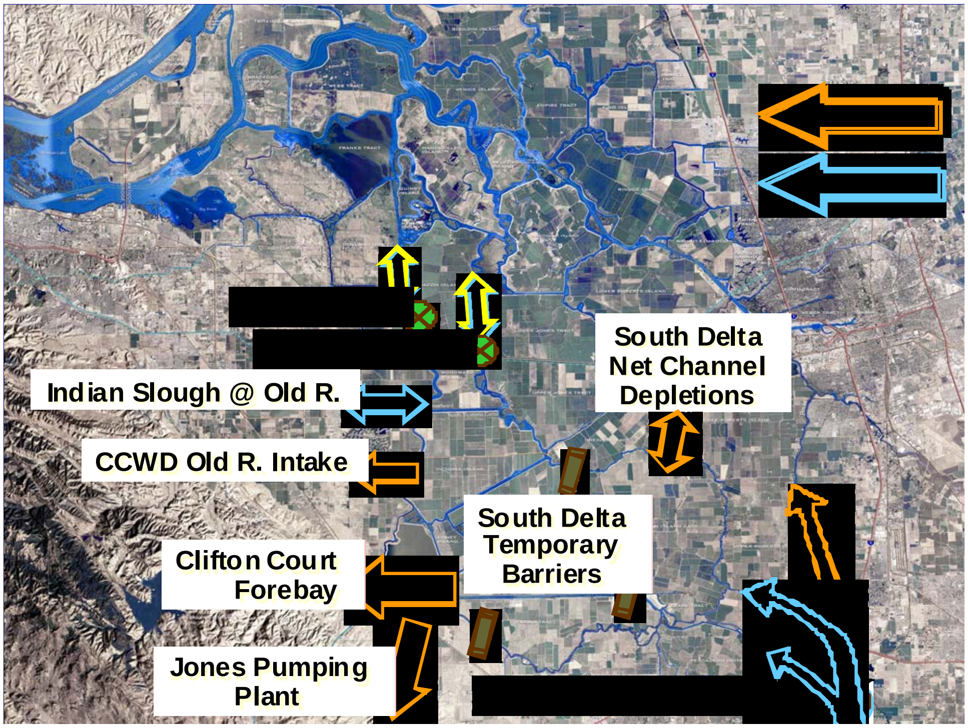
C.A. Ruhl, P.E. Smith, J.J. Simi, and J.R. Burau (2006). The Pelagic Organism Decline and Long-Term Trends in Sacramento-San Joaquin Delta Hydrodynamics, 4th Biennial CALFED Science Conference 2006, October 23-25, 2006, Sacramento Convention Center.

Table 2-1
Average South Delta Water Diversions
December-June 1998-2006

Month	San Joaquin River (cfs)[1]	South Delta Net Channel Depletions (cfs)[2]	SWP (cfs)	CVP (cfs)	CCWD (cfs)
December	2250	100	4400	3300	40
January	4030	-190	5100	3600	100
February	6310	-360	4600	3900	140
March	8290	-40	4300	3600	100
April	8680	160	2900	2200	140
May	8870	390	1100	1200	120
June	7500	720	2700	2900	190

[1] Measured at Vernalis
[2] Estimated. Agricultural return flows are often larger than agricultural diversions in high-precipitation months, resulting in negative net channel depletions.

Figure 2-1
Hydraulic Forces Contributing to OMR Flow



Several hydraulic forces determine the volume and direction of flows in Old and Middle Rivers. These forces may contribute to downstream (positive) flow or may contribute to upstream (reverse) flow.

Section 3
Performance and Limitations of Existing Models

As discussed in the previous sections, DWR and USGS have developed empirical models to predict daily OMR flow. The performance and limitations of these models, along with the performance of the physics-based DSM2 model in predicting OMR flow, are now discussed.

Data Used to Evaluate Performance of Existing Models

Observed OMR flow data for the period January 1, 1990 through September 30, 2006 were used to evaluate the performance of existing models. The following periods were excluded from the evaluation:

- Jan-Feb 1997. Vernalis flow data are suspect during this period due to flood conditions along the San Joaquin River. January 1997 data were also excluded from the USGS model development (Ruhl et.al. 2006).
- Jun-Dec 2004. Data collected during and after the Jones Tract levee breach were excluded due to the unique hydraulic conditions in the south Delta associated with island flooding and pump-off.

OMR flow data were obtained from the USGS National Water Information System (NWIS) website (USGS 2007). Pertinent data sites are the Old River @ Bacon Island (11313405) and the Middle River @ Bacon Island (11312676). Data provided on the web site are tidally filtered with a Godin filter and reported as daily values. The data record begins in January 1987 and continues up to the present. Raw 15-minute OMR flow data were also obtained directly from USGS staff (P. Smith 2007a). Calendar day average flows were computed from the raw data to estimate 7-day and 14-day average flows. As with most long-term data records, the OMR flow data record includes gaps. Correlations between observed Old River and Middle River flows were utilized to estimate OMR flow when one of the two flow records was available. Correlation statistics are provided in Table 3-1.

Data for daily averaged Jones Pumping Plant exports were obtained from DWR's DAYFLOW database (DWR 2007a). DWR's Operations Control Office provided data for daily averaged Clifton Court inflow (A. Sandhu 2007). Forebay stage measurements are used by DWR, along with Banks exports, to compute daily Clifton Court inflows.

South Delta temporary barrier operations data (installation and removal) were obtained from DWR Delta Simulation Model (DSM2) input files and summarized in Table 3-2. Details on historical installation and removal are available elsewhere (DWR 2007b).

Mathematical Form of Existing Models

Model forms assumed by the DWR and USGS OMR flow models, along with model constants, are provided in Table 3-3.

Evaluation of Existing Model Performance

DSM2. High frequency (15-minute) OMR flow data were extracted from a DSM2 simulation of historical hydrology and operations for the period January 1, 1990 through December 31, 2006. These data were tidally filtered with a Godin filter and averaged by calendar day. The resulting DSM2 data are compared with observed data in Figure 3-1. Differences with observed data are within ± 600 cfs over 70% of the time. Differences are greater than ± 1400 cfs less than 5% of the time. The DSM2 model shows a modest bias to under-predict OMR flow. The bias appears to be seasonal and is most pronounced during the months of June through November. A possible explanation for the observed bias is that south Delta net channel depletion estimates are higher than actual depletions.

Figure 3-2 shows that daily averaged DSM2 estimates of Clifton Court Forebay diversions can be considerably different from observed values. Differences between computed and observed values are considerably lower for longer averaging periods. Given the importance of Clifton Court Forebay diversions in determining OMR flow (and presumably other hydrodynamic characteristics in the central and south Delta), DSM2 input modifications appear to be warranted. One possible modification would be to more accurately specify forebay gate operations in DSM2 simulations. Another possible modification would be to specify Clifton Court Forebay diversions directly as a boundary condition.

DWR Empirical Model. OMR daily flows predicted by the DWR model are compared with tidally filtered observed data in Figures 3-3. Differences with observed data are within ±600 cfs about 40% of the time. Differences are greater than ±1400 cfs about 25% of the time. The DWR model shows a strong bias toward over-estimating OMR flow. This bias has the effect of under-estimating water supply impacts associated with potential OMR flow regulations. This bias is particularly pronounced in April and May. By not accounting for HORB installation, the model implicitly assumes that more San Joaquin River water will enter the south Delta and contribute to positive OMR flow than would actually occur. The bias is also pronounced during the late spring and summer months of June through September. By not accounting for in-Delta net channel depletions (highest during the irrigation season) and south Delta agricultural barrier installation, the model assumes that more San Joaquin River water will contribute to downstream OMR flow than would actually occur.

USGS Model. OMR daily flows predicted by the USGS model are compared with tidally filtered observed data in Figure 3-4. Similar to the DWR model, differences with observed data are within ±600 cfs about 45% of the time and are greater than ±1400 cfs about 25% of the time. Unlike the DWR model, the USGS model does not show a general predictive bias. However, the model tends to under-predict in January through March and over-predict in June through August. The late spring and summer over-prediction bias is likely due to lack of accounting for in-Delta net channel depletions during the irrigation season.

Model Limitations

The DWR and USGS empirical models have several limitations when used to answer "what if" questions within a planning analysis framework. These limitations are discussed below:

- <u>Modified Operational Regimes.</u> A typical planning application will be to evaluate required export reductions to meet prescribed OMR flows. It is anticipated that several of these operational regimes will be at levels of OMR flow and Delta exports that have been rarely observed in the historical record. Therefore, the existing models may not be adequately calibrated in the regions of interest for planning applications. This limitation is common to models that are calibrated with historically observed data. This limitation can be addressed by calibrating a model with hydrodynamic data that covers a wider operational range than observed historically. A numerical model such as DSM2 can produce such data.
- <u>Modified South Delta Barrier Operations.</u> Another possible planning application would be to evaluate how changes in south Delta barrier operations impact OMR flow. Such an application is timely, as the recent court decision (NRDC vs. Kempthorne 2007) prohibits HORB installation during the spring. The DWR model does not account for barrier operation. The USGS model does not distinguish between HORB operation and agricultural barrier operation. Neither model account for the influence of Paradise Cut on OMR flow. These limitations can be addressed by including specific barrier operations as independent variables.
- <u>Modified Net Channel Depletions.</u> One possible planning application would be to evaluate how changes in Delta land use impacts OMR flow. Neither model accounts for seasonal variability associated with in-Delta net channel depletions. This limitation can be addressed by including net channel depletions as an independent variable.
- <u>Modified Vernalis Flow.</u> Another possible planning application would be to evaluate how different San Joaquin River water operations upstream of Vernalis (e.g. Friant settlement releases) effect OMR flow. Under low and moderate flow regimes, the USGS model is not a function of Vernalis flow. This limitation can be addressed by including San Joaquin River flow as an independent variable.
- <u>Consistent Model Analysis.</u> Given the recent court decision, it is anticipated that an OMR flow model will be implemented in CALSIM. Given that CALSIM hydrology and operations are often used as input to the DSM2 model, Delta-related components of the CALSIM model should be designed to be consistent with DSM2. For example, see a discussion on development of CALSIM's flow-salinity routine (Hutton and Seneviratne 2001). It is unlikely that the existing empirical OMR flow models will provide a consistent model analysis between CALSIM and DSM2.

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Table 3-1
Correlations Used to Fill OMR Data Gaps
$Q_{Old\ River}$ (cfs) = A * $Q_{Middle\ River}$ (cfs) + B

Data Type	$Q_{Middle\ River}$	N	A	B	R2	SEE (cfs)
Tidally Filtered	< -4000 cfs	1682	0.578	-663	0.634	298
Tidally Filtered	≥ -4000 cfs	2881	0.836	367	0.977	388
Calendar Day Average	< -4000 cfs	1774	0.640	-345	0.643	383
Calendar Day Average	≥ -4000 cfs	3079	0.834	369	0.970	443

N= number of observations; R2=coefficient of determination; SEE=standard error of estimate

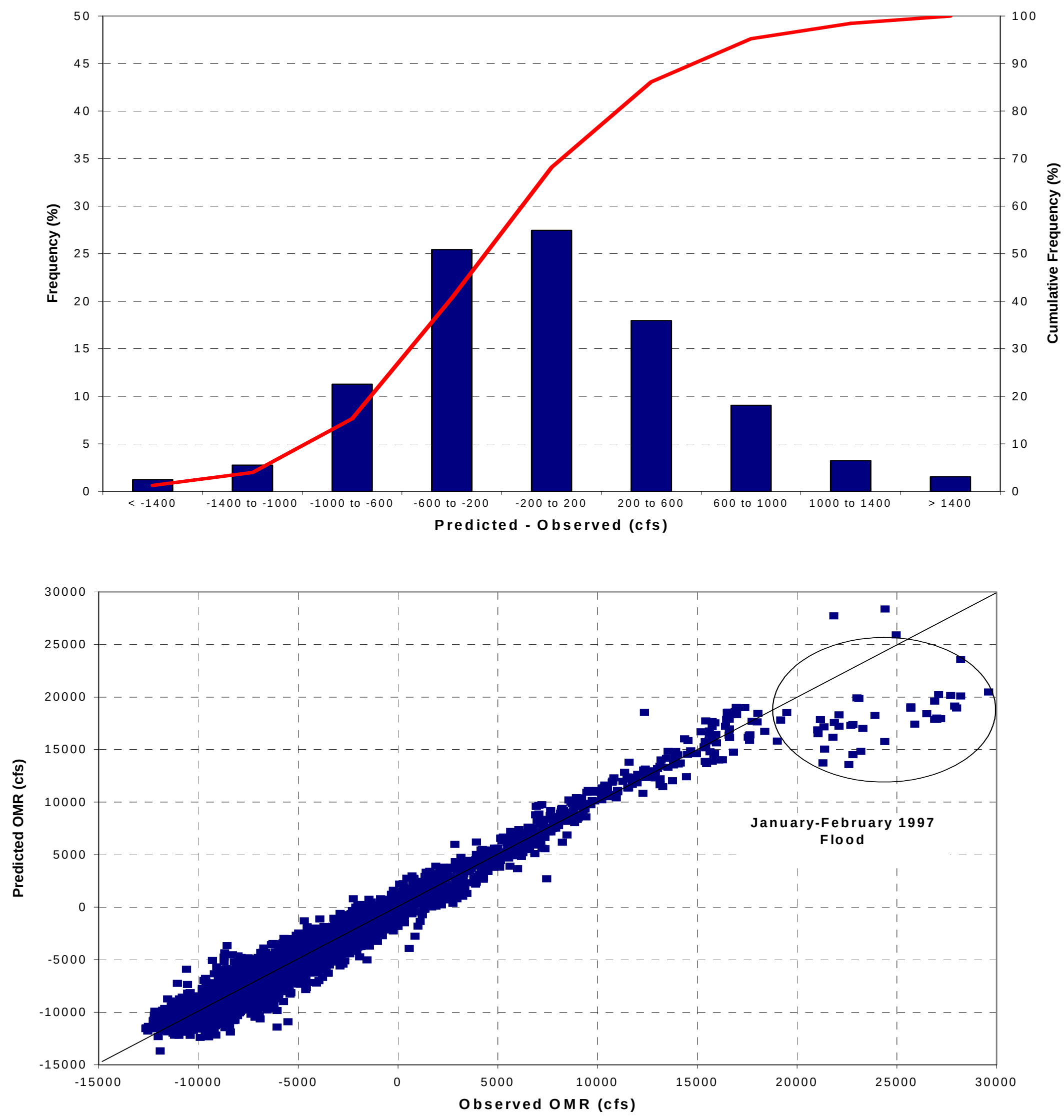
Table 3-2
South Delta Temporary Barrier Operations: 1990-2006

Year	HORB (Spring)		HORB (Fall)		Old River		Middle River		Grant Line Canal	
	In	Out	In	Out	In	Out	In	Out	In	Out
1990	---	---	Sep11	Nov27	---	---	Apr4	Sep29	---	---
1991	---	---	Sep13	Nov23	Aug26	Sep28	Apr4	Sep27	---	---
1992	Apr22	Jun5	Sep10	Dec3	Apr21	Oct1	Apr9	Sep29	---	---
1993	---	---	Nov10	Dec6	Jun2	Sep29	Jun17	Sep23	---	---
1994	Apr23	May18	Sep9	Nov29	Apr25	Oct4	Apr25	Sep30	---	---
1995	---	---	---	---	Aug8	Sep30	Aug10	Oct12	---	---
1996	May7	May17	Oct3	Nov20	---	---	May20	Sep29	Jul11	Oct3
1997	Apr10	May15	---	---	Apr17	Oct2	Apr5	Sep27	Jun5	Sep27
1998	---	---	---	---	---	---	---	---	---	---
1999	---	---	---	---	May25	Sep28	May19	Sep30	Jun4	Sep24
2000	Apr15	Jun1	Oct3	Dec8	Apr17	Sep30	Apr16	Sep30	Jun1	Sep29
2001	Apr25	May30	Oct7	Nov26	Apr27	Nov15	Apr21	Nov14	May4	Nov13
2002	Apr16	May24	Oct4	Nov21	Apr16	Nov19	Apr16	Nov21	Jun7	Nov18
2003	Apr16	May16	Sep22	Nov5	Apr15	Nov15	Apr15	Nov12	Apr16	Nov11
2004	Apr13	May21	Sep20	Nov2	Apr16	Nov13	Apr13	Nov11	Apr15	Nov12
2005	---	---	Sep29	Nov8	May31	Nov9	May12	Nov8	Jul13	Nov15
2006	---	---	---	---	Jul18	Nov17	Jul8	Nov18	Jul19	Nov21

Table 3-3
DWR and USGS OMR Flow Model Constants
Q_{OMR} (cfs) = A * $Q_{VERNALIS}$ (cfs) + B* $Q_{EXPORTS}$ (cfs) + C

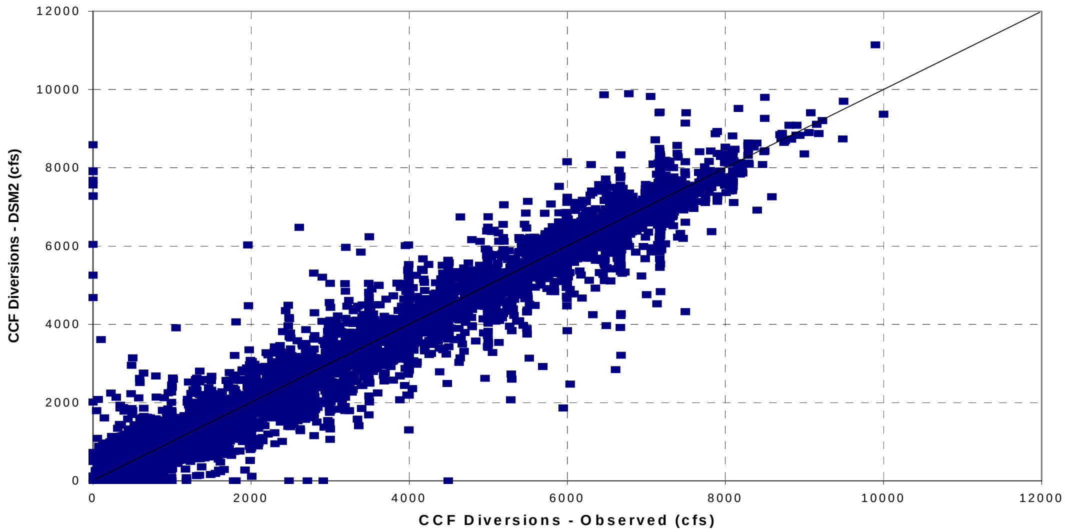
OMR Equation	$Q_{VERNALIS}$	Barriers	A	B	C
DWR	All	All	0.58	-0.913	0
USGS	<10,000 cfs	In	0	-0.8129	-365
USGS	<10,000 cfs	Out	0	-0.8738	1137
USGS	≥10,000 cfs	All	0.7094	-0.7094	-4619

Figure 3-1
Comparison of Predicted & Observed OMR Flow: DSM2 Model
January 1, 1990 – September 30, 2006 (Tidally Filtered Daily Values)



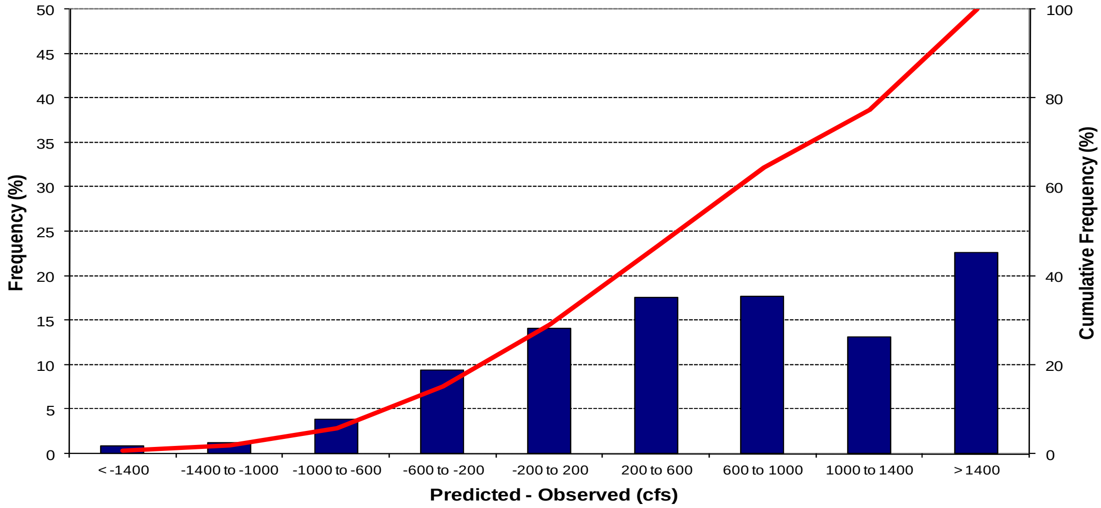
Differences with observed data are within ± 600 cfs over 70% of the time. Differences are greater than ± 1400 cfs less than 5% of the time. The DSM2 model shows a modest bias to under-predict OMR flow. Data corresponding to the 1997 flood (Jan-Feb 1997) were excluded from the evaluation. Vernalis flow data are suspect during early 1997 due to flood conditions along the San Joaquin River. In contrast to the DWR and USGS OMR model evaluations, data collected during and after the Jones Tract levee breach were included in the DSM2 evaluation because the unique hydraulic conditions in the south Delta associated with island flooding and pump-off were simulated by DSM2.

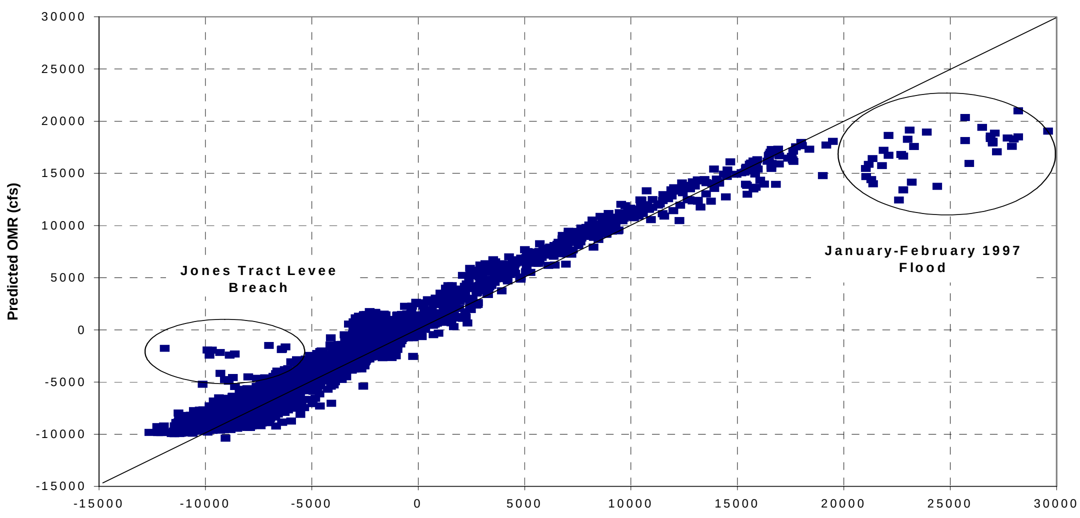
Figure 3-2
Difference Between Predicted & Observed Clifton Court Forebay Diversions
DSM2 Model January 1, 1990 – September 30, 2006 (24-hr Daily Values)



The above figure shows that DSM2 estimates for Clifton Court Forebay diversions can be considerably different from observed values. Given the importance of Clifton Court Forebay diversions in determining OMR flow, modifications to DSM2 appear to be warranted.

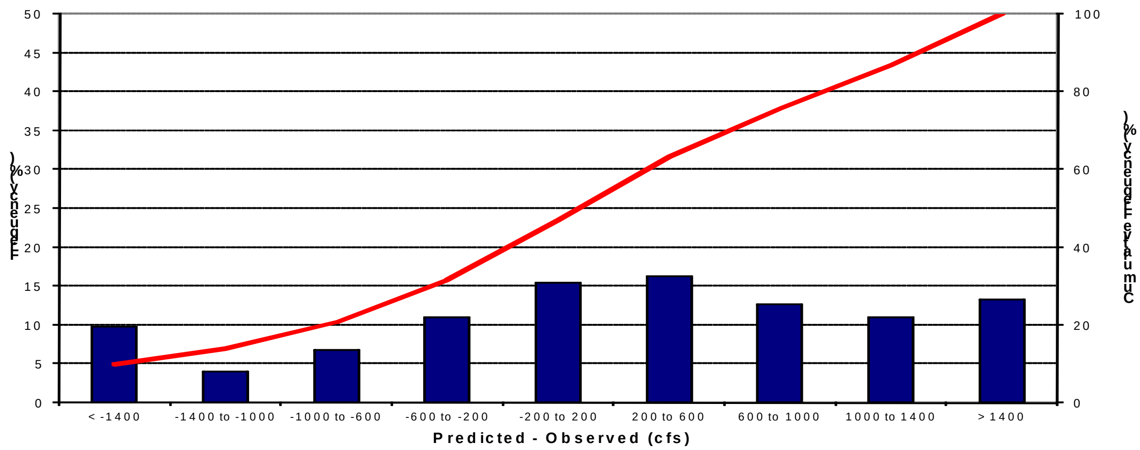
Figure 3-3
Comparison of Predicted & Observed OMR Flow: DWR Model
January 1, 1990 – September 30, 2006 (Tidally Filtered Daily Values)

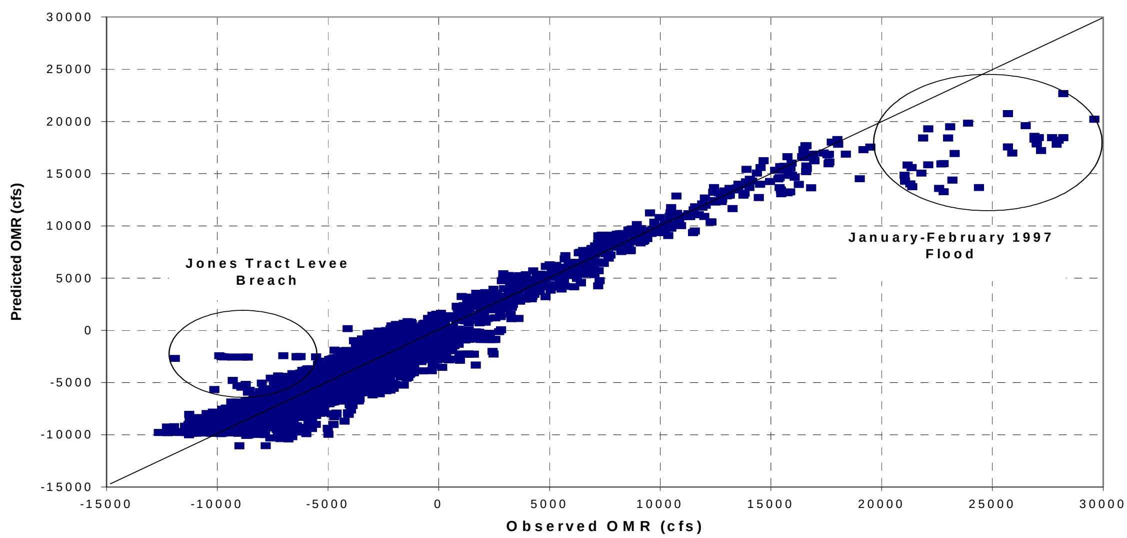




Differences with observed data are within ±600 cfs about 40% of the time. Differences are greater than ±1400 cfs about 25% of the time. The DWR model shows a strong bias toward over-estimating OMR flow. This bias has the effect of under-estimating water supply impacts associated with potential OMR flow regulations. Data corresponding to the 1997 flood (Jan-Feb 1997) and the Jones Tract levee breach (Jun-Dec 2004) were excluded from the evaluation. Vernalis flow data are suspect during early 1997 due to flood conditions along the San Joaquin River. Data collected during and after the Jones Tract levee breach were excluded due to the unique hydraulic conditions in the south Delta associated with island flooding and pump-off.

Figure 3-4
Comparison of Predicted & Observed OMR Flow: USGS Model
January 1, 1990 – September 30, 2006 (Tidally Filtered Daily Values)





Similar to the DWR model, differences with observed data are within ±600 cfs about 45% of the time and are greater than ±1400 cfs about 25% of the time. Unlike the DWR model, the USGS model does not show a general predictive bias. Data corresponding to the 1997 flood (Jan-Feb 1997) and the Jones Tract levee breach (Jun-Dec 2004) were excluded from the evaluation. Vernalis flow data are suspect during early 1997 due to flood conditions along the San Joaquin River. Data collected during and after the Jones Tract levee breach were excluded due to the unique hydraulic conditions in the south Delta associated with island flooding and pump-off.

Section 4
Methods: Developing a South Delta Water Balance

The new OMR flow model presented in this report is founded on a simple control volume or water balance and calibrated with data generated by DSM2. Definition and development of the water balance is presented in this section. Many, but not all, of the water balance terms are routinely measured or are estimated though currently available methods. A statistical method to estimate these unknown water balance terms is presented in Section 5. Results from Section 5 are incorporated into the water balance and presented in Section 6 as the new OMR flow model.

Data Used to Calibrate OMR Flow Model

The new OMR flow model was originally calibrated with DSM2 data generated to simulate 1990-2006 historical conditions. Data from three additional DSM2 simulations were used to validate the initial model calibration:

- Validation Study 1: 1990-2006 historical conditions without Clifton Court and Jones Pumping Plant diversions
- Validation Study 2: 1990-2006 historical conditions without temporary barrier installation
- Validation Study 3: 1990-2006 historical conditions without (1) Clifton Court and Jones Pumping Plant diversions and (2) temporary barrier installation.

The initial model calibration provided excellent validation with data from Studies 2 and 3. RMS errors were similar to those calculated with the calibration data. The initial model calibration did not validate as well with data from Study 1. RMS errors were higher in the summer months of July, August and September. This result suggested that the Old River flow split in the initial model calibration was biased when south Delta diversions were high and temporary barriers were installed. As a remedy, the new OMR flow model was recalibrated with the original data set plus data from Validation Study 1.

Section 3 identified several limitations associated with the use of existing empirical OMR models for planning purposes. Some of these limitations are linked to the shortcomings of existing field data used to calibrate the models. The use of DSM2 data for model calibration addresses these limitations in the following ways:

- <u>Modified Operational Regimes.</u> A numerical model such as DSM2 can produce data that cover a wider operational range than observed historically. For example, see the above discussion on the use of Validation Study 1 data to calibrate the new OMR flow model. Therefore, a model calibrated with DSM2 data will not rely on extrapolation to evaluate new operational regimes.
- <u>Modified Net Channel Depletions.</u> The true relationship between net channel depletions and OMR flow is difficult to discover in the observed data, presumably because of the limited accuracy of current depletion estimates. However, the

relationship between net channel depletions and DSM2-simulated OMR flow is mathematically defined and is therefore more distinct.

- Consistent Model Analysis. An OMR flow model calibrated with DSM2 data, if implemented in CALSIM, will allow for consistent analysis between CALSIM and DSM2.

DSM2 South Delta Water Balance

Section 2 described several hydraulic forces that determine the volume and direction of flows in Old and Middle Rivers. If the influence of tides is ignored, the following south Delta water balance can be defined to describe OMR flow in term of other riverine flows and diversions:

OMR flow = San Joaquin River flow @ Vernalis
+ Indian Slough flow @ Old River
– San Joaquin River flow downstream of HOR
– Clifton Court Forebay diversions
– Jones Pumping Plant diversions
– CCWD Old River Intake diversions
– South Delta net channel depletion

Indian Slough flow is defined in the above water balance to be positive when flowing upstream (east) into Old River. The assumed sign convention is opposite that used in the DSM2 model. Indian Slough is tidally influenced, so net flows may be positive or negative. Net channel depletion is defined to be positive when depletions exceed accretions. Net channel depletions may be negative in the winter when local precipitation and drainage returns are greater than channel diversions.

The flow in Tom Paine Slough is regulated such that ebbs are not allowed to return to the south Delta. An exact water balance would treat flow into Tom Paine Slough as a diversion from the south Delta, and net channel depletions along the slough would not be explicitly accounted for. This refinement was investigated and, although it improved the water balance marginally, it was not adopted for the sake of simplicity.

The above water balance provides a foundation for the proposed OMR flow model, herein referred to as the MWD model. Data used to compute the south Delta water balance and to calibrate the MWD model are listed in Table 4-1. DSM2 boundary conditions are used in the water balance for San Joaquin River flows at Vernalis and for diversions at Jones Pumping Plant and CCWD Old River intake. Computed data from DWR's Delta Island Consumptive Use (DICU) model (DWR 1995) are used in the water balance for south Delta net channel depletions. DSM2 computed data are used in the water balance for flows at Indian Slough at Old River and San Joaquin River downstream of HOR and for diversions at Clifton Court Forebay. The resulting south Delta water balance was averaged by month for eight years (1998-2006) and is summarized in Table 4-2. CCWD's Old River diversion became operational in late 1997; therefore, data prior to 1998 were excluded from the table.

If the south Delta water balance accounted for all mechanisms, it should exactly equal the DSM2-computed OMR flow. However, given that tidal influences are ignored, some differences are expected. Figures 4-1 and 4-2 compare 14-day averaged OMR flow from DSM2 with the south Delta water balance. The water balance closely approximates the OMR flow on a 14-day average basis. As shown in Figure 4-2, the south Delta water balance is within ± 150 cfs of the DSM2 estimate about 85% of the time and within ± 350 cfs 97% of the time.

Figure 4-3 illustrates the periodic behavior of the differences between DSM2-computed OMR flow and the south Delta water balance. The residuals exhibit periodic behavior when computed from 7-day averaged data. As shown in the figure, the phasing is not well predicted from the Martinez tidal range. Tidal range is defined as the difference between daily maximum and daily minimum water levels.

References

DWR (1995). *Estimation of Delta Island Diversions and Return Flows*. Division of Planning, February.

Table 4-1
DSM2 Data Used in South Delta Water Balance and MWD OMR Model Calibration

Data Type	Data Location	DSM2 Channel or Node	Observed or Computed Data
River Flow	Old River @ Bacon Island	Channel 106	Computed
River Flow	Middle River @ Bacon Island	Channels 144 and 145	Computed
River Flow	San Joaquin River @ Vernalis	Node 1	Observed
River Flow	Indian Slough @ Old River	Channel 236	Computed
River Flow	San Joaquin River d/s HOR	Channel 8	Computed
Diversion	Clifton Court Forebay	Node 72	Computed
Diversion	Jones Pumping Plant	Node 181	Observed
Diversion	CCWD Intake @ Old River	Diversion from Channel 90	Observed
Diversion	South Delta Net Channel Depletions	Diversions/returns from several nodes	Computed [1]
Temporary Barrier Operation	Head of Old River Fish Barrier	Channel 54	Observed
Temporary Barrier Operation	Grant Line Canal Agricultural Barrier	Channel 206	Observed
Temporary Barrier Operation	Old River Agricultural Barrier	Channel 79	Observed
Temporary Barrier Operation	Middle River Agricultural Barrier	Channel 134	Observed

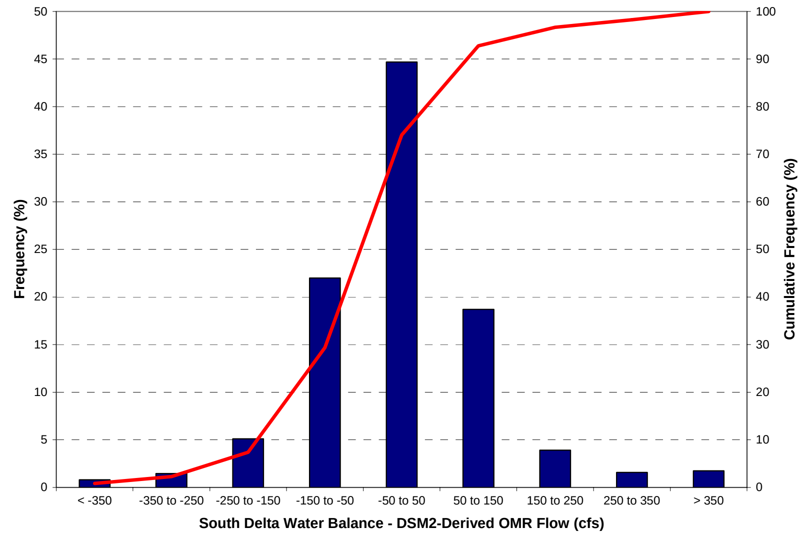
[1] From DICU model (DWR 1995)

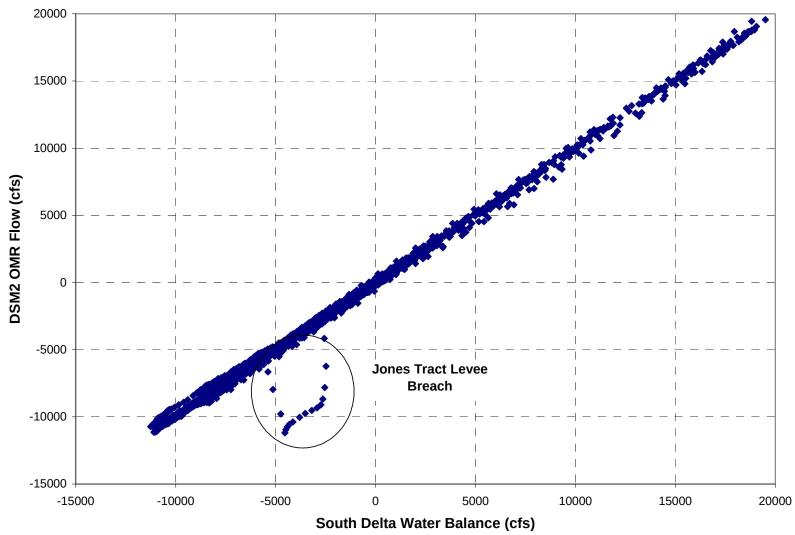
Table 4-2
Monthly Average South Delta Water Balance (cfs): 1998-2006

Month	Old & Middle Rivers	San Joaquin River @ Vernalis	Indian Slough @ Old River	South Delta Net Channel Depletions	San Joaquin River d/s HOR	Clifton Court Forebay Diversions	Jones Pumping Plant Diversions	CCWD Diversions @ Old River	Water Balance [1]	Difference (9) – (1)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Jan	-5850	4034	377	185	-1554	-5125	-3642	-98	-5824	26
Feb	-4275	6307	268	356	-2520	-4560	-3895	-139	-4183	92
Mar	-3043	8288	181	41	-3589	-4311	-3598	-99	-3085	-43
Apr	-718	8681	-14	-163	-3856	-2932	-2238	-144	-665	53
May	1271	8873	-193	-392	-4574	-1116	-1205	-116	1276	5
Jun	-2361	7503	6	-719	-3396	-2700	-2894	-191	-2392	-31
Jul	-7496	4785	294	-926	-2120	-5209	-4209	-154	-7539	-43
Aug	-9298	2621	440	-671	-1168	-6082	-4326	-135	-9320	-23
Sep	-8962	2368	476	-383	-1105	-5918	-4291	-118	-8971	-10
Oct	-7403	2633	414	-252	-1434	-4455	-4220	-94	-7407	-4
Nov	-6639	2490	388	-184	-1284	-4099	-3912	-74	-6675	-36
Dec	-5927	2246	359	-103	-741	-4378	-3266	-35	-5917	10

[1] Sum of Columns (2) thru (8)

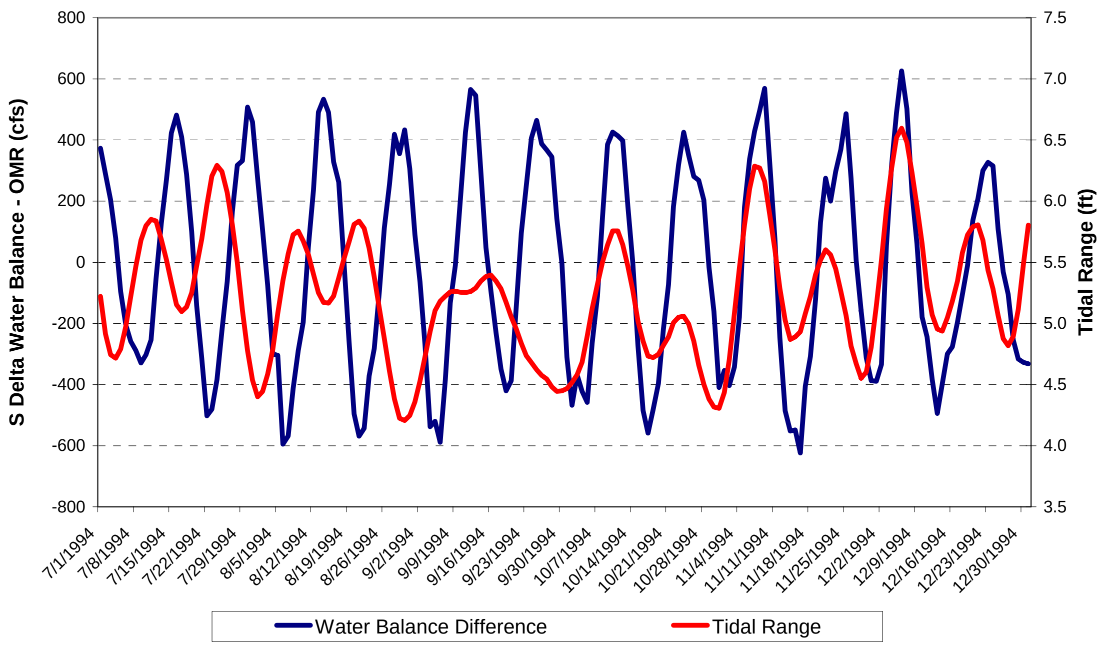
Figure 4-1
Comparison of OMR Flow and South Delta Water Balance
14-day Averaged DSM2 Data: 1990-2006





The south Delta water balance closely approximates DSM2-simulated OMR flow on a 14-day average basis. The south Delta water balance is within ± 150 cfs of the DSM2 estimate about 85% of the time and within ± 350 cfs 97% of the time. The water balance does not account for unique hydraulic conditions in the south Delta associated with Jones Tract island flooding and pump-off during and after the levee failure.

Figure 4-2
Comparison of Water Balance Residual and Martinez Tidal Range
7-day DSM2 Averages: Jul 1994 - Dec 1994



The residuals between DSM2-computed OMR flow and the south Delta water balance exhibit periodic behavior when computed from 7-day averaged data. As shown in the figure, the phasing is not well predicted from the Martinez tidal range. Tidal range is defined as the difference between daily maximum and daily minimum water levels.

Section 5
Methods: Developing Statistical Relationships for Unknown Water Balance Terms

As discussed in the previous section, a south Delta water balance developed with DSM2 data provides a foundation for the MWD OMR flow model. Since most of the water balance terms are measured in the field or estimated through currently available methods, these terms are defined as independent variables in the MWD model. Two key water balance terms, Indian Slough flow at Old River and San Joaquin River flow downstream of HOR, are not measured in the field or estimated through currently available methods. Therefore, regression equations were developed with DSM2 data to predict these terms.

Indian Slough Flow @ Old River

Figure 5-1 shows a linear relationship between 14-day averaged Indian Slough flow and 14-day OMR flow, as provided by DSM2, where positive flow is defined as flowing upstream (east) into Old River. Regression statistics are provided in Table 5-1. All data points generated in the DSM2 simulation of historical conditions were used to develop the relationship. This relationship suggests that, as OMR downstream flow increases, Indian Slough flow decreases (or moves downstream in a westerly direction away from Old River). A practical implication of this relationship is that, under low flow conditions, south Delta water diversions have less than a 1-to-1 effect on gauged Old and Middle River reverse flows. If this bypass did not exist, a 1-to-1 effect would exist (ignoring the influence of south Delta water diversions on the HOR flow split), i.e. an additional 100 cfs south Delta diversion would result in 100 cfs of additional reverse flow measured in Old and Middle Rivers.

A similar regression analysis was performed with daily averaged flows. The resulting relationship was nearly identical to the relationship developed with 14-day averaged flows; however, the data scatter was greater.

An attempt was made to refine the above relationship by removing data corresponding to periods when the south Delta water balance does not compare favorably with DSM2 generated OMR flows. Removing data from two specific periods (January-February 1997 flood and June-December 2004 Jones Tract levee breach) did not result in a more refined relationship, however.

A residuals analysis revealed a strong seasonal trend that was correlated with net channel depletions in Indian Slough and Rock Slough. For the same OMR flow, Indian Slough flows into Old River are higher when local net channel depletions are lower. The 14-day averaged Indian Slough flow relationship was improved by adding an additional term for local depletions (see Table 5-1). Curiously, CCWD diversions from Rock Slough did not appear to be a statistically significant factor in estimating Indian Slough flow.

Although the refined Indian Slough relationship provided better correspondence with DSM2 data, it was not incorporated into the final model discussed in Section 6. The better fit with DSM2 data did not translate into a better fit with observed data, probably due to difficulties in estimating net channel depletions in Indian Slough and Rock Slough. Therefore, it was determined that the additional model complexity was not warranted.

San Joaquin River Flow Downstream of HOR

Figure 5-2 shows a linear relationship between daily averaged San Joaquin River flow downstream of HOR and daily averaged San Joaquin River flow at Vernalis as provided by DSM2. As shown in the figure, the relationship is strongly influenced by operation of the HORB. When the HORB is not installed, San Joaquin River flows downstream of HOR increase as Vernalis flows increase. When the HORB is installed in the fall (partial) and spring (full), less water is diverted into Old River and San Joaquin River flows downstream of HOR increase at a faster rate as Vernalis flows increase. The actual flow split is dictated by culvert and weir operation and installed barrier height; these factors vary between fall and spring and also vary from year to year.

Focusing on lower-flow periods when the HORB is not installed, Figure 5-3 shows that installation of the Grant Line Canal barrier influences the flow split at HOR. Installation of the Grant Line Canal barrier results in a larger fraction of Vernalis flow remaining in the San Joaquin River downstream of the HOR by increasing water levels in the south Delta. Limited data suggests that the influence on HOR flow split is due solely to Grant Line Canal barrier installation rather than concurrent installation of all agricultural barriers. This conclusion is based on 95 data points simulated during the following periods: Jul 11-Oct 2, 1996, Nov 8-14, 2005, and Nov 17-20, 2006. During these periods, the Grant Line Canal barrier is installed alone or with one additional agricultural barrier. The flow split during these periods is consistent with periods when all agricultural barriers are installed.

The HOR flow split is also influenced by south Delta diversions when the HORB and Grant Line Canal barriers are not installed. South Delta diversions result in a smaller fraction of Vernalis flow remaining in the San Joaquin River downstream of the HOR by decreasing water levels in the south Delta. Figure 5-4 compares the flow split at low and high south Delta diversions. The figure shows that, as Vernalis flows increase, the influence of south Delta diversions on the HOR flow split diminishes.

An overflow weir is installed on Paradise Cut at the junction with the San Joaquin River. When Vernalis flows exceed 16,000 cfs, some flow is diverted into the south Delta at Paradise Cut before reaching the HOR (Hildebrand, A. 2007). The relationship between daily averaged Paradise Cut flow and daily averaged Vernalis flow, as provided by DSM2, is shown in Figure 5-5. Therefore, at higher Vernalis flows, a smaller fraction of Vernalis flow moves downstream of the HOR. The figure shows a change in slope when Vernalis and Paradise Cut flows exceed 28,000 cfs and 7,000 cfs, respectively.

The relationship between daily averaged San Joaquin River flow downstream of HOR and daily averaged San Joaquin River flow at Vernalis shows more data scatter at low Vernalis flows. Incorporating San Joaquin River net channel depletions between Vernalis and HOR did not reduce the observed scatter. By using daily averaged data, the proposed relationships assume tidal influence is negligible. As Vernalis flows decrease, this assumption becomes less valid. Under these conditions, downstream flows sometimes reverse and are dominated by tidal conditions. Regression analysis results are summarized in Table 5-2. Residuals analysis confirms that the flow split is influenced by tidal conditions when Vernalis flows are low to modest.

The regression analysis implies that the HOR flow split, defined as the ratio of Old River flow to Vernalis flow, decreases as Vernalis flows increase and approaches 0.5 at high Vernalis flows. The implied ratio is approximately 0.6-0.8 at moderate flow levels, depending on south Delta diversions. And as discussed above, under low flow conditions, tidal conditions can cause San Joaquin River flows downstream of HOR to reverse and result in all flow moving through Old River.

DWR has recently collected flow data on the San Joaquin River downstream of HOR at Lathrop (Mayr, S. 2007). Figure 5-6 compares these 24-hour daily averaged flow measurements for the period October 19, 2005 through September 30, 2006 with (1) estimates produced by the statistical relationship and (2) USGS flow measurements at Stockton (Smith, P. 2007b). All three data sets are generally consistent with two notable exceptions:

- The statistical relationship underestimates the peak flow of 14,000 to 15,000 cfs observed at Lathrop and Stockton in mid-April 2006.
- The observed data at Lathrop deviates from statistical estimates and Stockton measurements in late April and May 2006.

References

Hildebrand, A. (2007). Personal communication, September 18.

Mayr, S. (2007). Personal communication, October 15.

Smith, P. (2007b). Personal communication, November 9.

Table 5-1
Regression Analysis Results:
Statistical Models of Indian Slough Flow at Old River
$$Q_{\text{Indian Slough}} \text{ (cfs)} = A * Q_{\text{OMR}} \text{ (cfs)} + B * Q_{\text{Local Diversions}} \text{ (cfs)} + C$$

Model	N	A	B	C	R2	SEE (cfs)
Preferred	6194	-0.0638	0	-72	0.952	71
Alternate	6193	-0.0669	-0.679	-36	0.990	33

N= number of observations; R2=coefficient of determination; SEE=standard error of estimate

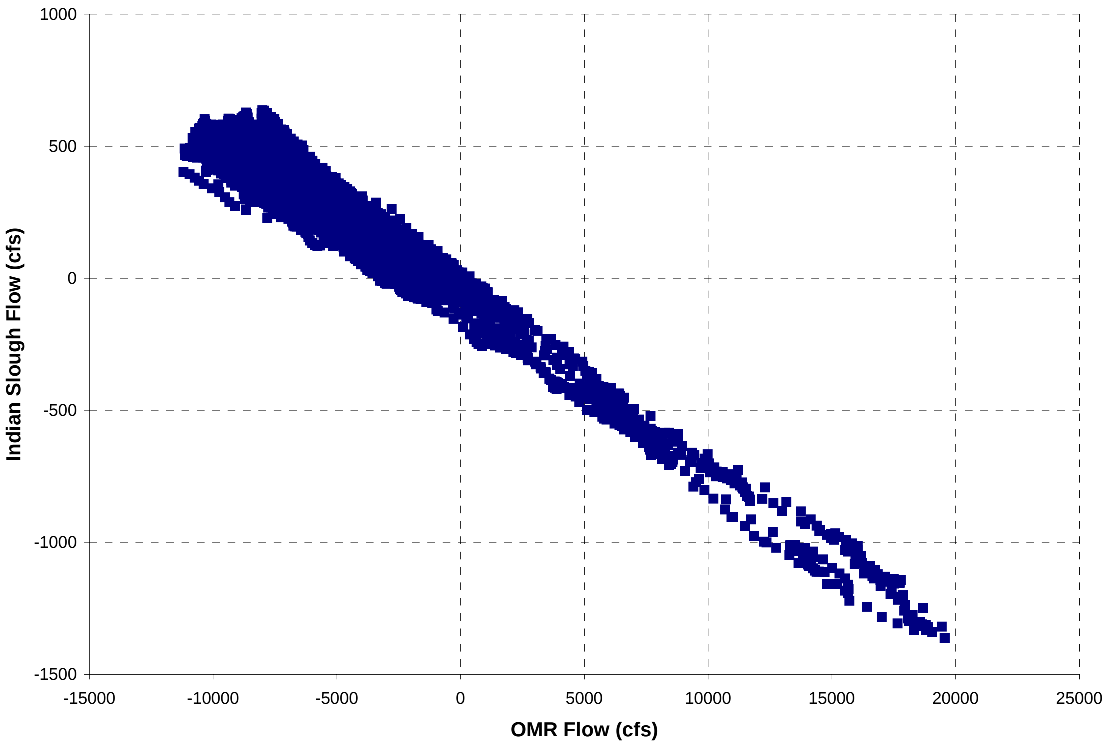
Table 5-2
Regression Analysis Results:
Statistical Model of San Joaquin River Flow Downstream of Head of Old River

$$Q_{\text{SJR d/s HOR}} \text{ (cfs)} = A * Q_{\text{Vernalis}} \text{ (cfs)} + B * Q_{\text{South Delta Diversions}} \text{ (cfs)} + C$$

HORB	GLC Barrier	Vernalis (cfs)	N	A	B	C	R2	SEE (cfs)	Comments
Out	Out	< 16,000	7167	0.499	-0.0312	-161	0.996	112	
Out	Out	16000-28000	622	0.276	0	3128	0.991	84	Weir allows flow in Paradise Cut
Out	Out	> 28000	214	0.327	0	1677	0.983	180	Weir allows flow in Paradise Cut, but at a lower rate
Out	In	All	2055	0.554	-0.0168	-45	0.918	127	
In (Spring)	Out/In	All	586	0.916	0	-146	0.978	219	
In (Fall)	Out/In	All	1251	0.747	-0.0109	-24	0.961	109	

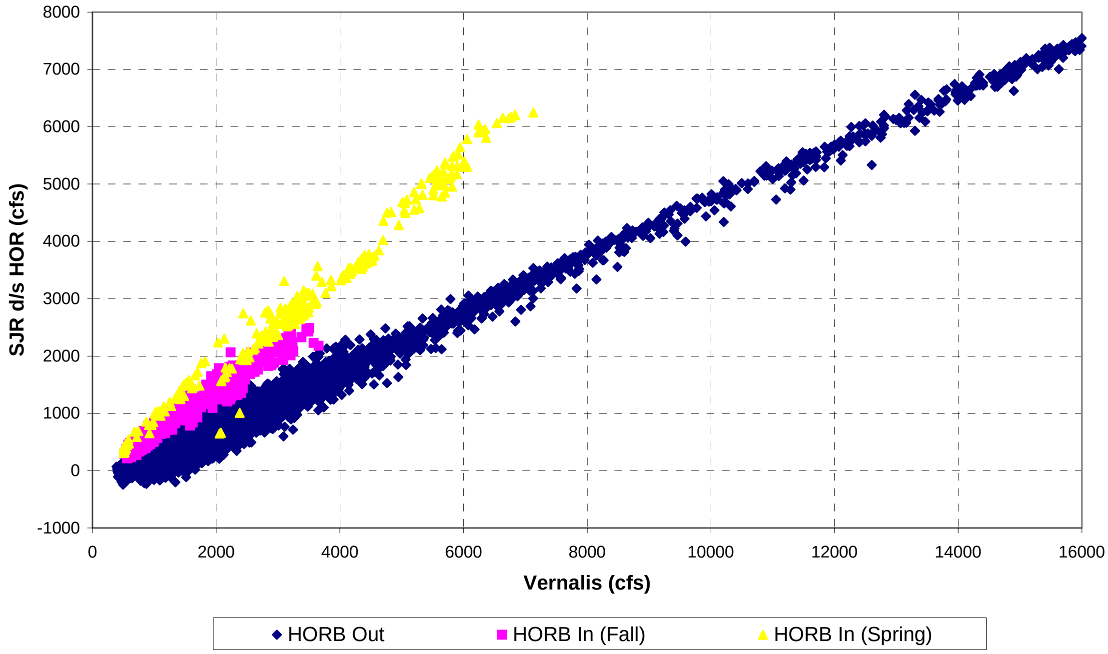
N= number of observations; R2=coefficient of determination; SEE=standard error of estimate

Figure 5-1
Flow Relationship Between Indian Slough @ Old River and OMR
14-Day Averaged DSM2 Data 1990-2006



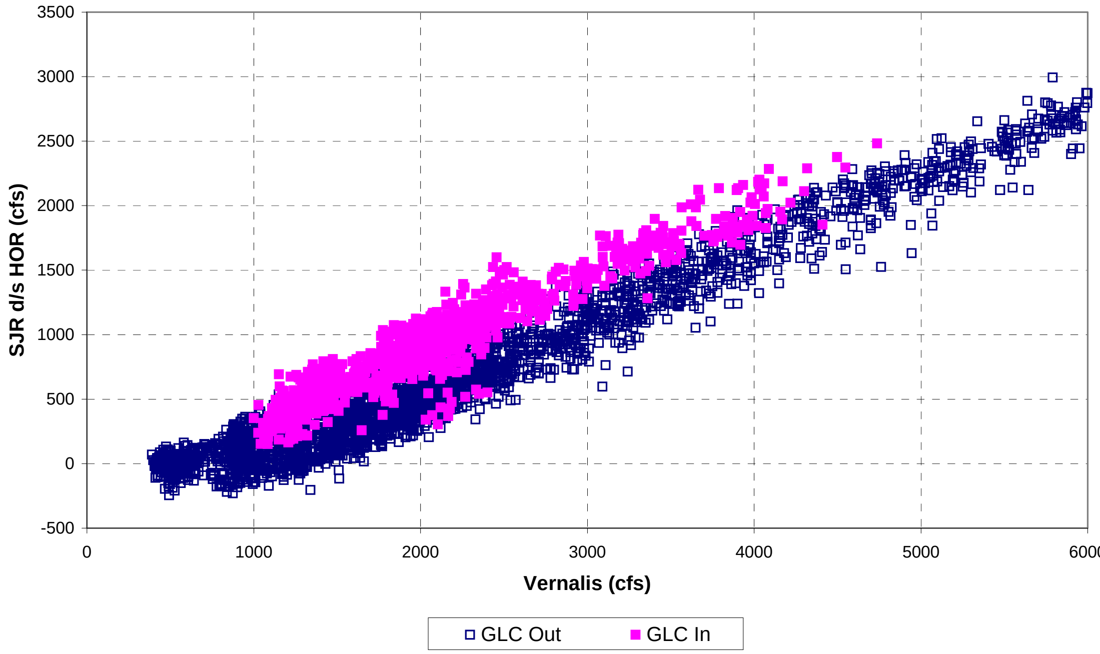
The above figure shows an inverse linear relationship between 14-day averaged Indian Slough flow and 14-day averaged OMR flow, where positive flow is defined as flowing upstream (east) into Old River. Thus, as OMR flows increase, Indian Slough flows decrease (or move downstream in a westerly direction away from Old River). A practical implication of this relationship is that, under low flow conditions, south Delta water diversions have less than a 1-to-1 effect on Old and Middle River reverse flows.

Figure 5-2
Flow Relationship Between San Joaquin River d/s HOR & Vernalis
Influence of HORB
Daily Average DSM2 Data 1990-2006



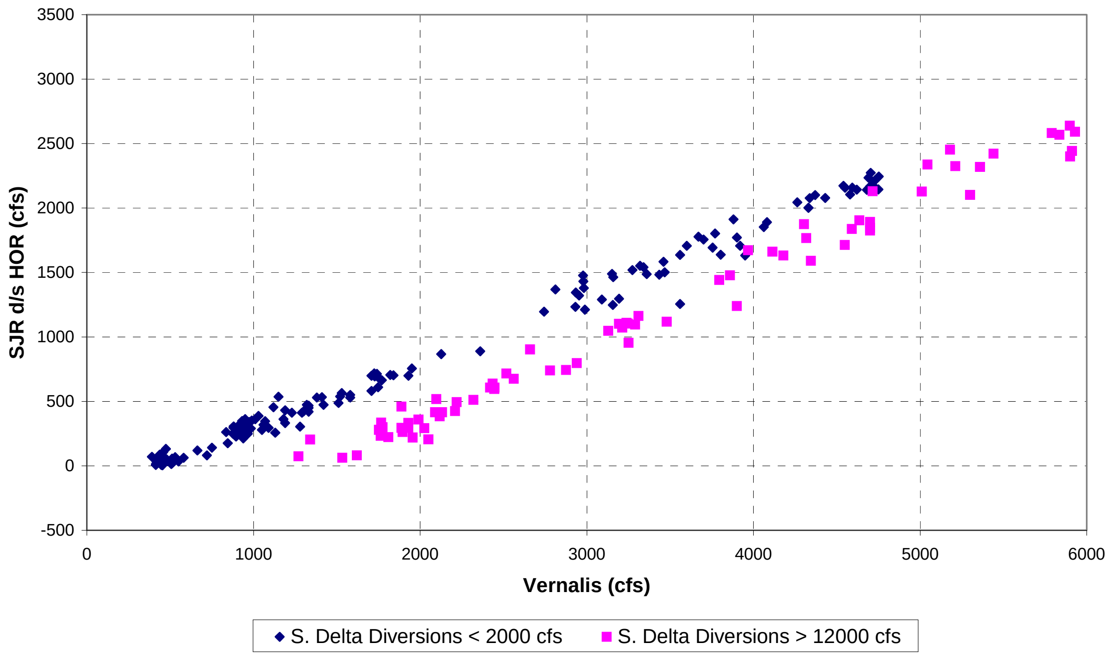
The above figure shows a linear relationship between daily averaged San Joaquin River flow downstream of HOR and daily averaged San Joaquin River flow at Vernalis. The relationship is strongly influenced by operation of the HORB. When the HORB is installed in the fall (partial) and spring (full), less water is diverted into Old River and San Joaquin River flows downstream of HOR increase at a faster rate as Vernalis flows increase.

Figure 5-3
Flow Relationship Between San Joaquin River d/s HOR & Vernalis
Influence of Grant Line Canal Barrier
Daily Average DSM2 Data 1990-2006 (HORB Out)



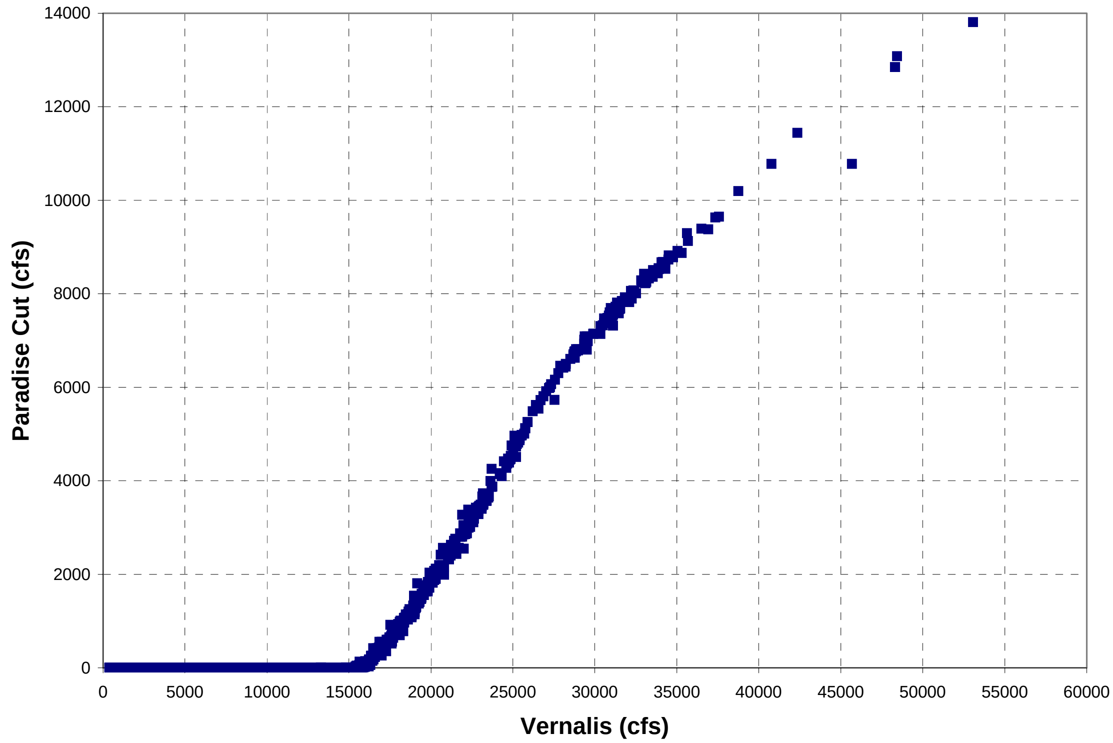
Installation of the Grant Line Canal barrier results in a larger fraction of Vernalis flow moving in the San Joaquin River downstream of the HOR by increasing water levels in the south Delta.

Figure 5-4
Flow Relationship Between San Joaquin River d/s HOR & Vernalis
Influence of South Delta Diversions
Daily Average DSM2 Data 1990-2006 (HORB & GLC Barriers Out)



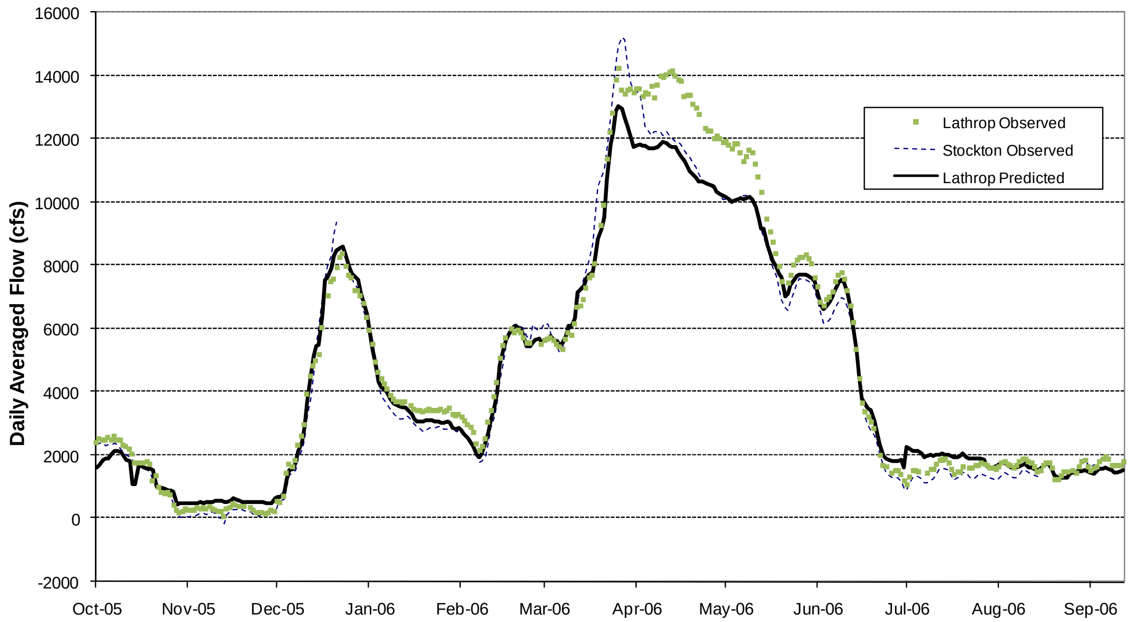
The HOR flow split is influenced by south Delta diversions when the HORB and Grant Line Canal barriers are not installed. South Delta diversions result in a smaller fraction of Vernalis flow remaining in the San Joaquin River downstream of the HOR by decreasing water levels in the south Delta. The figure shows that, as Vernalis flows increase, the influence of south Delta diversions on the HOR flow split diminishes.

Figure 5-5
Flow Relationship Between San Joaquin River at Paradise Cut & Vernalis
Daily Average DSM2 Data 1990-2006



An overflow weir is installed on Paradise Cut at the junction with the San Joaquin River. When Vernalis flows exceed 16,000 cfs, some flow is diverted into the south Delta at Paradise Cut before reaching the HOR. Thus, at higher Vernalis flows, a smaller fraction of Vernalis flow moves downstream of the HOR. The figure shows a change in slope when Vernalis and Paradise Cut flows exceed 28,000 cfs and 7,000 cfs, respectively.

Figure 5-6
Comparison of Predicted & Observed San Joaquin River Flow Downstream of HOR
October 19, 2005 – September 30, 2006



DWR has recently collected flow data on the San Joaquin River downstream of HOR at Lathrop (Mayr, S. 2007). These flow data are generally consistent with predictions from the statistical relationship and are generally consistent with USGS measurements at Stockton (Smith, P. 2007b). However, the observed data at Lathrop deviates from predicted values and Stockton measurements in late April and May 2006.

Section 6
Results

Predictive equations for OMR flow were developed by incorporating the statistical relationships for Indian Slough at Old River and San Joaquin River downstream of HOR (developed in Section 5) into the south Delta water balance presented in Section 4. The resulting MWD model is a function of Vernalis flow, south Delta diversions, and south Delta barrier operations. South Delta diversions are the sum of Clifton Court Forebay diversions, Jones Pumping Plant diversions, CCWD diversions at Old River, and south Delta net channel depletions. Model constants are provided in Table 6-1.

Comparison with DSM2 Data

Figure 6-1 compares 14-day averaged OMR flows as generated by DSM2 and the MWD model for the 1990-2006 period. The MWD model estimates are within ± 150 cfs of the DSM2 OMR estimates more than 75% of the time and are within ± 350 cfs 98% of the time.

Comparison with Observed Data

Daily averaged OMR flows predicted by the MWD model are compared with daily averaged observed data in Figure 6-2. Differences with observed data are within ± 600 cfs about 60% of the time. Differences are greater than ± 1400 cfs about 5% of the time. Similar to the DSM2 model, the MWD model shows a modest bias to underestimate OMR flow. Time series comparisons of predicted and observed 14-day averaged OMR flow are shown in Appendix 6A.

Model Uncertainty

Model uncertainty was evaluated by computing safety factors or “buffers” needed to avoid exceeding an OMR flow objective with 95% confidence. A buffer of 300 cfs indicates that, for a flow objective of -5000 cfs, operations decisions would be based on meeting a more stringent flow of -4700 cfs. Larger buffers result in higher water costs. The following forecast applications were evaluated:

- 3-day forecast of 14-day averaged OMR flows
- 5-day forecast of 14-day averaged OMR flows
- 3-day forecast of 7-day averaged OMR flows
- 5-day forecast of 7-day averaged OMR flows

Buffers required for the months of December through June are summarized in Table 6-2. Probability exceedence curves associated with 14-day and 7-day averages are presented in Appendix 6B. The exceedence curves may be used to select buffers with confidence levels other than 95%.

A 3-day forecast of 14-day averaged OMR flows takes advantage of 11 observed values; a 5-day forecast of 14-day averaged OMR flows takes advantage of only 6 observed values. Similarly, a 3-day forecast of 7-day averaged OMR flows takes advantage of 4 observed values; a 5-day forecast of 7-day averaged OMR flows takes advantage of 7 observed values. The buffer values and exceedence curves associated with the "MWD Equation" assume no knowledge of antecedent conditions.

The table and exceedence curves show that longer flow averaging periods can be forecasted with greater certainty, and therefore can rely on smaller buffers (and lower water costs) to meet OMR flow objectives. Buffers required to meet 7-day averaged flow objectives are approximately twice as large as buffers required to meet 14-day averaged flow objectives.

The table and exceedence curves also show that 3-day forecasts can be estimated with greater certainty than 5-day forecasts, and therefore can rely on smaller buffers. Buffers required for a 5-day forecast are approximately 50% greater than those required for a 3-day forecast. When no knowledge of antecedent conditions are available for a forecast (e.g. a 7-day averaged OMR flow forecasted beyond 7 days), required buffers are approximately twice as large as those required for a 3-day forecast.

Buffer size does not vary greatly between months, although April and May tend to be somewhat higher. Because the buffers were developed from measured data, the April and May buffers represent data that measures the influence of HORB operations. It is anticipated that the MWD model will provide more accurate OMR flow estimates for conditions when the HORB is not installed; therefore, buffer requirements for April and May could be more consistent with other months.

Tables 6-3 and 6-4 compare planning-level estimates of water costs associated with 300 cfs and 600 cfs operations buffers. These estimates are useful for comparison only, as the assumed OMR objectives only roughly approximate the recent court ruling. The 300 cfs buffer is representative of a 3-day forecast of 14-day averaged OMR flows; the 600 cfs buffer is representative of a 3-day forecast of 7-day averaged OMR flows.

The annual costs of a 300 cfs buffer range from 90-150 TAF for a -750 cfs OMR objective and from 20-70 TAF for a -5000 cfs OMR objective, depending on water year type. The annual costs of a 600 cfs buffer range from 190-230 TAF for a -750 cfs OMR objective and from 50-140 TAF for a -5000 cfs OMR objective.

Table 6-1
MWD OMR Flow Model Coefficients

$$Q_{OMR}\text{ (cfs)} = A * Q_{Vernalis} + B * Q_{South\ Delta\ Diversions} + C$$

Where: $Q_{South\ Delta\ Diversions} = Q_{CCF} + Q_{Jones} + Q_{CCWD} + Q_{South\ Delta\ NCD}$

HORB	GLC Barrier	Vernalis (cfs)	A	B	C
Out	Out	< 16,000	0.471	-0.911	83
Out	Out	16,000-28,000	0.681	-0.940	-3008
Out	Out	> 28,000	0.633	-0.940	-1644
Out	In	All	0.419	-0.924	-26
In (Spring)	Out/In	All	0.079	-0.940	69
In (Fall)	Out/In	All	0.238	-0.930	-51

Table 6-2
OMR Flow Buffers with 95% Confidence (cfs)

Month	14-Day Averaged OMR Flow			7-Day Averaged OMR Flow		
	3-Day Forecast	5-Day Forecast	MWD Equation	3-Day Forecast	5-Day Forecast	MWD Equation
Dec	300	450	700	600	850	1000
Jan	250	350	450	500	700	800
Feb	250	350	500	500	700	850
Mar	200	300	300	350	550	600
Apr	300	450	700	600	900	1050
May	300	450	850	600	950	1200
Jun	250	350	700	450	650	850
12 Months	300	400	750	550	850	1000

Notes on USGS Observed Data Used to Develop Buffers:
1) 24-hour averages were computed from raw 15-minute data
2) 24-hour data were filled based on correlations between Old and Middle Rivers
3) The period Jan 1, 1990 thru Sep 30, 2006 was used to develop buffers except as noted below
    3a) Events when OMR flow was > 0 cfs were excluded from buffer calculations
    3b) The period Jun 1, 2004 thru Dec 31, 2004 was excluded from buffer calculations (Jones Tract levee failure)

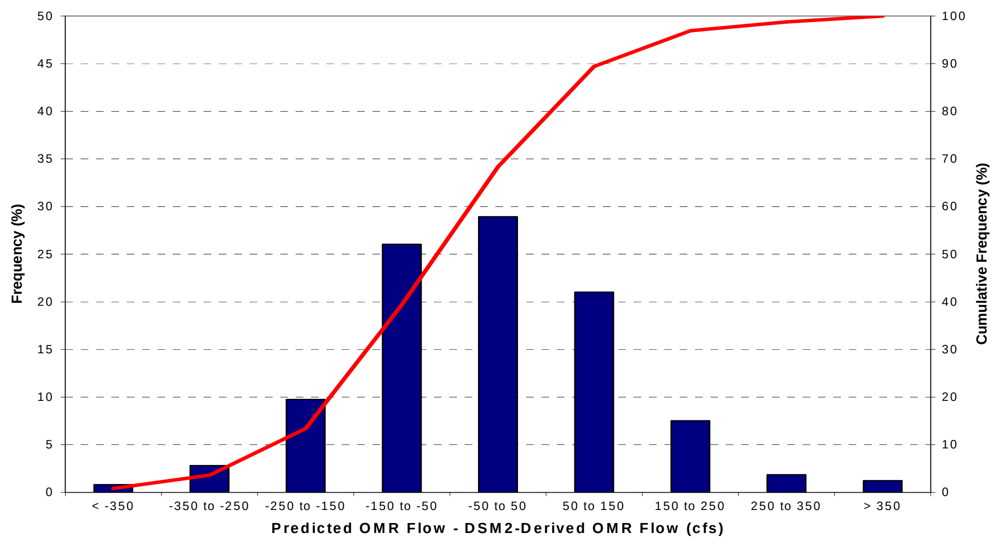
Table 6-3
Export Reductions Required to Meet a 300 cfs OMR Buffer January-June with No South Delta Barrier Operations (TAF per year)

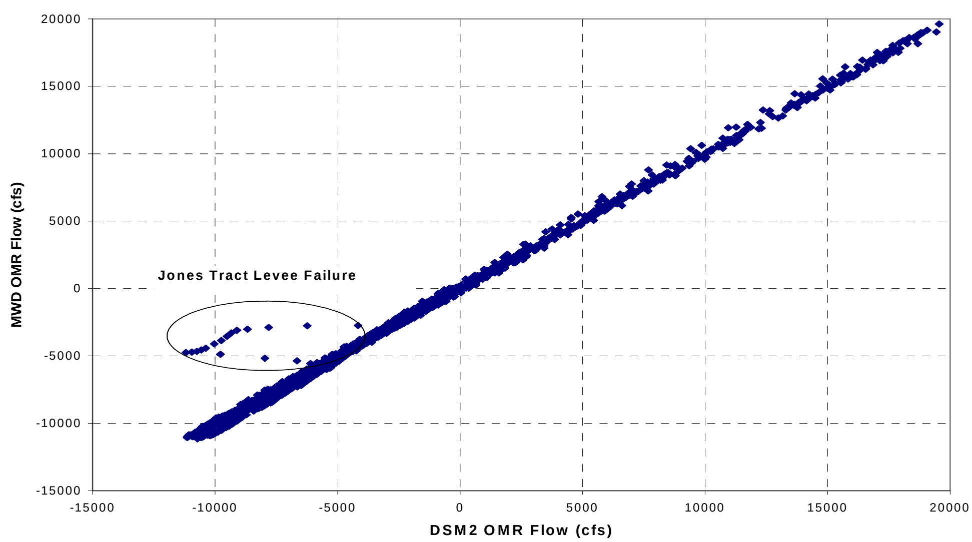
Water Year Type	OMR > -750 cfs			OMR > -5000 cfs		
	Without Buffer	With Buffer	Water Cost	Without Buffer	With Buffer	Water Cost
73-Year Average	1540	1650	110	380	430	50
Wet	1390	1480	90	310	350	40
Above Normal	1800	1920	120	480	540	60
Below Normal	1840	1960	150	480	550	70
Dry	1710	1830	120	450	510	60
Critical	890	990	100	190	210	20

Table 6-4
Export Reductions Required to Meet a 600 cfs OMR Buffer January-June with No South Delta Barrier Operations (TAF per year)

Water Year Type	OMR > -750 cfs			OMR > -5000 cfs		
	Without Buffer	With Buffer	Water Cost	Without Buffer	With Buffer	Water Cost
73-Year Average	1540	1760	220	380	490	110
Wet	1390	1580	190	310	400	90
Above Normal	1800	2030	230	480	610	130
Below Normal	1840	2070	230	480	620	140
Dry	1710	1940	230	450	580	130
Critical	890	1090	200	190	240	50

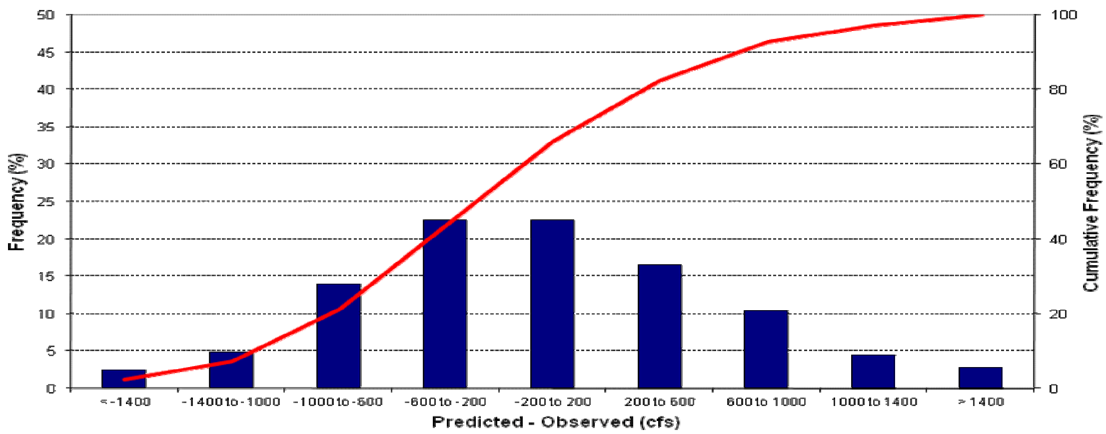
Figure 6-1
Comparison of DSM2 and MWD Model OMR Flow Predictions
14-Day Averaged Flows 1990-2006

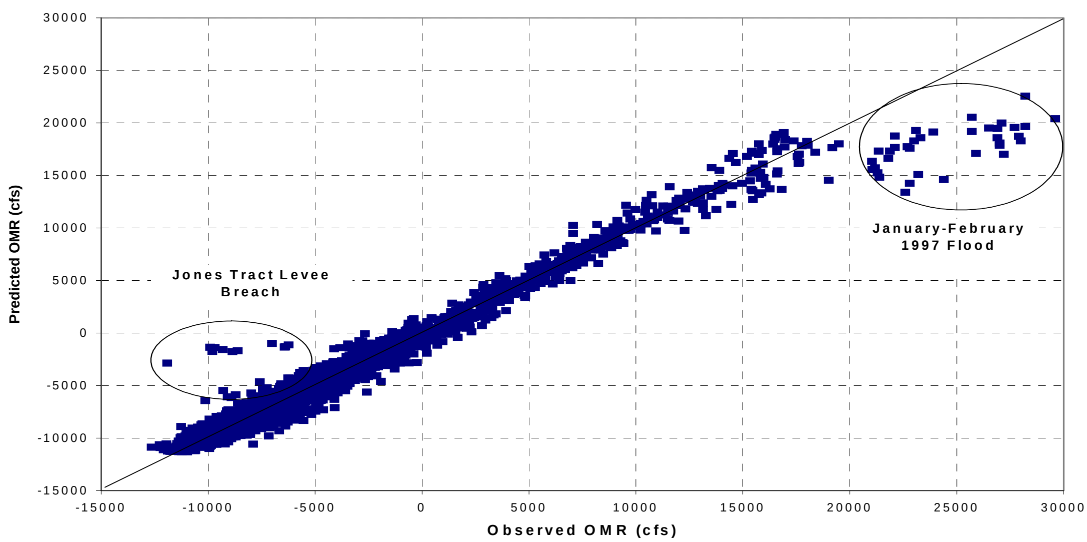




The MWD model closely approximates DSM2-simulated OMR flow on a 14-day average basis. The MWD model estimates are within ± 150 cfs of the DSM2 OMR estimates more than 75% of the time and are within ± 350 cfs 98% of the time. The MWD model does not account for unique hydraulic conditions in the south Delta associated with Jones Tract island flooding and pump-off during and after the levee failure.

Figure 6-2
Comparison of Predicted & Observed OMR Flow: MWD Model
January 1, 1990 – September 30, 2006





Differences with observed data are within ± 600 cfs over 60% of the time. Differences are greater than ± 1400 cfs about 5% of the time. As with the DSM2 model, the MWD model shows a modest bias to underestimate OMR flow. Data corresponding to the 1997 flood (Jan-Feb 1997) and the Jones Tract levee breach (Jun-Dec 2004) were excluded from the evaluation. Vernalis flow data are suspect during early 1997due to flood conditions along the San Joaquin River. Data collected during and after the Jones Tract levee breach were excluded due to the unique hydraulic conditions in the south Delta associated with island flooding and pump-off.

Appendix 6A
MWD Model Time Series Graphs

Figures

Figure 6A-1
Observed & Predicted 14-Day OMR Flow
1990-91

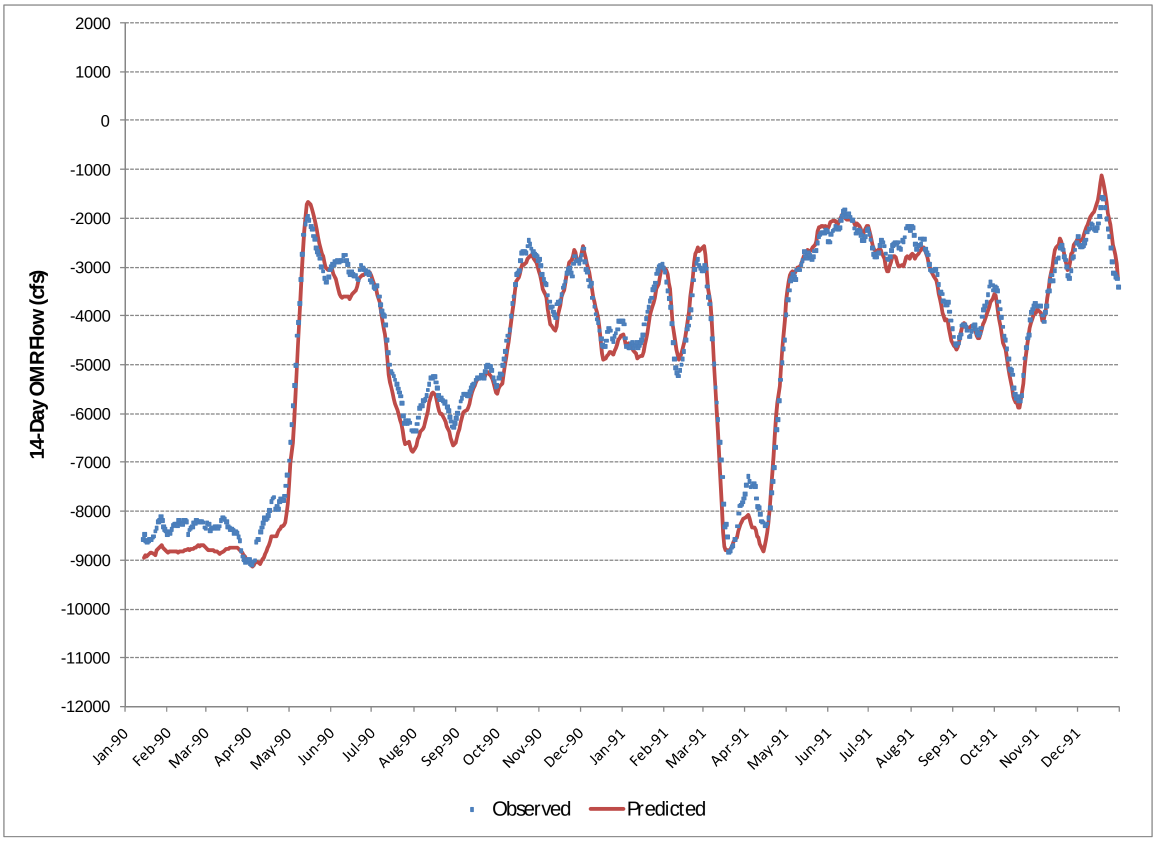


Figure 6A-2
Observed & Predicted 14-Day OMR Flow
1992-93

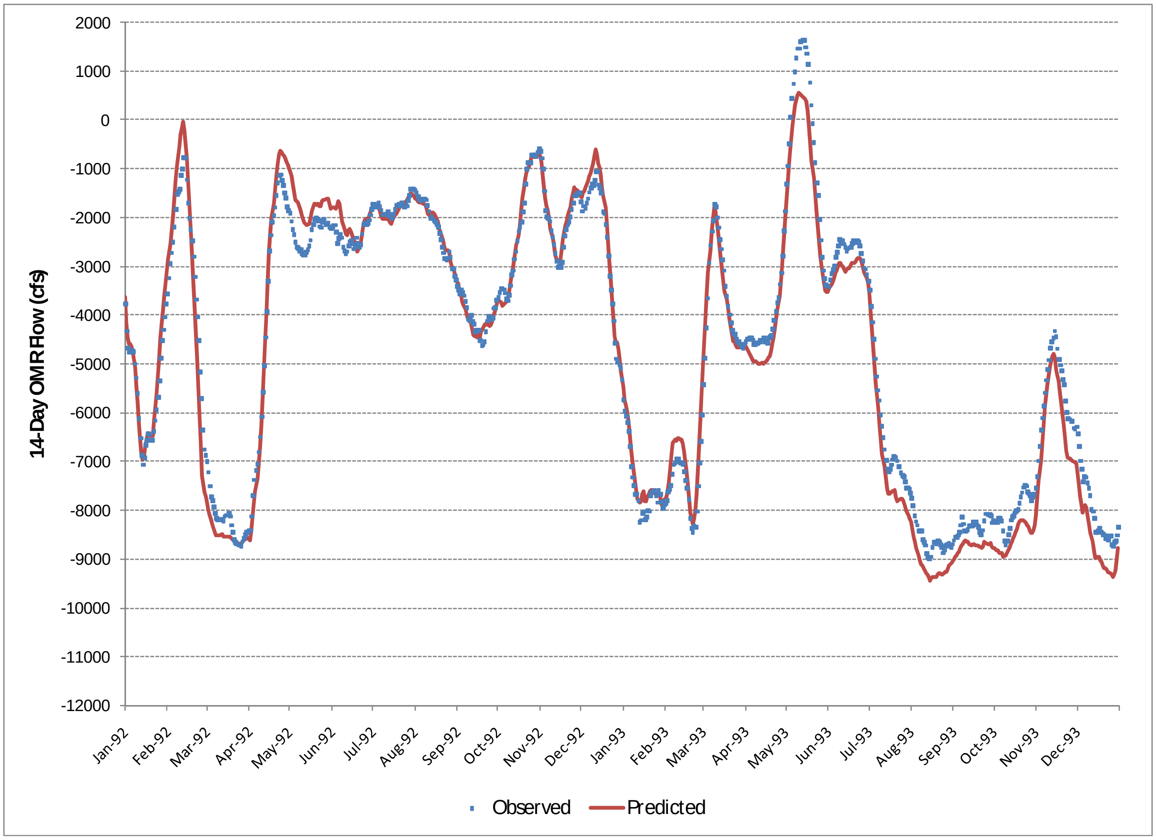


Figure 6A-3
Observed & Predicted 14-Day OMR Flow
1994-95

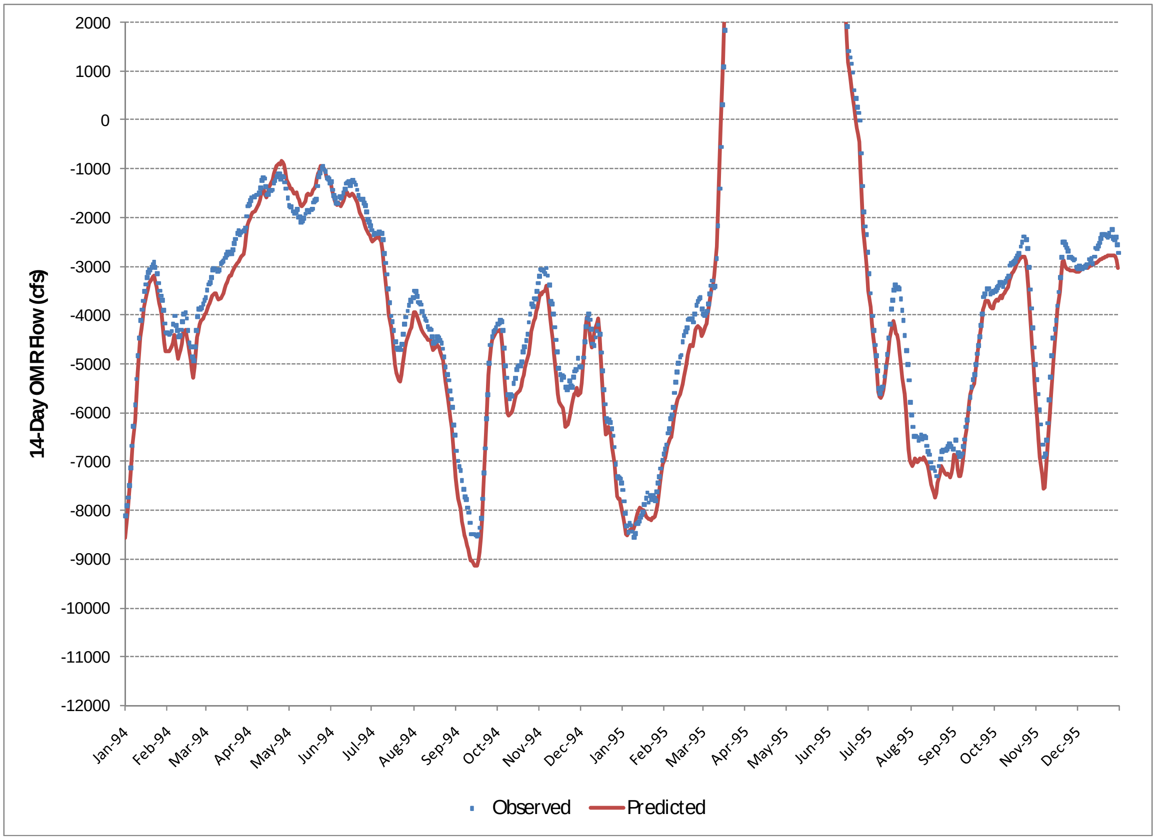


Figure 6A-4
Observed & Predicted 14-Day OMR Flow
1996-97

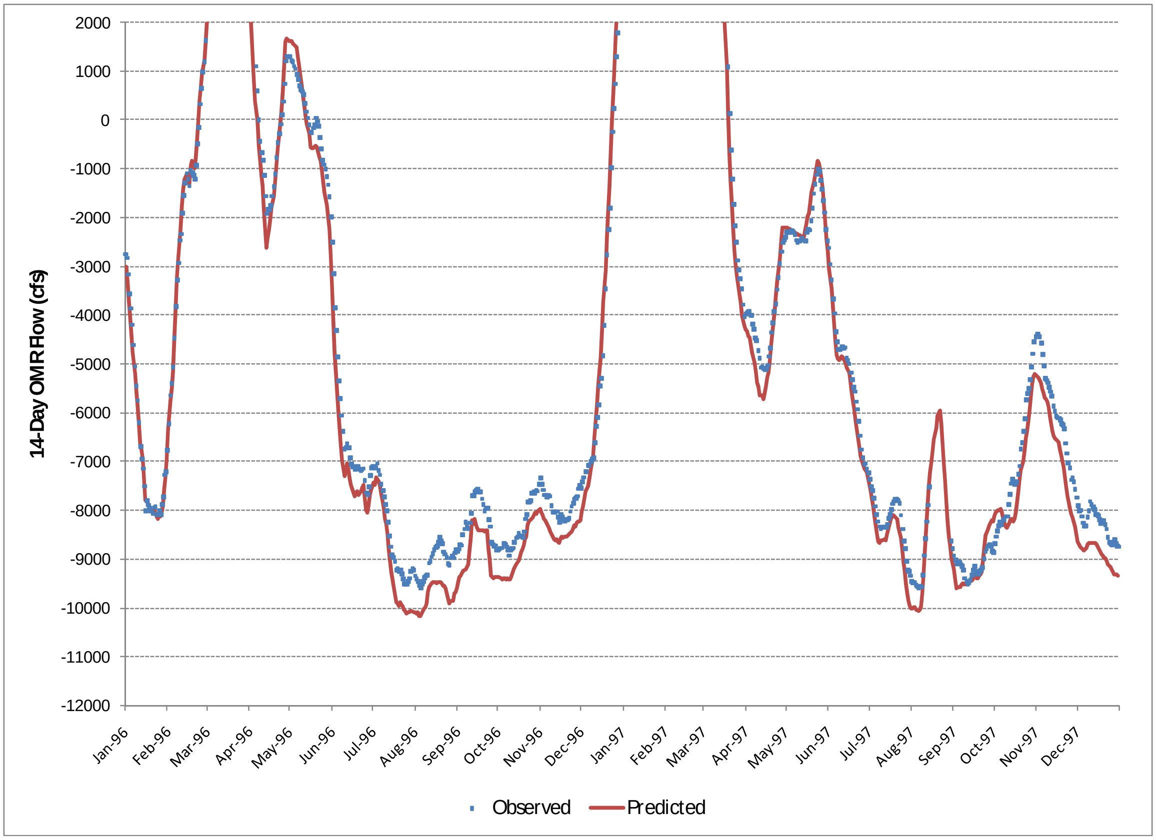


Figure 6A-5
Observed & Predicted 14-Day OMR Flow
1998-99

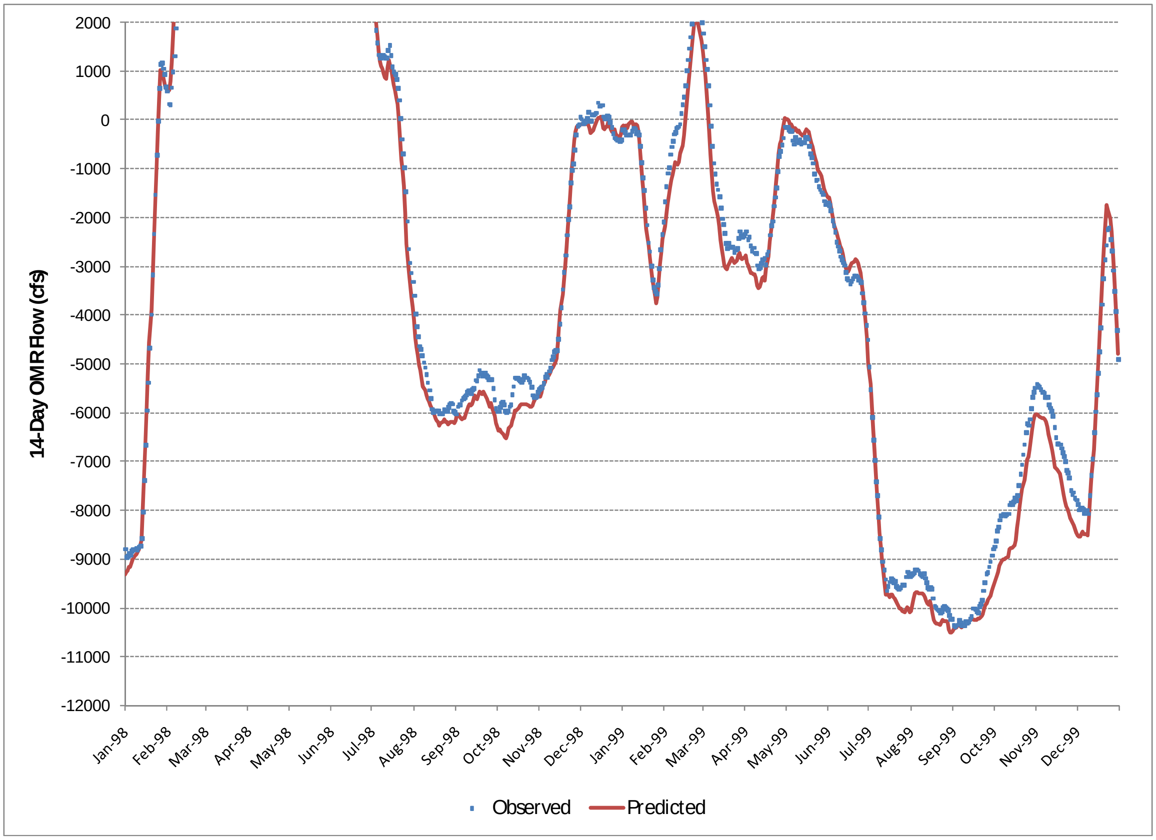


Figure 6A-6
Observed & Predicted 14-Day OMR Flow
2000-01

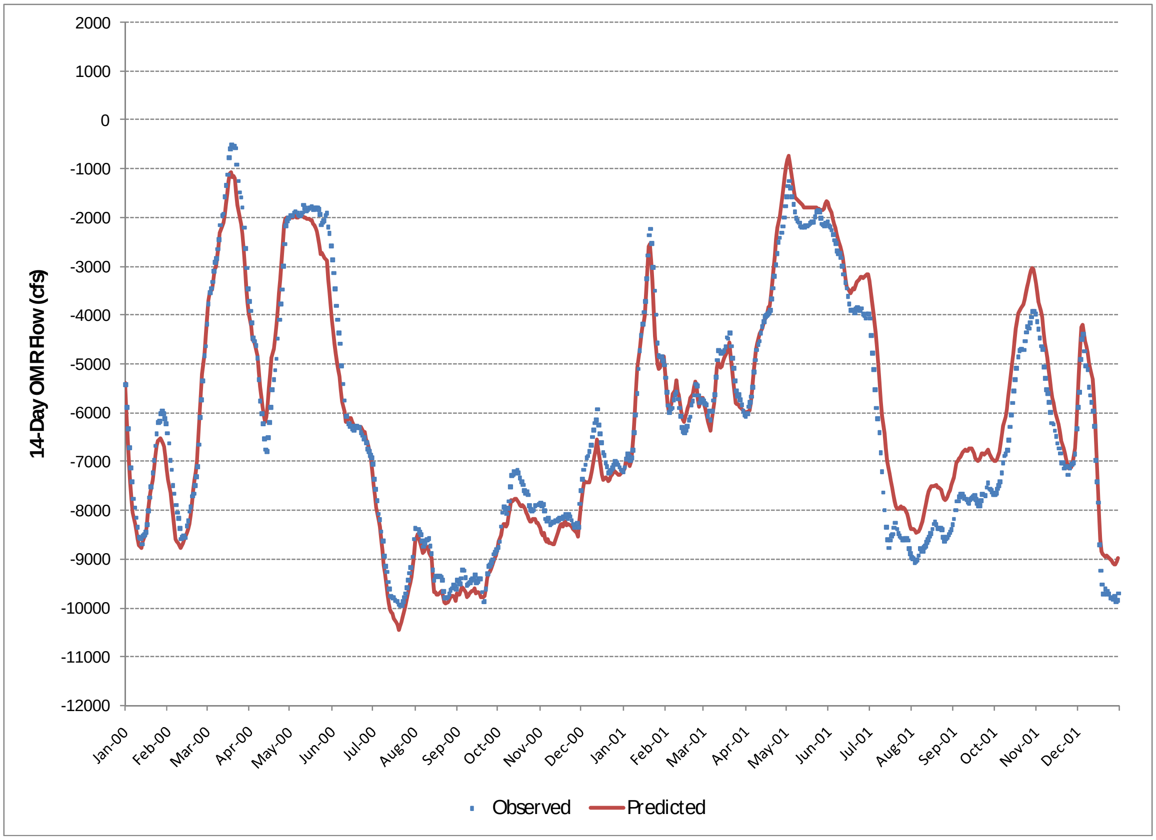


Figure 6A-7
Observed & Predicted 14-Day OMR Flow
2002-03

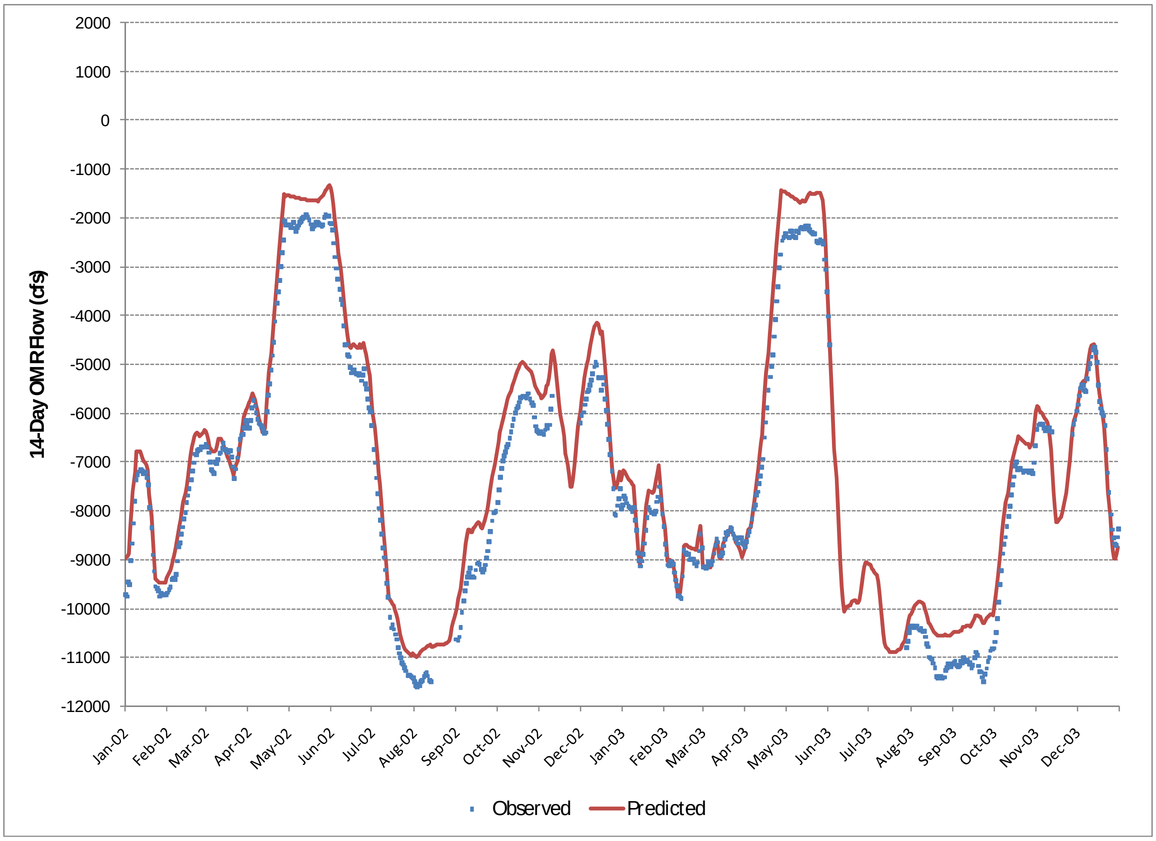
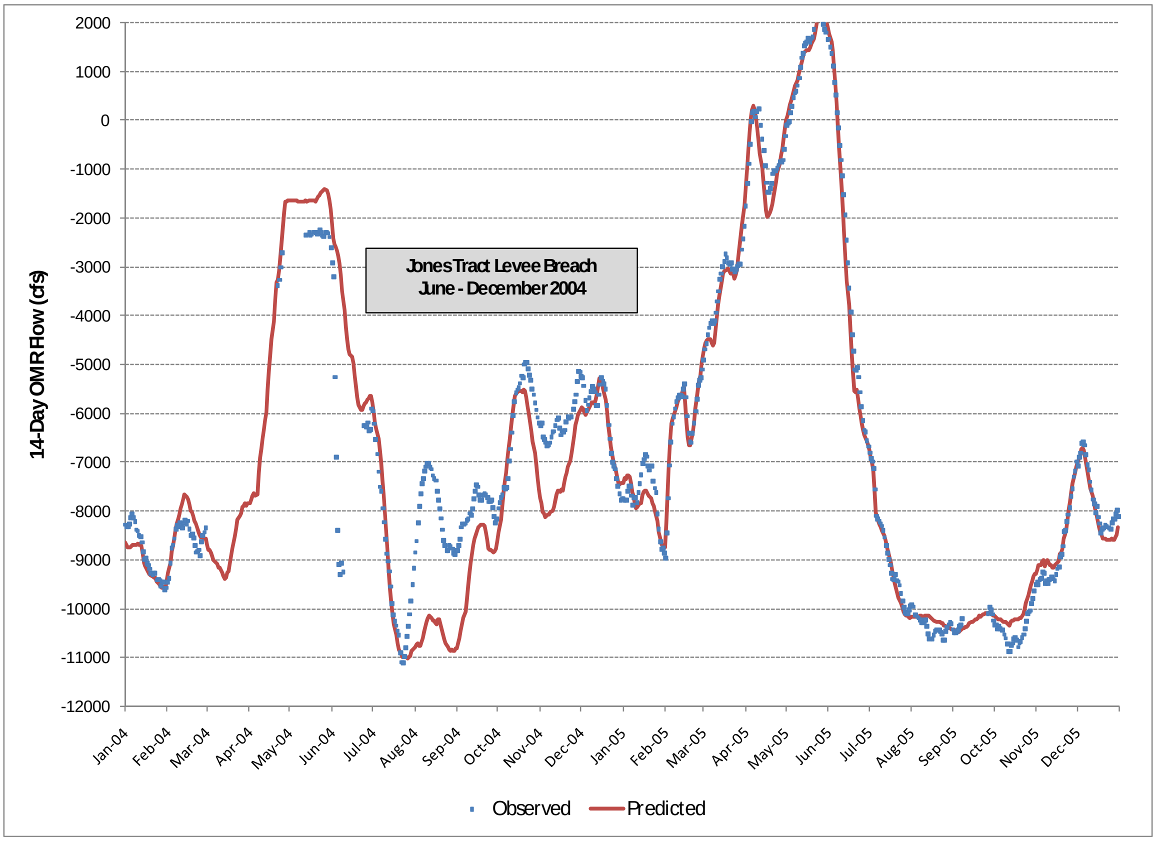


Figure 6A-8
Observed & Predicted 14-Day OMR Flow
2004-05



Appendix 6B
MWD Model Probability Exceedence Graphs

Figures

Figure 6B-1
14-Day OMR Flow
Forecast Model Performance
December

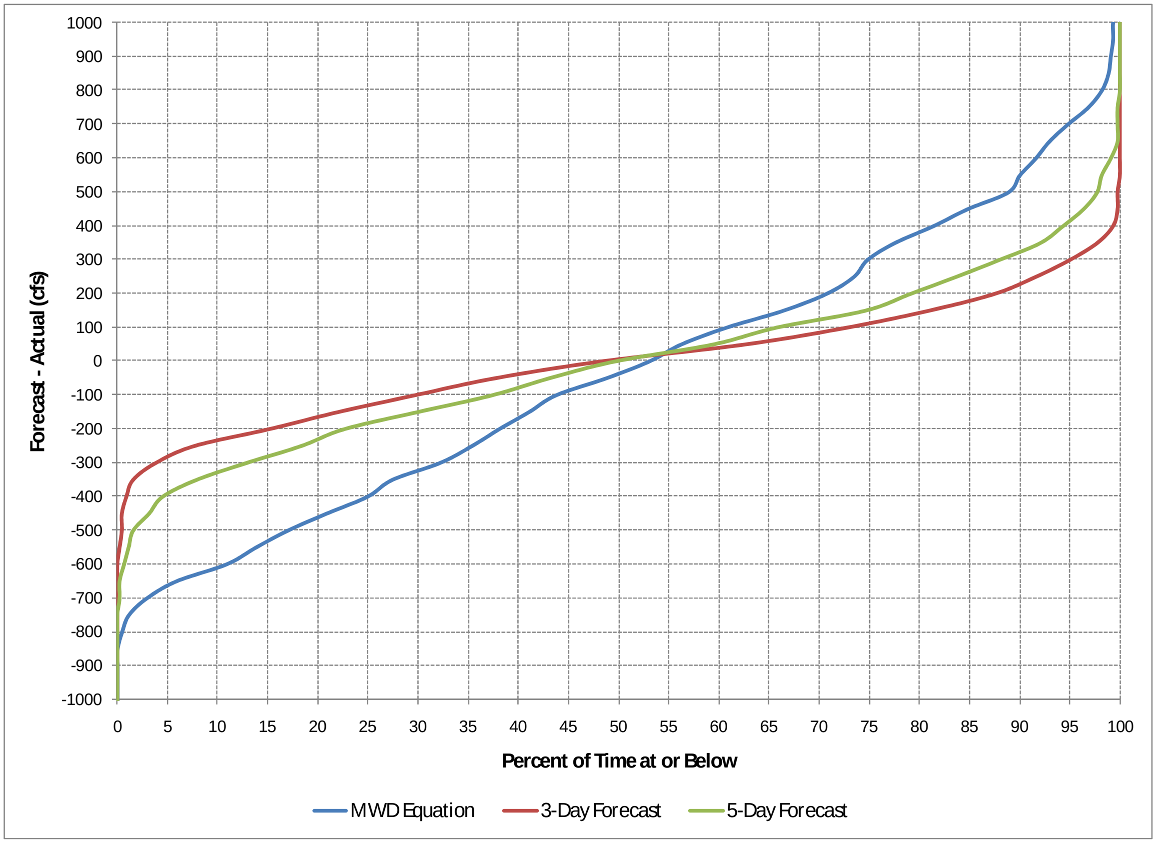


Figure 6B-2
14-Day OMR Flow
Forecast Model Performance
January

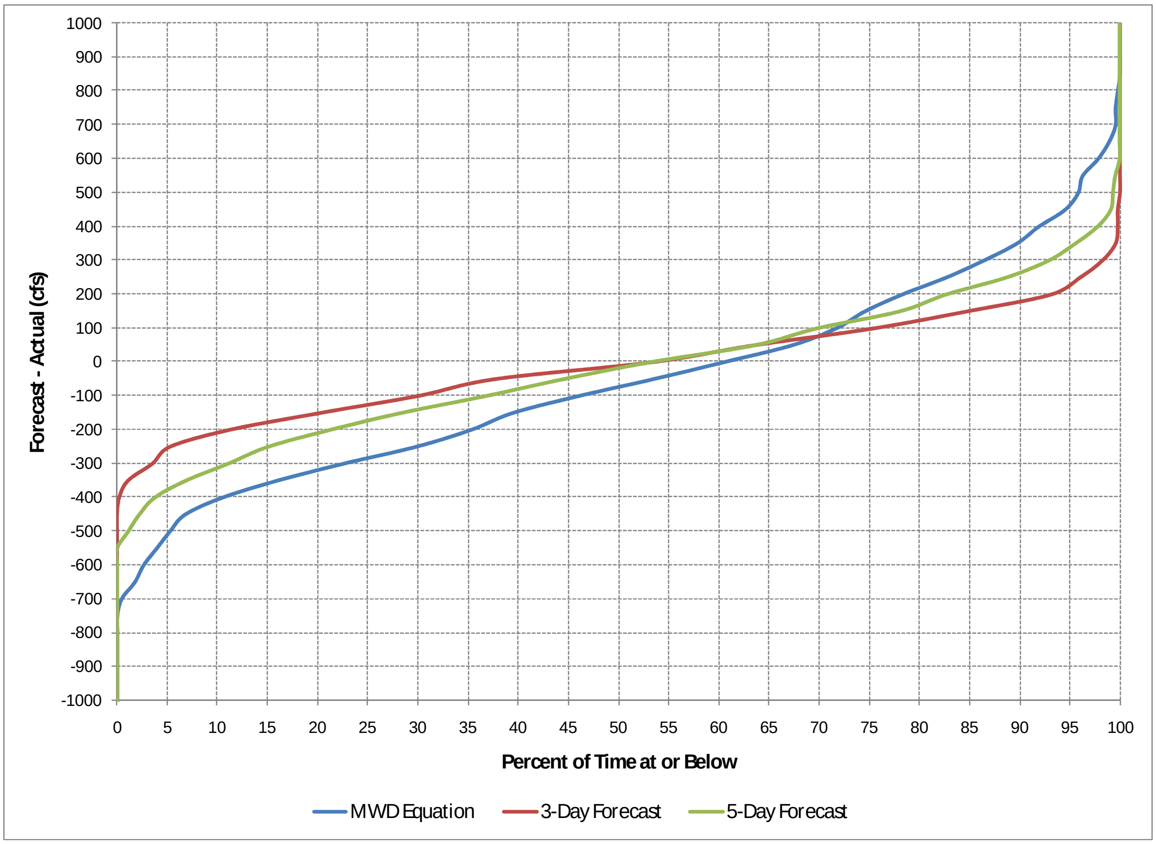


Figure 6B-3
14-Day OMR Flow
Forecast Model Performance
February

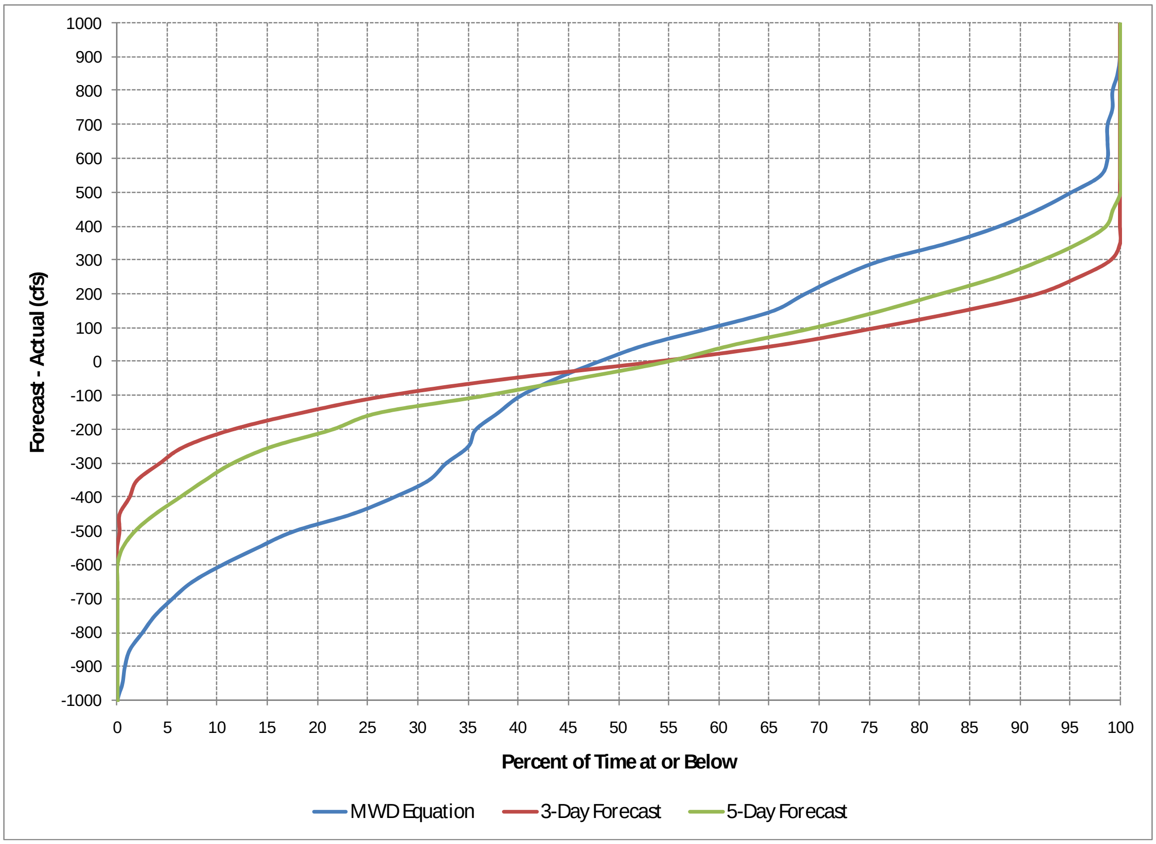


Figure 6B-4
14-Day OMR Flow
Forecast Model Performance
March

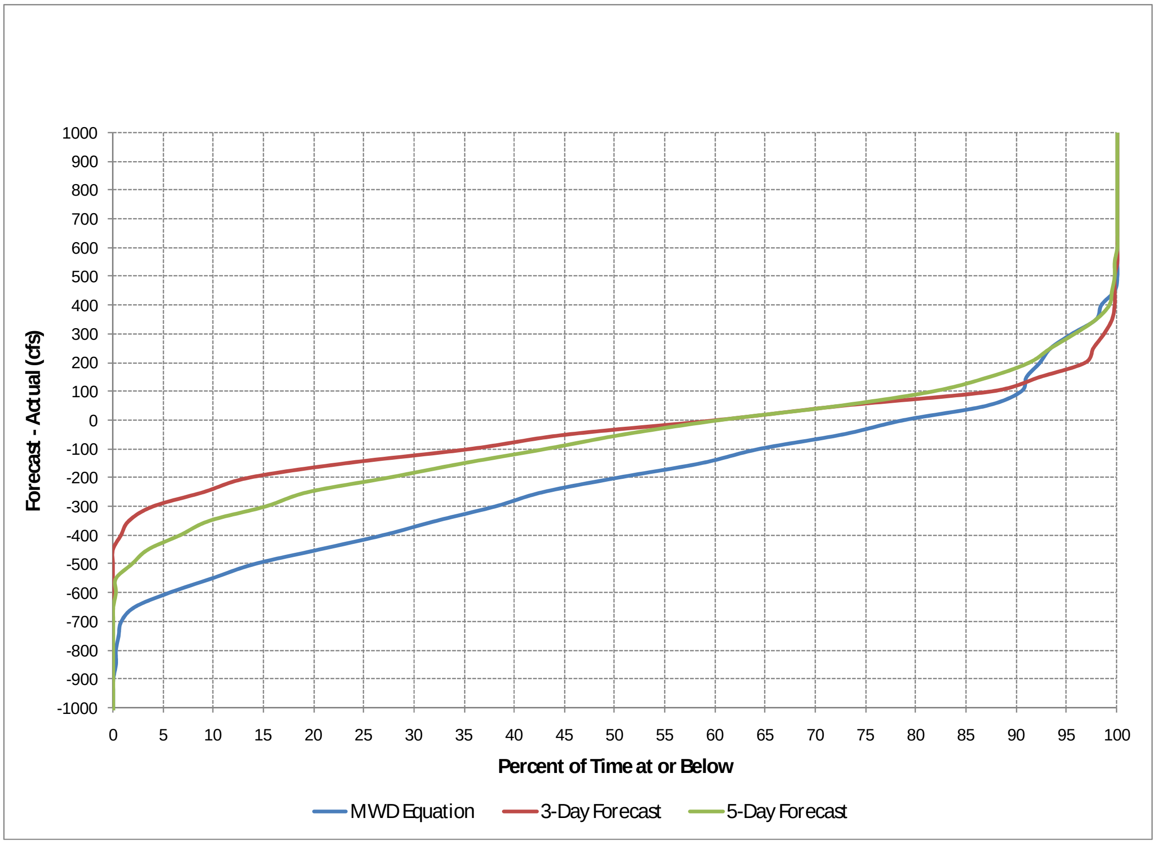


Figure 6B-5
14-Day OMR Flow
Forecast Model Performance
April

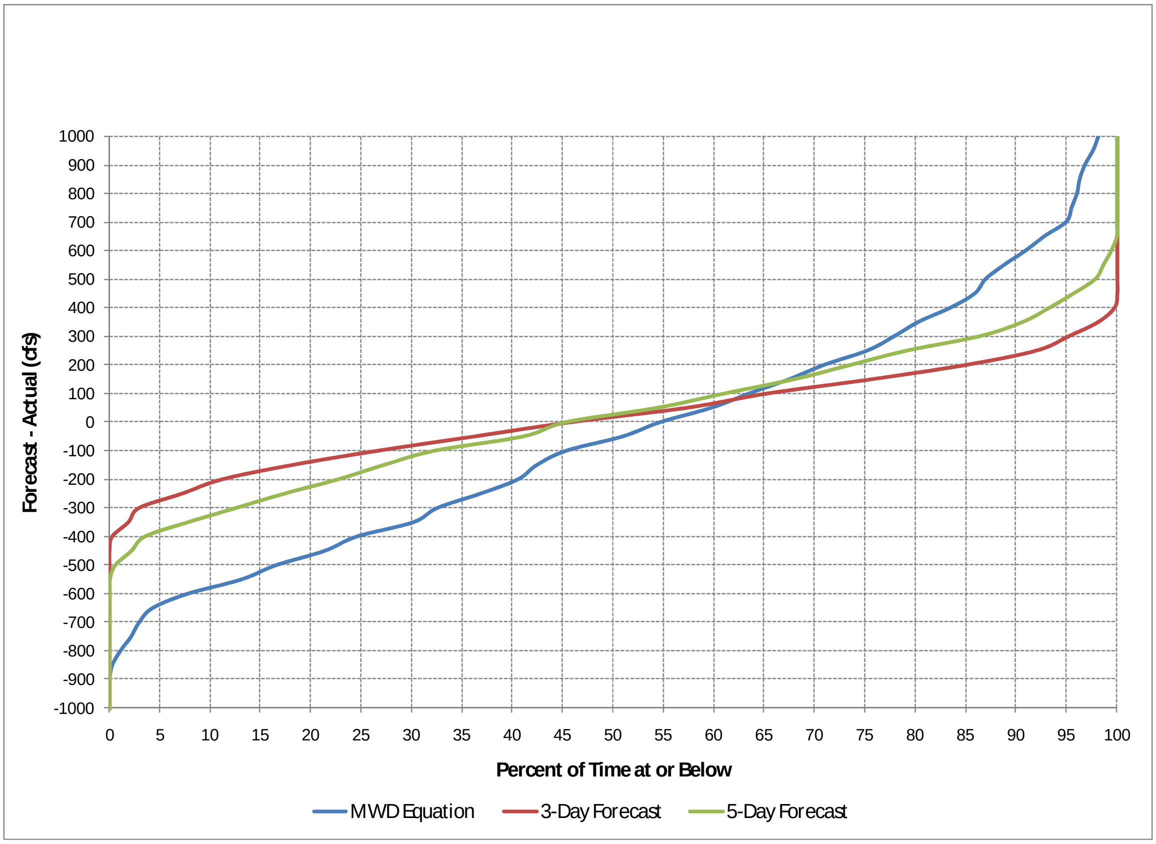


Figure 6B-6
14-Day OMR Flow
Forecast Model Performance
May

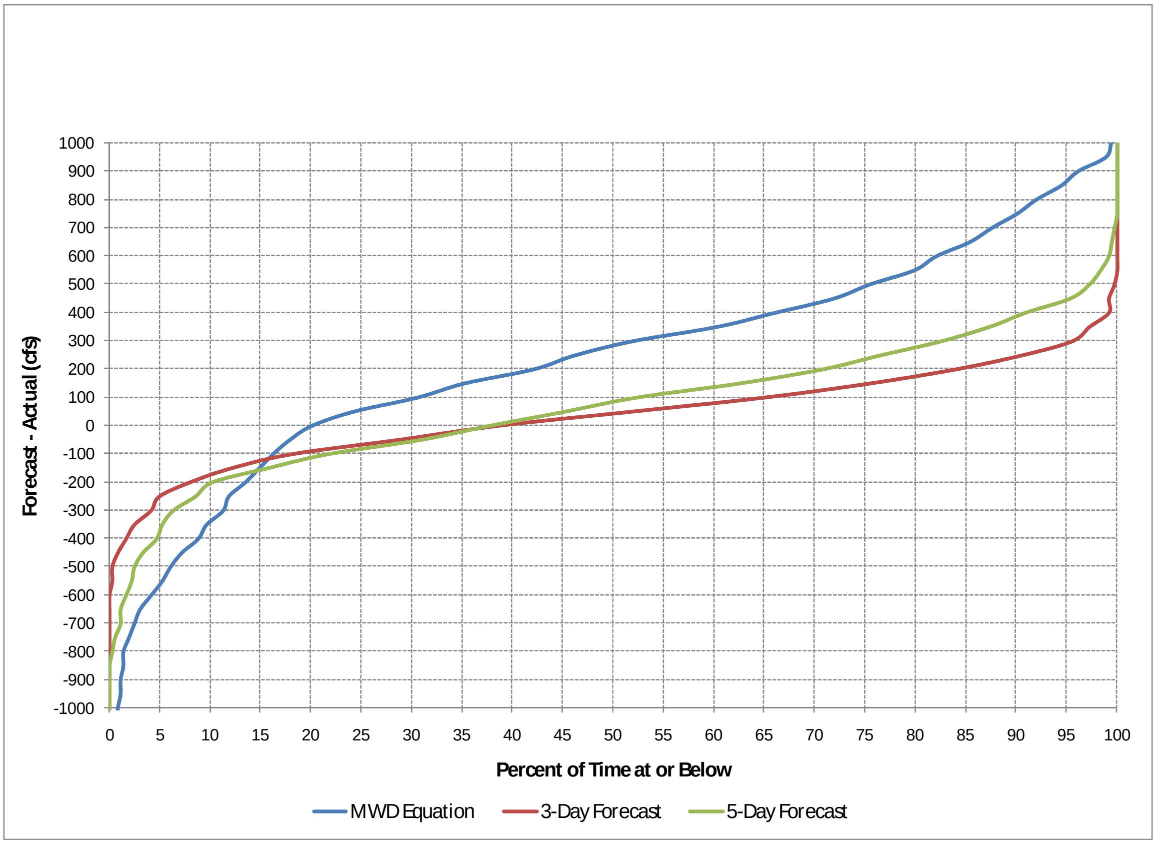


Figure 6B-7
14-Day OMR Flow
Forecast Model Performance
June

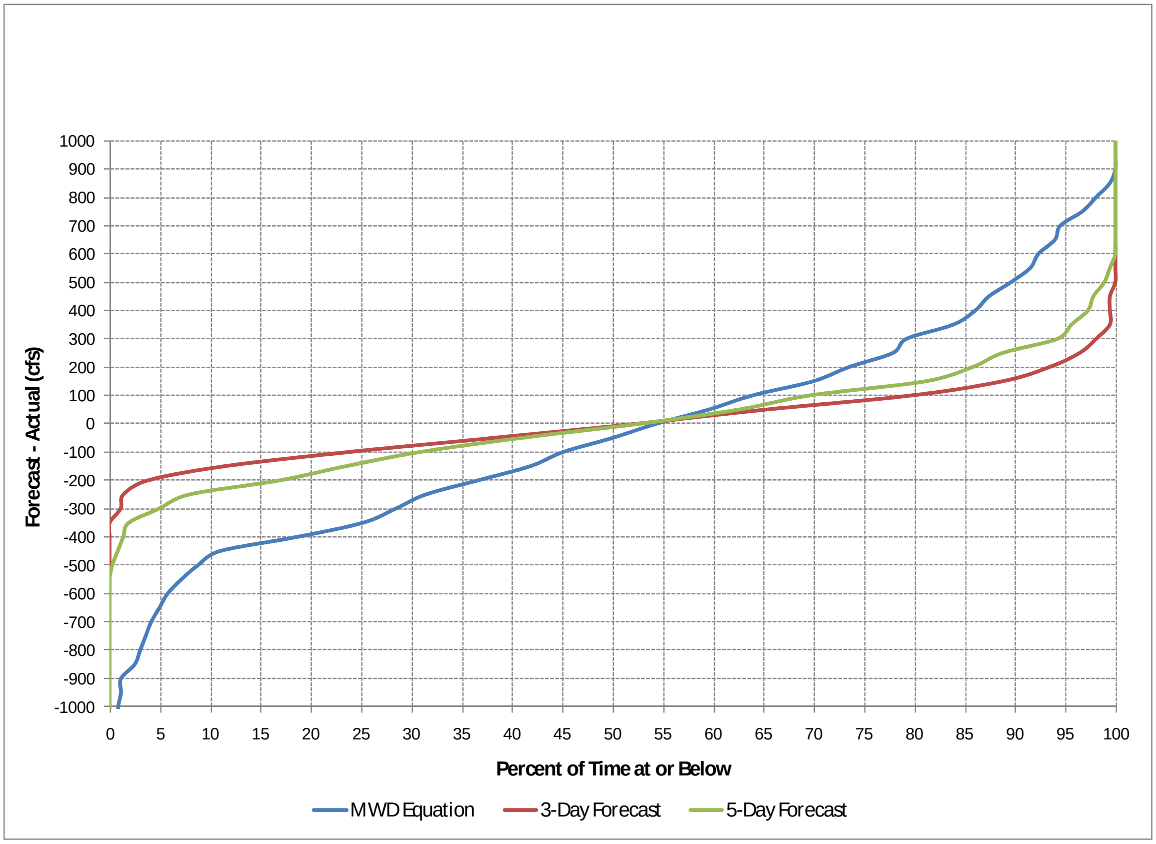


Figure 6B-8
7-Day OMR Flow
Forecast Model Performance
December

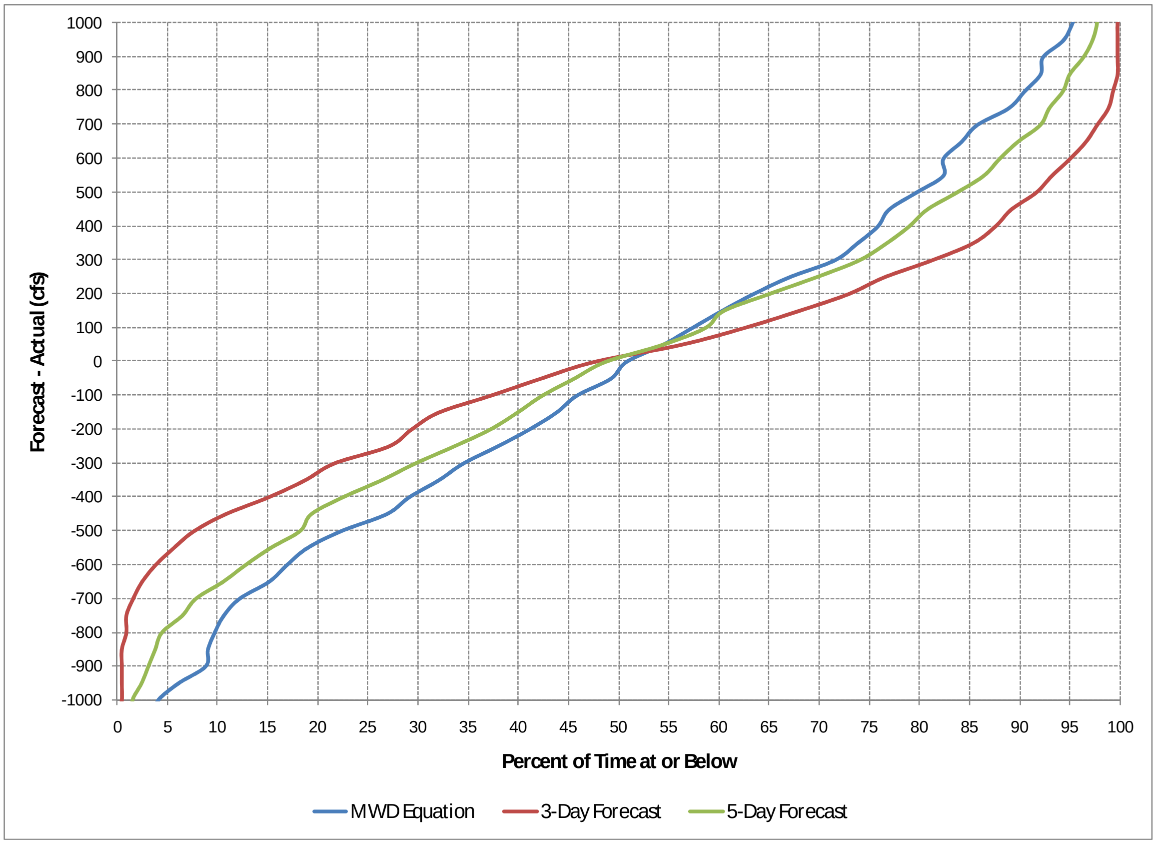


Figure 6B-9
7-Day OMR Flow
Forecast Model Performance
January

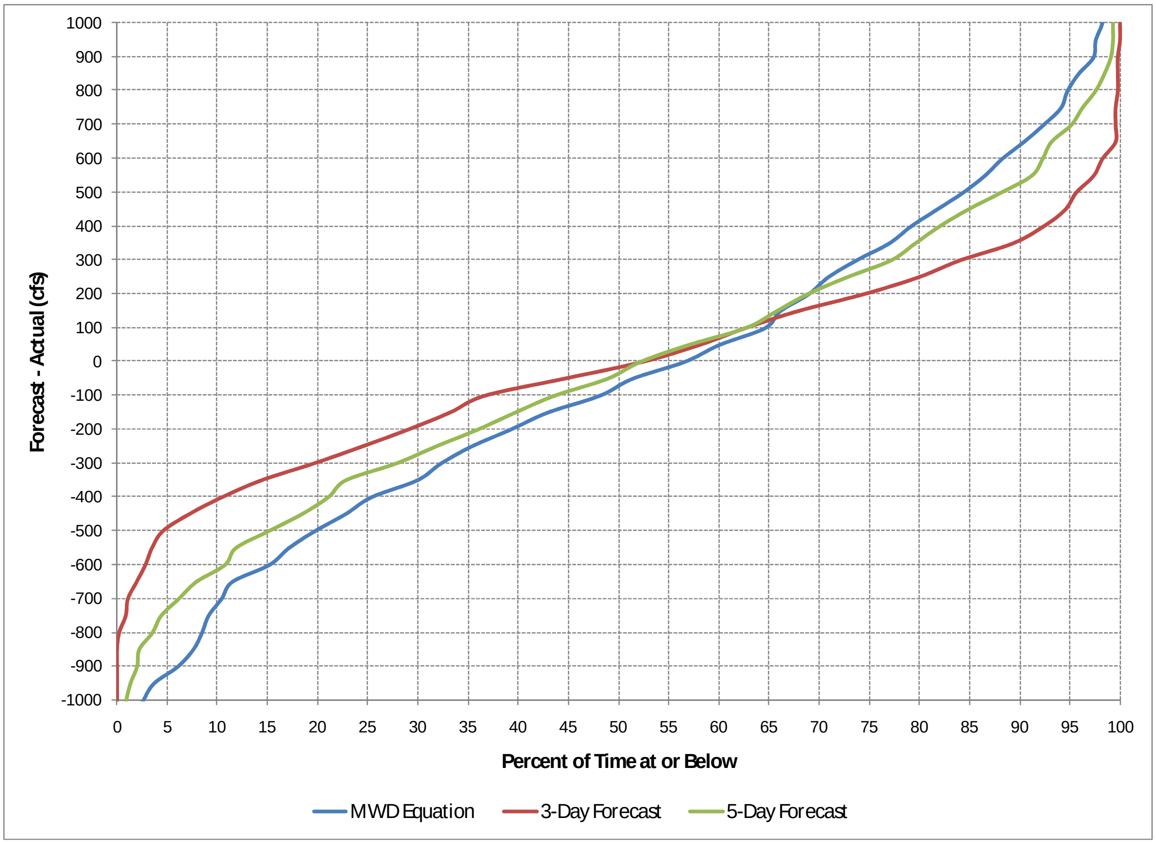


Figure 6B-10
7-Day OMR Flow
Forecast Model Performance
February

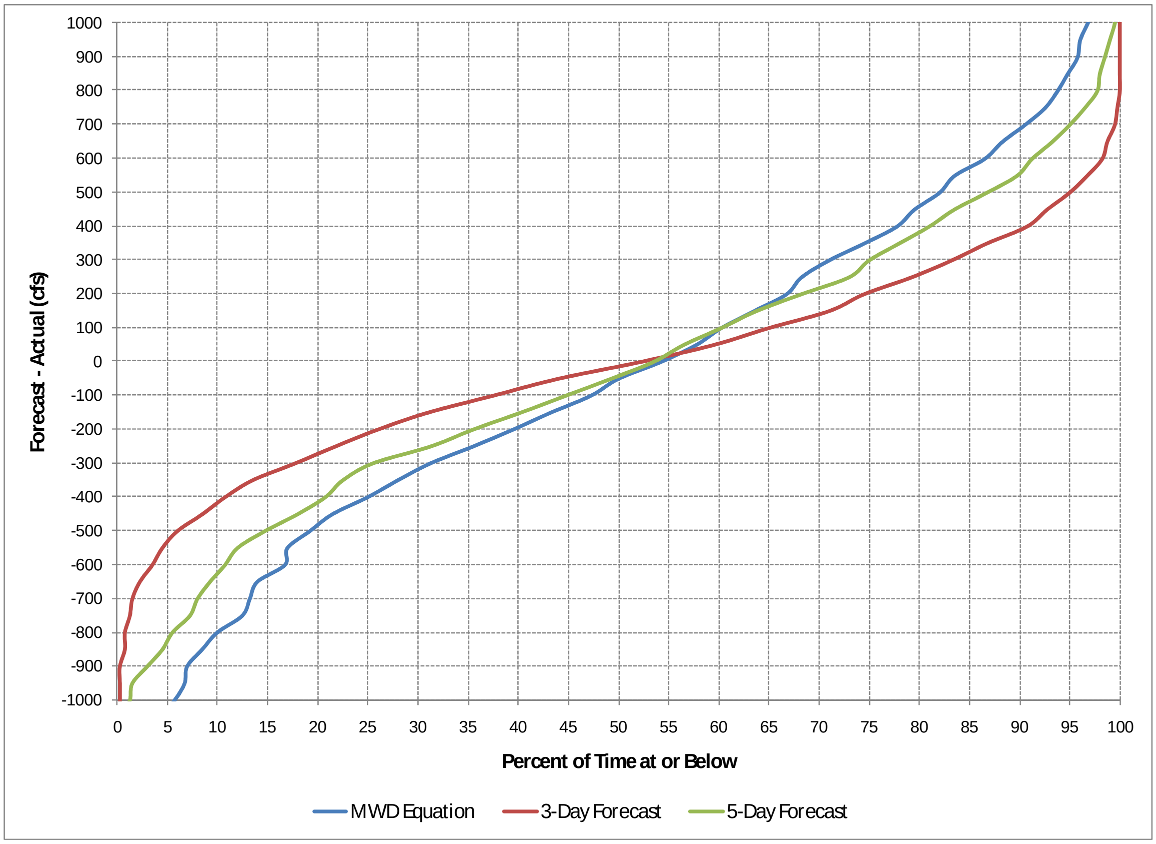


Figure 6B-11
7-Day OMR Flow
Forecast Model Performance
March

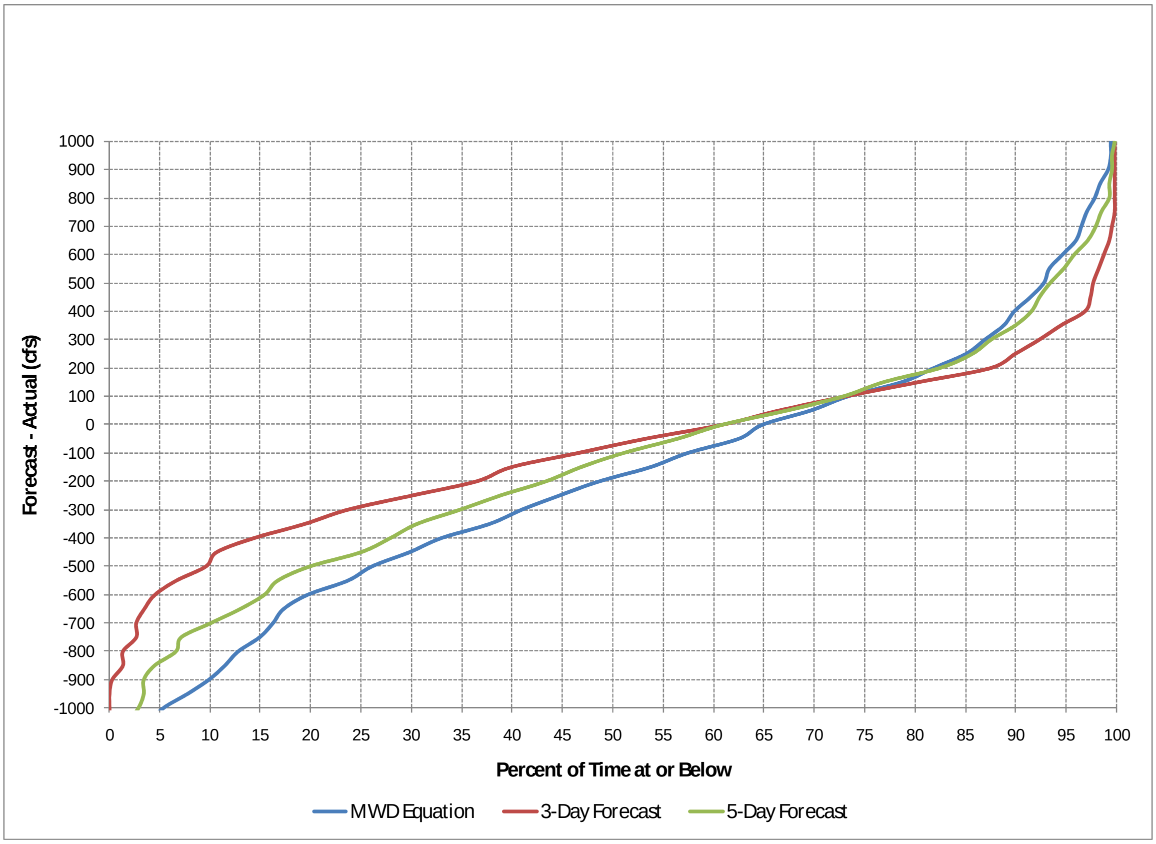


Figure 6B-12
7-Day OMR Flow
Forecast Model Performance
April

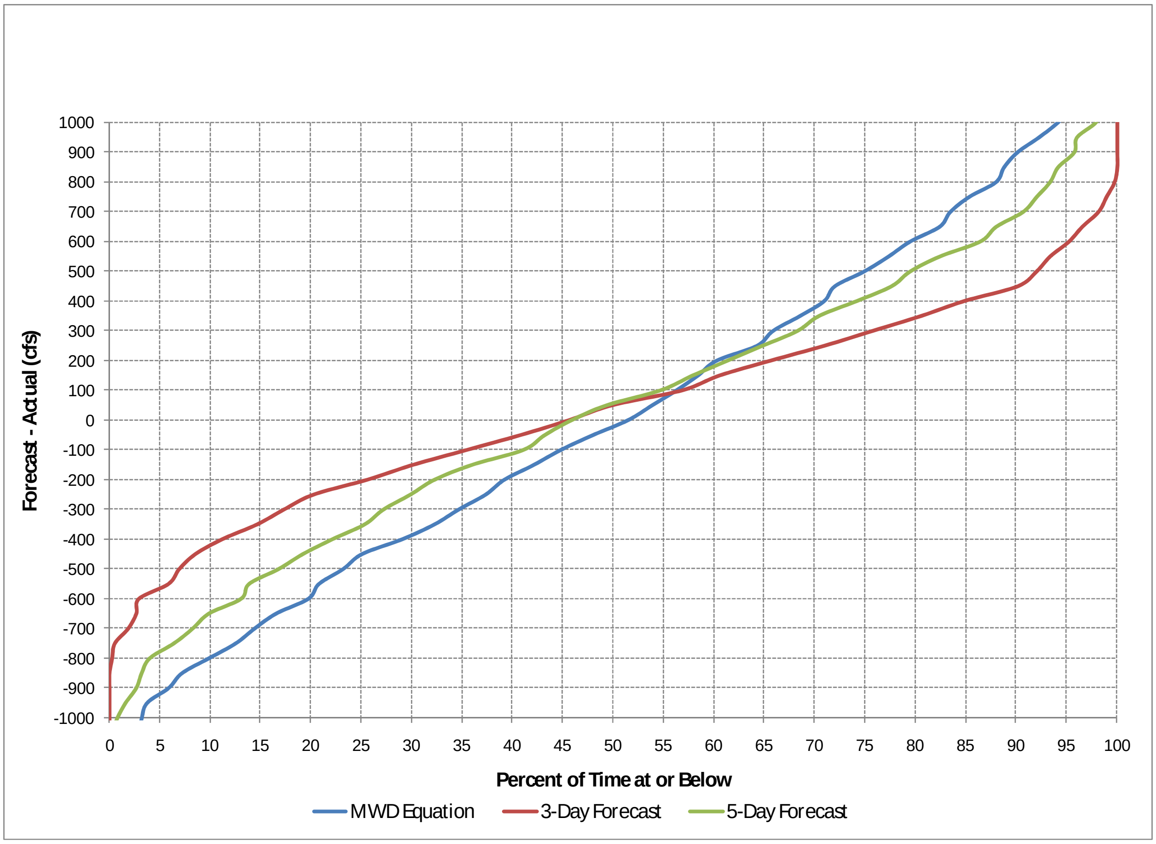


Figure 6B-13
7-Day OMR Flow
Forecast Model Performance
May

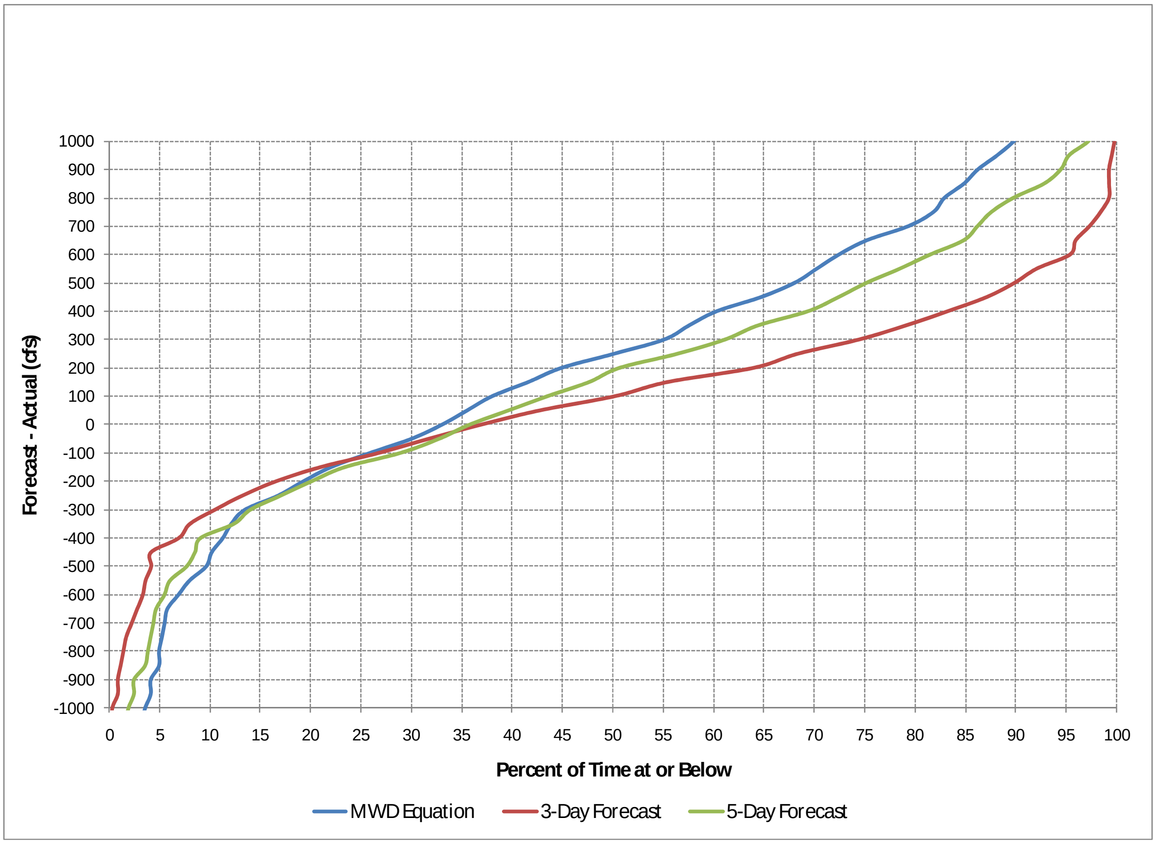
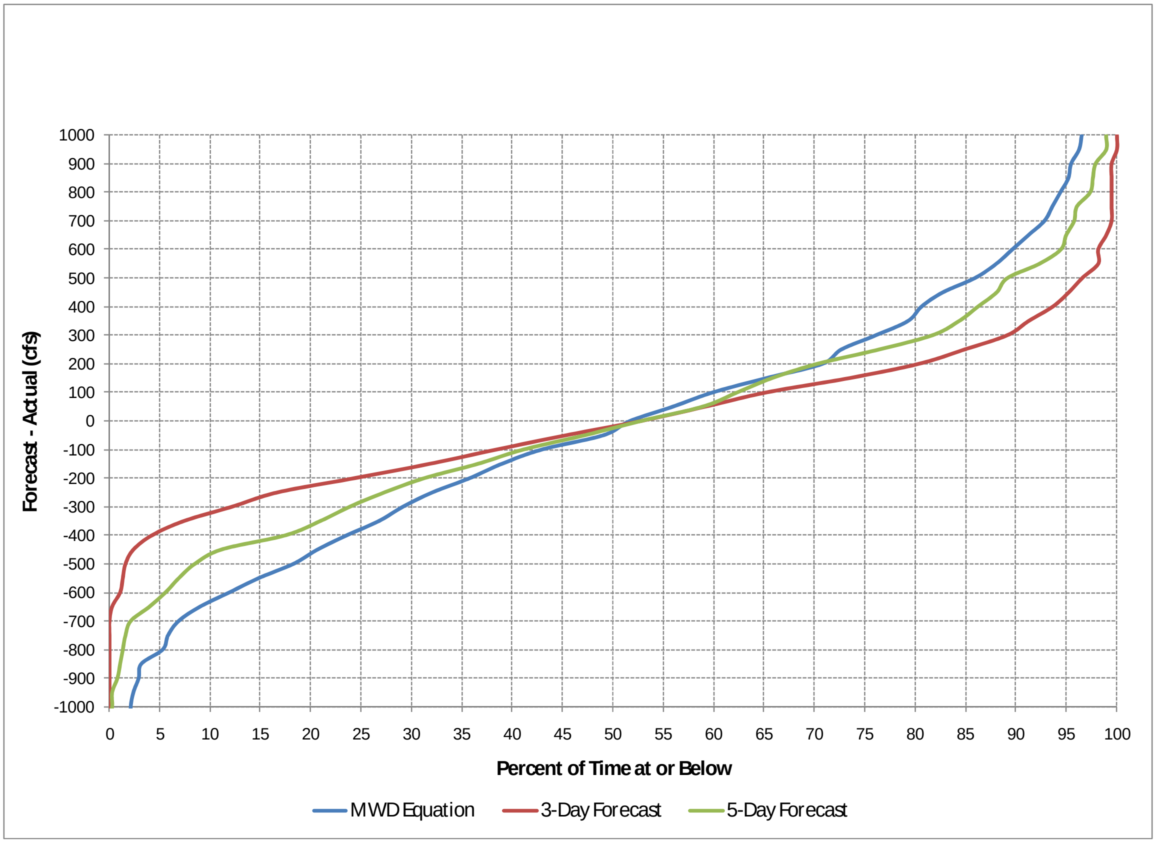


Figure 6B-14
7-Day OMR Flow
Forecast Model Performance
June



Section 7
Discussion

Comparison with Other Models

Validation With Observed Data. The MWD model provides significantly better estimates of daily averaged observed OMR flow compared with existing statistically-based models. The MWD model performance is similar to that of DSM2 on a daily averaged basis. Compare Figure 6-2 with Figures 3-3 and 3-4.

Tables 7-1 through 7-3 summarize, by month, absolute differences or residuals between model predictions and measured OMR flows. Table 7-1 summarizes residuals for daily (tidally filtered) averaged estimates. Tables 7-2 and 7-3 summarize residuals for 7-day and 14-day averaged estimates, respectively. Some observations are outlined below.

- The MWD model, with few exceptions, provides the lowest residuals for each month.
- The DWR model provides the lowest residuals in February and the USGS model provides the lowest residuals in November for the 7-day and 14-day averaged estimates.
- All models show a general decrease in residuals as the averaging period increases. The decrease is most pronounced with the MWD model.
- The USGS model gives the highest residuals during the winter months (December-March).
- The DWR model generally gives the highest residuals in the remaining months.

Baseline Estimates. Appendix 7A compares average OMR flow estimates by month for a 73-year average and by 40-30-30 water year type. Baseline estimates assume Delta hydrology and operations as represented in CALSIM (CALSIM 2007); baseline estimates also assume south Delta temporary barrier installations are triggered by San Joaquin River flows (DWR 2003). The following discussion is limited to the months of January through June, as these are the months when OMR flow restrictions are imposed by the recent court decision (recognizing that restrictions may sometimes occur in late December).

The DWR model consistently provides the highest OMR flow estimate over the 73-year average. This observation is consistent with the finding that the DWR model shows a strong bias toward over-estimating OMR flow (see Section 3). The DWR estimates are particularly high relative to the other models in April, May and June under all water year types. The high April-May estimates result because the DWR model does not account for HORB installation.

The USGS model estimates tend to deviate from the other model estimates in February and March. The USGS model gives lower OMR estimates during wetter water years and gives higher OMR estimates during dryer water years. The former observation is consistent with the finding that the USGS model tends to under-predict OMR flow in

January through March (see Section 3). This deviation probably occurs because the USGS model does not consider the relationship between Vernalis flow and OMR flow under most hydrologic conditions.

The MWD model consistently provides the lowest OMR flow estimates in June. This deviation probably results because the MWD model considers the relationship between south Delta net channel depletions and OMR flow (net channel depletions are typically high in June).

<u>Export Reductions Necessary to Meet OMR Flow Restrictions.</u> Table 7-4 compares estimated export reductions necessary to meet January through June OMR flows greater than –750 cfs and –5000 cfs. These flow restrictions are generally representative of those imposed by the recent court decision. In wet, above and below normal years, the MWD model consistently gives estimates that fall between the DWR model estimates (low) and USGS model estimates (high). The MWD model consistently gives the highest estimate for export reductions in dry and critical years.

<u>Sensitivity Analysis.</u> The MWD model was compared with the other OMR flow models through sensitivity analysis.

Figure 7-1 compares predicted relationships between combined CVP-SWP exports and OMR flow for three typical hydrologic conditions: January, April-May and June. Some observations are outlined below.

- The MWD and DWR models show similar sensitivity under a typical January condition. The USGS model suggests lower exports are required to maintain OMR flows. As discussed above, the USGS model validates relative poorly to observed data in winter months, tending to under-predict OMR flows. This deviation probably occurs because the USGS model does not consider the relationship between Vernalis flow and OMR flow under most hydrologic conditions.

- The MWD and USGS models show similar sensitivity under a typical spring condition when the HORB is installed. The DWR model suggests higher exports are permitted to maintain OMR flows. As discussed above, the DWR model validates relatively poorly to observed data in April-May and has a strong bias to over-predict OMR flows. The high April-May estimates result because the DWR model does not account for HORB installation. MWD model estimates fall between the USGS and DWR model estimates when the HORB is not installed.

- The MWD model suggests lower exports are required to maintain OMR flows in June. This finding is consistent with the above discussion on baseline estimates. This deviation from the other models probably results because the MWD model considers the relationship between south Delta net channel depletions and OMR flow (net channel depletions are typically high in June).

Table 7-5 provides another model sensitivity analysis, summarizing marginal water costs and savings associated with applying various Delta actions during January thru June when OMR flow restrictions are in place. Some observations are outlined below.

- The DWR model is, by definition, insensitive to changes in barrier operations. The USGS model is more sensitive than the MWD model to changes in GLC barrier operations and less sensitive to changes in HORB operations. Both models show barrier installation is more costly when OMR flow requirements are more stringent.
- The DWR and USGS models are, by definition, insensitive to changes in south Delta net channel depletions. The MWD model shows a small water savings associated with a 50% reduction in south Delta net channel depletions.
- While all models show savings associated with a 20% increase in Vernalis flows, the USGS model is less sensitive than the MWD and DWR models. The USGS model sensitivity is limited to high flow periods when Vernalis flows exceed 10,000 cfs.

Discussion on Model Input

South Delta Net Channel Depletions. The MWD model requires estimates of south Delta net channel depletions to predict OMR flow. While Delta-wide estimates of net channel depletions are available, estimates for south Delta net channel depletions are generally not available. The ratio of Delta-wide net channel depletions that represents south Delta net channel depletions was computed each month for the 1990-2006 period to arrive at an average ratio. These ratios are summarized in Table 7-6. Based on this analysis, it is recommended that a ratio of 0.25 be used to estimate south Delta net channel depletions from Delta-wide net channel depletions. This ratio is consistent with a ratio of 0.2889 proposed by DWR (DWR 1986).

Clifton Court Forebay Diversions. The MWD model, as well as the DWR and USGS models, requires estimates of Clifton Court Forebay diversions to predict OMR flow. For many planning applications, estimates of forebay diversions may not be available. Under such conditions, estimates of Banks Pumping Plant diversions would be the best available data for model input. As shown in Figure 7-2, differences between forebay diversions and Banks pumping can be significant at a daily time scale. These differences collapse, however, as data is averaged over longer time scales such as a 14-day average. Clifton Court Forebay diversions are related to Banks Pumping Plant diversions through the following water balance:

Clifton Court Forebay diversions = Banks Pumping Plant diversions + Byron-Bethany Irrigation District net diversions ± Change in Forebay storage

Findings and Conclusions

Model Development & Application. The following findings and conclusions relate to MWD model development and application:

- The model, which was formulated as a water balance and calibrated with DSM2 data, provides (1) superior validation to observed data and (2) more robust sensitivity to key hydrologic variables. The model should be adopted as a planning tool for predicting OMR flow. Including a tidal influence term could enhance model performance.
- Clifton Court Forebay diversion is a better measure than Banks Pumping in predicting OMR flow. This consideration is important for short-term forecasting. For long term planning, the distinction is less important.

Potential Control Measures. The following findings and conclusions relate to potential measures to control OMR flow:

- Comparison of model estimates with observed OMR flows was used to develop planning "buffers" to account for estimate uncertainty.
    - Longer flow averaging periods can be forecasted with greater certainty, and therefore can rely on smaller buffers to meet OMR flow objectives. Buffers required to meet 7-day averaged flow objectives are approximately twice as large as buffers required to meet 14-day averaged flow objectives.
    - 3-day forecasts can be estimated with greater certainty than 5-day forecasts, and therefore can rely on smaller buffers. Buffers required for a 5-day forecast are approximately 50% greater than those required for a 3-day forecast.
- The only south Delta agricultural barrier that has a significant impact on OMR flow is the Grant Line Canal. This finding seems reasonable given that the Grant Line Canal barrier provides the greatest flow restriction. Therefore, any future Delta smelt protections should focus on operation of this barrier.
- Water savings will result from delaying or prohibiting installation of HORB and Grant Line Canal barriers. But will delayed installation require export curtailments to meet south Delta water levels?
- Measures that increase San Joaquin River flows at Vernalis would be effective in controlling OMR flow. Such measures would be even more effective if the Paradise Cut weir operation was modified to allow more San Joaquin River water into the south Delta.

References

CALSIM (2007). Study OCAP_2001D10A_TODAY_B2

DWR (2003). Proposed Temporary Barrier Operations for 2001 and 2020 Base Case SDIP 16-Year DSM2 Simulations, Office Memorandum from Jamie Anderson to Parviz Nader-Tehrani, January 23.

Table 7-1
Comparison of OMR Flow Model Residuals by Month
Daily (Tidal) Averaged Estimates

Month	N	Absolute Difference (cfs)		
		DWR Model	USGS Model	MWD Model
Jan	496	585	1026	560
Feb	452	636	1126	688
Mar	503	676	1025	608
Apr	501	1204	884	547
May	527	1588	845	578
Jun	452	1277	945	503
Jul	478	1179	1145	555
Aug	489	973	947	525
Sep	475	854	766	551
Oct	465	875	684	554
Nov	442	701	528	526
Dec	465	699	848	656
All	5745	944	900	571

Table 7-2
Comparison of OMR Flow Model Residuals by Month
7-Day Averaged Estimates

Month	N	Absolute Difference (cfs)		
		DWR Model	USGS Model	MWD Model
Jan	483	467	877	420
Feb	452	487	1035	522
Mar	491	619	965	493
Apr	494	1099	847	506
May	522	1654	841	523
Jun	452	1269	886	416
Jul	466	1216	1124	487
Aug	477	980	972	534
Sep	469	884	813	615
Oct	465	911	774	625
Nov	430	690	512	546
Dec	465	540	712	501
All	5666	909	866	515

Table 7-3
Comparison of OMR Flow Model Residuals by Month
14-Day Averaged Estimates

Month	N	Absolute Difference (cfs)		
		DWR Model	USGS Model	MWD Model
Jan	469	312	709	251
Feb	452	373	1013	407
Mar	485	517	882	358
Apr	479	913	778	346
May	515	1663	761	383
Jun	452	1236	764	338
Jul	458	1236	1065	386
Aug	457	949	921	385
Sep	462	776	684	389
Oct	465	783	609	453
Nov	416	633	310	375
Dec	465	411	604	357
All	5575	824	761	369

Table 7-4
Comparison of Export Reductions Required to Meet OMR Restrictions January-June with No South Delta Barrier Operations (TAF per year)

Water Year Type	OMR > -750 cfs			OMR > -5000 cfs		
	DWR Model	USGS Model	MWD Model	DWR Model	USGS Model	MWD Model
73-Year Average	1300	1640	1540	320	440	380
Wet	1110	1680	1390	250	460	310
Above Normal	1520	2130	1800	420	640	480
Below Normal	1570	2000	1840	380	530	480
Dry	1510	1570	1710	410	390	450
Critical	760	690	890	180	150	190

Table 7-5
January-June Marginal Water Costs & Savings of Various Delta Actions[1]
(TAF per year)

Action	OMR > -750 cfs			OMR > -5000 cfs		
	DWR Model	USGS Model	MWD Model	DWR Model	USGS Model	MWD Model
GLC Installation	0	-170	-30	0	-50	-10
GLC and HORB Installation	0	-210	-120	0	-50	-40
50% Reduction of Net Channel Depletions	0	0	30	0	0	<10
20% Increase in Vernalis Flow	150	90	140	50	30	50

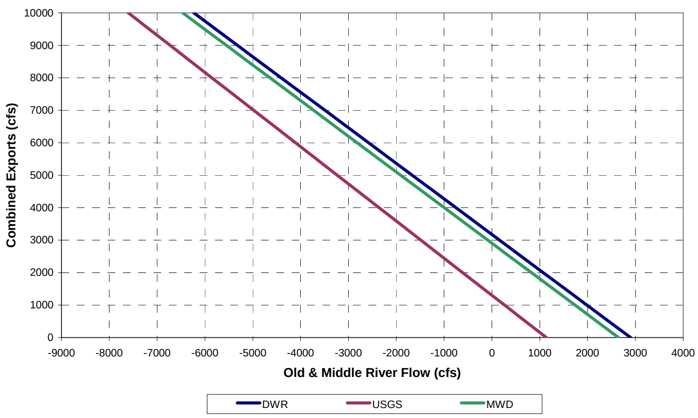
[1] Marginal costs and savings measured against 73-year average export reductions presented in Table 7-3. Savings are denoted by a positive value; costs are denoted by a negative value.

Table 7-6
Fraction of Delta-Wide Net Channel Depletions
Contributing to South Delta Net Channel Depletions: 1990-2006

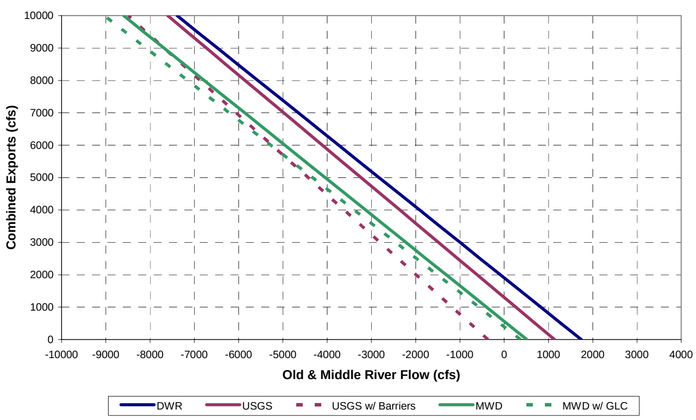
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	0.01	(1)	0.36	0.27	0.20	0.27	0.25	0.25	0.24	0.24	0.23	0.23
1991	0.36	0.26	(1)	0.28	0.28	0.31	0.25	0.26	0.25	0.22	0.22	0.22
1992	(1)	0.13	0.09	0.26	0.27	0.27	0.25	0.25	0.24	0.24	0.21	(1)
1993	0.12	0.20	0.32	0.23	0.22	0.30	0.25	0.25	0.24	0.21	0.24	0.24
1994	0.04	0.08	0.28	0.25	0.20	0.27	0.25	0.25	0.24	0.22	0.28	0.36
1995	0.12	0.32	0.14	0.23	0.29	0.30	0.25	0.25	0.24	0.22	0.22	(2)
1996	0.21	0.23	0.35	0.22	0.28	0.29	0.25	0.25	0.24	0.22	0.24	0.11
1997	0.18	0.23	0.25	0.26	0.26	0.26	0.25	0.25	0.24	0.23	0.29	0.34
1998	0.18	0.21	0.05	0.23	0.10	0.28	0.25	0.25	0.24	0.21	0.25	0.21
1999	0.18	0.10	(2)	0.23	0.25	0.27	0.25	0.25	0.23	0.22	0.23	0.22
2000	0.13	0.20	0.25	0.26	0.28	0.28	0.25	0.25	0.23	0.22	0.21	0.21
2001	0.19	0.07	0.35	0.27	0.28	0.27	0.25	0.25	0.24	0.23	0.24	0.15
2002	0.17	0.47	0.27	0.25	0.28	0.28	0.25	0.25	0.24	0.22	0.24	0.09
2003	0.12	0.05	0.49	0.62	0.29	0.29	0.25	0.26	0.24	0.22	0.23	0.74
2004	0.15	0.14	0.25	0.25	0.26	0.27	0.24	0.25	0.23	0.23	0.23	0.09
2005	0.18	0.21	0.01	0.20	0.26	0.29	0.25	0.25	0.24	0.22	0.22	(1)
2006	0.16	(1)	0.12	0.13	0.25	0.28	0.25	0.25	0.24	0.22	0.23	0.23
avg	0.16	0.19	0.24	0.26	0.25	0.28	0.25	0.25	0.24	0.22	0.24	0.24

(1) Negative ratios removed from calculation of averages
(2) Extreme outliers removed from calculation of averages

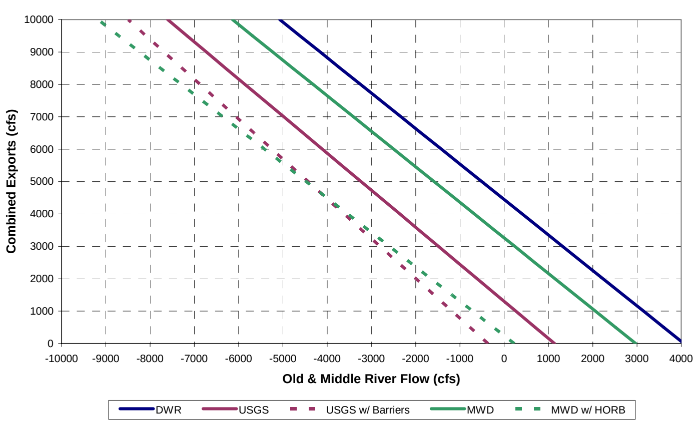
Figure 7-1
Predicted Relationships Between OMR Flow and Exports



Typical January
Vernalis = 5000 cfs
South Delta NCD = -300 cfs

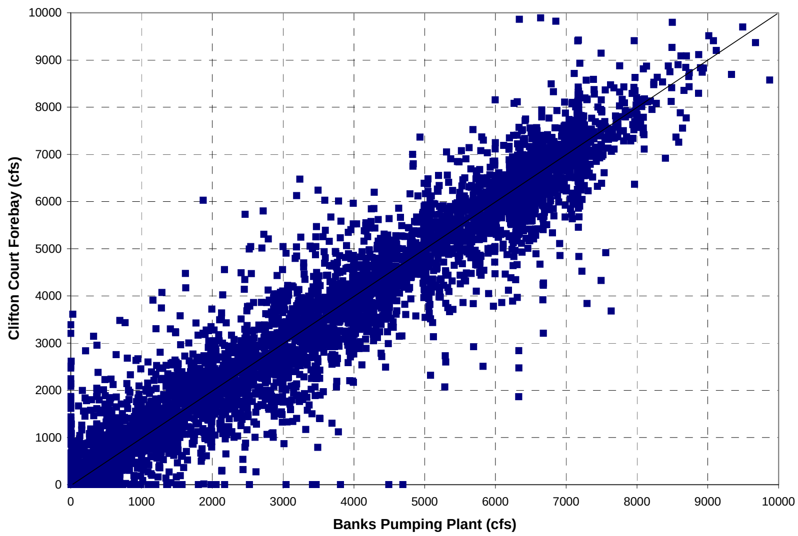


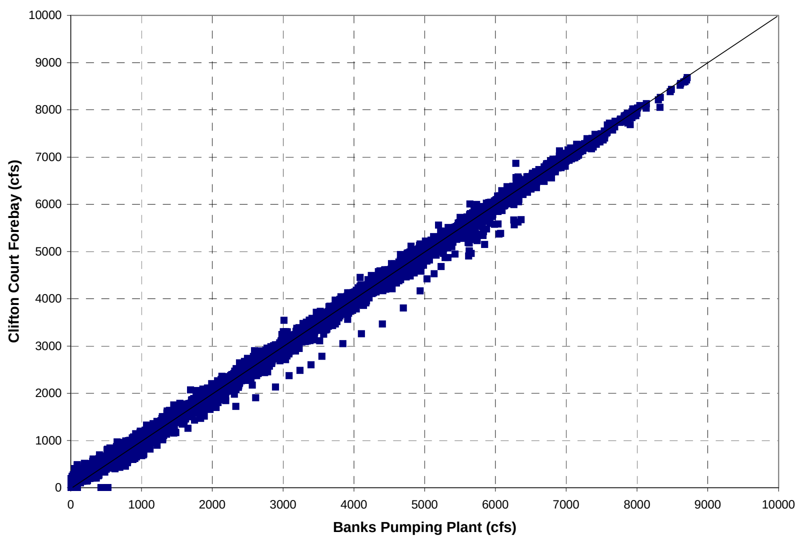
Typical April-May
Vernalis = 7000 cfs
South Delta NCD = 350 cfs



Typical June
Vernalis = 3000 cfs
South Delta NCD = 1000 cfs

Figure 7-2
Comparison of Clifton Court Forebay & Banks Pumping Plant Diversions
Daily Averaged Observed Data January 1, 1990 – September 30, 2006



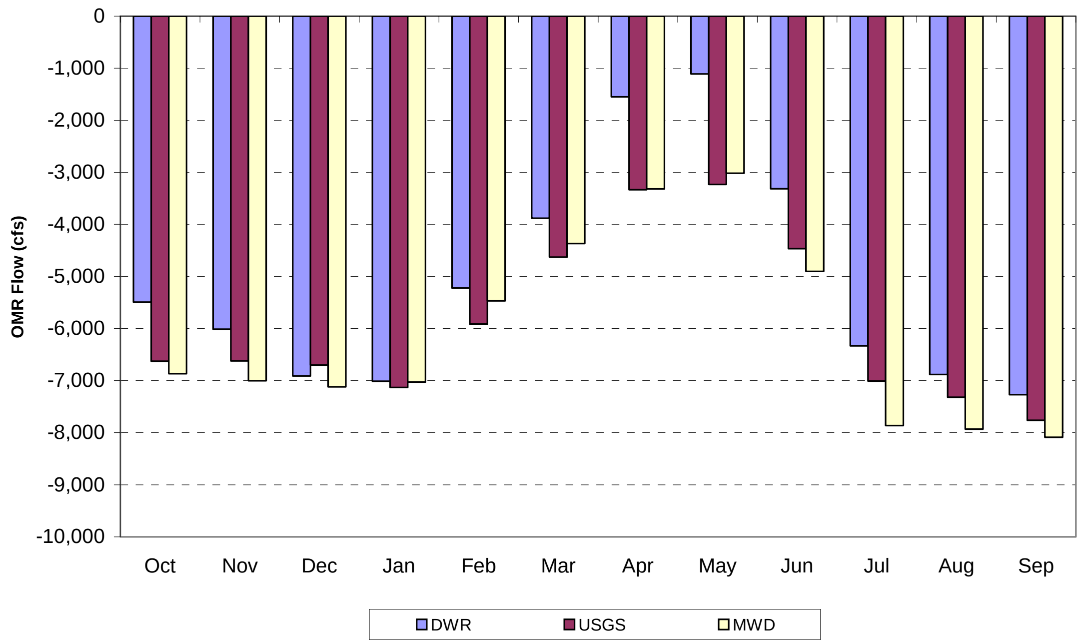


Differences between forebay diversions and Banks pumping can be significant at a daily time scale (see top graph). These differences collapse as data is averaged over a 14-day average (see bottom graph).

Appendix 7A
Comparison of CALSIM Baseline OMR Flow Estimates

Figures

Figure 7A-1
Comparison of CALSIM Baseline OMR Flow Estimates
73-Year Averages



The DWR model consistently provides the highest OMR flow estimate over the 73-year average. This observation is consistent with the finding that the DWR model shows a strong bias toward over-estimating OMR flow (see Section 3). The DWR estimates are particularly high relative to the other models in April, May and June under all water year types. The high April-May estimates result because the DWR model does not account for HORB installation.

The MWD model consistently provides the lowest OMR flow estimates in June. This deviation probably results because the MWD model considers the relationship between south Delta net channel depletions and OMR flow (net channel depletions are typically high in June).

Figure 7A-2
Comparison of CALSIM Baseline OMR Flow Estimates
Wet Years

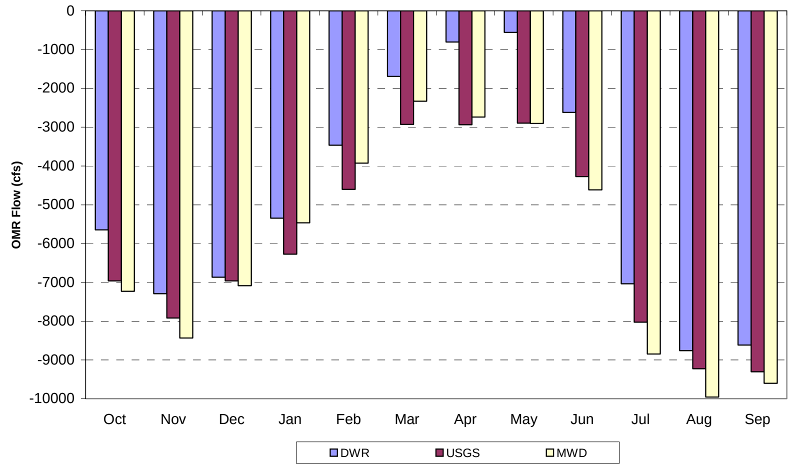


Figure 7A-3
Comparison of CALSIM Baseline OMR Flow Estimates
Above Normal Years

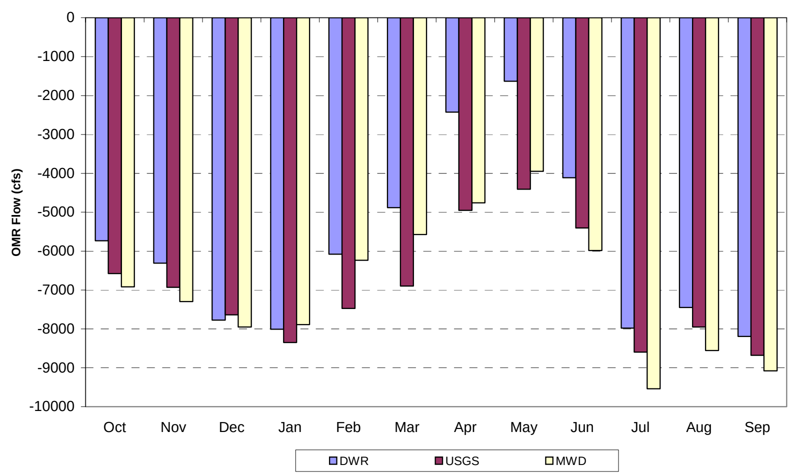


Figure 7A-4
Comparison of CALSIM Baseline OMR Flow Estimates
Below Normal Years

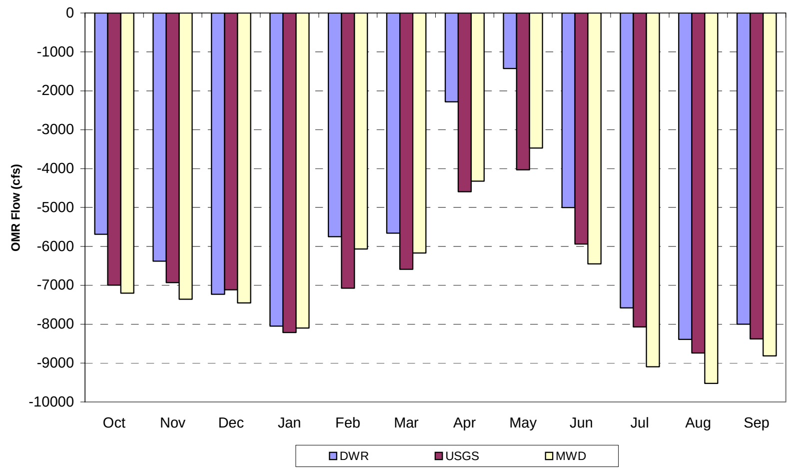


Figure 7A-5
Comparison of CALSIM Baseline OMR Flow Estimates
Dry Years

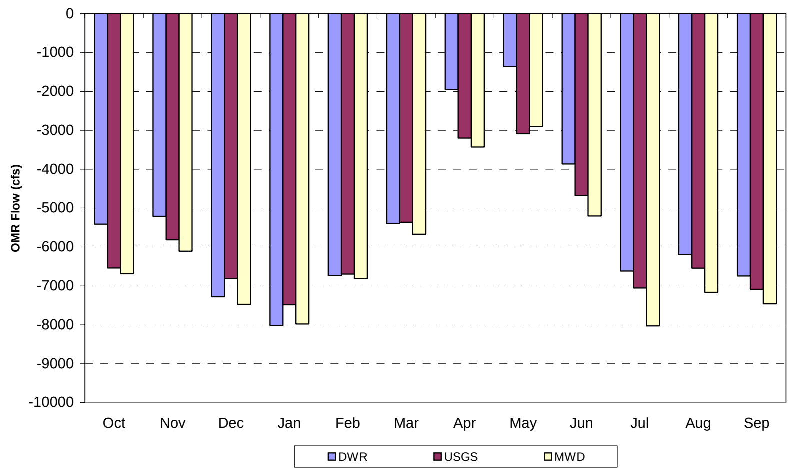


Figure 7A-6
Comparison of CALSIM Baseline OMR Flow Estimates
Critical Years