Appendix B
DSM2 Model Methods and Results

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Abbreviations and Acronyms

Banks Pumping Plant	Harvey O. Banks Pumping Plant
CalSim II	California Simulation Model II
Delta	Sacramento-San Joaquin River Delta
DMC	Delta-Mendota Canal
DSS	Data Storage System
DSM2	Delta Simulation Model II
DWR	California Department of Water Resources
EC	electrical conductivity
Jones Pumping Plant	C.W. “Bill” Jones Pumping Plant
μmhos/cm	micromhos per centimeter
SJR	San Joaquin River

Appendix B
DSM2 Model Methods and Results

B.1 Overview of DSM2 Model

Delta Simulation Model II (DSM2) is a one-dimensional mathematical model for dynamic simulation of one-dimensional hydrodynamics, water quality, and particle tracking in a network of riverine or estuarine channels. DSM2 can calculate stages, flows, velocities, mass transport processes for conservative and nonconservative constituents including salts, water temperature, dissolved oxygen, and trihalomethane formation potential, and transport of individual particles. DSM2 thus provides a powerful simulation package for analysis of complex hydrodynamic, water quality, and ecological conditions in riverine and estuarine systems. Information on DSM2, its development, and calibration can be found in the Delta Modeling section annual reports on California Department of Water Resources' (DWR's) website (http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/annualreports.cfm).

DSM2 consists of two modules that have been used for this project: HYDRO and QUAL. HYDRO simulates one-dimensional hydrodynamics including flows, velocities, depth, and water surface elevations. HYDRO provides the flow input for QUAL. QUAL simulates one-dimensional fate and transport of conservative and nonconservative water quality constituents given a flow field simulated by HYDRO.

DSM2 is capable of using the Sacramento-San Joaquin River Delta (Delta) boundary conditions from California Simulation Model II (CalSim II) to evaluate conditions in the Delta. For this project, CalSim II is first run for the No-Action Alternative condition, to provide DSM2 with boundary conditions (flow and electrical conductivity [EC] at Vernalis, and Delta outflow). DSM2 is then run for the No-Action Alternative condition. DSM2 provides Delta-Mendota Canal (DMC) water quality conditions back to CalSim II to establish a background water quality condition. CalSim II is then run again to evaluate water operations for the alternative plans, and then revised Delta boundary conditions (flow and EC at Vernalis) from the second CalSim II simulation are input to DSM2, which is run again to determine effects on the Delta for the alternative plans. This iterative process is shown on **Figure B-1**.

Note that only one feedback iteration of DSM2 results is fed into CalSim II in the methodology used. Greater accuracy would be obtained if the final DSM2

Simulation: CalSim II No-Action Alternative

CalSim II Output used as Input for DSM2: No-Action Alternative Delta boundary conditions including Vernalis flow and EC, Jones and Banks pumping rates, Delta outflow

↓

Simulation: DSM2 No-Action Alternative

DSM2 Output used as Input for CalSim II: FNA EC in DMC

↓

Simulation: CalSim II alternative plans

CalSim II Output (Alternatives A2, B2, C, D) and post-processing spreadsheet tool output (Alternatives A1, B1) used as Input for DSM2: Alternative Vernalis flow and EC, Jones and Banks pumping (Delta outflow was not significantly different from No-Action Alternative run; therefore revised values not used for next DSM2 runs)

↓

Simulation: DSM2 action alternative

DSM2 Output: Action alternative flow, EC, source fraction at all locations inside the Delta

Figure B-1. CalSim II and DSM2 Model Iterations

results for water quality in the DMC were again fed back into CalSim II, which would then generate new boundary conditions for DSM2, which would again be run to predict water quality throughout the Delta, including in the DMC. This procedure would be repeated until the difference in DMC water quality did not vary between iterations. However, such a procedure is too computationally expensive, so only one feedback iteration has been performed. After viewing the results of the single iteration, the need for future iterations was assessed and is described in the uncertainty/sensitivity portion of this appendix (**Section B6**).

A map of the Delta and DSM2 boundary conditions is shown on **Figure B-2**.

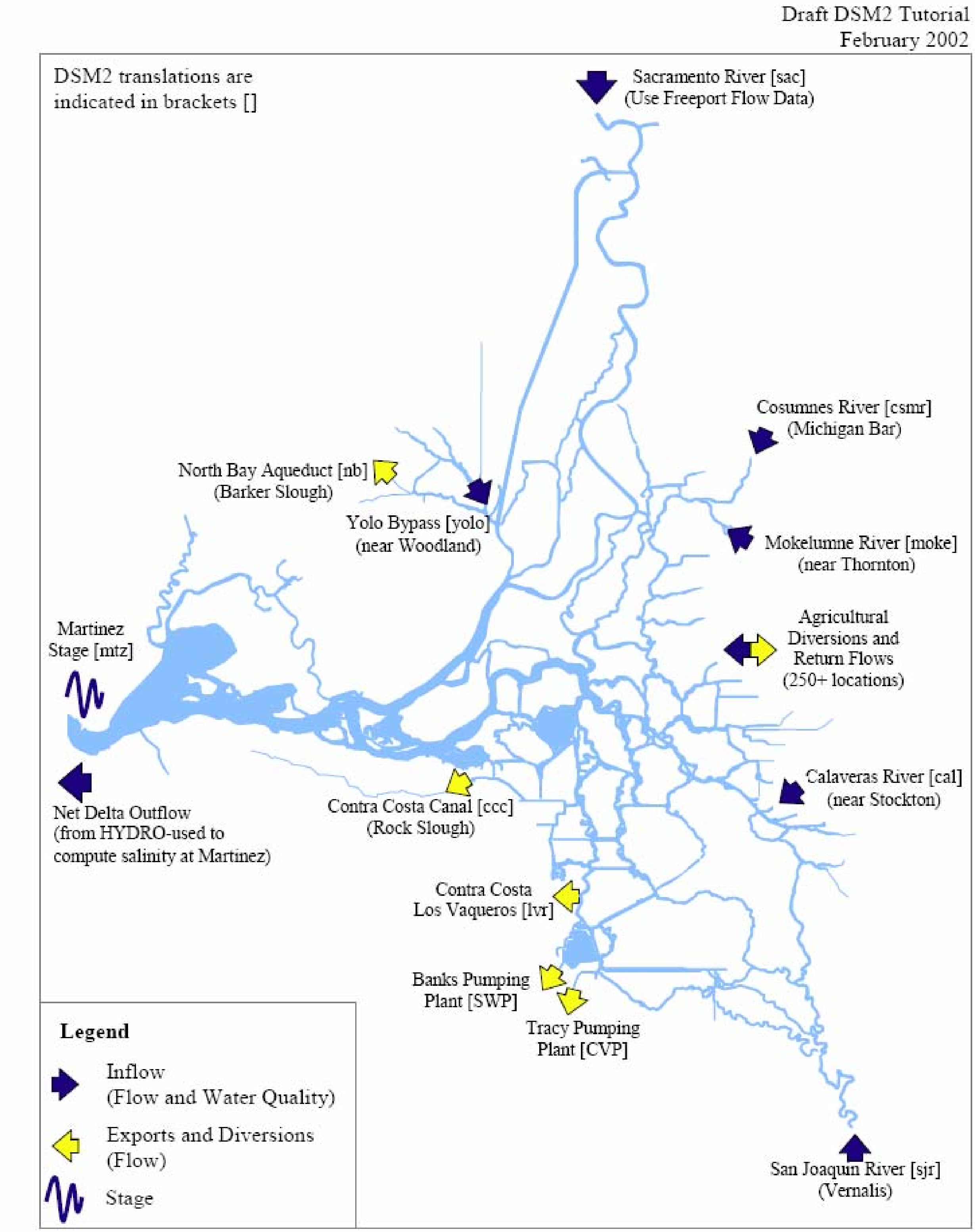

Figure B-2. Map of the Delta and DSM2 Boundary Conditions

B.2 Key Input Assumptions

B.2.1 General Assumptions

DWR Modeling Support Branch staff set up DSM2 for use in the DMC Recirculation Feasibility Study. The analysis assumes that all future alternative plans, including the No-Action Alternative, would utilize temporary barriers and the existing geometry that does not include dredging. The Common Assumptions future Level of Development setup includes the permanent operable gates recommended in the Final Environmental Impact Statement/Report for the South Delta Improvements Program, so for this project the Common Assumptions Version 8D DSM2 setup was modified to include the temporary barriers instead of permanent gates. The Common Assumptions Program is an effort to develop consistency and efficiency among the various surface water storage investigations carried out by DWR, the Bureau of Reclamation, and the California Bay-Delta Authority, and includes standard parameters for existing and future levels of development, agricultural water use, gate operations, dredging, and diversions. MBK Engineers performed the hydrology simulations (**Appendix A**). They used a calibrated modified CalSim II San Joaquin River (SJR) model and a spreadsheet tool that they developed. Some alternative plans require use of the spreadsheet model to post-process CalSim results and generate the DSM2 inputs. Eighty-two years of hydrology with adjusted astronomical tides were run for existing conditions (No-Project Alternative), the No-Action Alternative, and each of the recirculation alternative plans. **Appendix A** includes hydrologic and hydraulic simulations for the alternative plans given in **Figure B-3**.

Table B-1 lists general modeling assumptions that were considered when setting up the DSM2 model for the Plan Formulation Report analysis. In addition to the alternative plans in **Figure B-3**, the alternative analysis requires simulations of existing conditions and future conditions under the No-Project Alternative and the No-Action Alternative, respectively.

All of the CalSim alternative plan simulations depend on the No-Action Alternative output from DSM2. DSM2 is used to determine EC at C.W. “Bill” Jones Pumping Plant (Jones Pumping Plant) and in the DMC for the No-Action Alternative; EC in the DMC is then input back to CalSim (or the MBK spreadsheet model for Alternative B1, which was not modeled with CalSim) to determine the amount of recirculation required to meet water quality standards at Vernalis. Output from CalSim (Vernalis flow and EC and Harvey O. Banks [Banks] and Jones pumping rates) then serves as input to DSM2 for the alternative plans.

A	B	C	D
Federal Facilities Only	**Federal and State Facilities**	**Federal and State Facilities**	**Federal and State Facilities**
		Limited Reduction of CVP Deliveries	**Recirculation Priority to CVP Deliveries**
• Excess Jones PP • No CVP/SWP impact	• Excess Jones PP • Excess Banks PP	• Excess Jones PP for Vernalis flow and water quality • Excess Banks PP for Vernalis flow and quality • CVP facilities then used for recirculation for Vernalis flow in priority to CVP Delta export deliveries	• Excess Jones PP and Banks PP used first for Vernalis flow and quality • CVP facilities then used for recirculation for Vernalis flow and quality in priority to CVP Delta export deliveries
A1 **Supplement Vernalis Compliance**	**B1** **Supplement Vernalis Compliance**		
• Supplemental to New Melones release	• Supplemental to New Melones release		
A2 **Supplement Vernalis Compliance and Enhance New Melones Water Supply**	**B2** **Supplement Vernalis Compliance and Enhance New Melones Water Supply**		
• Prior to New Melones release	• Prior to New Melones release	• Prior to New Melones release	• Prior to New Melones release

Key:

CVP = Central Valley Project

PP = Pumping Plant

SWP = State Water Project

Figure B-3. Alternative Plan Matrix

Table B-1. General Modeling Assumptions

Existing Conditions	**Future Conditions**
Temporary Barriers	Temporary Barriers
Contra Costa Water District intakes at Rock Slough and Highway 4	All 3 CCWD CalSim outputs are used but AIP flows are lumped at Highway 4
2005 LOD	2030 LOD
2005 DICU	2030 DICU
No SDIP (temporary barriers used)	No SDIP (temporary barriers used)
No Dredging	No Dredging
North of Delta operations ignored	North of Delta operations ignored

Key:

AIP = Alternative Intake Project

CalSim = California Simulation Model II

CCWD = Contra Costa Water District

DICU = Delta Island Consumptive Use

LOD = Level of Development

SDIP = South Delta Improvements Program

Detailed Model Assumptions:

- Model output is used from 1922 to 2003, after a spin-up year in 1921.
- DWR's astronomical tide is used for water level at Martinez, which accounts for spring-neap and seasonal variations in tidal elevation, as opposed to earlier DSM2 studies that used tides with only a semidiurnal variation.
- EC at Martinez is estimated using DWR's astronomical tide and total Delta outflow from CalSim II, assuming constant values for seawater salinity and freshwater salinity. The Martinez EC for the alternative plans is considered the same as for the No-Action Alternative, because total Delta outflow varies only slightly with the alternative plans. For Alternative D (in which Delta outflow differs from that of the No-Action Alternative the most), this introduces a maximum error in EC of 2.7% at Station RSAN007 (Suisun Bay, close to Martinez), but this error decays to less than 1% in the Middle and Old Rivers and at the intakes to the Jones and Banks pumping plants.
- Boundary flows and tides from CalSim II are divided into 14 periods per year (10 full months + 4 Vernalis Adaptive Management Plan periods).
- EC for the SJR: from CalSim II.
- EC for Delta Island return flows: DWR standard values (constant monthly values).
- EC for other flows: Sacramento, Calaveras rivers at 175 microSiemens per centimeter; Mokelumne and Cosumnes rivers (Eastside Streams), and Yolo Bypass at 150 microSiemens per centimeter.
- South Delta barriers: Physical features and operation as temporary barriers for existing and future runs.
- Delta Cross Channel output: from CalSim II.
- Contra Costa Water District diversions at Rock Slough, Los Vaqueros Intake, and (for future) the Alternative Intake Project; note that the Alternative Intake Project export flows are added to the Contra Costa Water District's Old River Highway 4 pumping plant. Due to the South Delta geometry and export flows, DWR has indicated that any difference between water pulled from Old River and water pulled from Victoria Canal should be negligible (DWR memo, February 5, 2008).

B.2.2 Source Fraction Analysis

In addition to tracing EC throughout the Delta, DSM2 was configured to track the waters from each boundary source (SJR, Sacramento River, Yolo Bypass, Eastside streams, Delta Island drains, and Calaveras River) and from Martinez and, thus, to determine the volume fraction of water originating from each source, at any location in the Delta (described in detail at http://modeling.water.ca.gov/delta/reports/annrpt/2002/2002Ch14.pdf). Source fraction data are used to understand better the effect of subtle flow changes between the alternative plans and to assess potential effects on migration of anadromous fish.

This effort required the addition of a distinct tracer at each boundary stream, each with a concentration of 10,000 parts per million. After spinning up the model, each point throughout the Delta consisted of waters originating from all of these sources. The volume fraction of water coming from a given source *i* is thus

$$V_{i,\%} = \frac{C_i}{\sum_i C_i} \times 100\% \qquad \text{(B-1)}$$

where C_i is the concentration of the tracer from source *i* in the channel or reservoir of interest.

For the case of future project conditions with recirculation occurring, the volume fraction of recirculated Sacramento River water was tracked as well, which required an additional spreadsheet calculation to find the dilution of Sacramento River water. The concentration C_i of water from each source *i* in the DMC was assumed to be the C_i of that constituent at Jones Pumping Plant for the No-Action Alternative. The concentration of original Sacramento River water reentering the SJR via the DMC is then

$$C_{SAC,recirc} = [Q_{recirc} * C_{SAC}] / Q_{total} \qquad \text{(B-2)}$$

where C_{SAC} is the concentration of Sacramento River water at Jones Pumping Plant for the No-Action Alternative, Q_{recirc} is the flow rate being recirculated, and Q_{total} is the total SJR flow rate at Vernalis. For the purposes of this calculation for the alternative plans, C_{SAC} at Jones Pumping Plant is taken from the results of the No-Action Alternative model run because no better estimate of C_{SAC} at Jones Pumping Plant exists than that from the No-Action Alternative model run. Therefore, volume fingerprinting for recirculated water is only an approximation. Volume fraction for non-recirculated water (new water entering the model at a boundary), however, is exact for all cases.

B.2.3 Generation of DSM2 Input Files

DSM2 uses Data Storage System (DSS) files to read in boundary flows, Martinez tides, barrier operations, and Delta Island Consumptive Use diversions and returns. Monthly output from the CalSim II "transfer" (Delta) model by MBK engineers is used for all boundary flows other than Jones and Banks pumping plants, and SJR flow and EC at Vernalis. This "transfer" model was run for the No-Project/No-Action Alternatives; for the alternative plans, the No-Action Alternative model was used, and only Jones and Banks pumping plants and Vernalis flow and EC are altered based upon either CalSim II SJR results (for Alternatives B2 and D) or MBK spreadsheet calculations (for Alternative B1).

Preprocessing consisted of interpolating monthly CalSim II data to daily values, varying with month and pulse period, and modifying a Middle River gate operation to prevent the river channel from drying up in the simulation. After preprocessing, DSM2 was run for existing conditions (the No-Project Alternative), the No-Action Alternative, and Alternatives B1, B2, and D.

B.3 DSM2 Model Output

Table B-2 summarizes the locations at which DSM2 output DSS files containing flow, stage, velocity, EC, and source fractions with a 1-day period. Channel and node locations, and positive flow directions, are as specified on the DSM2 grid map located on the DWR website (http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/DSM2_Grid2.0.pdf).

Table B-2. Output Data Locations

Station	Location	Output Parameters	DSM2 Channel or Node Number
RSAN072	SJR at Brandt Bridge	Flow, stage, EC, source fraction	Channel 10, 9,400 feet from upstream end
ROLD059	Old River at Tracy Road	Flow, stage, EC	Channel 71, 3,116 feet from upstream end
RSAN112	SJR at Vernalis	Flow, stage, EC	Channel 17, downstream end
RMID041	Middle River at Mowry	Flow, stage, EC	Channel 125, 1,700 feet from upstream end
RSAN007	SJR at Antioch	Flow, stage, EC, source fraction	Channel 52, 366 feet from upstream end
RSAN037	SJR Mandeville Island	Flow, stage, EC, source fraction	Channel 42, 286 feet from upstream end

Table B-2. Output Data Locations

Station	Location	Output Parameters	DSM2 Channel or Node Number
RSAN087	SJR Mossdale	Flow, stage, EC, source fraction	Channel 6, upstream end
ROLD024	Old River west of Bacon Island	Flow, stage, EC, source fraction	Channel 106, 2,718 feet from upstream end
ROLD034	Old River west of Victoria Island	Flow, stage, EC, source fraction	Channel 90, 3,021 feet from upstream end
midr_s_turn_cut	Middle River south of Turner Cut	Flow, stage, EC, source fraction	Channel 149, upstream end
CHGLR009	Grant Line Canal at Tracy Road	Flow, stage, EC, source fraction	Channel 207, 36 feet from upstream end
CHVTOOO	Victoria Canal	Flow, stage, EC	Channel 229, 1,328 feet from upstream end
SLRCK005	Rock Slough CCWD intake	Flow, stage, EC	Channel 247, upstream end
CLFCT	Clifton Court Forebay	Flow, stage, EC	Node 72
chdmc006	Tracy Pumping Plant	Flow, stage, EC, source fraction	Channel 216, upstream end
RSAN052	SJR at Ringe Pump	Flow, stage, EC, source fraction	Channel 24, 2,643 feet from upstream end

Key:

CCWD = Contra Costa Water District
DSM2 = Delta Simulation Model II
ED = electrical conductivity
SJR = San Joaquin River

B.4 Quality Checking

DSM2 outputs were quality checked by comparing the output SJR flow and salinity at Vernalis to the boundary input (CalSim II) values. Since the locations of input and output Vernalis flow and salinity values differ only by the length of one channel segment (of length 13,150 feet), the values follow each other closely, as expected. Differences are usually due to transients present in the DSM2 model; since the model is time-dependent, responses to inputs are not immediate, but take time to propagate through the system. Outputs were also detail checked to ensure that data were transferred from the output DSS files to the correct columns on the output data template spreadsheets.

B.5 Results

B.5.1 Electrical Conductivity

Water quality objectives for the South Delta require 30-day running averages of EC be less than 1,000 µmhos/cm (September 1–March 31) or 700 µmhos/cm (April 1–August 31). The sites at which these EC criteria must be met are the SJR at Vernalis, SJR at Brandt Bridge, Middle River near Mowry, and Old River at Tracy Road Bridge. **Table B-3** shows the number of days during which EC is predicted to be above the objective at each site, for all modeled alternative plans. These occurrences are enumerated for three cases:

Table B-3. Number of 30-Day Running Averages During Which Electrical Conductivity is Above Water Quality Objective

EC tolerance = 0	Alternative Plans				
Site	No-Project Alternative	No-Action Alternative	B1	B2	D
Middle River at Mowery	1921	570	498	482	458
Old River at Tracy Road	2258	1061	923	922	895
SJR at Brandt Bridge	1940	580	498	486	456
SJR at Vernalis	770	227	165	178	174

EC tolerance = 0.005 * EC standard	Alternative Plans				
Site	No-Project Alternative	No-Action Alternative	B1	B2	D
Middle River at Mowery	1285	270	237	246	215
Old River at Tracy Road	2029	928	814	801	789
SJR at Brandt Bridge	1269	317	285	291	239
SJR at Vernalis	507	61	46	42	28

EC tolerance = 0.01 * EC standard	Alternative Plans				
Site	No-Project Alternative	No-Action Alternative	B1	B2	D
Middle River at Mowery	732	108	94	87	76
Old River at Tracy Road	1585	729	670	660	639
SJR at Brandt Bridge	685	136	116	114	96
SJR at Vernalis	392	28	27	11	11

Key:

µmhos/cm = micromhos per centimeter
EC = electrical conductivity
SJR = San Joaquin River

Figures B-4 to B-7 also present the number of 30-day running averages during which EC rises above water quality objectives at each station, and shows how the numbers of events vary from year to year. Dry years (such as the 1987–1992 drought) show many more such events than do wet years (such as the 1997-1998 El Nino season).

Table B-4 presents the same results as in **Table B-3**, but shows the percentage of all running averages of the 82-year DSM2 simulation for which the predicted EC is above objectives. **Table B-5** presents the mean, median, and standard deviation of the difference between the modeled EC and the objective, for each event where the model predicts EC above the objective. These statistics do not change significantly among alternative plans, indicating that the events removed through recirculation are small events with EC only slightly above water quality objectives, while large events (likely the results of drought years) remain in all cases.

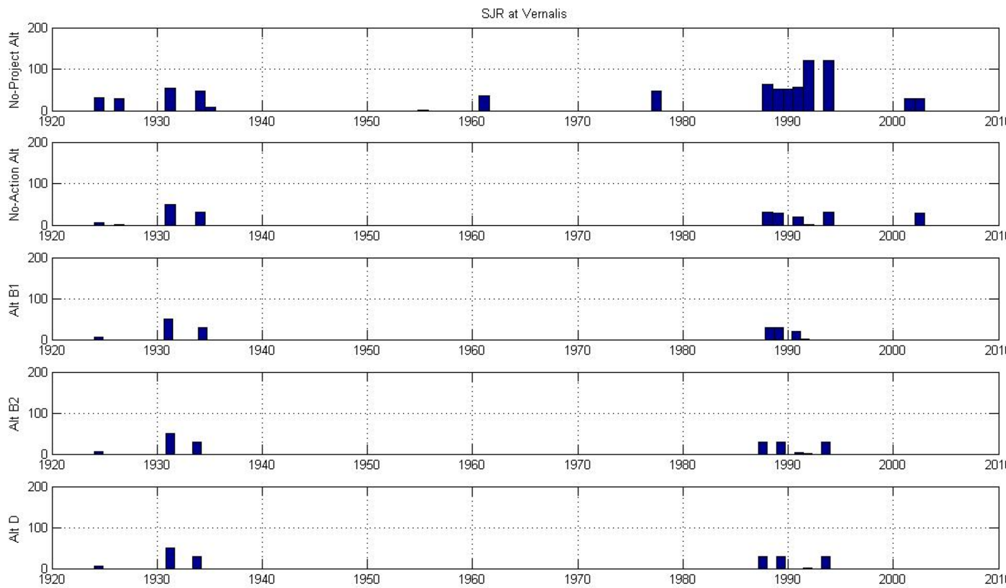

Figure B-4. Number of 30-day Running Averages of Electrical Conductivity that are Higher than the Water Quality Objective for Years between 1922 and 2002 for San Joaquin River at Vernalis

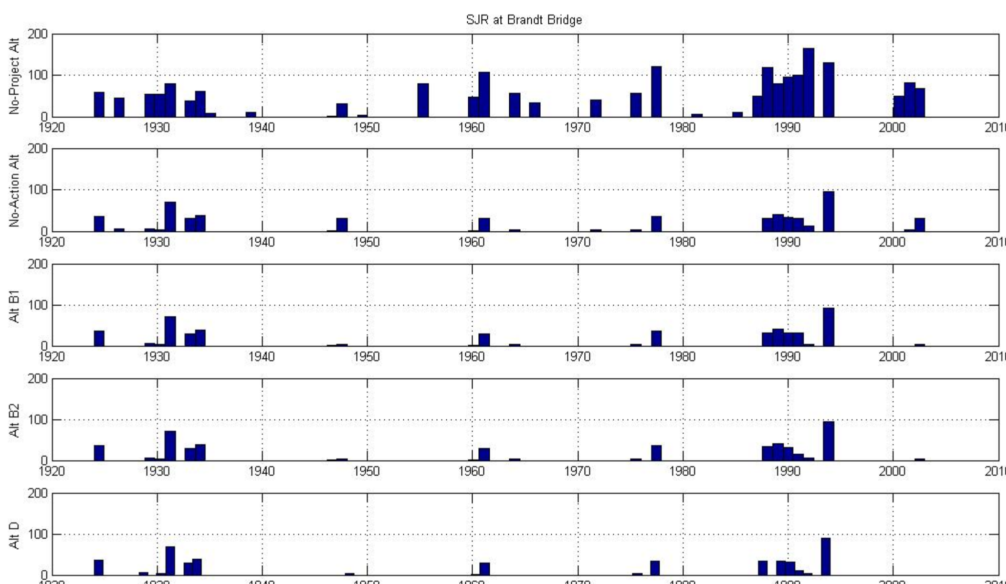

Figure B-5. Number of 30-day Running Averages During Which Electrical Conductivity Rises Above Water Quality Objectives in the San Joaquin River at Brandt Bridge

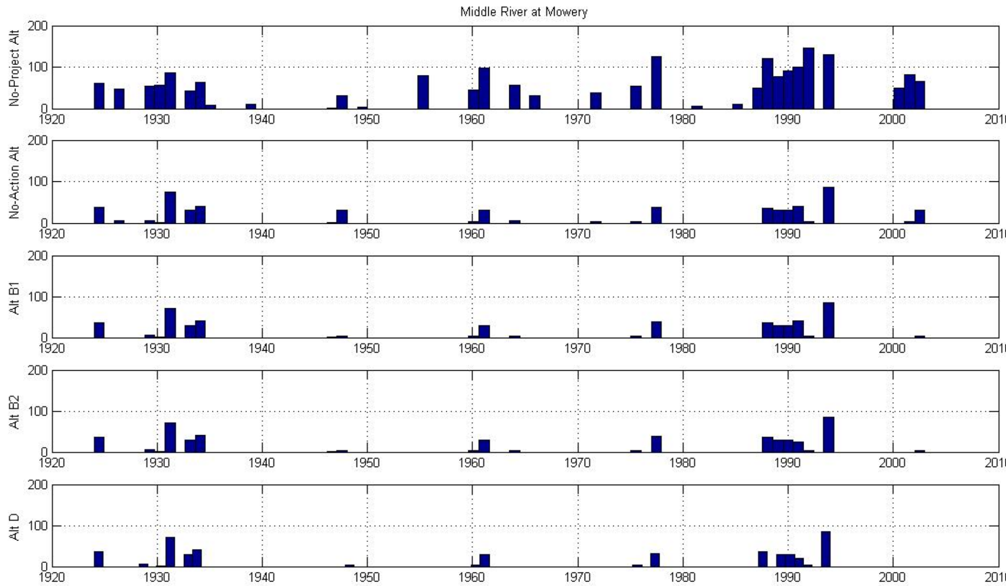

Figure B-6. Number of 30-day Running Averages During Which Electrical Conductivity Rises Above Water Quality Objectives in the Middle River at Mowery

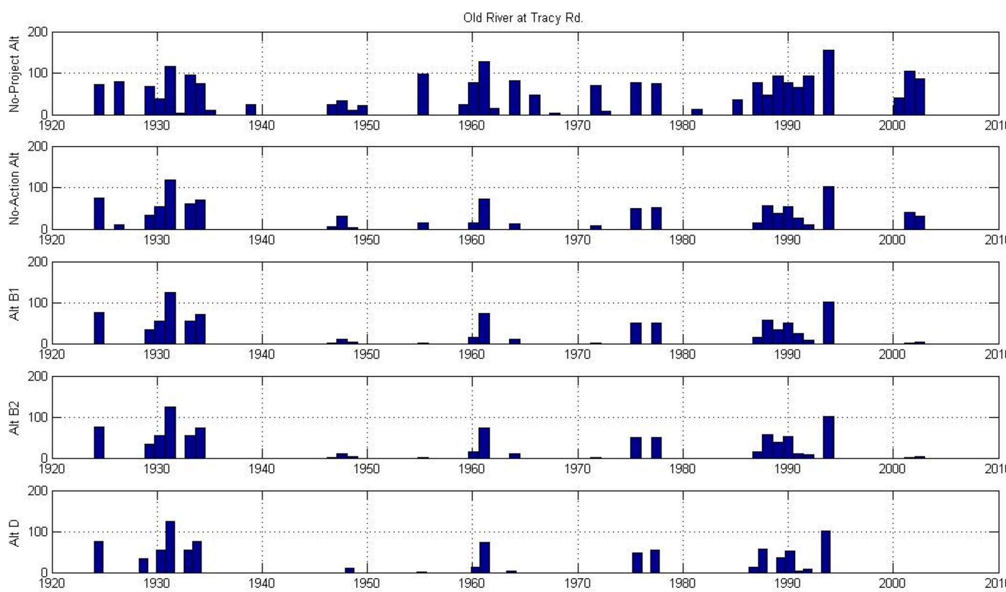

Figure B-7. Number of 30-day Running Averages During Which Electrical Conductivity Rises Above Water Quality Objectives in the Old River at Tracy Road

Table B-4. Percent of All 30-Day Running Averages During Which Electrical Conductivity is Above Water Quality Objective

EC tolerance = 0	**Alternative Plans**				
Site	**No-Project Alternative**	**No-Action Alternative**	**B1**	**B2**	**D**
Middle River at Mowery	6.41	1.90	1.66	1.61	1.53
Old River at Tracy Road	7.54	3.54	3.08	3.08	2.99
SJR at Brandt Bridge	6.48	1.94	1.66	1.62	1.52
SJR at Vernalis	2.57	0.76	0.55	0.59	0.58

EC tolerance = 0.005 * EC standard	**Alternative Plans**				
Site	**No-Project Alternative**	**No-Action Alternative**	**B1**	**B2**	**D**
Middle River at Mowery	4.29	0.90	0.79	0.82	0.72
Old River at Tracy Road	6.77	3.10	2.72	2.67	2.63
SJR at Brandt Bridge	4.24	1.06	0.95	0.97	0.80
SJR at Vernalis	1.69	0.20	0.15	0.14	0.09

EC tolerance = 0.01 * EC standard	**Alternative Plans**				
Site	**No-Project Alternative**	**No-Action Alternative**	**B1**	**B2**	**D**
Middle River at Mowery	2.44	0.36	0.31	0.29	0.25
Old River at Tracy Road	5.29	2.43	2.24	2.20	2.13
SJR at Brandt Bridge	2.29	0.45	0.39	0.38	0.32
SJR at Vernalis	1.31	0.09	0.09	0.04	0.04

Key:
EC = electrical conductivity
SJR = San Joaquin River

Table B-5. Mean Magnitude Above Objective (µmhos/cm)

EC tolerance = 0	Alternative Plans				
Site	**No-Project Alternative**	**No-Action Alternative**	**B1**	**B2**	**D**
Middle River at Mowery	18	6	6	6	5
Old River at Tracy Road	21	16	16	16	16
SJR at Brandt Bridge	18	7	7	6	6
SJR at Vernalis	34	5	6	3	3

Median magnitude above objective (µmhos/cm)					
EC tolerance = 0	**Alternative Plans**				
Site	**No-Project Alternative**	**No-Action Alternative**	**B1**	**B2**	**D**
Middle River at Mowery	6	4	4	4	4
Old River at Tracy Road	12	12	12	12	12
SJR at Brandt Bridge	6	5	5	5	5
SJR at Vernalis	8	2	2	2	1

Standard deviation of magnitude above objective (µmhos/cm)					
EC tolerance = 0	**Alternative Plans**				
Site	**No-Project Alternative**	**No-Action Alternative**	**B1**	**B2**	**D**
Middle River at Mowery	37	7	7	4	4
Old River at Tracy Road	31	15	16	16	16
SJR at Brandt Bridge	37	7	7	5	4
SJR at Vernalis	54	9	10	3	3

Key:
µmhos/cm = micromhos per centimeter
EC = electrical conductivity
SJR = San Joaquin River

Figures B-8 through B-11 show time series of EC and EC limits throughout the DSM2 simulation, for each station. On each of these figures, it is apparent that EC rises above water quality objectives in the springtime of drought years, such as 1987–1992. These cases are where the volume of freshwater necessary to meet water quality objectives does not exist in the water storage system.

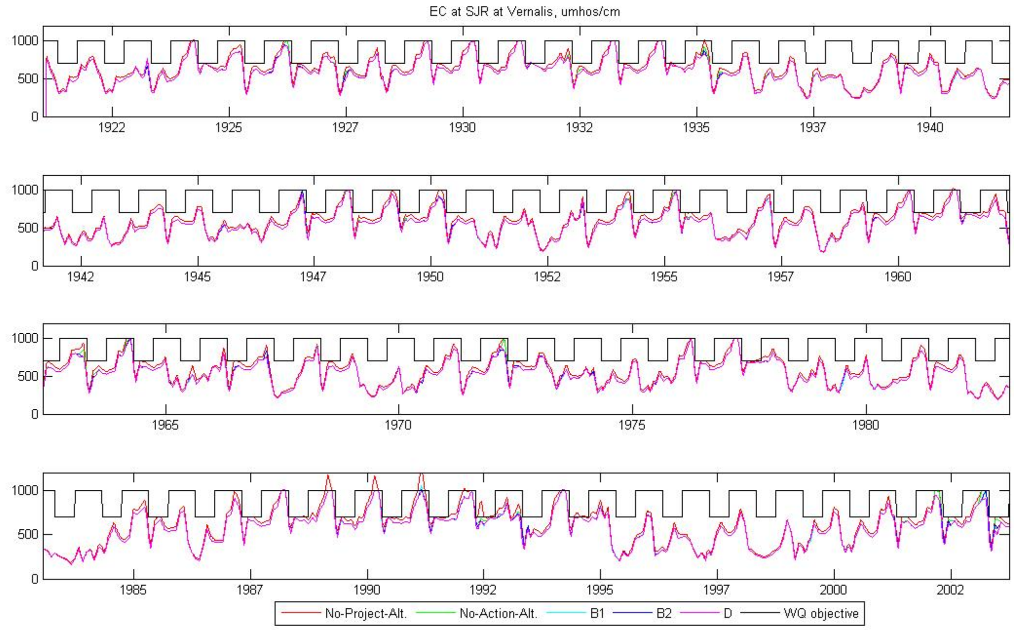

Figure B-8. Electrical Conductivity of the San Joaquin River at Vernalis

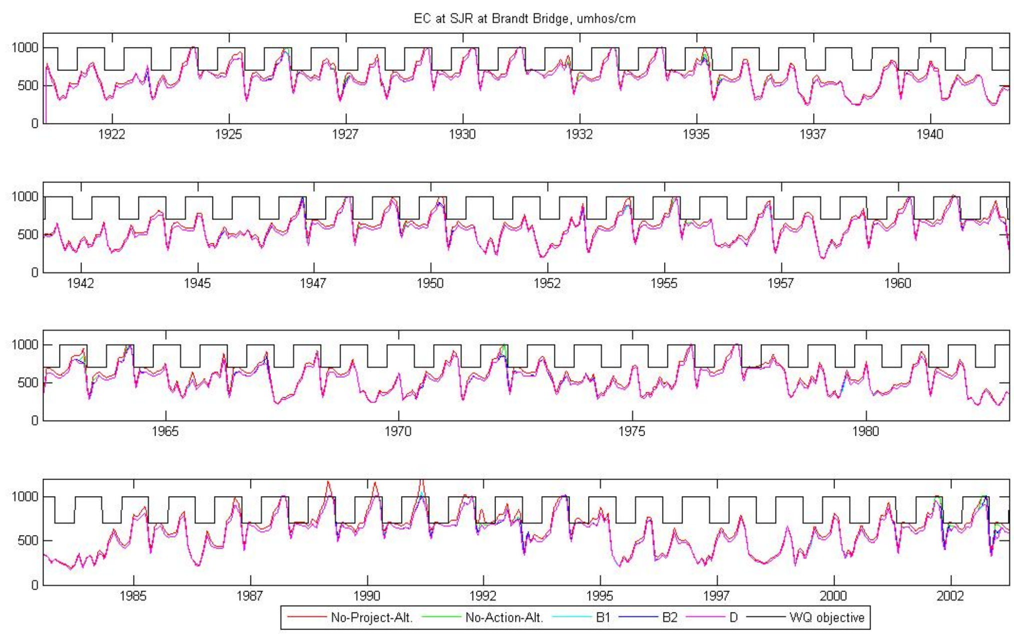

Figure B-9. Electrical Conductivity of the San Joaquin River at Brandt Bridge

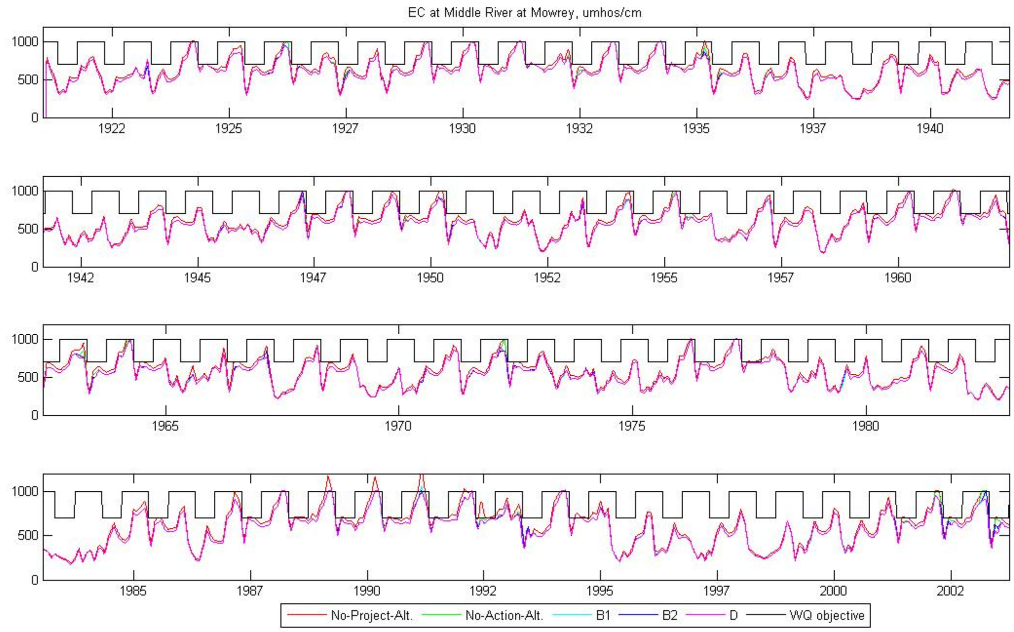

Figure B-10. Electrical Conductivity of the Middle River at Mowry

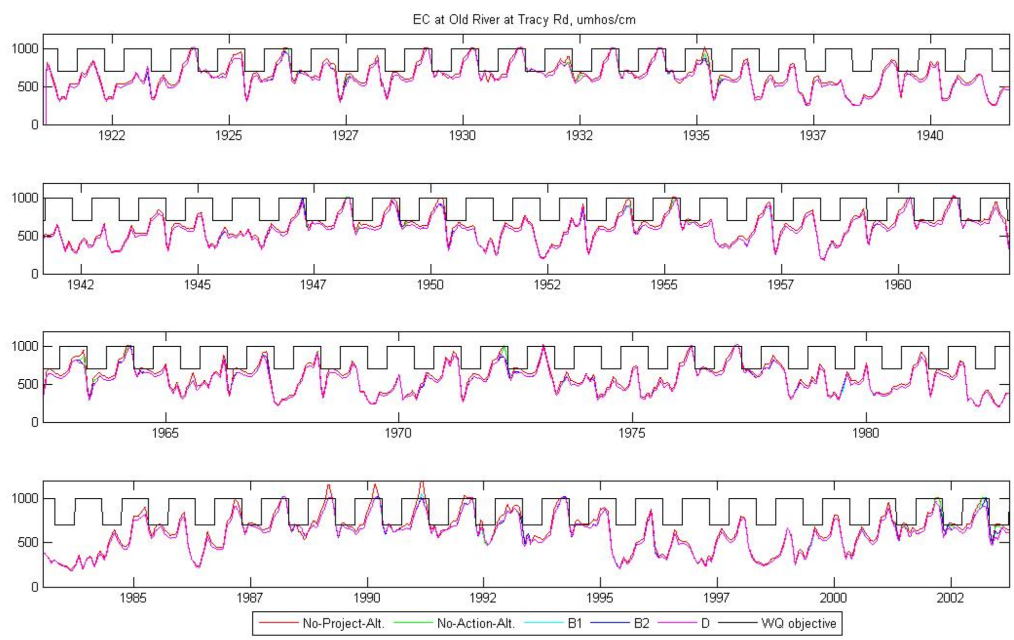

Figure B-11. Electrical Conductivity of the Old River at Tracy Road

B.6 Uncertainty and Sensitivity

The uncertainty in the approach used to calculate the fraction of recirculated water is gauged by calculating the difference in the volume fraction of each source at Tracy Pumping Plant for Alternative D and the volume fraction of the same source for the No-Action Alternative. The resulting error (difference divided by the No-Action Alternative volume fraction) is displayed on **Figures B-12 and B-13**. Considering only the cases with recirculation occurring, the mean error is 0.001, with a standard deviation of 0.13. These small errors indicate that the approximation used is a reasonable one.

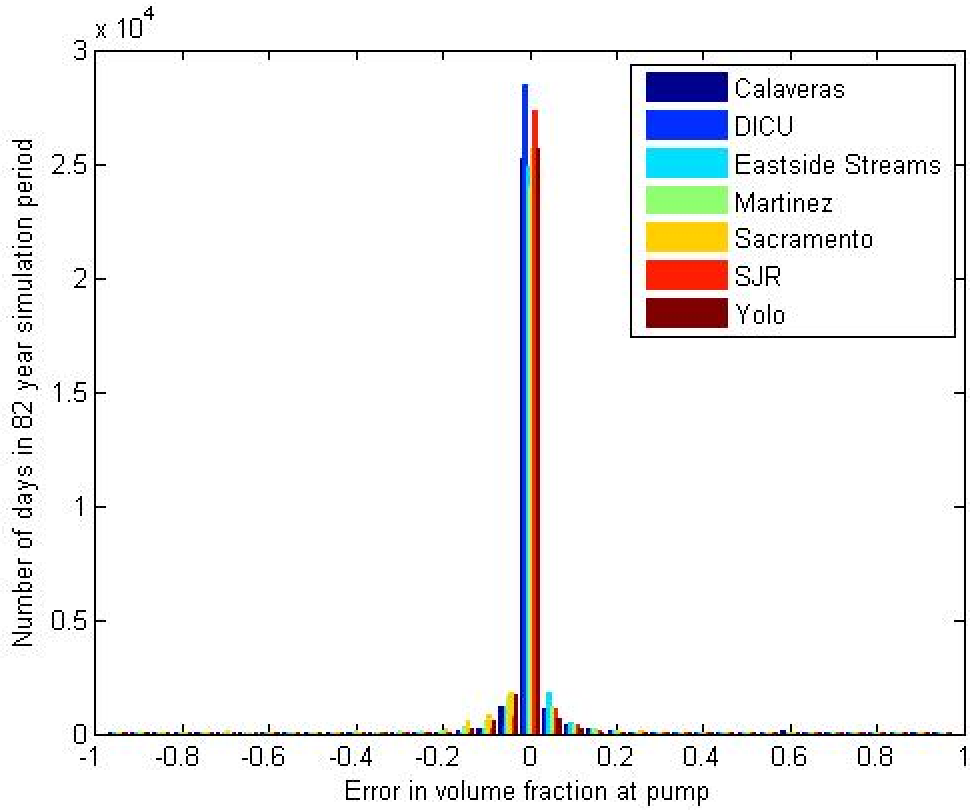

Figure B-12. Histogram of Error in Volume Fraction between Alternative D and No-Action Alternative, at Tracy Pumping Plant (all days of 82-year simulation considered)

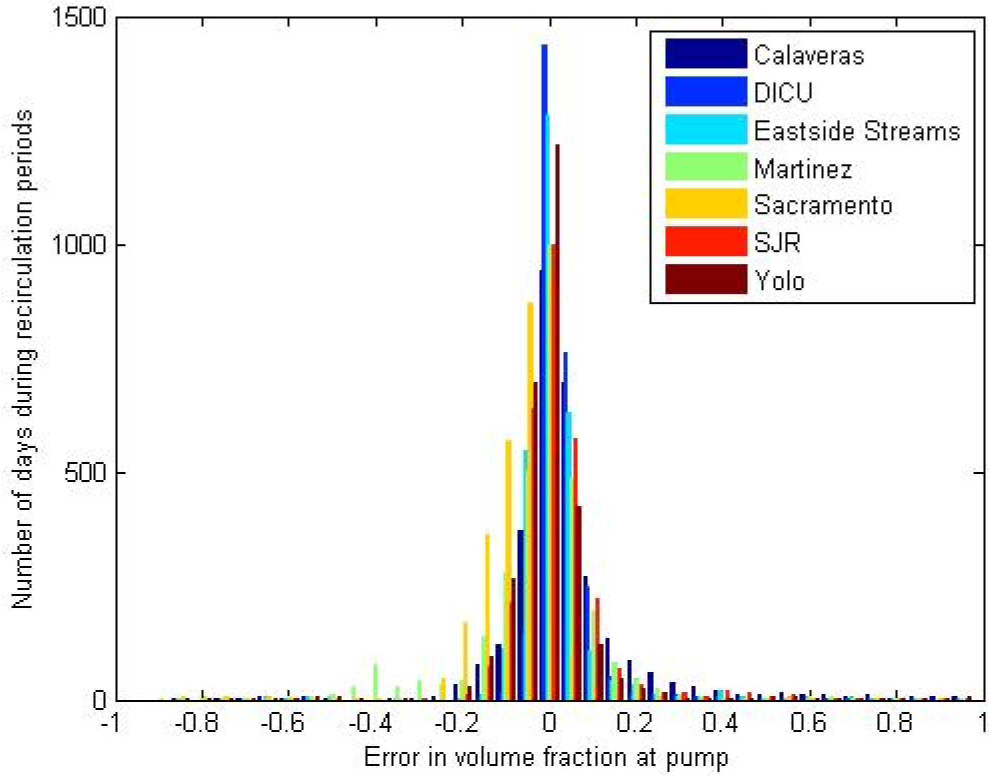

Figure B-13. Histogram of Error in Volume Fraction between Alternative D and No-Action Alternative, at Tracy Pumping Plant (only periods of recirculation considered)

B.7 References

Anderson, J. 2002. Chapter 14: DSM2 Fingerprinting Methodology *In* Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. Accessible at: http://modeling.water.ca.gov/delta/reports/annrpt/2002/2002Ch14.pdf

DWR (Department of Water Resources) website (http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/annualreports.cfm). Accessed March 2009.

DWR. 2008. DMC Recirculation Project DSM2 Modeling Assumptions and Setup Technical Memorandum. February 5

DWR. DSM2 grid map Accessible at: (http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/DSM2_Grid2.0.pdf).