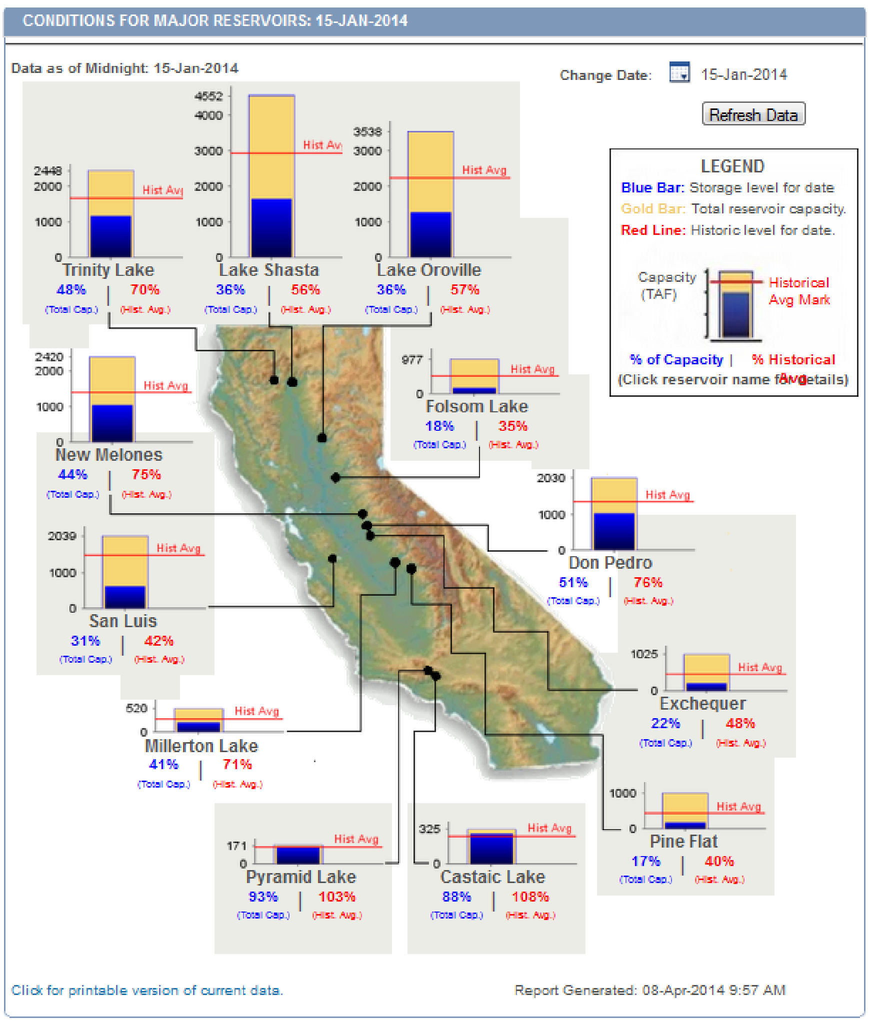
Chapter 6. Delta Modeling for Emergency Drought Barriers

The National Weather Service reported that in California, 2013 was the driest calendar year on record. By mid-January 2014, very little precipitation had occurred across California. The statewide precipitation value was 0.10 inches (with an average January experiencing around 3 inches of rain). Reservoir storage levels, shown in Figure 6-1 for January 15, were well below the historical average for that day.

Figure 6-1 DWR's California Data Exchange Center Reservoir Storage Graph January 15, 2014



Discussions began on whether emergency rock barriers, similar to those installed in 1976-1977, should be installed in the Delta to minimize the salinity intrusion from San Francisco Bay into the Delta and help meet the State Water Resources Control Board (SWRCB) D-1641 water quality objectives. In this chapter, these rock barriers are referred to as "emergency barriers." This chapter discusses the modeling approaches that were taken to:

- evaluate the drought’s impacts on water quality in the Delta, if another dry year occurs,
- review and analyze salinity modeling results (DSM2 and SELFE) due to the installation of the rock barriers,
- analyze water level, flow and velocity impacts of installing the barriers, and
- analyze water savings (water that would remain in reservoirs instead of being released to reduce salinity intrusion) that potentially could occur with installation of the barriers.

6.1 Summary of Emergency Barrier Work Completed

This chapter is a summary of work and documentation completed by several staff members from the Department of Water Resources’ (DWR's) Bay-Delta Office, and Operations and Maintenance office. Some work from Resource Management Associates is also presented. As both an acknowledgement of their hard work and contributions, and as a reference for where to find more complete data or documentation, Table 6-1 lists Delta emergency barrier related work performed and the staff associated with that work. The remainder of this report provides an overview of these emergency barrier analyses.

Table 6-1 DSM2 and SELFE Emergency Barrier Drought Modeling Tasks and Contacts

Work/Task	Name(s)	DWR Office/Division
Delta Coordinated Operations (DCO) Modeling	Amritpal Sandhu, Tracy Pettit	Operations and Maintenance
Modeling for 2009 Emergency Barriers Report	Subir Saha	Bay-Delta Office
DSM2 Forecasts – DCO Minimum Releases, Early February Forecast	Bryant Giorgi, James Edwards, Dan Yamanaka, Tracy Hinojosa	Operations and Maintenance
DSM2 Forecasts – DCO Minimum Releases, Early February Forecast With and Without Barriers	Siqing Liu	Bay-Delta Office
Delta Island Consumptive Use	Lan Liang, Bob Suits	Bay-Delta Office
Flow balance on South Delta Area	Aaron Miller, Ming-Yen Tu	Operations and Maintenance, Bay Delta Office
Net Delta Outflow Analysis using USGS Flow Stations	Rueen-Fang Wang, Eli Ateljevich	Bay-Delta Office
DSM2 Forecasts – DCO Minimum Releases, February 20 Forecast With and Without Barriers	Siqing Liu	Bay-Delta Office
DSM2 Forecasts – DCO Meet Delta Water Quality Objectives Until Storage Water is Unavailable, February 20 Forecast	Bryant Giorgi	Operations and Maintenance
DSM2 Quality Assurance/Quality Control and Analysis of RMA, DSM2 and SELFE Result Differences	Nicky Sandhu, Bob Suits, Eli Ateljevich	Bay-Delta Office
Historical Data Analysis	Bob Suits, Joey Zhou	Bay-Delta Office
DSM2 Forecast, March 21 Forecast With and Without Barriers	Siqing Liu	Bay-Delta Office

Table 6-1 DSM2 and SELFE Emergency Barrier Drought Modeling Tasks and Contacts (Cont.)

Work/Task	Name(s)	DWR Office/Division
SELFE Simulation using March 21st Forecast	Eli Ateljevich, Kijin Nam, Rueen-Fang Wang, Inez Ferreira, Jon Shu	Bay-Delta Office
SELFE Animations	Jon Shu	Bay-Delta Office
Full Delta Graphics Tool Modification	Subir Saha	Bay-Delta Office
Specific Location Graphics Tools	Ming-Yen Tu	Bay-Delta Office
Presentation Graphics	Jamie Anderson	Bay-Delta Office
Water Cost Savings Analysis	Eli Ateljevich	Bay-Delta Office
RMA Bay-Delta Forecasts	John DeGeorge, Richard Rachiele, Stacie Grinbergs	Resource Management Associates, Inc

6.2 Modeling Process

6.2.1 Data Analysis and Modeling Process to Determine Potential Salinity Impacts

In analyzing potential salinity intrusion into the Delta, we used historical observed data and computer modeling of forecasted conditions. The modeling process is shown in Figure 6-2.

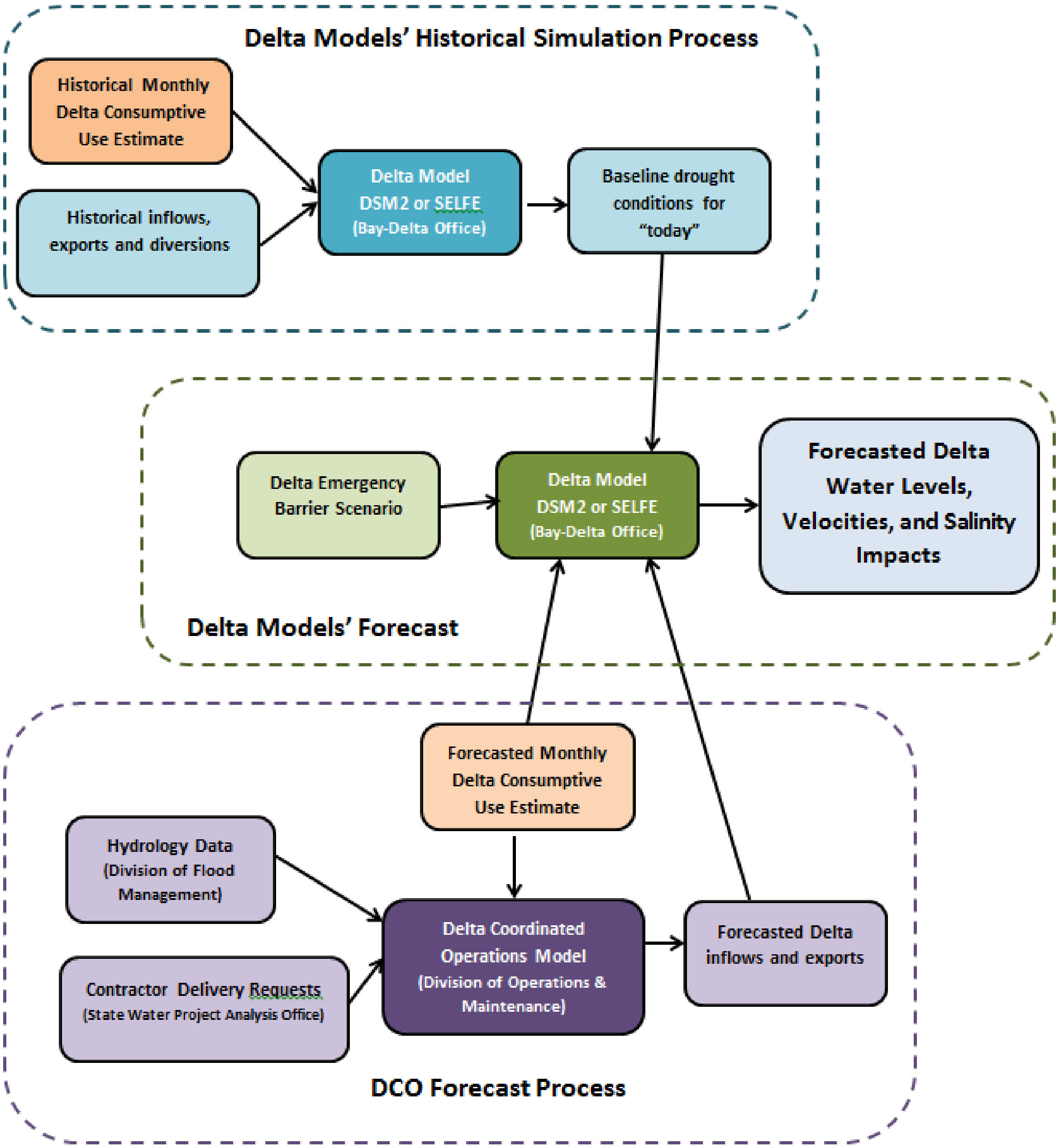
The Delta models that we used in this analysis were Delta Simulation Model 2 (DSM2) and the Bay-Delta Semi-implicit Eulerian Lagrangian Finite Element (SELFE) model (Ateljevich 2014). DSM2 is a one-dimensional, physically-based model that assumes flows are moving either upstream or downstream in a channel. In SELFE, the direction and magnitude of flow can also change across the channel or down the water column. DSM2 runs much faster than SELFE and requires less input data, but SELFE has a greater resolution.

We chose to use forecasted flow conditions under a dry (90%) hydrology to get a better understanding of what we might expect under a worst-case scenario. Fortunately, DSM2 and its input had been set up and streamlined to do longer term forecasts as part of the DWR's Municipal Water Quality Investigations Program. As a result, we did not have to spend a lot of time setting up and testing the simulations.

We then compared the modeling results to what happened historically in dry years. In a recent project for the State Water Contractors and the San Luis and Delta Mendota Water Authority, staff from Tetra Tech compiled western Delta historical salinity data, from various historical sources, from 1921 to 2012 (Roy, 2012). DWR staff then ran DSM2 for that period. (DSM2 had been run from the mid-1970's onward, but had never been used to simulate earlier historical conditions.)

One of the other areas that we focused on in doing the analysis was the in-Delta diversions and returns. These values are calculated using the Delta Island Consumptive Use (DICU) model. There has not been a good way to validate these values Delta-wide, and in a dry year the quantities of water involved are commensurate with total outflow; thus, a relatively small difference in these consumptive use estimates in a dry year can have significant impacts on salinity intrusion. This will be further discussed later in the chapter.

Figure 6-2 Modeling Process



6.2.2 Forecasted Inflows, Diversions, Consumptive Use and Exports

To model the Delta flows, water levels, and salinity, Delta models such as DSM2 and SELFE need boundary inflows, exports, diversions, consumptive use diversions and returns, water levels, and salinity. For inflows to and exports from the Delta, the models use forecasted flows extracted from the Delta Coordinated Operations (DCO) studies that DWR's Division of Operation and Maintenance (O&M) conducts to determine State Water Project allocations (Figure 6-2). DCO studies incorporate hydrology data (developed by the Flood Management Division), contractor delivery requests (compiled by State

Water Project Analysis Office), and regulatory and court restrictions on exports. The DCO allocation forecasts that we used for this analysis assumed a 90% hydrology. A 90% hydrology is one that assumes, based on historical statistics, only one in ten years would be drier than this forecast. The models also use observed historical data up until the forecast period begins.

There were three forecast periods that were used to evaluate the need for barriers, early February, February 21, and March 20. Each forecast incorporated the historical precipitation up until the forecast began. The first Delta forecast that was evaluated was an early February forecast (before the February 9 storm). The flows produced by the DCO model that were used for the first forecasts represented a minimum releases assumption. These minimum releases met upstream flow requirements but did not attempt to meet the D-1641 water quality objectives in the Delta. Even without releasing flows to meet the D-1641 water quality objectives, Shasta, Oroville, and Folsom reservoirs were forecasted to be at very low storage levels by August.

The first DSM2 forecasts, run by O&M staff using the early February DCO forecast, showed that DSM2 was underestimating the historical salinity at D-1641 water quality objective locations in the Delta. One of the potential errors in input was determined to be consumptive use during the February time period. Typically, during February, consumptive use is estimated to be very small, assuming that there recently has been some precipitation (Mahadevan, 1995). However, because the winter of 2013-2014 was very dry, the consumptive use values were adjusted to reflect a higher consumptive use. This higher consumptive use was designated "Run 3" and represented a consumptive use approximately 700 cfs more than the dry year historical estimate that had been previously used. The higher consumptive use scenario also assumed no precipitation and a high evapotranspiration rate.

Table 6-1 Dry Historical and High Estimated Delta Consumptive Use (Run 3)

	Consumptive Use Estimate			Consumptive Use Estimate	
	Dry Historical (cfs)	**Run3 (cfs)**		**Dry Historical (cfs)**	**Run3 (cfs)**
January	304	1008	July	4302	5106
February	1274	1998	August	2788	3577
March	2052	2829	September	1589	2353
April	2272	3059	October	1250	1967
May	2899	3691	November	1025	1731
June	3936	4740	December	1000	1707

6.3 Review of Documents on Salinity Impacts of Barriers in Droughts

To investigate potential sites for barriers, we examined historical drought barrier installation and reviewed results from other studies investigating the placement of barriers to improve water quality in the central Delta. The report that provided the most useful information was the Draft Delta Drought Emergency Barrier Report completed by DWR in April 2009 (DWR 2009). In that report, several alternatives for barrier installation impacts on salinity were investigated. Phase 1 was the identification of alternatives where a fairly comprehensive list of barrier salinity impacts were evaluated. The locations are shown by the red rectangles in Figure 6-3 and Figure 6-4. The effectiveness of the alternatives was measured by looking at the percentage reduction in EC at SWP and CVP export locations between each barrier alternative and the base condition (no project). The analysis was conducted for the July through

November period using 2001 and 2002 hydrology (dry years) and using DSM2 for the modeling analysis. If the reduction in EC was less than 5% it was not included in the Phase 2 analysis. The black X's show the barrier locations that did not provide a 5% or better reduction.

Figure 6-3 Barrier Locations - Phase 1, 2009 Emergency Barriers Report Map 1

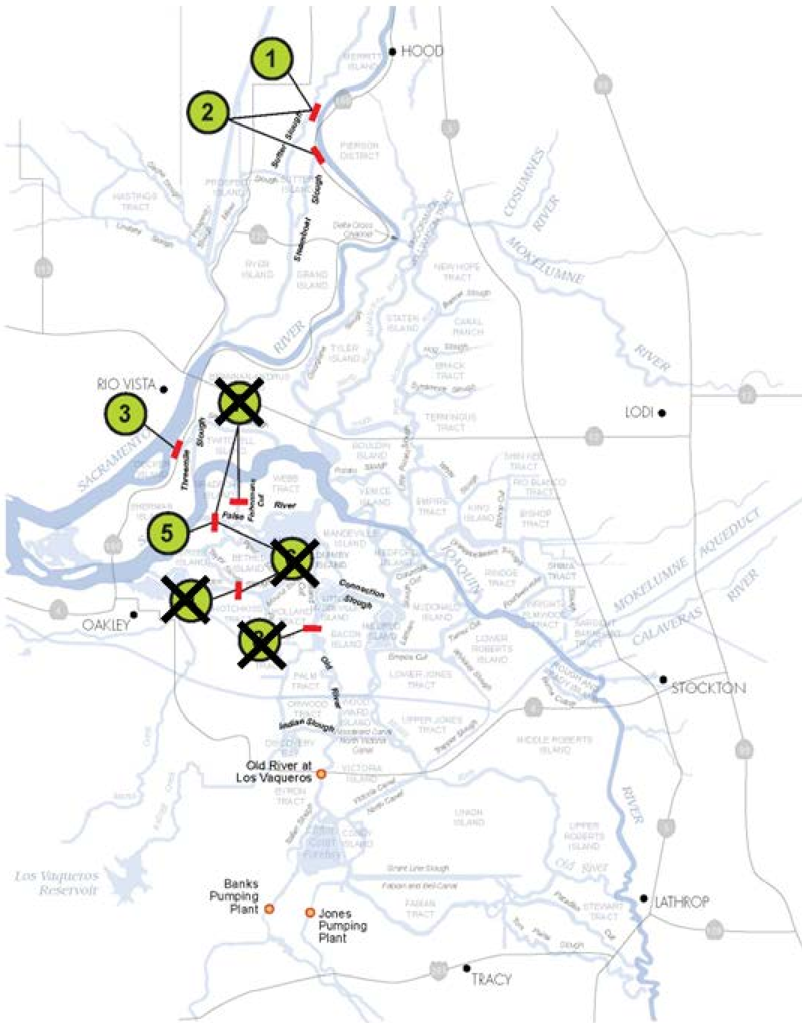


Figure 6-4 Barrier Locations - Phase 1, 2009 Emergency Barriers Report Map 2

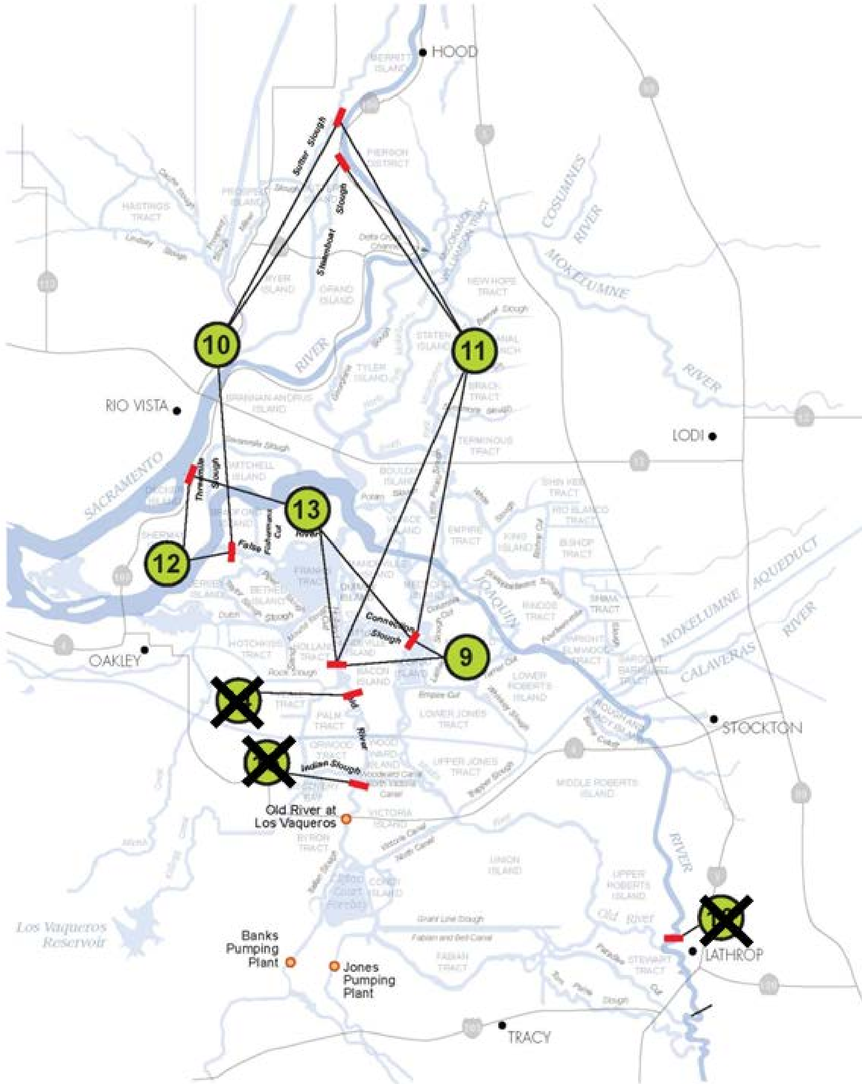
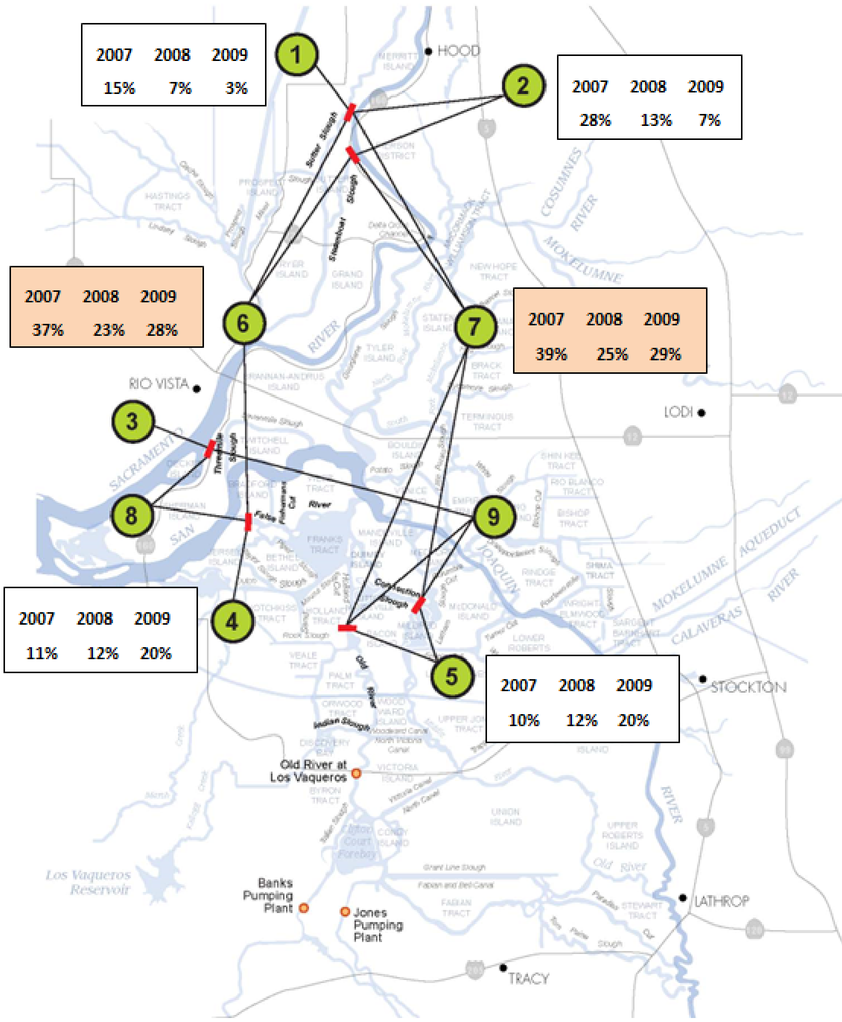


Figure 6-5 shows the barrier locations for the Phase 2 analysis. The Phase 2 alternatives were modeled and analyzed using DSM2 for the July through November historical period of the three years, 2007 to 2009.

6.3.1 Checking if DSM2 Forecast Results Matched Conclusions of 2009 Emergency Barriers Report

DSM2 was run with each of the proposed barrier locations shown in Figure 6-5. The Three Mile Slough barrier and any combination of barriers with Three Mile Slough were dropped from consideration because that barrier/gate must be operable to be effective. Three Mile Slough, with its high tidal flows and velocities, could not reasonably be constructed in time to help reduce pumping salinities. As a result, the barrier locations that were evaluated for impacts were Sutter Slough, Steamboat Slough, False River, and Two Gate (Connection Slough and Old River). Reductions in salinity for the combinations of Sutter, Steamboat and Two Gate versus Sutter Steamboat, and False River were very similar with the former combination resulting is slightly better EC. However, the Two Gate configuration was dropped in favor of the Sutter, Steamboat and False River configuration for reasons not related to salinity modeling.

Figure 6-5 Location of Barriers and Average Electrical Conductivity Reduction at Banks Pumping Plant - Phase 2, 2009 Emergency Barriers Report



Figures 6-6 and 6-7 show the flow boundary conditions for DSM2 for the early February forecast. Inflows and export values were given by the DCO model. Consumptive use was the very high consumptive use (Run 3) mentioned earlier, and the net Delta outflow was calculated by adding all inflows and subtracting exports and diversions. For this simulation, net Delta outflow drops to less than 3000 cfs in February and drops to less than 1000 cfs in August before rising again to more than 3000 cfs in September.

Figure 6-6 Early February 2014 Forecasted Inflows and Net Delta Outflow

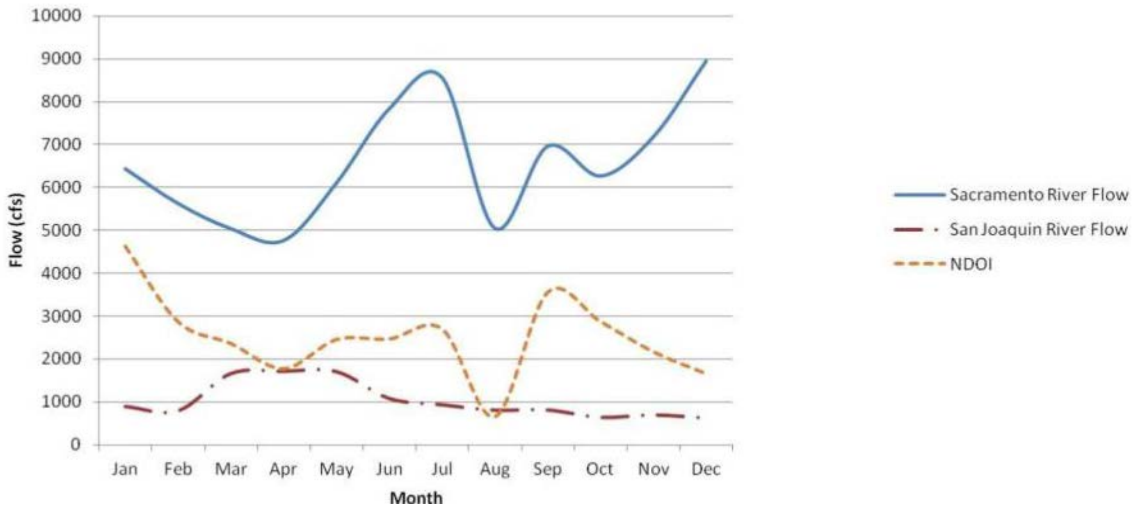
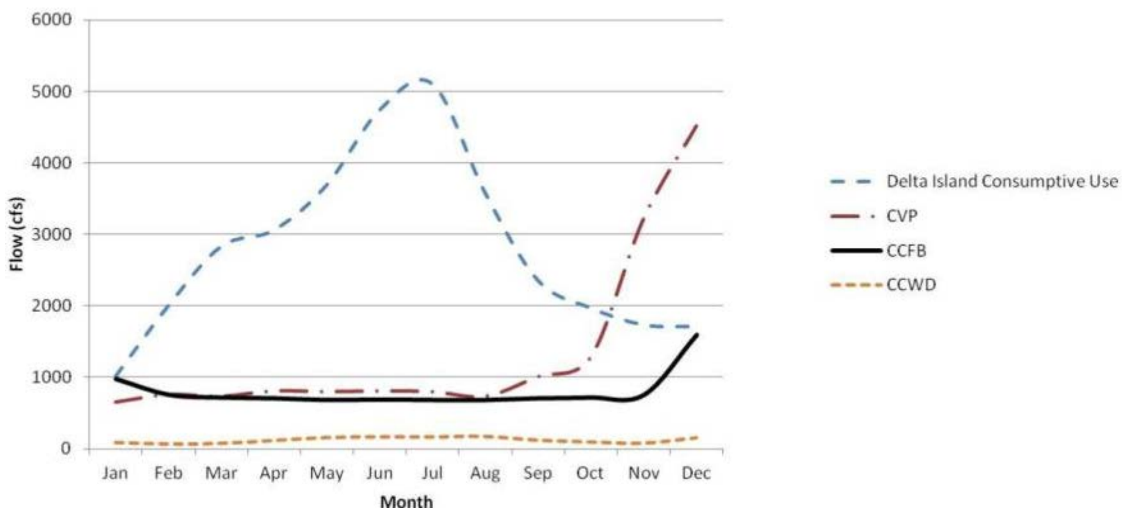


Figure 6-7 Early February 2014 Forecasted Exports and Diversions



Figures 6-8 and 6-9 show the impacts of the individual barriers and combined barriers for Clifton Court Forebay and Emmaton. The selection of installing the barriers on April 1 in the model was arbitrary and a starting point for evaluating the impacts of the barriers. In 2009 (Figure 6-5), the Sutter Slough barrier provided a 3% reduction in EC at Clifton Court Forebay. These simulations checked, among other things, that the installation of a Sutter Slough barrier would provide a significant reduction in salinity in the central/south Delta. The simulations, not surprisingly, indicated that there would be degradation in EC along the Sacramento River at Emmaton and Rio Vista due primarily to the Sutter and Steamboat Slough barriers.

Figure 6-8 Early February 2014 Forecast

With and Without Barriers - Clifton Court Forebay EC

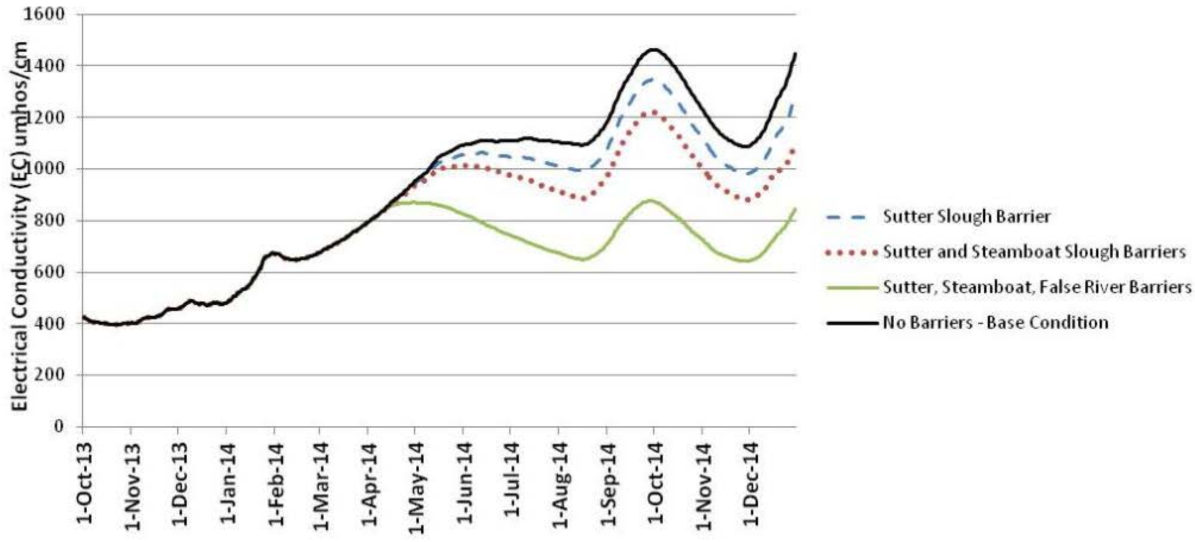


Figure 6-9 Early February 2014 Forecast With and Without Barriers - Emmaton EC

6.4 February 20 and March 21 Forecasts

6.4.1 Evolving Objectives for Studies

Early on, the goal for the barriers was to reduce the EC in the Delta so that most of the D-1641 water quality standards could be met given that a limited amount of water was available for release to help prevent salinity intrusion. Early forecasts, including the February 20 forecast, indicated that if the reservoirs were operated so that all of the water quality objectives were met, then by midsummer there would not be enough water to release to prevent salinity from intruding, resulting in large increases in EC throughout most of the Delta.

Later forecasts that included historical precipitation prior to March 21 had enough reservoirs storage to meet the 1000 EC or 250 CL objectives through August. The available storage in Oroville, Shasta and Folsom barely touched Power Pool levels in the March 21 forecast. DWR currently cannot release water below Power Pool.

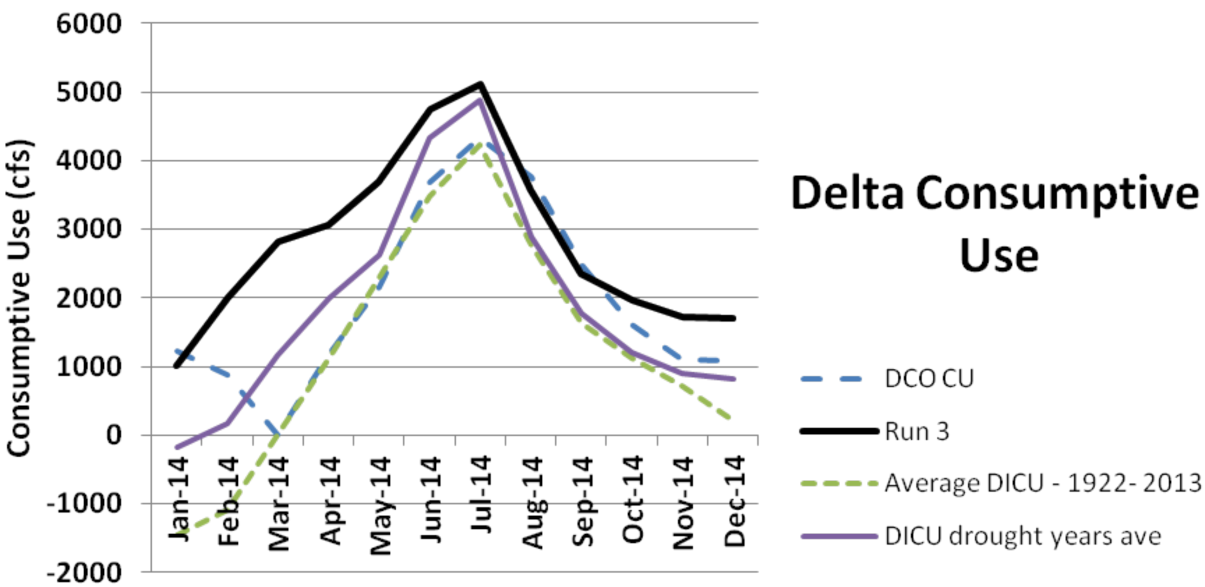
After the March 21 forecast, the goal for the barriers was to see if the reservoirs could release less water and still meet most of the objectives. This saved water could be released later in the year or next year if dry conditions persisted. Additional model simulations were performed to determine the water cost or savings.

The sections below describe a few of the simulations completed to evaluate the effectiveness of the barriers for water quality, velocities and water levels. Although the initial focus was on water quality when choosing the barrier locations, other hydrodynamic impacts needed to be evaluated. A summary of that work is also presented below.

6.4.2 Delta Island Consumptive Use Estimates

As stated earlier, Delta Island consumptive use was an important input into the Delta models. This section describes some of the different consumptive use values used in the various forecasts. Figure 6-10 shows a comparison between Run 3, DCO CU, DICU drought year average consumptive use, and DICU average consumptive use.

Figure 6-10 Monthly Consumptive Use Values Used in DSM2 Simulations



For the early February forecast, before the February 9 storm, the very high consumptive use values, Run 3, were used as input into the model. The February 20 forecast also used the Run 3 consumptive use values for the minimum release simulations. There were also simulations that investigated impacts with other consumptive use levels including a no diversions and no drainage scenario. For the forecasts that looked at meeting water quality objectives until storage water was not available, DSM2 also was run using the consumptive use in the DCO model (DCO CU). In both cases, where Run 3 and DCO CU were used as input, there was not enough storage water to meet water quality objectives in the Delta for the February 20 forecast. For the March 21 forecast, the DCO CU was used as input to the DSM2 simulations. Because of the additional rain that had occurred during February and March, the lower consumptive use values seemed to be a better estimate than the previous Run 3 values.

6.4.3 February 20 Forecast

6.4.3.1 February 20 Forecast Assumptions

The assumptions for the February 20 forecasts are the following:

- The DSM2 simulations used as their input, output from the February 20 DCO forecast by DWR's Operations and Maintenance. The forecast assumes a 90% historical hydrology. Two types of forecasts were analyzed. The first was a minimum releases forecast where water is released over time but does not meet the D-1641 water quality objectives. In the second forecast type, water was released to meet the D-1641 water quality objectives until there was not water available to release.

- Three different operations of the Delta Cross Channel were evaluated:
  - Delta Cross Channel operated to D-1641,
  - Delta Cross Channel operated diurnally through May 22,
  - and Delta Cross Channel open.
- The high consumptive use, Run 3, was used as input to DSM2. No consumptive use and the DCO consumptive use was also used as input for some of the simulations.
- The temporary barriers in Grant Line Canal, Old River at Tracy, and at the head of Old River were installed at the end of March for the simulations.
- Separate simulations were made evaluating the salinity impacts of installing the emergency barriers on April 1, May 1, and June 1.

Figures 6-11 and 6-12 show the forecasted inflows, net Delta Outflow, exports, and the high Run 3 consumptive use values used as input to DSM2.

Figure 6-11 February 20, 2014 Forecasted Inflows and Net Delta Outflow

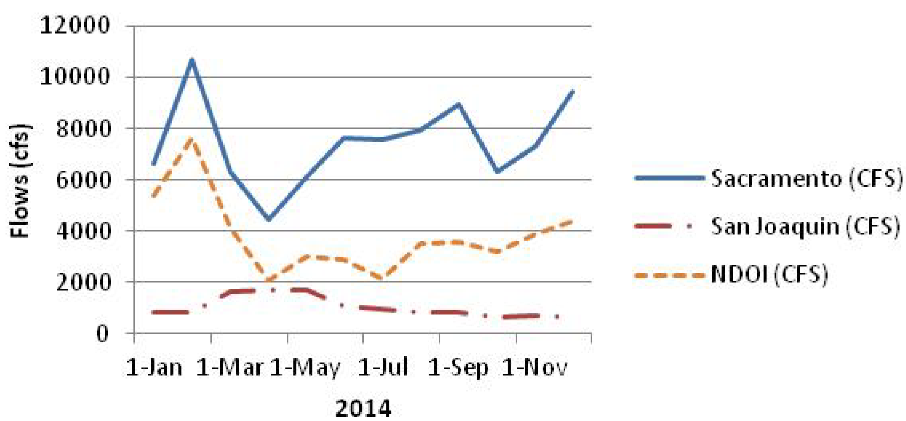
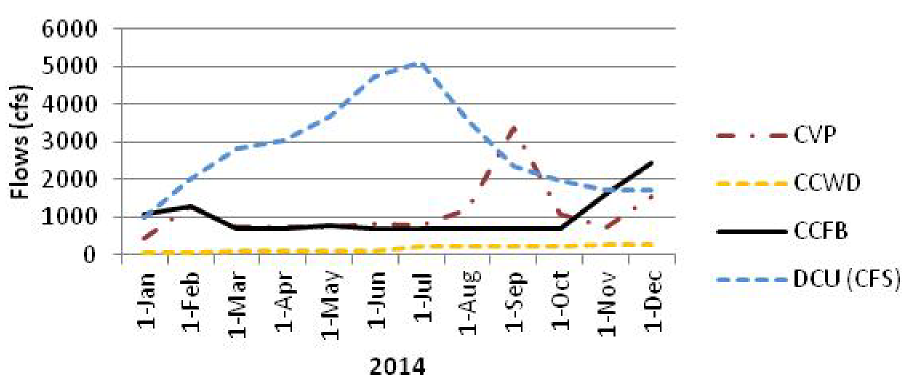


Figure 6-12 February 20, 2014 Forecasted Exports and Diversions



6.4.3.2 February 20 Forecast Results

Figures 6-13 and 6-14 show EC results for various emergency barrier installation times and the end of month reservoir storage for Oroville, Shasta, and Folsom. In Figure 6-13, there is a salinity increase at

Rio Vista, due to the emergency barriers. This is expected, due primarily to the flow moving through the north and central Delta because of barriers in Sutter and Steamboat Slough. In Figure 6-14, there is a decrease in salinity at Clifton Court Forebay due the emergency barriers. The barriers keep the EC below 1000 uS/cm for the minimum releases scenario for Clifton Court Forebay.

Figure 6-15 shows the same forecast plotted with 2013-2014 historical data and 1976-1977 historical data at Clifton Court Forebay. There are a few items to note from this graph.

- 2013 and 1976 were dry years leading into a dry year.
- DSM2 underpredicts historical EC at Clifton Court Forebay by more than 100 uS/cm.
- 2013- 2014 follows the salinity pattern of 1976-1977.
- Emergency barriers provide a significant reduction in salinity at Clifton Court Forebay.

Figure 6-16 shows EC results at Clifton Court Forebay with the assumption that water is released from reservoirs so that the D-1641 water quality objectives are met in the Delta through higher Sacramento River flow. When the reservoirs reach Power Pool, the reservoirs no longer release water. (DWR currently cannot release below the Power Pool level). Figure 6-17 also shows that when barriers are installed July 1, the EC at Clifton Court Forebay reduces but does not make it to less than 1000 uS/cm. This indicates that in order to meet a 1000 uS/cm EC at Clifton Court Forebay or a 250 Cl at Rock Slough, barriers would need to be installed earlier in the season with a reduced Sacramento inflow.

Figure 6-13 February 20th, 2014 Forecasted Rio Vista Electrical Conductivity and End of Month Storage

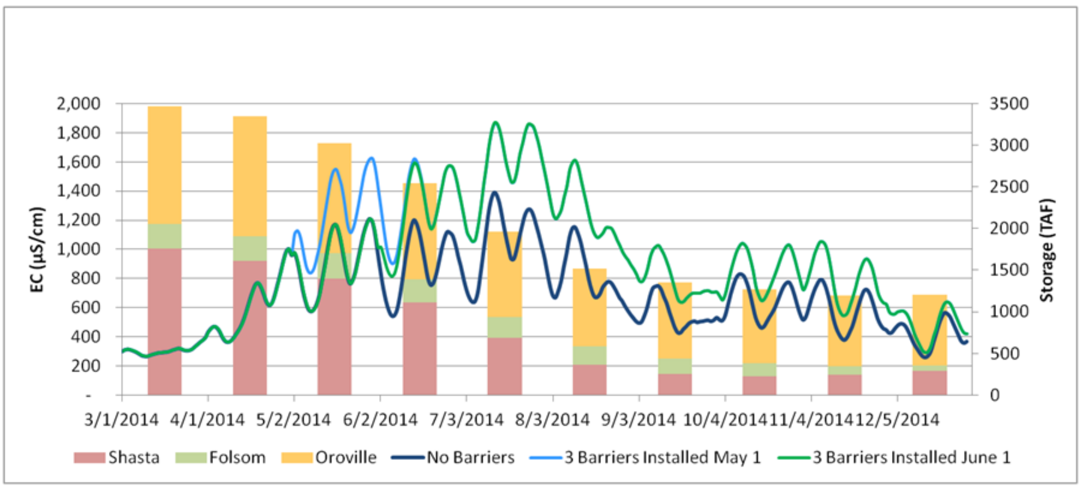


Figure 6-14 February 20, 2014 Forecasted Clifton Court Forebay Electrical Conductivity and End of Month Storage

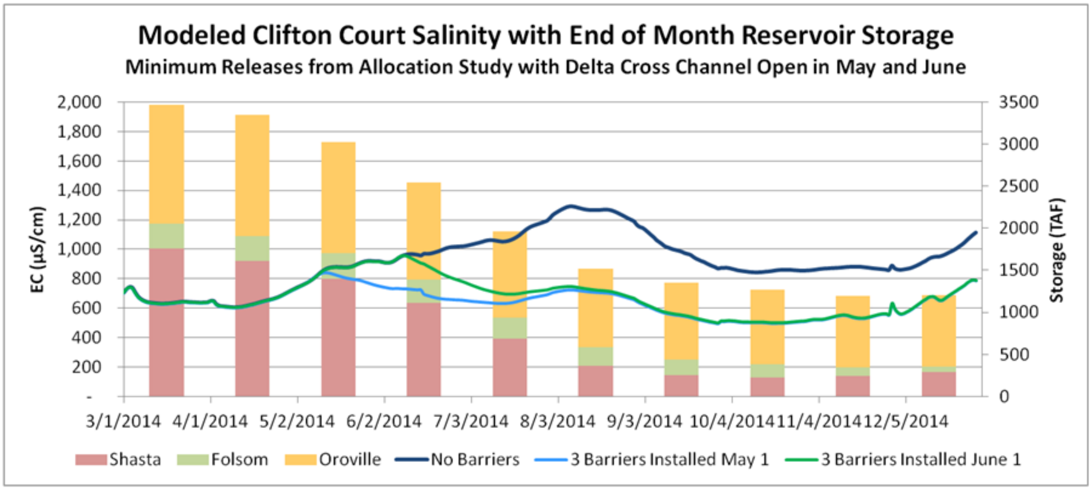


Figure 6-15 DSM2 Historical and February 20, 2014 Forecasted Clifton Court Forebay Electrical Conductivity Shown with EC from 1976-1977

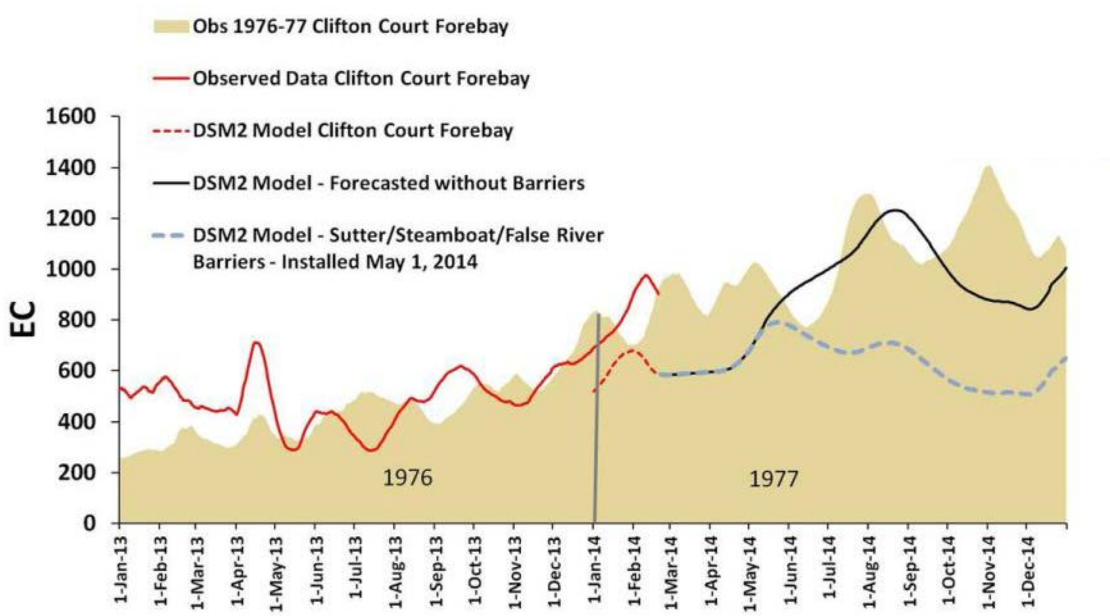


Figure 6-16 Modeled Clifton Court EC with End of Month Reservoir Storage February 20, 2014 Forecast

6.4.3.3 Discussion of Differences in Salinity Results between Different Delta Models

As part of the emergency barrier investigation, the State Water Contractors hired Resource Management Associates (RMA) to model different forecasted hydrologies with different barrier configurations using Water Allocation Model (WAM) and the RMA Bay-Delta Model. WAM is a one dimensional model that uses tidally averaged input and runs extremely fast so that many simulations can be made quickly. The RMA Bay-Delta Model is a combination 1-D/2-D model, representing the more complex western Delta and open water areas with a two dimensional grid. WAM has been calibrated to the RMA Bay-Delta Model.

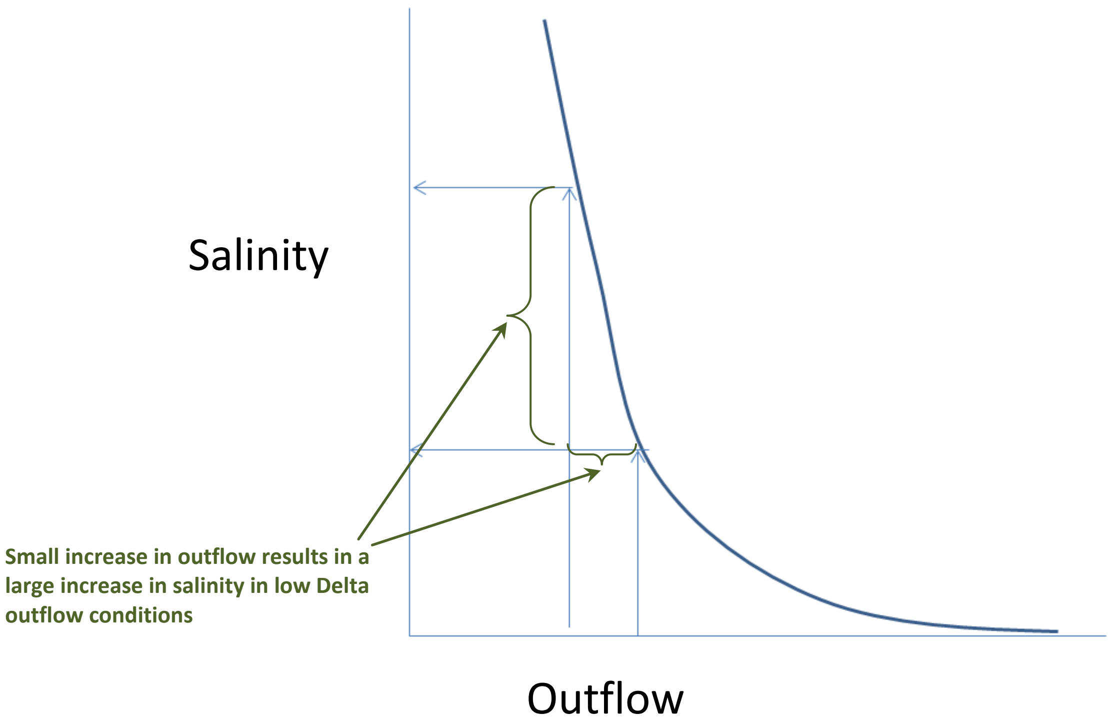
One of the hydrologies that RMA used as boundary conditions was the same February 20 forecast that DSM2 used. There were some differences in how the boundary conditions were incorporated but after some investigation, those differences did not account fully for the large differences in model results between the two models. RMA's EC results were quite a bit higher than DSM2's EC results. For example, at Clifton Court Forebay, peak EC for the RMA Bay-Delta Model reached 2100 uS/cm EC for the minimum releases forecast, where DSM2 was closer to 1300 uS/cm. Differences at the Northbay Aqueduct were much larger still. SELFE was also run and resulted in EC values higher than either RMA or DSM2.

So which of the three models is "right?" There is no simple answer to that question given the uncertainty in consumptive use, net Delta outflow and the lack of catastrophic salinity intrusion in the last 70 years to serve as ground truth. Although the salinity results from different modeling studies seem vastly different, the differences were mostly due to one model passing just over a "tipping point" with no operational attempt to intervene and the other model not – in such cases a relatively small change in Delta outflow can have large salinity effects. Figure 6-17 shows the conceptual relationship between outflow and salinity intrusion at the brink of non-compliance when salinity intrusion is fully developed on the east-west axis and starts to move south. The equilibrium response to outflow and the speed of salinity intrusion is slightly different between models, a point that is exacerbated by the fact that this regime is well out of their calibration range on modern data.

For these simulations, consumptive use in the Delta is a major component of outflow (Figure 6-11 and Figure 6-12) and also has the greatest uncertainty of any input. Figure 6-10 shows different consumptive use estimates derived from different year types and assumptions, all proposed for use in this year's drought modeling. The DICU estimate labeled Run 3 was used with DSM2, and has the highest consumptive use. With this consumptive use pattern DSM2 matches winter field data well. In contrast, SELFE, our 3-D model, over predicts runaway salinity intrusion with this level of consumptive use, but agrees well if the drought year average estimate shown in Figure 6-10 is used instead. The differences in outflow between the two estimates (800-1200 cfs) is substantial in terms of upstream storage depletion, but these estimates nonetheless represent the state of the art. Differences of 1000 cfs, coupled with a clear statement of operational intent, may be more palatable than allowing salinity to diverge without reason.

The differences between models also triggered an as-yet unresolved discussion as to the existence of equilibrium salinity ceiling at Martinez for low flow. Figure 6-18 was developed as part of the model investigation. The red and black lines are RMA forecasted EC and DSM2 boundary EC at Martinez for this year. The remaining lines are historical EC reconstructions at Martinez during severe drought years. The salinity data before 1991 were grab samples taken an hour and a half after high-high tide (roughly peak salinity), then converted to daily averages using historical relationships. Corresponding outflows are calculated using modern consumptive use estimates and do not account for agricultural response to high salinity.

Figure 6-17 Conceptual Plot of Relationship between Net Delta Outflow and Salinity in the Delta



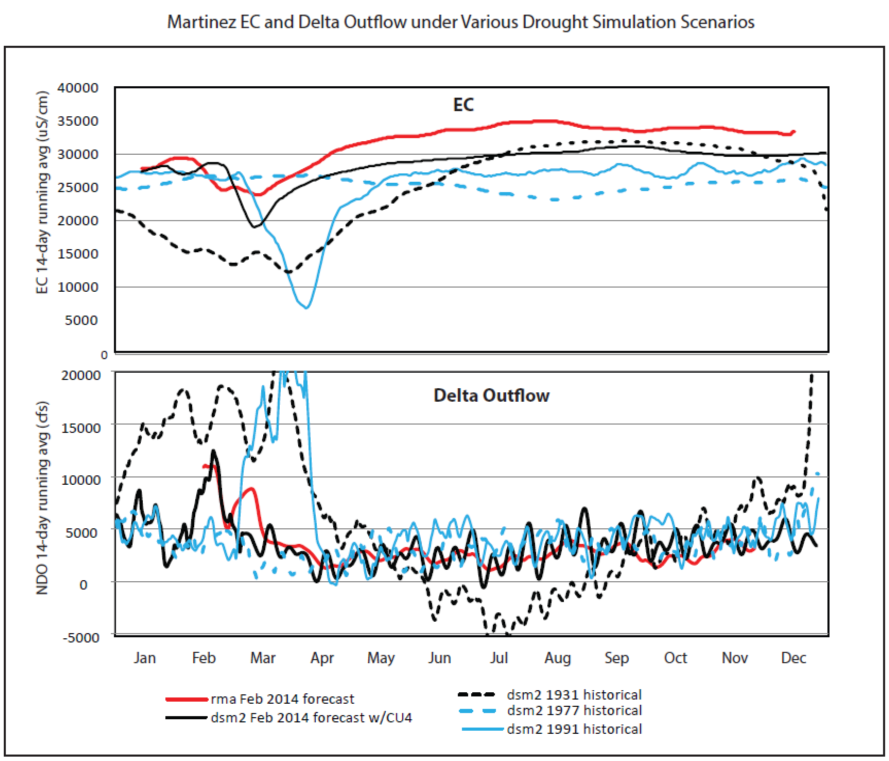
The processed grab sample data suggest, inconclusively, conductivity is bound from above at Martinez even in 1931, a year when outflow was probably less than zero and the 2 ppt chloride isohaline (roughly 3.5 ppt salinity) advanced within a few miles of Hood and the head of Old River. The existence of such a ceiling is consistent with data since the mid-1980s, when more modern monitoring began. However, for that part of the record the possibility of a physical maximum salinity is hard to confirm -- confounded by the regulatory maximum induced by upstream water quality standards

The existence of a near-ceiling to EC over a broad range of very low outflows has repercussions for modeling. An asymptotic limit is built into G-model, which is then carried over to the boundary estimation process for DSM2. Hence, DSM2 has no trouble reproducing this phenomenon, but our modeling workflow would need adjustments should the ceiling be disproved. Other models with boundaries much farther west do not reproduce the maximum. As shown in Figure 6-18, RMA predicts conditions at Martinez to be worse than 1931, 1977, and 1991, well outside its historical upper bound. The labels DSM2 1931 historical, DSM2 1977 historical, and DSM2 1991 historical are observed historical Martinez boundary condition data use for DSM2 and not G-Model determined values. SELFE had similar difficulties, although as previously mentioned the problems are resolved (and would, we think, be resolved in the RMA model also) by swapping consumptive use assumptions.

More investigation also needs to be made into how well the G-model represents the Martinez boundary condition in drought conditions. Given the estimated outflows, the G-model under-predicts the historical EC conditions at Martinez in 1991.

There is no resolution thus far on whether these differences arise from the models or the data, and a frustrating fraction of the data sources (including modern estimates of flow) have large, systematic sources of error and obvious historical non-stationarities. The Delta Modeling Section has begun an investigation into whether the current flow monitoring network can be used to better estimate historical outflow or consumptive use. This is difficult because net Delta outflow is a delicate residual phenomenon that is hard to accurately extract from instantaneous tidal flows that are 1-2 orders of magnitude larger.

Figure 6-18 February 20, 2014 Forecasted EC and Delta Ouflow as Compared to Historical Dry Years



6.4.4 March 21 Forecast

6.4.4.1 DSM2 March 21 Forecast Assumptions

The assumptions for the March 21 forecast are the following:

- The forecast incorporates storms up to March 21 but not following.
- The DSM2 simulations used as their input, output from the March 21 DCO forecast from DWR's Operations and Maintenance. The forecast assumes a 90% historical hydrology. In this forecast, water was released to meet the D-1641 water quality objectives. There was enough water to not go below Power Pool levels in the reservoirs.
- Two different operations of the Delta Cross Channel were evaluated:
  - Delta Cross Channel operated to D-1641,
  - Delta Cross Channel kept open.
- A total Delta consumptive use value from the DCO forecast was used (Figure 6-10, DCO CU). The monthly value was distributed among the DSM2 nodes using the ADICU program.
- The temporary barriers in Grant Line Canal, Old River at Tracy, and at the head of Old River were installed at the end of March for the simulations.
- Separate simulations were made evaluating the salinity impacts of installing the emergency barriers on May 1 and June 1.
- Separate simulations were made investigating the effects of keeping the culverts open on the Sutter and Steamboat Slough locations.

Figures 6-19 and 6-20 show the forecasted inflows, net Delta outflow, exports, and the consumptive use values used as input to DSM2 for the March 21 forecast. Net Delta outflow values are at about 4000 cfs or above for this forecast. In contrast, the net Delta outflow went to 2000 cfs at times in the February 20 forecast.

Figure 6-19 March 21, 2014 Forecasted Inflows and Net Delta Outflow

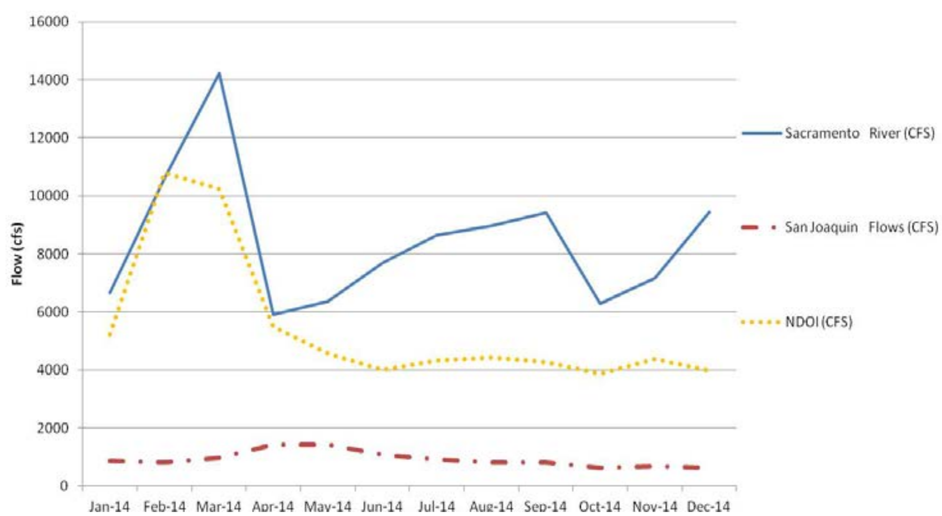
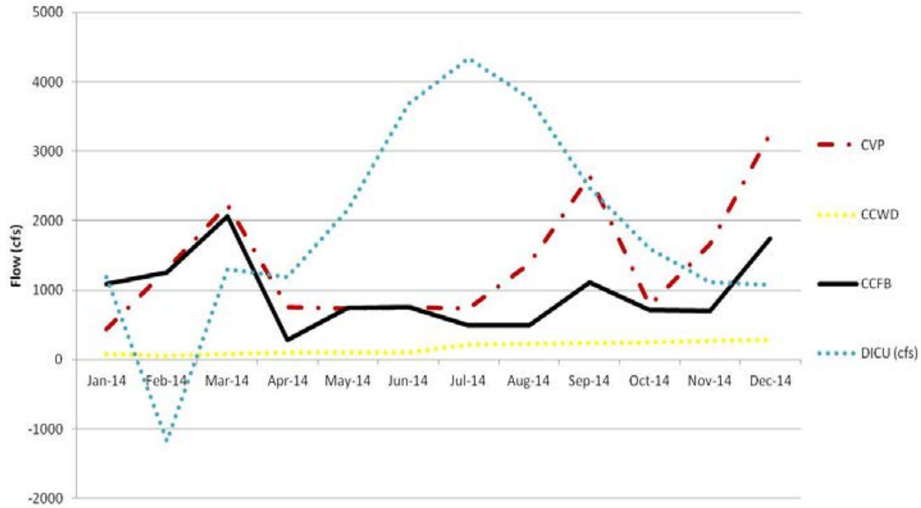


Figure 6-20 March 21, 2014 Forecasted Exports and Diversions



6.4.4.2 DSM2 March 21 Forecast Results

Figures 6-21 and 6-22 show the differences in results between the February 20 forecast and the March 21 forecast. Storms in late February and early March resulted in higher outflows which resulted in better water quality for the no-barrier simulations. EC starts to climb in the late fall due in part to increased exports beyond the health and safety levels (1500 cfs).

Figure 6-21 February 20 and March 21 Forecasted EC at Clifton Court Forebay

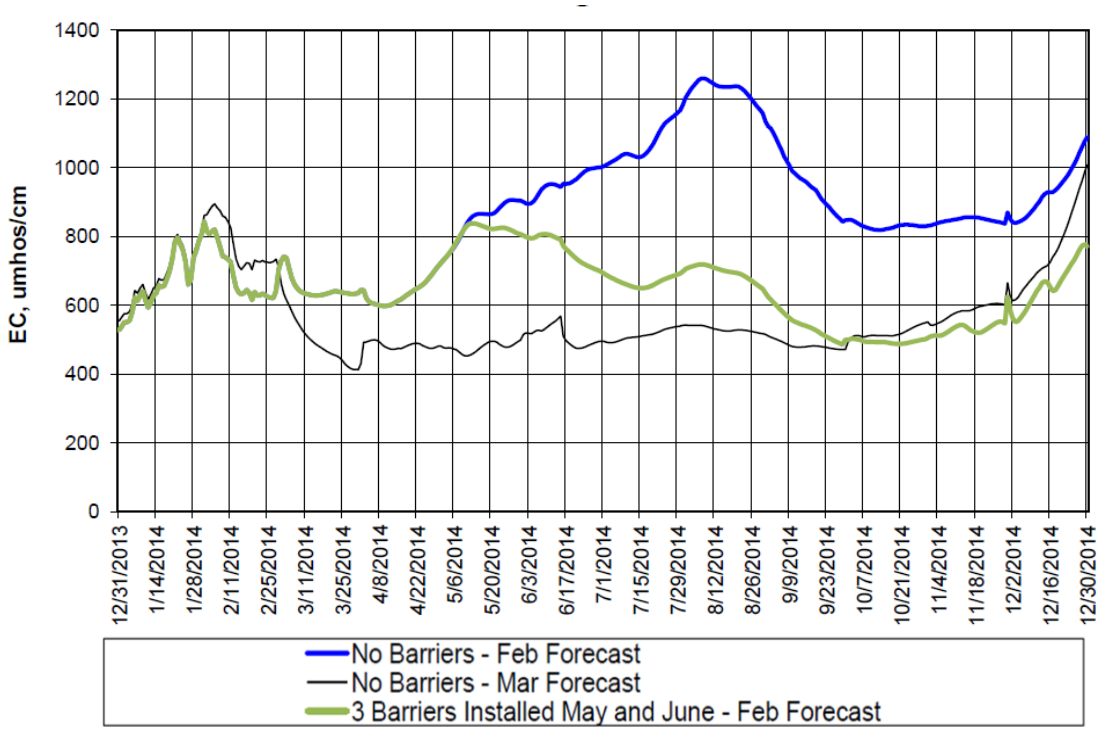
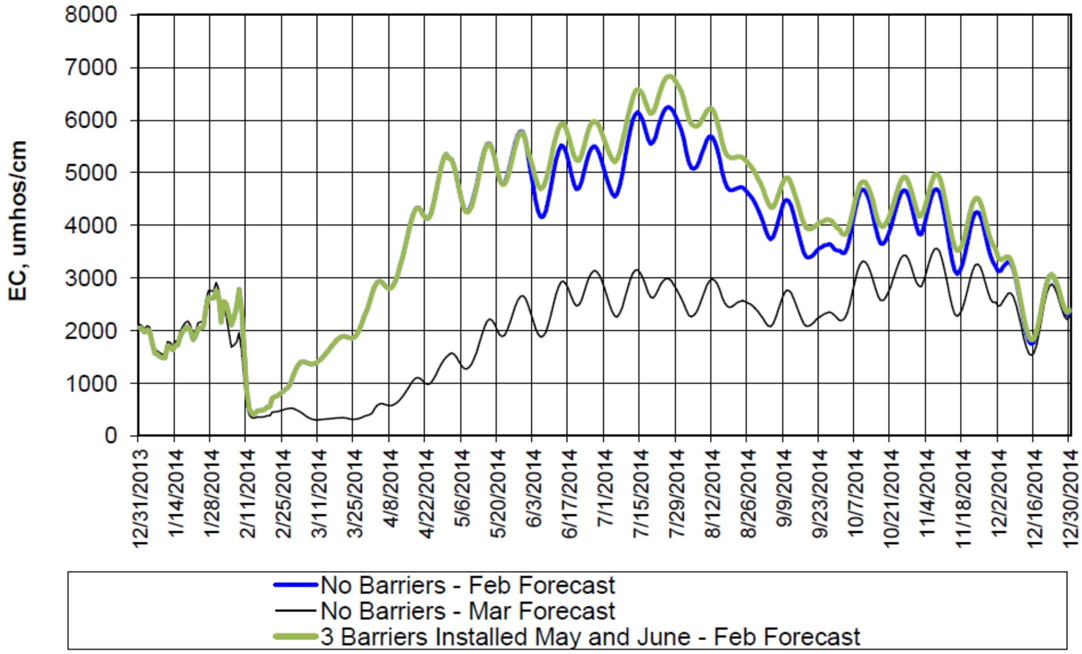


Figure 6-22 February 20 and March 21 Forecasted EC at Emmaton



6.4.5 Analysis Tools and Providing Information to Stakeholders

Due to the number of stakeholders affected and the need to quickly analyze and distribute the results, a few tools were developed or modified to streamline the process. Figures 6-23 and 6-24 show a spatial salinity comparison plot and a screen shot of a visualization tool originally developed by CH2M Hill for the Bay Delta Conservation Plan to evaluate different alternatives. The excel spreadsheet tool creates various graphs on water level, velocity, flow, and water quality results for several locations in the Delta. The tool was modified to give results for the one-year forecast (as opposed to the 16 years used in planning studies). Additional locations were added as needed.

Figure 6-25 shows a screen shot of an Excel spreadsheet velocity tool used to plot water levels and water quality in the areas upstream and downstream of the different barrier sites. These graphs were used to help in determining if mitigation measures were necessary because of potential harm caused by the barriers to farmers and other Delta water users.

Figures 6-26 and 6-27 show spatial velocity plots for Dutch Slough and Fisherman’s Cut. The results are from SELFE simulations and the plots, when animated over time, show where and when velocity hot spots occur. Higher velocities could cause scour, so these plots were used to aid in determining if the barriers would cause harm to the levees.

Figure 6-23 March 21 Forecast - Spatial Seasonal EC Comparison

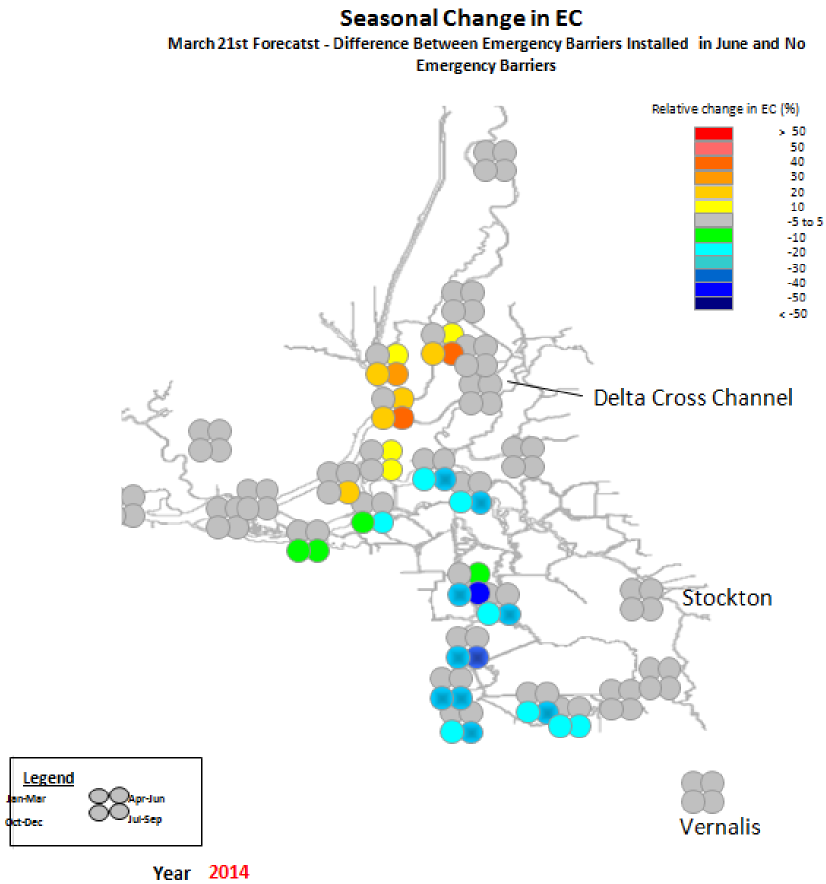


Figure 6-24 Modified BDCP Visualization Tool

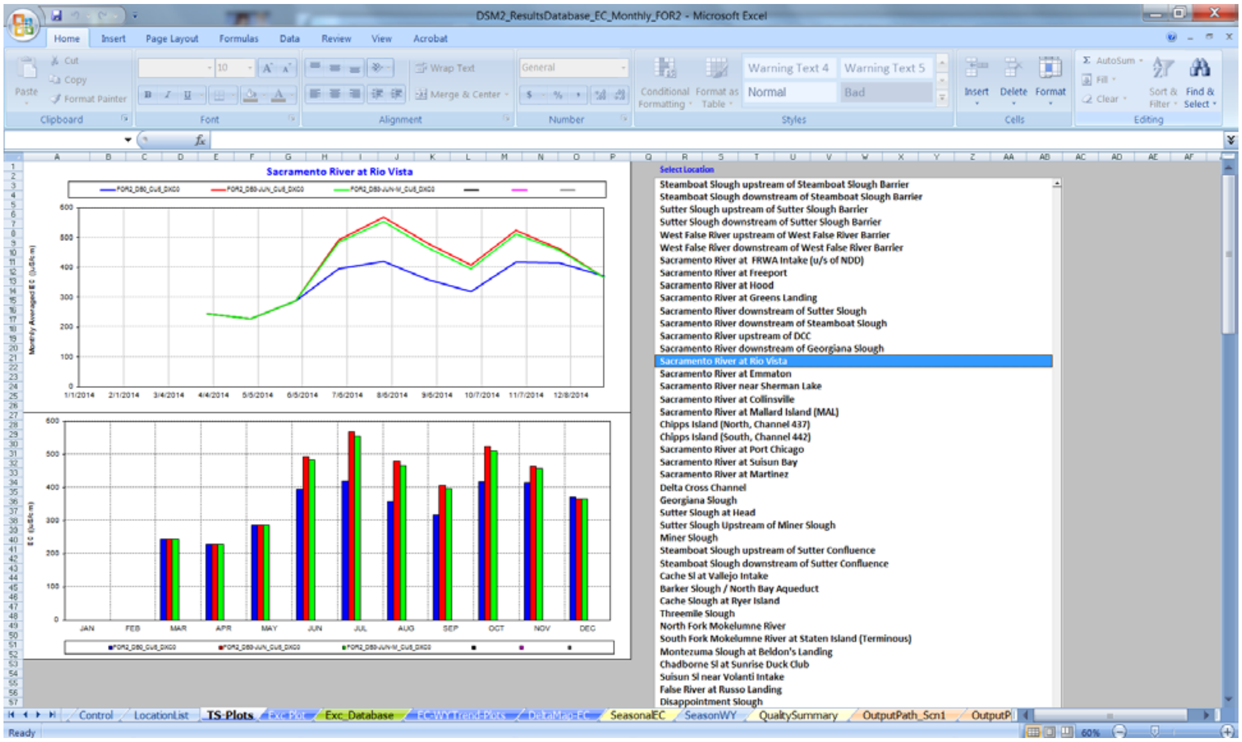


Figure 6-25 Stage and Velocity Tool for Locations Around the Barriers

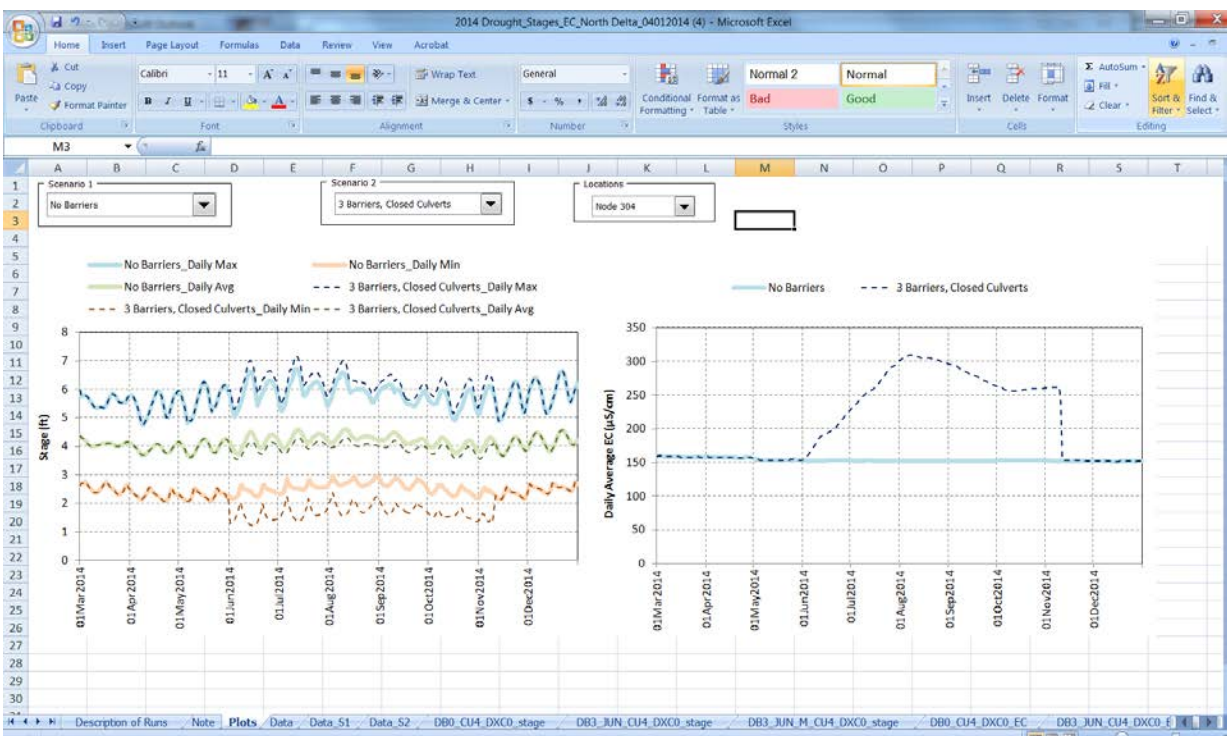


Figure 6-26 SELFE Spatial Velocity Distribution Plot for Dutch Slough

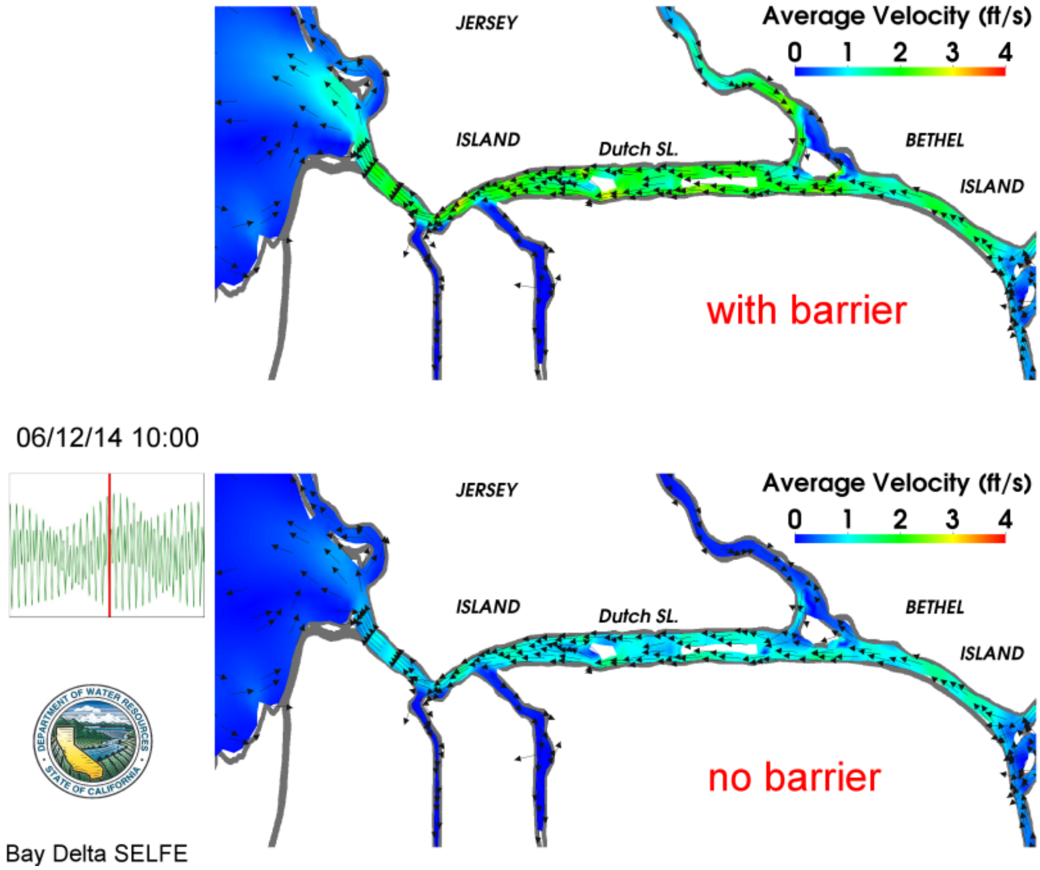
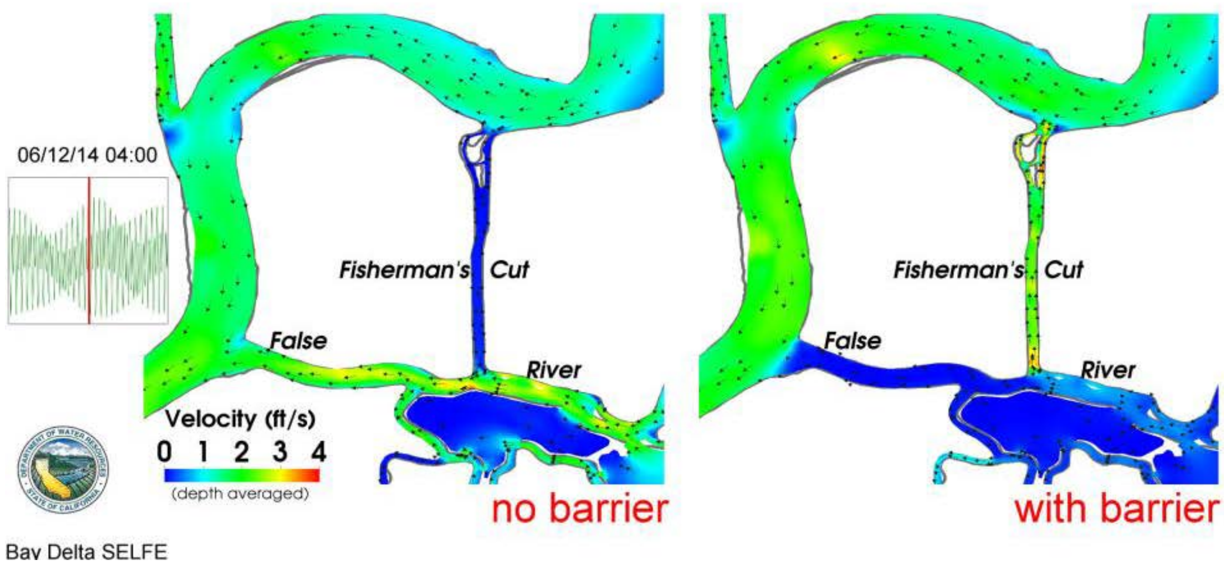


Figure 6-27 SELFE Spatial Velocity Distribution Plot for Fisherman's Cut



6.5 Water Cost Analysis Using the March 21, 2014 Forecast

In section 6.4.1, the evolving objectives of the studies were briefly discussed. When the March 21 forecast demonstrated that there would most likely be enough storage water to meet health and safety exports and keep salinity from intruding, further studies were done to determine if the emergency barriers could help in saving reservoir storage water for carry over storage, additional exports, or for environmental releases.

In order to determine water savings, DSM2 was run in an iterative process using a modified minimum water cost compliance problem tool (Ateljevich, 2002), http://modeling.water.ca.gov/delta/reports/annrpt/2002/2002Ch10.pdf.

In order to determine the water savings, the March 21 forecasted Sacramento flows are modified to change the net Delta outflow so that the salinity results for each alternative comply with the following D-1641 salinity objectives.

- Emmaton – 2.78 mmhos/cm
- San Joaquin at Jersey Point – 2.20 mmhos/cm
- South Fork at Terminous - 0.54 mmhos/cm
- San Joaquin at San Andreas Landing - 0.87 mmhos/cm
- West Canal at Mouth of CCFB – 1.0 mmhos/cm
- DMC at Tracy Pumping Plant – 1.0 mmhos/cm
- Rock Slough - 1.0 mmhos/cm (the assumption is that 1.0 mmhos/cm is approximately equal to 250 mg/l Cl)

Table 6-2 Net Delta Outflow Needed to Meet D-1641 Objectives for Various Alternatives

Objective	**Without Emergency Barriers**	**Emergency Barriers**	**NDO Difference(positive indicates water savings with barriers)**
Emmaton	3657 cfs	3893 cfs	-236 cfs
Relaxed	3045 cfs	2769 cfs	276 cfs
NDO Difference (positive indicates water savings with relaxed objectives)	612 cfs	1124 cfs	

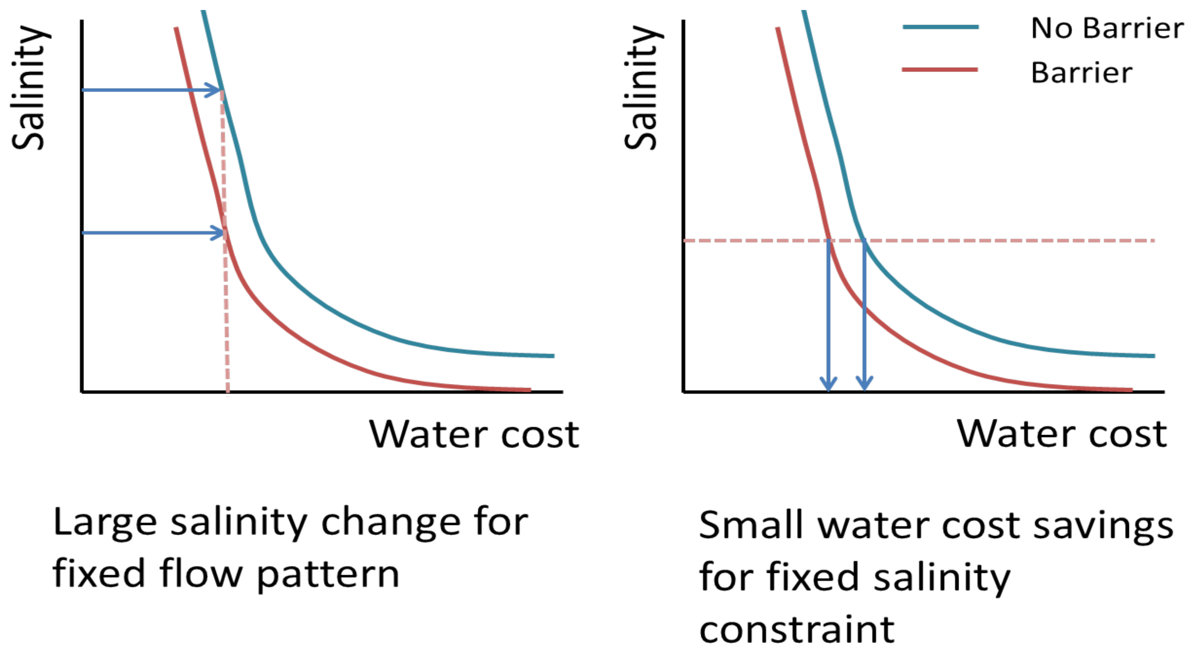
The average net Delta outflow needed over a five month horizon from the time of forecast to meet the D-1641 objectives for the various alternatives are shown in Table 6-3. (These are not equilibrium outflow-salinity relationships). These results reflect optimal release schedules and show the following:

- Meeting the Emmaton objective and installing the emergency barriers would result in a season-averaged water cost of 236 cfs. This is expected because with the barriers, the water quality is degraded at Emmaton.
- Relaxing the Emmaton objective without emergency barriers results in a season-averaged water savings of approximately 612 cfs, as compared to an Emmaton objective without barriers.
- Relaxation of the Emmaton D-1641 objective results in a season-averaged water savings of 1124 cfs when emergency barriers are installed.

- If the Emmaton objective is relaxed, the three barriers provide an additional water savings of about 280 cfs.

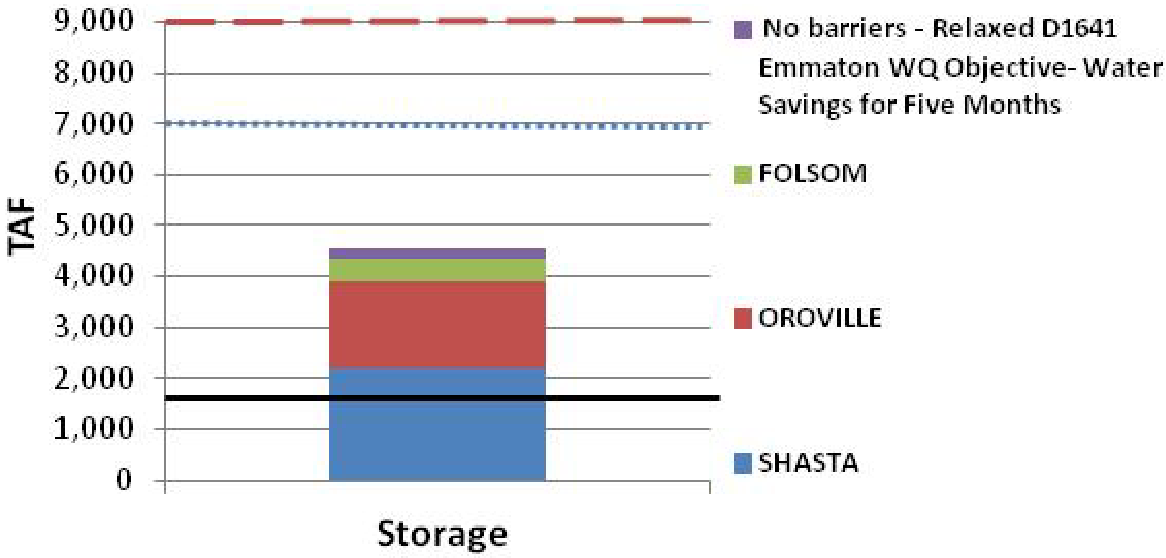
In this study, initial expectations by some were that the water savings would be larger. Conclusions concerning the limited water savings of the barriers do not conflict with earlier findings that the barriers provide significant water quality benefits for a fixed release schedule. "Salinity improvement for a given water cost" and "water cost for a given salinity" are different goals. Figure 6-28 illustrates the relationship between salinity improvement for a fixed water supply and water savings for a given salinity target for dry hydrological conditions.

Figure 6-28 Water Cost Savings and Salinity Relationship



To get a better idea of the water savings in relation to reservoir storage, the water savings calculated above were converted to thousand acre-feet per month or thousand acre-feet per 5 months, and plotted with the reservoir storage from March 31. Figure 6-29 shows the results for one of the alternatives. The black horizontal line represents the Power Pool level for the three reservoirs (Folsom, Shasta, and Oroville). The dotted blue line is the historical average reservoir storage for March 31. The dashed red line is the capacity of all three reservoirs.

Figure 6-29 Relaxed Emmaton Objective Water Savings Plotted with March 31, 2014 Reservoir Storage



After looking at the water savings/costs for relaxation of the Emmaton standards and the emergency barriers, additional modeling studies were done to analyze the water costs or savings that would occur by moving the D-1641objective at Emmaton to Three Mile Slough. Table 6-4 shows the net Delta outflow needed for relaxed Emmaton objectives, meeting the D-1641 objective at Emmaton, and moving the objective to Three Mile Slough, with and without emergency barriers.

For the case without barriers, the relaxed objective and the objective that is moved to Three Mile Slough results in the same net Delta outflow. Without barriers, the Three Mile Slough objective is not the controlling water quality objective. When emergency barriers are in place, moving the objective to Three Mile Slough results in only 5 cubic feet per second difference over the Three Mile Slough objective without barriers.

Table 6-3 Net Delta Outflow Needed to Meet D-1641 Objectives When Moved to Three Mile Slough

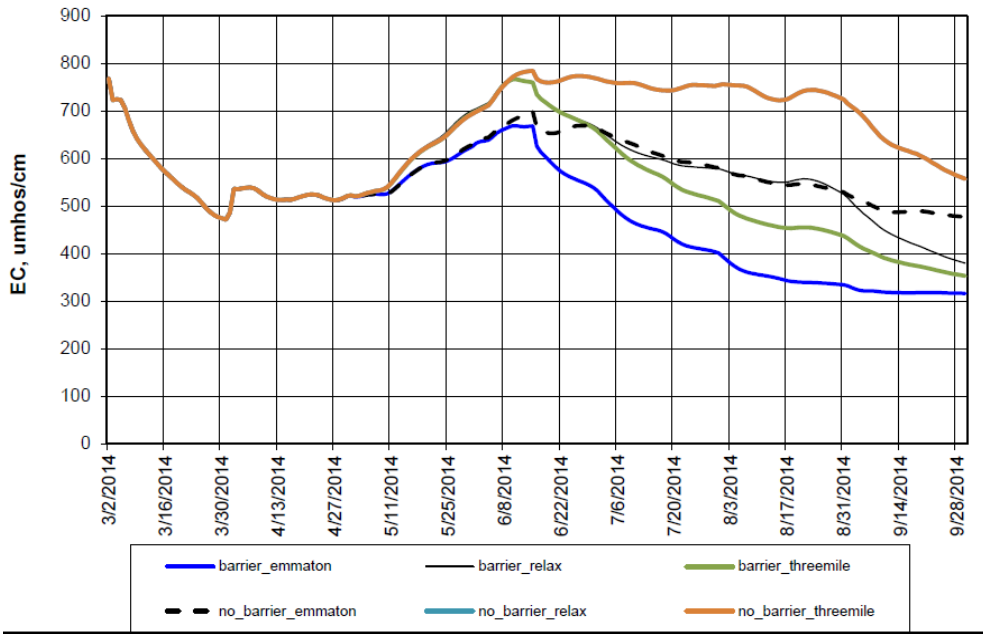
Objective	Without Emergency Barriers	Emergency Barriers	NDO Difference(positive indicates water savings with barriers)
Emmaton	3657 cfs	3893 cfs	-236 cfs
Three Mile	3045 cfs	3050 cfs	-5 cfs
Relaxed	3045 cfs	2769 cfs	276 cfs

Figure 6-30 shows the EC at Clifton Court Forebay for the alternatives described in Table 6-5. The without barriers alternative with the relaxed objective or the objective moved to Three Mile Slough results in the highest salinity at Clifton Court Forebay. With emergency barriers and a relaxed objective results in salinity that is about equal to or less in salinity than maintaining the Emmaton objective without emergency barriers.

Table 6-4 Description of Alternatives Shown in Figure 6-3

no_barrier _emmaton The 2.78 EC objective is met at Emmaton without barriers. This is the base condition. Net Delta Outflow is 3657 cfs.
barrier_emmaton The 2.78 EC objective is met at Emmaton with barriers installed. Net Delta Outflow is 3893 cfs
barrier_relax The water quality objectives are relaxed at Emmaton. Other locations still meet the water quality objectives. (Objectives that have number of days under 150 mg/l Cl have not been checked as part of this study). Net Delta outflow is 2769 cfs.
no_barrier_relax The water quality objectives are relaxed at Emmaton without barriers. Net Delta outflow is 3045 cfs.
barrier_threemile The water quality objective at Emmaton is shifted to Three Mile Slough (near Sacramento River). Barriers are installed. Net Delta outflow is 3050 cfs.
no_barrier_threemile The water quality objective at Emmaton is shifted to Three Miles Slough without barriers. Net Delta outflow is 3045.

Figure 6-30 Optimized DSM2 Forecasted EC at Clifton Court Forebay Using March 21 Forecast



6.6 Summary

Through the late winter and spring, Delta modeling was performed using historical information and forecasts that represented very dry conditions. Each forecast fed into the decision making process of if, when, and/or where emergency barriers would be installed. In early February, with a dry conditions forecast, the outlook was grim in terms of having enough water for upstream releases, meeting water quality objectives in the Delta, and being able to export enough water for health and safety needs. This led to the analysis on how to best meet most of the water quality objectives in the Delta. As part of the modeling output, potential negative impacts (and mitigation) for other stakeholders including western and northwestern Delta farmers/marinas, salmon migration, and smelt survival were considered. As precipitation occurred during the spring, the immediacy of installing the barriers started to diminish due to the likelihood that there was enough reservoir storage to make it through the summer. When this occurred, the objective of studies shifted to evaluate the water savings due to the installation of the barriers.

With the installation of the barriers, if all of the D-1641 water quality objectives are met, there is a water cost, not savings. The only water savings with barriers occur when the Emmaton objective is relaxed or moved. The largest water savings occurs with the relaxation or movement of the Emmaton objective. The barriers provide 1/4th of the water savings of relaxing the Emmaton objective alone. The barriers also improve water quality in the central and south Delta, and degrade water quality in the western and northwestern Delta.

At the writing of this chapter, additional studies are in process evaluating the impacts of relaxing or moving standards. Updated forecasts are being used to evaluate the effects of all three barriers and the False River barrier alone.

6.7 References

Ateljevich, E (2002). Optimal Control of Delta Salinity. Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh, 23rd Annual Progress Report. Chapter 10. State of California, Department of Water Resources

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