Public Comment
Bay Delta Plan Workshop 3
Deadline: 10/26/12 by 12:00 noon

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10-26-12
SWRCB Clerk

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

Via email: commentletters@waterboards.ca.gov

SUBJECT: Bay-Delta Workshop 3 – Analytical Tools for Evaluating Water Supply, Hydrodynamic and Hydropower Effects

Dear Chairman Hoppin and Members of the Board:

The Department of Water Resources (DWR) appreciates the opportunity to participate in the ongoing process for Phase 2 of the Bay-Delta Water Quality Control Plan (WQCP) update. In the attached submission, DWR presents a discussion of the computer simulation models that could be used to analyze water supply and hydrodynamic effects of a proposed update to the WQCP, and the development of a multi-dimensional model called SELFE. We also address climate change analysis, as well as elaborate on the differences between "Natural" versus "Unimpaired" flow. Our submittal includes excerpts from the draft Bay Delta Conservation Plan (BDCP) Environmental Impact Report (EIR) which contains a complete list of models used to evaluate alternatives related to the BDCP and the BDCP Effects Analysis.

As part of our submittal, we present an assessment based on model output of potential impacts associated with the implementation of the Fall X2 action set forth in the 2008 U.S. Fish and Wildlife Service (USFWS) Biological Opinion. This analysis uses the CalSim-II model, and describes the possible impacts to combined State Water Project (SWP) and Central Valley Project (CVP) exports as well as combined storage in Shasta and Oroville reservoirs. This analysis is intended to present a more complete picture of the impact of the Fall X2 action on the CVP and SWP.

As discussed in the submittal, in addition to the potential impacts to water supply, the imposition of a Fall X2 standard that significantly draws down reservoir levels can have a significant impact on water temperature management at the reservoirs. In the case of Oroville Reservoir, the cold water pool is critical for providing protection to listed species such as spring-run Chinook salmon and Central Valley steelhead. Access to the cold water pool at Oroville is limited. If the water level in the reservoir drops below a certain point, the project's ability to provide the amount of cold water necessary to support the Feather River Hatchery, as well as to maintain suitable temperatures in the lower Feather River for spawning and egg incubation, becomes compromised and can lead to adverse impacts to the species.

Also discussed in the attached submission are the various models available to analyze impacts to the Bay-Delta hydrology and ecosystem. Below is a summary of the models discussed in the submittal:

CalSim-II

CalSim-II is used to simulate much of the water resources infrastructure in the Central Valley and Delta Regions, and is the best available planning model for SWP and CVP operations. Inputs to the model include water diversion requirements, stream accretions and depletions, return flows and groundwater operations. The model is capable of investigating the impacts resulting from unimpaired flow requirements, as well as incorporating the storage to temperature relationship. It can also incorporate the effects of climate change.

CalLite

CalLite is a rapid and interactive screening model best used to screen various Central Valley water management alternatives, and for developing improved understanding of operational decisions during consensus-based decision making.

DSM2

The Delta Simulation Model 2 (DSM2) is a one-dimensional open channel flow and water quality simulation model, which can capture processes influenced by tidal dynamics. Applications of DSM2 include simulating historical conditions, forecasting future conditions, and planning studies using input from CalSim-II. It can help assess the incremental impacts caused by future facilities and operations, as well to determine the impacts of potential changes in the Delta associated with changes in flow patterns.

DSM2 does not adequately represent the complex behaviors of juvenile and adult migrating fish. Attempts to incorporate fish behavior have not been validated by field observations due to the lack of Delta-wide data availability. However, continued development of the model may allow limited representation of delta smelt, Chinook salmon and steelhead behavioral characteristics. Thus, currently there is no widely accepted model which represents fish behavior.

Bay-Delta SELFE

SELFE is an open source, three-dimensional computational model which can depict the major flow characteristics of the Delta. It features a variety of transport, sediment and biological processes. DWR has incorporated into SELFE practical details such as agricultural sources and sinks, gates and barriers. It is best used for a three-dimensional hydrodynamic and salinity transport model of the full Bay-Delta system, and is also well suited to model the effects of sea level rise. A full Delta calibration is planned for release in Spring 2013 and, shortly after that, training is to be offered within the modeling community.

In addition to the models presented, the submittal includes as an attachment an excerpt from the draft Appendix 5A of the BDCP EIR. DWR has been, and continues to be, very active in developing methodologies for projecting future hydrologic conditions that take into account climate change trends. While BDCP Appendix 5A details an approach for evaluating climate change effects that works well for the BDCP, we recommend your staff evaluate the relevant information contained in the appendix as it may not be appropriate for the purposes in updating the WQCP. For instance, the BDCP approach looks at two distinct future periods centered around 2025 and 2060. Other types of approaches provide a continuous projection of climatology and hydrology spanning from current conditions out to the future, rather than focusing on a specific future period or periods. This distinction along with others are important to consider to when choosing a climate change analysis approach. DWR invites your staff to meet with the DWR Climate Change Technical Advisory Group for additional focused discussions and more detailed guidance and recommendations on qualitative and quantitative analytical approaches.

Finally, the submittal includes a discussion of the differences between the terms "Natural Flow" and "Unimpaired Flow." It is being included to illustrate the factors that should be considered when applying these specific terms correctly. Natural flow and unimpaired flow may be the same when applied to an upstream location, such as the Sacramento River at Shasta Dam; but, they would definitely not be the same when applied to the Sacramento River at Freeport. The included example illustrates why.

Thank you for your consideration of the comments and the attached report. If you have any questions, feel free to contact me at (916) 653-8045

Sincerely,

Katherine Kelly for

Russ Stein
Acting Deputy Director

Attachment

SWRCB Workshop 3

Analytical Tools for Evaluating Water Supply, Hydrodynamic and Hydropower Effects

DWR Contribution
October 26, 2012

The following discussion focuses on the computer simulation models used by the Department of Water Resources (DWR) that could be used by the State Water Resources Control Board (SWRCB) to analyze water supply and hydrodynamic effects of a proposed update to the Bay-Delta Plan. The models are CalSim-II, the related CalLite model, the Delta Simulation Model (DSM2) and its modules simulating hydrodynamics, water quality, and particle movement. This submittal also describes the development of a multi-dimensional model called SELFE. SELFE is capable of simulating the hydrodynamics and water quality at both the Sacramento San Joaquin Delta and the San Francisco Bay. A short discussion on incorporating climate change into analyses of future conditions is included as well as one on the distinction between “Natural” versus “Unimpaired” Flow.

Included as an attachment are excerpts from Appendices 4 and 5 of the draft Environmental Impact Report/Statement for the Bay-Delta Conservation Plan (BDCP). Appendix 5A illustrates how CalSim-II and DSM2 can be used in assessing potential impacts. It gives a complete description of all the modeling tools used to study the effects of the alternatives related to the BDCP. We have also included excerpts from draft Chapter 4 of the BDCP EIR/S which include a complete list of models used to analyze the BDCP alternatives (Section 4.3); an illustration of the sequence of the application of the modeling tools required to complete the analysis (Figure 4.1) and a table describing the utilization of the models in the BDCP Effects Analysis (Table 4.1).

1- CalSim-II

DWR and the U.S. Bureau of Reclamation Mid-Pacific Region (Reclamation) have jointly developed CalSim-II, which simulates much of the water resources infrastructure in the Central Valley of California and Delta region. CalSim-II is a generalized reservoir-river basin simulation model that allows for water allocation targets or goals (Draper et al. 2002) to be specified by the user. CalSim-II represents the best available planning model for the SWP and CVP system operations and has been used in previous system-wide evaluations of SWP and CVP operations (USBR, 1994, 2004, 2008). CalSim-II simulates an 82-year period using monthly time increments.

CalSim-II models all areas that contribute flow to the Delta. The geographical coverage includes: the Sacramento River Valley; the San Joaquin River Valley; the Sacramento-San Joaquin Delta; the Upper Trinity River; the CVP and SWP deliveries to the Tulare Basin; and the SWP deliveries to the central and south coast regions. CalSim-II includes major reservoirs in the Central Valley of California including Trinity, Lewiston, Whiskeytown, Shasta, Keswick, Folsom, Oroville, San Luis, New Melones and Millerton reservoirs. CalSim-II also includes all the major CVP and SWP facilities including the Clear Creek Tunnel, Tehama Colusa Canal, Corning Canal, Jones Pumping Plant, Delta Mendota Canal, Mendota Pool, Banks Pumping Plant, California Aqueduct, South Bay Aqueduct, North Bay Aqueduct, Coastal Aqueduct and East Branch Extension. In addition, it includes some locally managed facilities such as the Glenn Colusa Canal, Contra Costa Canal and the Los Vaqueros Reservoir.

Inputs to CalSim-II include water diversion requirements (demands), stream accretions and depletions, rim basin inflows, irrigation efficiencies, return flows, non-recoverable losses, and groundwater operations. Sacramento Valley and tributary rim basin hydrologies are developed using a process designed to adjust the historical sequence of monthly stream flows over an 82–year period (1922 to 2003) to represent a sequence of flows at a future level of development. Adjustments to historic water supplies are determined by imposing defined level of land use on historical meteorologic and hydrologic conditions. The resulting hydrology represents the water supply available from Central Valley streams to the CVP and SWP at the current or future level of development.

A CalSim-II simulation provides sequential monthly values for river flows and diversions, reservoir storage, Delta flows and exports, Delta inflow and outflow, deliveries to project and non-project users, reservoir operations controlling variables (e.g. in-stream flow, water quality standards, flood control, Delta exports, etc.). Reclamation’s 2008 Operations Criteria and Plan (OCAP) Biological Assessment (BA) Appendix D provides more information about CalSim-II (USBR, 2008a). CalSim-II output provides the basis for multiple other hydrologic, hydrodynamic, and biological models and analyses. CalSim-II results are used to determine water quality, hydrodynamics, and particle tracking in the DSM2 model. The outputs feed into temperature models including the Upper Sacramento River Water Quality Model (USRWQM), the Reclamation Temperature Model, and other habitat and biological models.

CalSim–II model can be re-formulated to investigate impacts resulting from a new flow requirement at a location based on a certain percentage of unimpaired flows. DWR has conducted analyses of the effects of potential flow requirements based upon an assumed percentage of unimpaired flow.

CalSim-II is also amenable to incorporating the effects of climate change. This is accomplished by changing the streamflow values and incorporating sea level rise. Changes in runoff and streamflows are simulated through VIC modeling under representative climate scenarios. These simulated changes in runoff are applied to the CalSim-II inflows as a fractional change from the observed inflow patterns (simulated future runoff divided by historical runoff). Sea level rise in CalSim-II is incorporated through development of a new flow-salinity response relationship.

It is noted that CalSim-II is structured to meet current water right priorities in the Sacramento and San Joaquin valleys as well as Delta in-basin use and regulatory requirements. If any new flow requirements necessitate reduction of applied water demands in Sacramento valley, CalSim-II model will need to be modified accordingly.

Case-Study of the Potential Impact of Fall X2

CalSim-II is best used in a comparative mode or comparative analysis that compares a No Action Alternative to a With Action Alternative. System performance metrics are then compared and analyzed to determine levels of impacts to the No Action condition that occur because of the With Action condition. Some typical system performance metrics include reservoir storage, river flows, Delta outflow, deliveries, exports, and water quality. These performance metrics can be quantitatively analyzed in many ways such as evaluating long-term average impacts, worst case impacts, best case impacts, dry period impacts, frequency of impacts, etc. The quantitative analysis is then often enhanced or supported with qualitative analyses.

An example analysis that compared a future condition with and without 2008 USFWS Biological Opinion Reasonable and Prudent Action 4, more commonly referred to as the Fall X2 Standard, is presented below.

Major Assumptions

No Action Alternative Simulation (With Fall X2)

- 1922 – 2003 Simulation Period
- Future Level of Development Land-Use and Demands (2030)
- Future Level of Climate Change (2025)
- Future Level of Sea Level Rise (15 cm)
- Water Rights Decision 1641 regulations
- 2008 USFWS Biological Opinion Reasonable and Prudent Actions including Fall X2 requirements which occur only in years following Wet or Above Normal years
- 2009 NMFS Biological Opinion Reasonable and Prudent Actions

No Fall X2 Alternative Simulation

- Same as No Action with the exception of the removal of the Fall X2 requirement

Results

Summary results for combined SWP and CVP exports as well as combined storage in Shasta, Folsom, and Oroville reservoirs are presented below. Table 1 shows the combined export impacts for multiple time periods. One period is for the long term average. The long term (1922 – 2003) average impact to exports is 199 TAF per year. This means that on average, the CVP and SWP have an average export reduction of 199 TAF per year over the simulation period due to meeting Fall X2 requirements. A long-term average impact however can be a misleading oversimplification because of the nature of California’s varied yearly hydrology. California hydrology typically has dry periods followed by wet periods and vice versa. The wet periods can help the systems to recover lost reservoir storage and in a sense “reset”, which can mask some shorter period impacts.

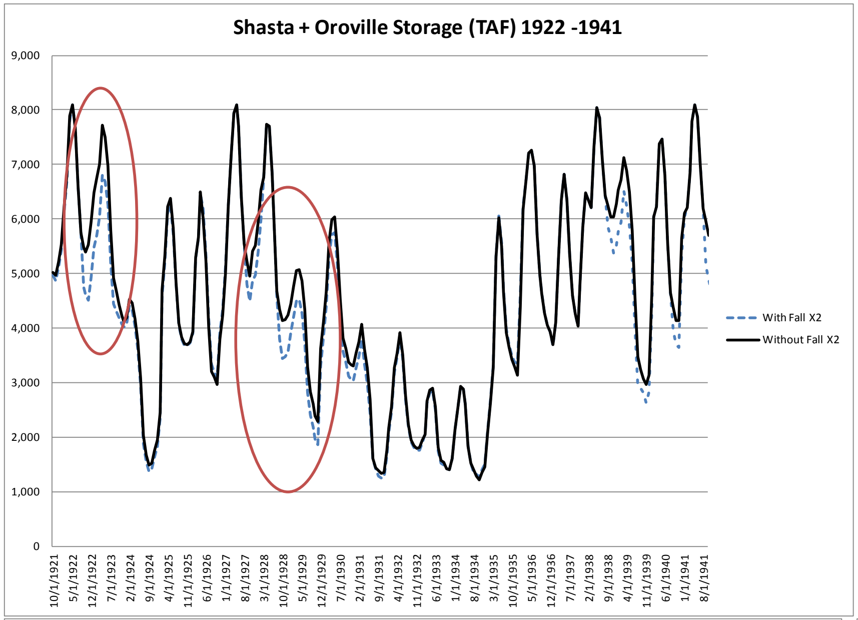
Table 1: Combined SWP and CVP Annual Export (TAF)

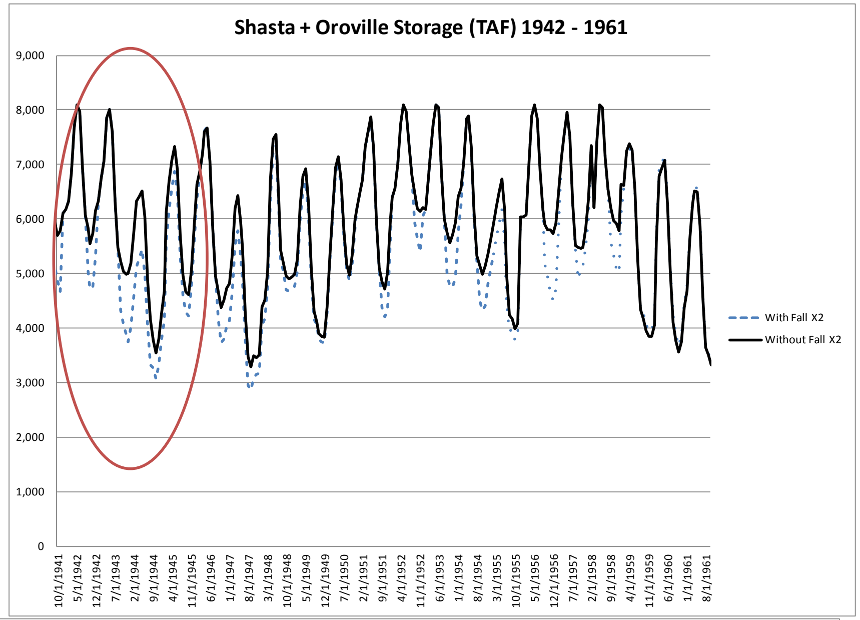
Total SWP + CVP Export	With Fall X2	Without Fall X2	Diff
1922 - 2003 Average	4728	4927	199
Average of 1 Year Following W or AN	5040	5374	335
Max Impact of Year Following (1944)	3915	4690	775
Min Impact of Year Following (2000)	4987	4997	10

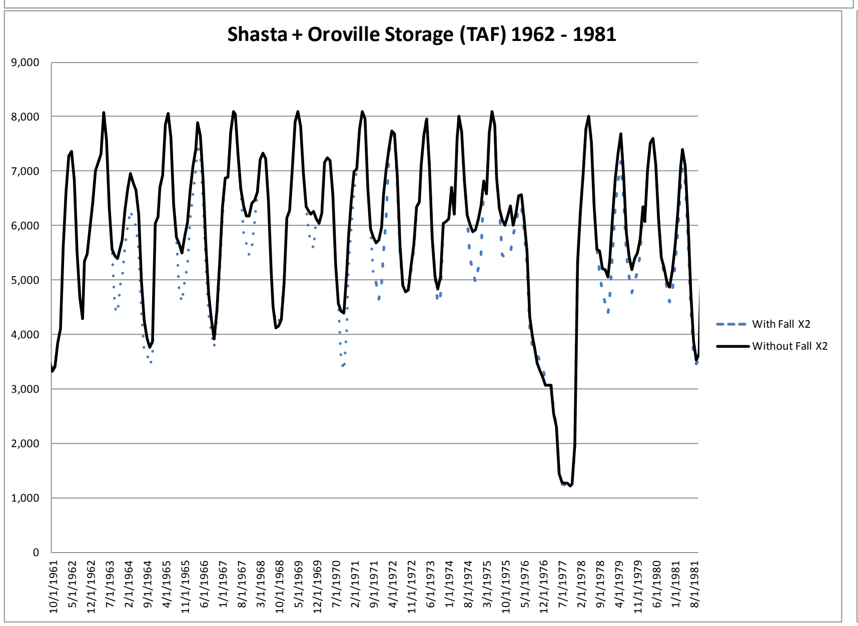
Another way to examine the impact of meeting the Fall X2 requirement is to evaluate the years immediately following a year in which Fall X2 is required. The average impact to exports for those years is 335 TAF per year. The impact for the years following the implementation of the Fall X2 requirement is obviously larger than the long-term average but may be more indicative of the magnitude of impact caused by the Fall X2 requirement. Table 1 also shows the maximum and minimum one-year impact of the Fall X2 requirement on exports for years following the action. Water Year 1944 exhibited the maximum single year export impact of 775 TAF, while Water Year 2000 showed the minimum single year export impact of 10 TAF. The maximum and minimum impacts give a range of potential impacts.

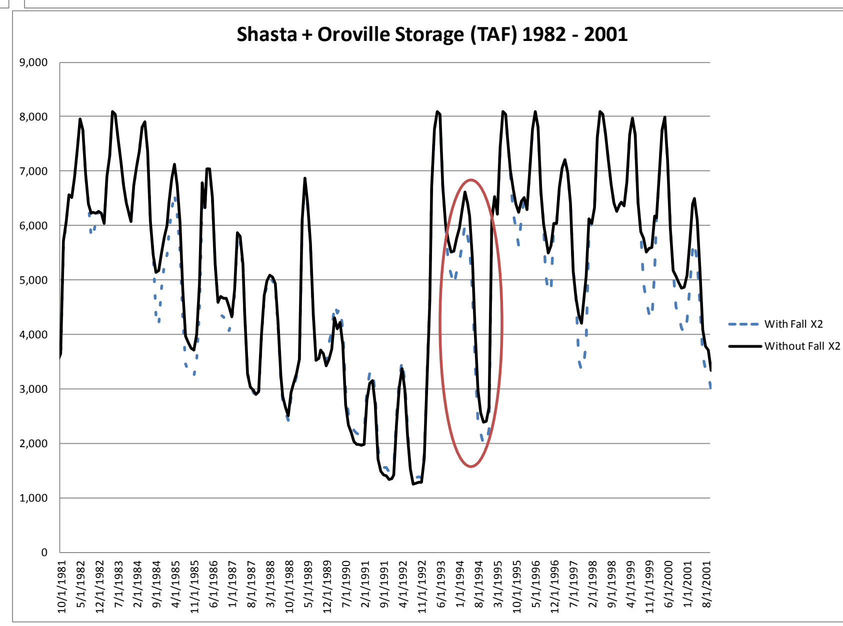
Export impacts are only one metric for evaluating system performance. Another metric is system storage. Lower storages in fall would have negative impacts on the cold water pool, as well as result in a lower carryover (storage at the end of September) for the following year to meet in-basin obligations and potential water supply impacts. For example, the impact of the Fall X2 requirement on the cold water pool at Oroville and its subsequent ability to meet various temperature requirements for the protection of listed species such as Spring-run Chinook salmon and Central Valley Steelhead could be very pronounced depending upon the following year’s hydrology, i.e., if conditions are dry in the winter and spring period and storage is not recovered. As releases are made from the facilities to meet regulatory and other requirements over the course of the following year, the storage level at Oroville drops and the cold water pool is subsequently lowered. Due to the configuration of the Oroville Facilities, access to the cold water pool needed to meet temperature requirements becomes more limited as the reservoir is drawn down. Once the cold water pool goes below a certain depth, the facilities’ ability to provide water at the temperatures needed to support the Feather River Hatchery and the spawning and holding habitat in the lower river below the dam becomes compromised. This in turn can lead to disease outbreaks, and in some circumstances, mortality of both eggs and fish.

Changes in exports due to increased outflow requirements are normally balanced with changes in upstream reservoir storage. The next page shows the full simulation period trace of combined Shasta and Oroville storage. Shorter periods of interest for further analysis are circled in red.


Shasta + Oroville Storage (TAF) 1922 -1941
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
10/1/1921
5/1/1922
12/1/1922
7/1/1923
2/1/1924
9/1/1924
4/1/1925
11/1/1925
6/1/1926
1/1/1927
8/1/1927
3/1/1928
10/1/1928
5/1/1929
12/1/1929
7/1/1930
2/1/1931
9/1/1931
4/1/1932
11/1/1932
6/1/1933
1/1/1934
8/1/1934
3/1/1935
10/1/1935
5/1/1936
12/1/1936
7/1/1937
2/1/1938
9/1/1938
4/1/1939
11/1/1939
6/1/1940
1/1/1941
8/1/1941
With Fall X2
Without Fall X2


Shasta + Oroville Storage (TAF) 1942 - 1961
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
10/1/1941
5/1/1942
12/1/1942
7/1/1943
2/1/1944
9/1/1944
4/1/1945
11/1/1945
6/1/1946
1/1/1947
8/1/1947
3/1/1948
10/1/1948
5/1/1949
12/1/1949
7/1/1950
2/1/1951
9/1/1951
4/1/1952
11/1/1952
6/1/1953
1/1/1954
8/1/1954
3/1/1955
10/1/1955
5/1/1956
12/1/1956
7/1/1957
2/1/1958
9/1/1958
4/1/1959
11/1/1959
6/1/1960
1/1/1961
8/1/1961
With Fall X2
Without Fall X2


Shasta + Oroville Storage (TAF) 1962 - 1981
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
10/1/1961
5/1/1962
12/1/1962
7/1/1963
2/1/1964
9/1/1964
4/1/1965
11/1/1965
6/1/1966
1/1/1967
8/1/1967
3/1/1968
10/1/1968
5/1/1969
12/1/1969
7/1/1970
2/1/1971
9/1/1971
4/1/1972
11/1/1972
6/1/1973
1/1/1974
8/1/1974
3/1/1975
10/1/1975
5/1/1976
12/1/1976
7/1/1977
2/1/1978
9/1/1978
4/1/1979
11/1/1979
6/1/1980
1/1/1981
8/1/1981
With Fall X2
Without Fall X2


Shasta + Oroville Storage (TAF) 1982 - 2001
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
10/1/1981
5/1/1982
12/1/1982
7/1/1983
2/1/1984
9/1/1984
4/1/1985
11/1/1985
6/1/1986
1/1/1987
8/1/1987
3/1/1988
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5/1/1989
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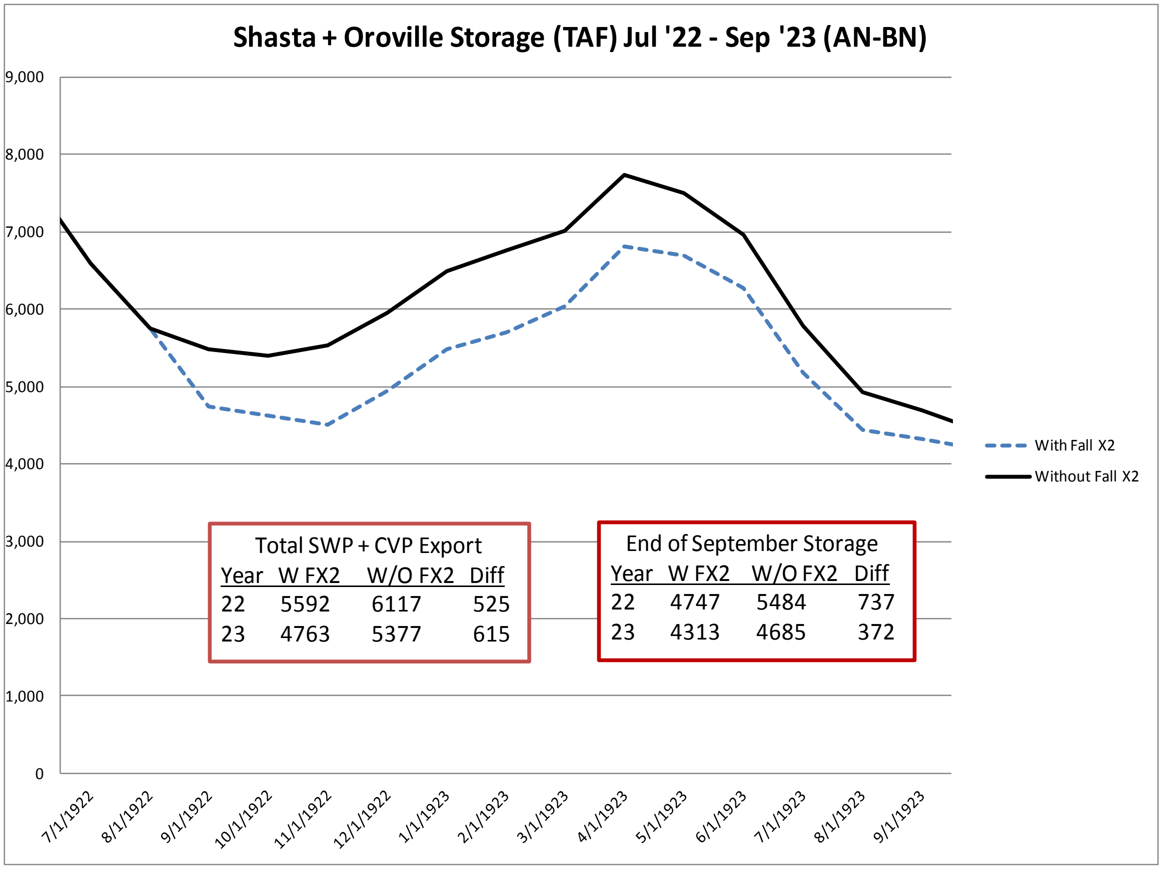
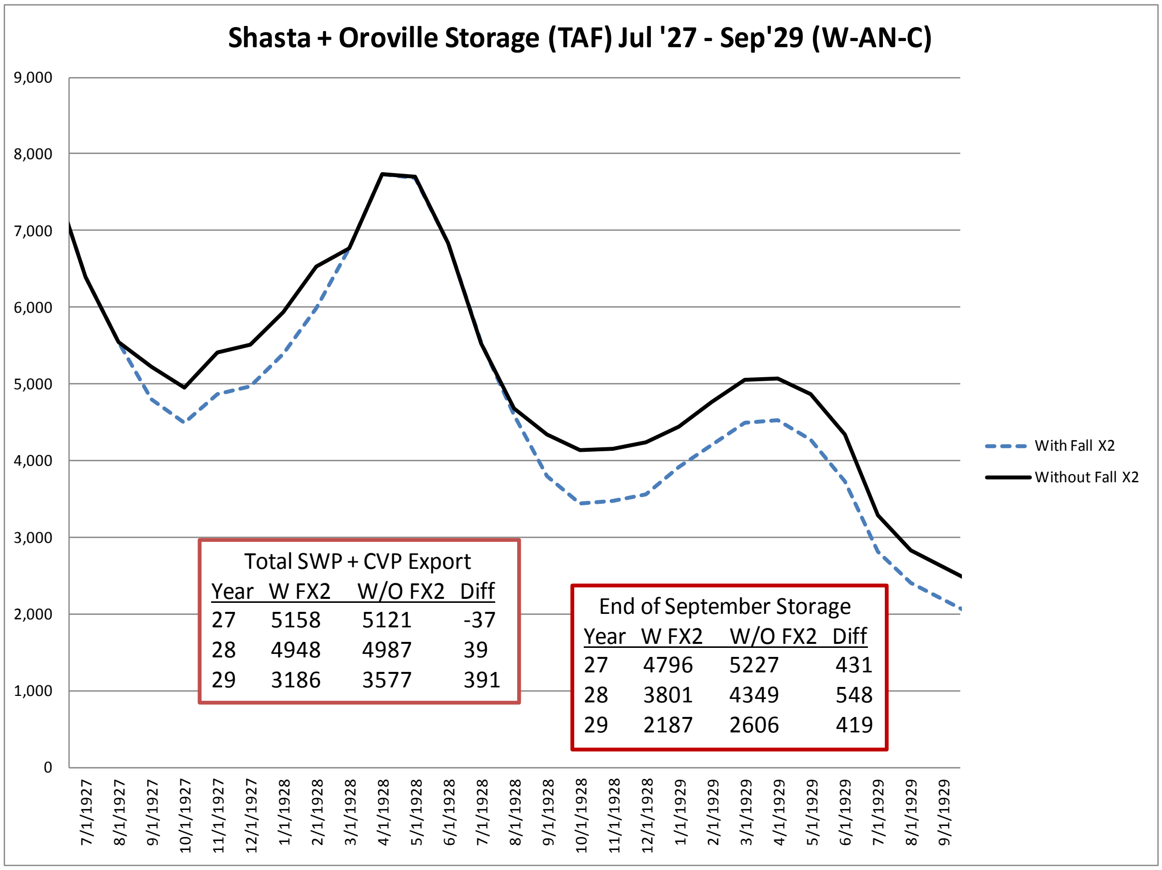
3/1/1995
10/1/1995
5/1/1996
12/1/1996
7/1/1997
2/1/1998
9/1/1998
4/1/1999
11/1/1999
6/1/2000
1/1/2001
8/1/2001
With Fall X2
Without Fall X2

Examining storage impacts due to Fall X2 actions over a shorter time period can give more insight into the effect of meeting the action. The first period evaluated below is July 1922 – September 1923, which is an Above Normal year followed by a Below Normal year. The two alternatives start out with similar storage.



The storage then diverges beginning when the Fall X2 action is implemented in the No Action Alternative (NAA). The 1923 hydrology is dry in the winter and spring period and storage is not recovered. The decreases in combined Shasta and Oroville storage at the end of September for each year indicates the potential of an adverse impact on reservoirs' cold water pools needed to support adequate river temperatures for salmon.

The next period to be examined is July 1927 – September 1929 which is a Wet year, followed by an Above Normal year, followed by a Critical year.



Total SWP + CVP Export

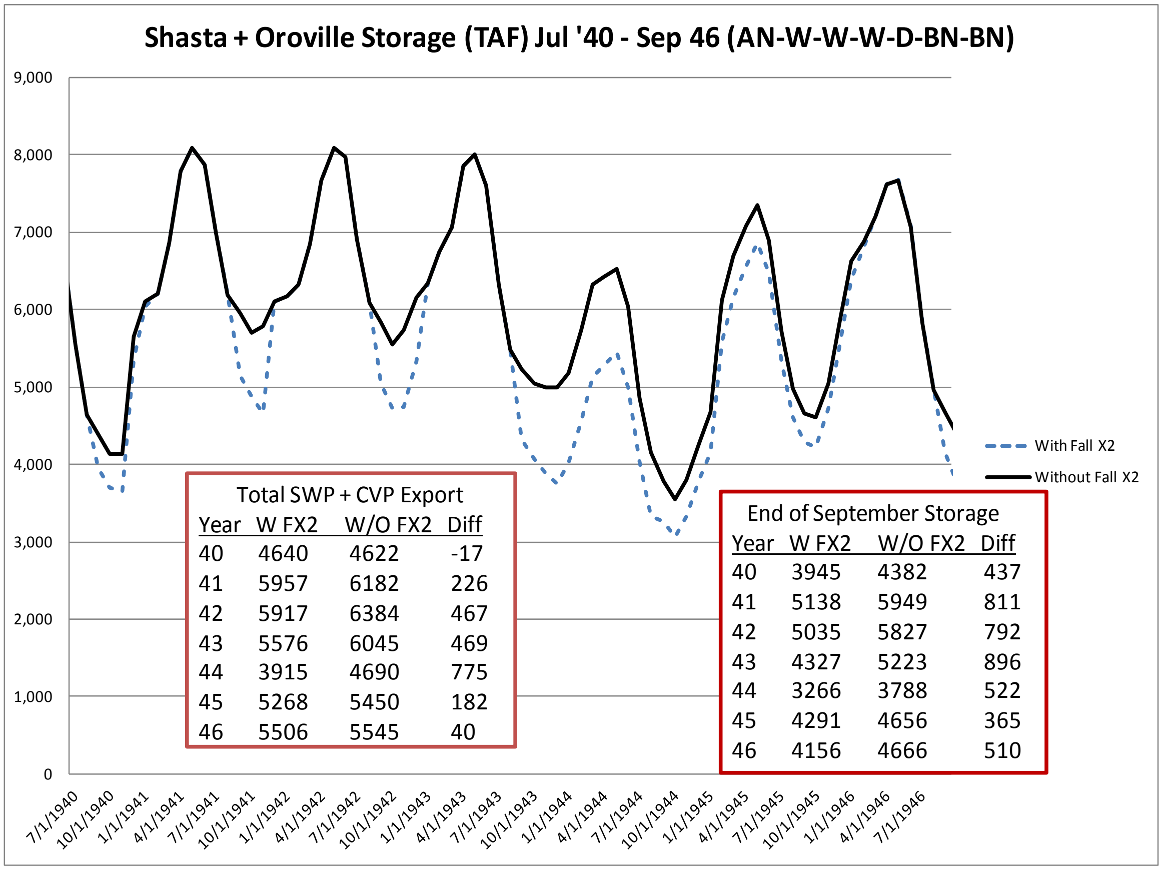
Year	W FX2	W/O FX2	Diff
27	5158	5121	-37
28	4948	4987	39
29	3186	3577	391

End of September Storage

Year	W FX2	W/O FX2	Diff
27	4796	5227	431
28	3801	4349	548
29	2187	2606	419

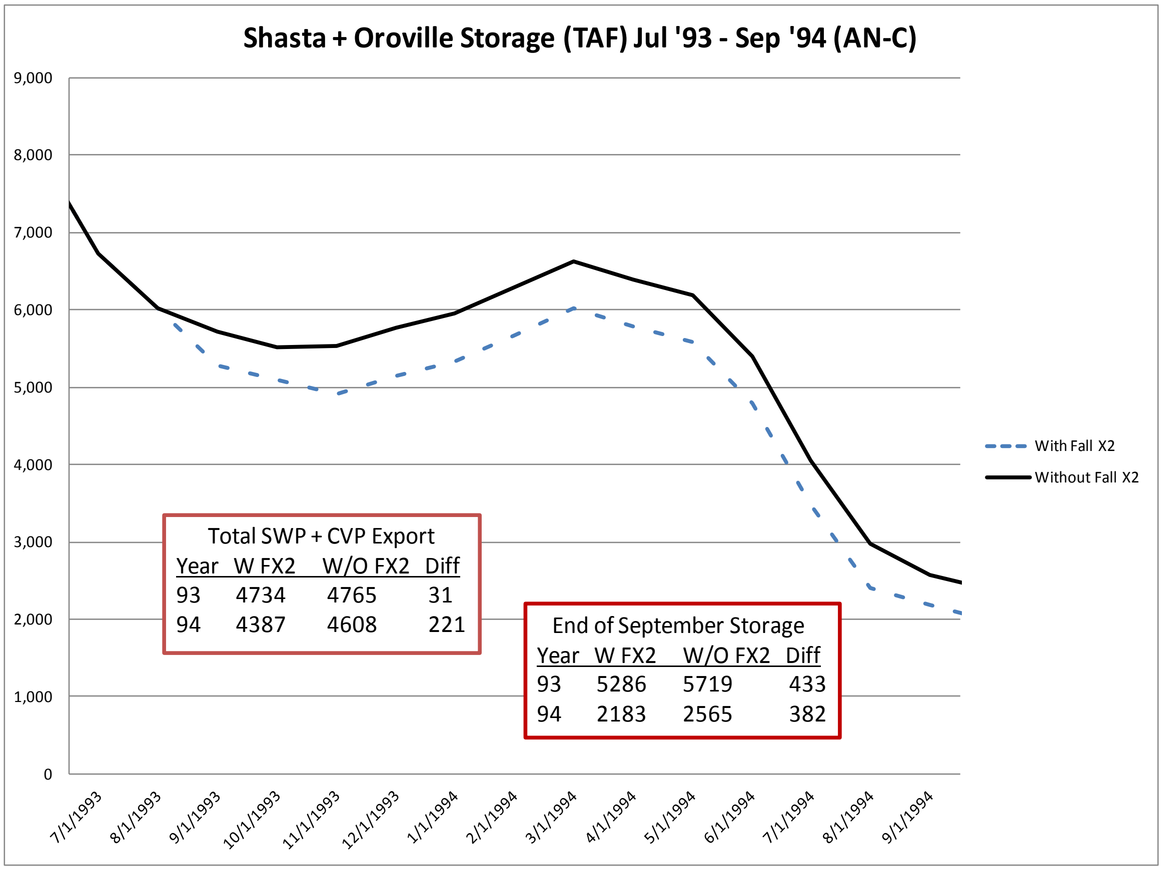
In this period, the storages in each alternative again start out about the same and then diverge when the Fall X2 action is implemented in the NAA. The hydrology in Water Year 1928 is wet enough to recover the storage lost from the Fall X2 action and the storages are once again in sync between the alternatives. The storages diverge once more in the Fall of Water Year 1929 due to the implementation of the Fall X2 action and stay apart due to the Critical-year hydrology. Export impacts are minimal for 1927 and 1928 but are significant in 1929. As shown in the above chart, combined storages in Shasta and Oroville at the end of September for each of the three years are substantially lower. The reduced storages indicate the potential for significant adverse impacts on cold water pools especially for years 1928 and 1929.

The third period is July 1940 – September 1946. This is a 7 year period that starts with an Above Normal year followed by 3 Wet years, a Dry, and finally two Below Normal years.



The four years of wetter hydrology show that the system was able to recover storage each of those years. Exports however were significantly impacted. Water Year 1944, the Dry year in the sequence, shows the largest export impact of the entire simulation. In the NAA, the storage and exports recover significantly due to the low export level of 1944 and not having Fall X2 obligations for 3 consecutive years (1944-1946). As shown, the end of September storages are significantly lower in each of the seven years. Lower fall storages in some of the years indicate potentially significant adverse impacts on the cold water pool especially year 1944.

The fourth period is from July 1993 – September 1994 and is an Above Normal year followed by a Critical year.



This sequence again starts with the storages of both alternatives nearly identical and diverging when the Fall X2 action is implemented in the NAA in the fall of 1993. The resulting storage reduction (433 TAF) is essentially carried through 1994 under the NAA. Exports also start off similar in 1993 but are reduced 221 TAF in 1994. Lower storage is especially significant for 1994. The storage projected for September 1994 in both scenarios is very low due to the dry conditions. The additional reduction of storage as shown indicates the potential for a significant impact on the cold water pool.

Conclusions

The results analysis shows that, given the operational assumptions of the CalSim-II simulations, storage is generally lower in the major CVP and SWP reservoirs when implementing the Fall X2 requirement. The storage impact can be more pronounced in periods following years when a Fall X2 requirement would be triggered under the 2008 USFWS Biological Opinion. The reduced storage condition is also accompanied by a reduction in the ability to provide water at a temperature necessary for the protection of listed species, as well as a reduction in exports.

Together, the storage impacts, temperature/species impacts and export impacts give a more complete picture of the impact of the Fall X2 action on the CVP and SWP. Monthly storage values resulting from these simulations are often used as inputs into temperature models that estimate river temperatures at certain locations in the river downstream from the reservoirs. In general, lower reservoir storage is directly correlated to warmer downstream river temperatures.

Currently, CalSim-II does not simulate water temperature directly. Temperature compliance is checked post simulation. DWR intends to incorporate temperature simulation within CalSim-II (or CalLite) using a methodology consistent with Sacramento River Water Quality Model (SRWQM). DWR hopes to have this capability ready by spring 2013.

2- CalLite Model

DWR and Reclamation have developed the CalLite model, a rapid and interactive screening model for evaluating various Central Valley water management options. The CalLite model is used as a computer aided tool for negotiations in a variety of stakeholder processes for improved understanding of the Central Valley water system operations and consensus based decision-making. CalLite maintains the same hydrologic, operational and institution integrity as represented in the full companion model, CalSim-II. CalLite simulates the most important dynamic system responses and simplifies or aggregates less important system features. Major reservoirs such as Shasta and Oroville are modeled consistent with CalSim-II, however, the accretions and depletions within Sacramento and San Joaquin Valley are aggregated and simulated on a coarser resolution. CalLite obtains the preprocessed data from the CalSim-II model as an input to the model. The simulation results obtained from a typical CalLite run are within 1% of a corresponding CalSim-II run, while the runtime is less than 10 minutes (compared to 30 minutes for a corresponding CalSim-II run) (Islam et al. 2009).

The geographical coverage of the CalLite model includes: the Upper Trinity River; the simplified Sacramento River Valley; the simplified San Joaquin River Valley; the Sacramento-San Joaquin Delta; and the Central Valley Project (CVP) and State Water Project (SWP) service areas. The model simulates in monthly time steps over a simulation period of water year 1922-2003.

CalLite allows interactive modification of a variety of water management actions including Delta regulation options, demand management, Delta channel flow, and salinity targets. Model users can choose different regulations from the graphical user interface (GUI) or can enter their own data to analyze the impact of a desired regulation. (See Figure 1)

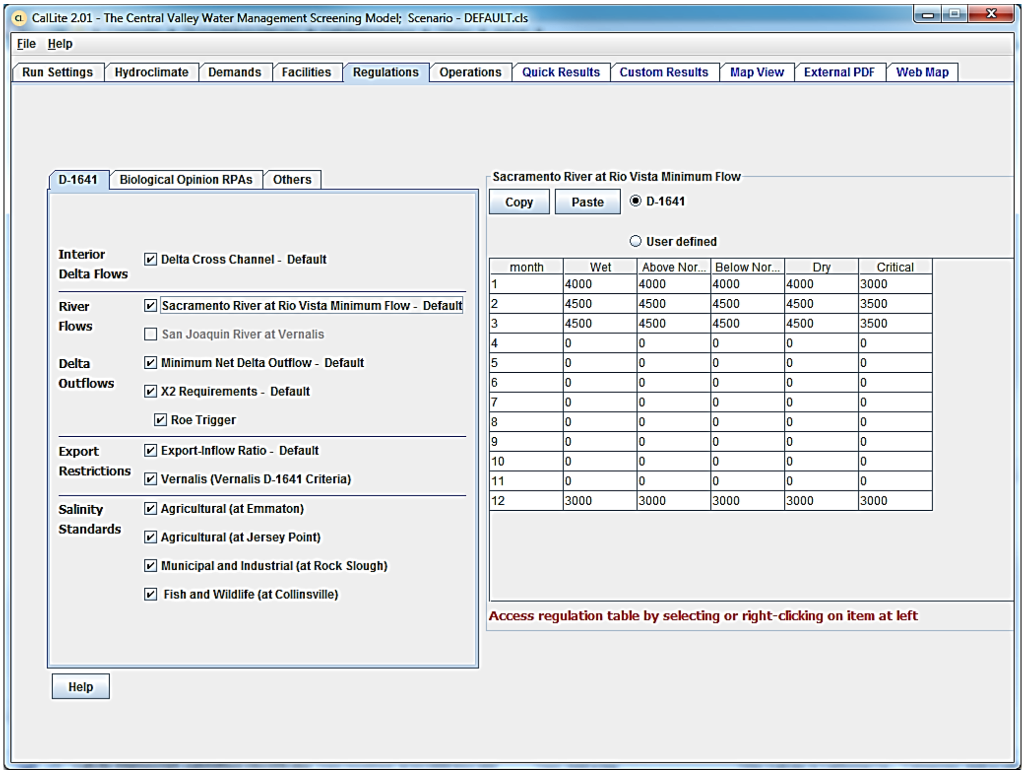


Figure 1: Delta regulation dashboard of CalLite GUI.

The GUI input dashboards permit users to specify model options such as: the simulation periods, demand levels, current and future hydrology, regulations, and operation procedures. In addition, the GUI post-processing dashboards provide quick access to key simulation results for reservoir storages, river flows, Delta inflows, salinity, and Delta outflow, and Delta exports (Figure 2). Results can be post-processed and displayed instantaneously on the GUI (Figure 3).

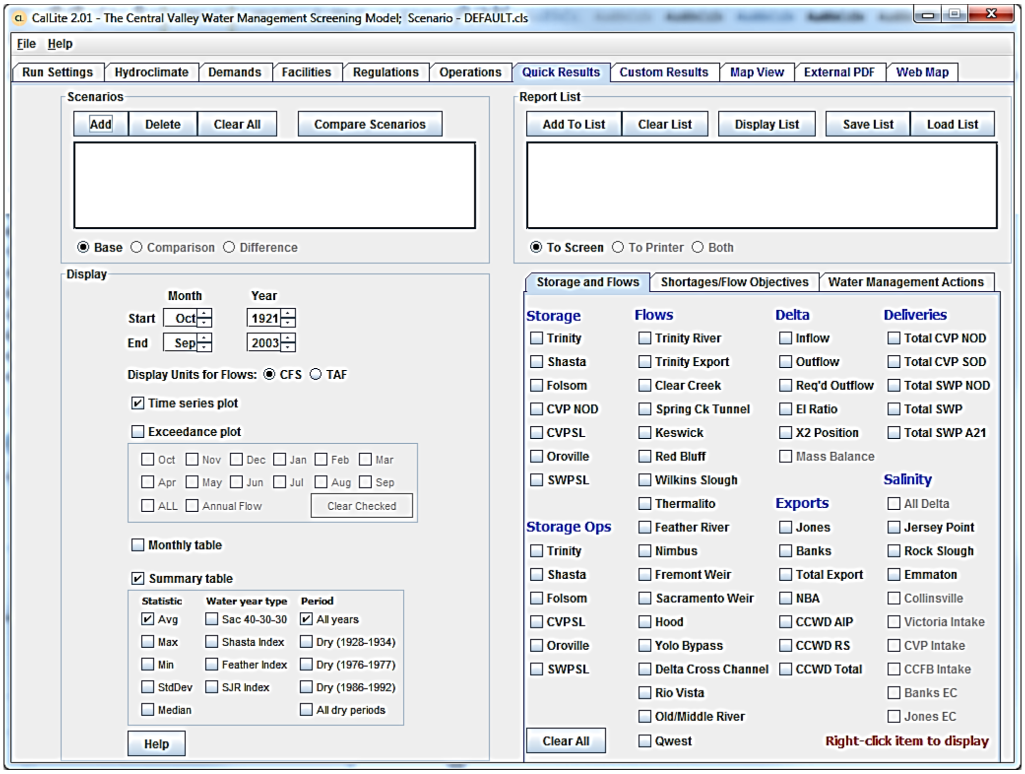


Figure 2: Results dashboard dashboard of CalLite GUI.

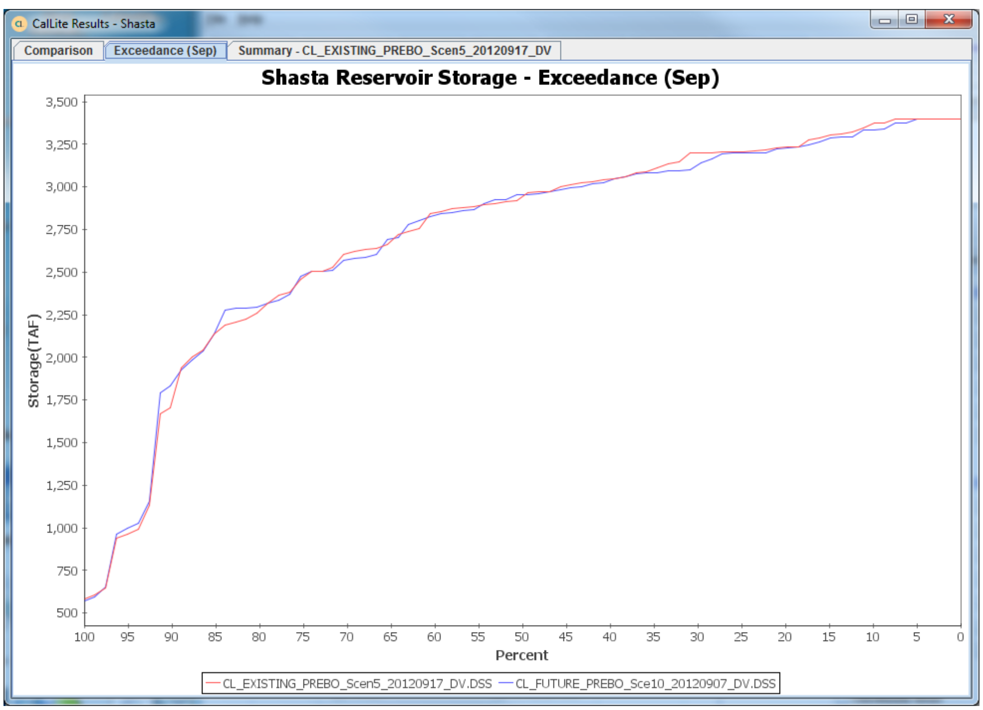


Figure 3: Example of model output from CalLite GUI result dashboard.

CalLite simulation results can be exported to other graphical and statistical software (such as Excel) for further analysis. Figure 4 demonstrates an analysis of different regulation impacts on water deliveries for a dry period (1987-1992). The CalLite GUI has utilities to produce a report comparing two scenario results (an example is attached).

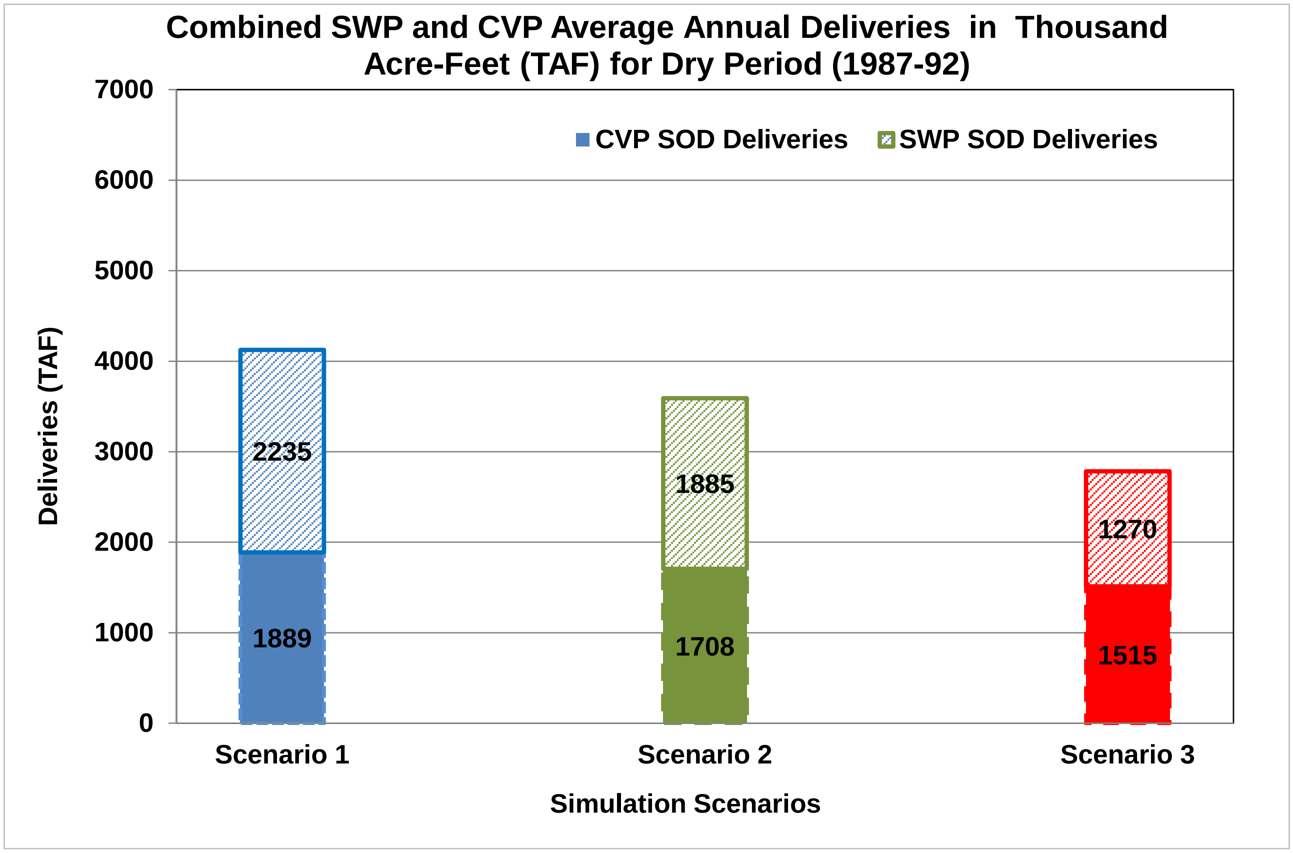


Figure 4: Example of model output from CalLite GUI postprocess in another software.

The CalLite model is best suited for screening a suite of alternatives to identify a smaller subset of promising options that should be modeled and studied more thoroughly. Examples of potential applications would be to explore and experiment with new Delta regulations, a new storage facility, or a conveyance facility. CalLite is not a replacement for existing detailed and complex models (such as CalSim-II), but rather it is informed by the data and results of existing models and allows users to explore future water management actions, improve understanding, and support more stakeholder-involved decision-making processes.

3- DSM2

The Delta Simulation Model 2 (DSM2) is a one-dimensional hydrodynamic and water quality simulation model used to simulate hydrodynamics, water quality, and particle movement in the Sacramento-San Joaquin Delta (Delta). Although the model grid has been extended beyond the Delta for certain applications, the standard grid focuses primarily on the Delta. The DSM2 model grid is bounded by the Sacramento River at Sacramento to the North, the San Joaquin River at Vernalis to the South, Martinez to the West, and State and federal export facilities to the Southwest.

Although DSM2 can run the entire 82 years covered under CalSim–II, it is normally based on 16 years of hydrologic data (1976 through 1991). This particular hydrologic period captures about the same mix of hydrologic conditions in the 1922-2003 period. The time step for the calculations is on the order of five minutes, capturing processes influenced by tidal dynamics. Applications of DSM2 include simulating historical conditions, forecasting future conditions, and planning studies using input from CalSim-II. DSM2 represents one of the most widely used planning models for Delta tidal hydraulics and salinity transport. DSM2 has frequently been used to determine the impacts of potential changes in the Delta (salinity, flow, and water level) associated with changes in flow patterns caused by variations in conveyance, river inflows, exports, diversions, or installation of new hydraulic structures.

DSM2 was first calibrated and validated in 1997. Then in 1999-2000, in coordination with a number of other agencies, DSM2 was recalibrated through a much more comprehensive effort. The results of this effort are documented in Chapter 2, Twenty-second annual progress report (2001) of the California Department of Water Resources' San Francisco Bay-Delta Evaluation Program at:

http://modeling-prod.water.ca.gov/delta/reports/annrpt/2001/2001Ch2.pdf

and the corresponding plots can be viewed via a "clickable" map at:

http://modeling.water.ca.gov/delta/studies/validation2000/map.html

In support of the BDCP program, DSM2 underwent another recalibration effort (performed by CH2MHill staff in coordination with DWR) to update the model. The update includes the addition of the flooded Liberty Island, updated Sacramento River bathymetry in anticipation of the need to simulate the proposed diversion intakes, and an extension of the model grid along Sacramento River to the North. More information on this effort is available at:

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/BDCP/DSM2_Recalibration_102709_doc.pdf

DSM2 is appropriate for studying the existing conditions in the Delta, as well as performing simulations for the assessment of incremental environmental impacts caused by future facilities and operations. DSM2 has three separate modules: HYDRO, QUAL, and PTM.

3.1 DSM2 Hydrodynamics Model – DSM2-HYDRO (HYDRO)

HYDRO is a one-dimensional, implicit, unsteady, open channel flow model. HYDRO simulates flows, velocities, and water surface elevations and provides these values as output. The resulting HYDRO flow values are used as input for DSM2-QUAL and PTM. HYDRO uses an unconditionally stable implicit finite difference formulation. Hydro solves the equations of continuity and momentum which are discretized in both time and space. Hydro is capable of simulating hydraulic devices, including operable gates that function based on some user-defined hydrodynamic conditions.

3.2 DSM2 Water Quality Model – DSM2-QUAL (QUAL)

QUAL simulates fate and transport of both conservative and non-conservative water quality constituents, including salts, based on a flow field simulated by HYDRO. QUAL is most often used to model Electrical Conductivity (EC) (an indirect measure of salt concentration) throughout the Delta but has also been used to model the transport of non-conservative constituents.

QUAL includes the capability to simulate ten non-conservative water quality constituents including dissolved oxygen (DO), water temperature, carbonaceous biochemical oxygen demand (BOD), chlorophyll *a*, organic nitrogen, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, organic phosphorus, and dissolved phosphorus. These variables are inter-dependent and, with the exception of temperature, simulation of one requires simulation of all other variables. The rates of mass transfer from one water quality variable to another are assumed to be affected by temperature. Applications of QUAL in modeling non-conservative constituents include:

1- TMDL DO Project-- Investigation of the effectiveness of installation of low-head pumps to improve the low DO conditions in Stockton Ship Channel
2- In-Delta Storage Project-- Determine the Impacts of the releases from the In-Delta islands on the DO and temperature in the nearby areas
3- BDCP Nutrient Modeling-- This work was performed by staff from Resource Management Associates (RMA). RMA staff performed several iterations of calibration and validation for water temperature and nutrients. They also made several improvements including using multiple meteorological regions, and the addition of inflows and water quality data from most waste water treatment plants. This work also allowed an analysis of ammonia levels in the Delta, which potentially affects the primary production.
4- Turbidity Modeling: QUAL was modified using BOD function as a surrogate using a first order decay rate. However, capabilities are currently limited since sediment re-suspension is not included and settling rate is not correlated to flow velocity and suspended sediment properties. DWR in cooperation with UC Davis, has laid the foundations for the development of a sediment transport module inside

QUAL. Delta Modeling will continue the work of incorporating that functionality within DSM2.

5- The addition of mercury modeling is being investigated in response to the Regional Board's recent TMDL, however, the development of a functional mercury model may take a few years.

3.3 DSM2 Particle Transport Modeling – DSM2-PTM (PTM)

PTM simulates pseudo 3-D transport of neutrally buoyant particles based on the flow field simulated by HYDRO. PTM simulates the transport and fate of individual particles traveling throughout the Delta. PTM uses velocity, flow, and stage output from the HYDRO to monitor the location of each individual particle using assumed vertical and lateral velocity profiles and specified random movements to simulate mixing. The output of PTM is the time series of the percentage of injected particles at any user defined reach(es)/group(s) and also particle fluxes at given node(s). A graphical animation for the outputs is available. PTM has multiple applications ranging from visualization of flow patterns to simulations of discrete organisms such as fish eggs or larvae. Although, PTM has the capability to model certain particle behavior, it has only been used to a limited extent in the past.

Limitations of PTM

Like all the other models described, it is important to understand that PTM has limitations. Perhaps the most challenging application of the PTM is its use to represent migrating juvenile or adult fish. The current model has been most frequently used by simulating particles that move passively with flow. However, there is a substantial and growing body of evidence that both juveniles and adults show complex behaviors that are not adequately represented by passive particles. To try and address this issue, there has been continued development of the model to allow at least limited behaviors that might better represent target species like delta smelt, Chinook salmon, and steehead trout. The list of improvements includes:

1) Particle surfing ability: a particle can move to the upper layer or the bottom layer to make it move faster or slower depending on tides or time of day;
2) Falling velocity: vertical velocity can be added to a particle;
3) Particle mortality: the age of a particle can be tracked and mortality included through the use of some assumed decaying function.
4) Filters: preventing particles to go through a filter to simulate the effects of fish screens

The behavior features were developed based on literature and hypotheses, but these have not been validated by field observations due to the lack of Delta-wide field data. As a promising sign, Sommer et al. (2011) found that addition of particle surfing behavior (Improvement #1 above) to simulations of delta smelt upstream migration resulted in migration rates similar to estimates based on fish trawl and salvage data. Additional field studies on fish behavior are clearly needed to refine and validate the model.

Future developments

Recent extensive field monitoring for acoustic telemetry salmon/steelhead tag studies in Georgiana Slough and the south Delta may make it possible to establish mathematical relationships that provide a better description for fish movement within the Delta waterways. These relationships can also be validated by field observations. A generalized linear model (GLM) for the route entrainment possibility has been developed by the Georgiana Slough non-physical barrier study group. The GLM relates the possibility of salmon/steelhead entering Georgiana Slough to the non-physical barrier operations, fish position at the junction, river flow conditions and timing (day or night). The application of GLM is currently limited to Georgiana Slough, and may only apply to high flow conditions since it was based on 2011 tagging data. The implementation of GLM in the PTM code has been completed. Testing and analysis are underway.

Analysis of 2012 (a drier year) acoustic telemetry tag data for Georgiana Slough and other south Delta junctions has been started and more GLMs will be produced for different river junctions and flow conditions. Once the new GLMs are developed, they will be implemented in PTM and tested within a larger geographical area and under more variable flow conditions.

In summary, while there has been substantial progress in the development of particle tracking models, there is still no widely accepted model to model fish behavior. Model refinements are needed to capture the full range of fish behaviors, and field studies are needed to provide the appropriate biological input data. This does not mean, however, that PTM models are not currently useful. For example, the models provide a helpful starting point for testing different hypotheses for potential fish behaviors, and to identify field data that are needed to accurately reflect movements. Moreover, in many circumstances (e.g. impact analyses) PTM may represent the best available tool to examine different operational scenarios. Such applications may be reasonable provided the model limitations and assumptions are clearly stated.

4- The Bay-Delta Salmon Ecosystem Simulation and Management Evaluation (SELFE) Modeling Project

The Bay-Delta SELFE project will offer users the capability to study cross-scale, multidimensional phenomena in the Bay Delta. DWR is applying SELFE, an open source, 3D computational model, to depict the major flow characteristics of the estuary with fidelity. DWR has also incorporated into SELFE many of the practical details needed to model the Bay-Delta, such as agricultural sources and sinks, gates and seasonal gates and barriers. A full Delta calibration is planned for release in Spring 2013, and shortly after that, training is to be offered within the modeling community.

SELFE is an accurate, robust model that combines modern hydrodynamic, particle and transport algorithms with practical features for modeling the Bay-Delta. The software is open source, and has a growing user community around the world. The theoretical papers describing the algorithm can be found in Zhang and Baptista (2008), Rodrigues et al. (2009), Pinto et al. (in press), Roland et al. (2012). The model features a variety of transport, sediment and biological processes, with published shallow water applications as diverse as salt plumes and salmon larvae modeling in the Columbia River; ecological modeling in Portugal, New Zealand and Chesapeake Bay; the Prestige Oil Spill; and super-regional storm surge flooding. After a rigorous multi-year benchmark study, SELFE is one of six models certified as an inundation model by the National Tsunami Mitigation Program and the model has been used to produce tsunami inundation maps for the state of Oregon since 2008.

The model is also fast -- in 2D mode, SELFE runs extremely fast and as a parallel, 3D application the model won recognition during the IOOS/SURA project (http://testbed.sura.org/; Teng 2012) for its ability to scale well on high parallel performance computational systems. This speed allows the user to offer a medium-resolution application for the region (130,000 nodes, 35 layers, Figure 5), rather than eliminating key physics to suit computational constraints.

Applications

The core Bay-Delta application of SELFE is a 3D hydrodynamic and salinity transport model of the full Bay-Delta system. The base model is our "base case" for studies, the basis of our general ongoing calibration and validation work and is designed to model and resolve the most basic processes affecting global accuracy in the estuary. Extending from this core model are focal studies that develop particular regions or physical and ecological processes.

SESAME

SESAME is a full life cycle energy-based model of salmon migration through the upper Sacramento River, Estuary and Coastal Ocean. The project is a collaboration between DWR, NASA and NMFS. SELFE is the estuary hydrodynamic and transport component of SESAME, and the application involves hydrodynamics, biology at several trophic levels and particle tracking. In this project, focus was on transport through the Sacramento corridor, but key policy questions hinge on detrimental pathways leading to the interior Delta.

Sea Level Rise

To model the effects of sea level rise, the model domain has been extended to the ocean, including San Francisco Bay, San Pablo Bay, and the Carquinez Strait. SELFE provides features that are well suited to these types of problems. In addition to an unstructured grid that can capture undulations in the Bays and channels, the model uses a particularly accurate depiction of the bathymetry, as sea level rise fills a new part of the tidal prism. The model also resolves the vertical structure of salinity in the Carquinez Straits. Finally, the SELFE model includes atmospheric data generated from a fine grain climate re-analysis models so it is well suited to represent not only sea-level rise but also to investigate the affects of atmospheric forcing.

SELFE Modules and Capabilities

SELFE has been adapted for hydrodynamics, temperature, salt, oil spill, sediment, biology and wind-wave interaction. The complete modeling system is shown in Figure 6. The model is relatively easy for experienced modelers to set up on a new study domain, though it does require grid generation software such as SMS. The immediate project goal is to provide hydrodynamic, salinity and scalar transport support on the larger Bay-Delta domain and a thorough calibration and validation (Please see Figure 7).

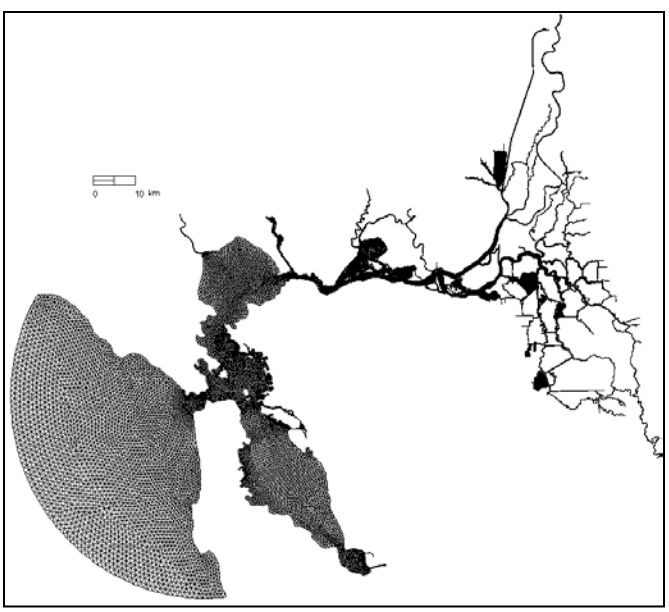


Figure 5: The Full Bay-Delta SELFE mesh.

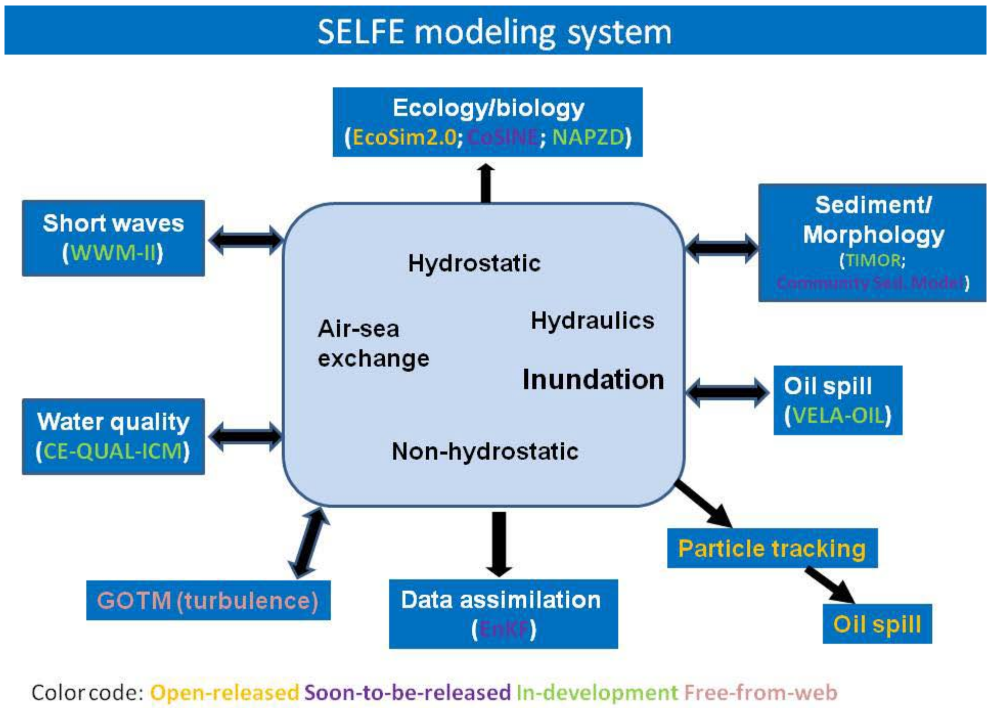


Figure 6: The SELFE modeling system.

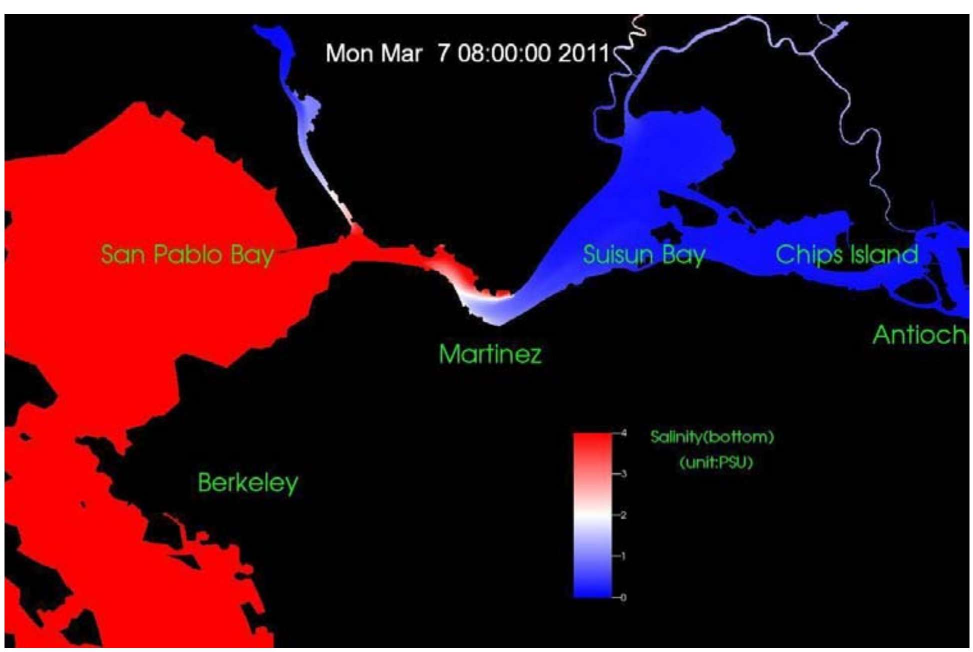


Figure 7: Still image from an animation showing the position of X2 (Shown in White)

The SELFE model application to the Bay-Delta has recently been completed within the full domain, and is already being used by DWR's NASA partners. As mentioned earlier, a full Delta calibration is to be released in Spring 2013, and shortly after that, training will be offered within the modeling community.

5- Climate Change

If the SWRCB plans to evaluate the potential future impacts of proposed changes to the water quality and flow standards of the Bay-Delta Plan, then future climate changes should be considered in the evaluation.

DWR has been and continues to be very active in developing methodologies for projecting future hydrologic conditions that take account of climate change trends. One such methodology was devised through a multi-agency effort for the BDCP to evaluate the environmental impacts and benefits of the BDCP project. This methodology is described in detail in attached draft Appendix 5A . While the process, tools, and data outlined in the attachment are illustrative of the considerations that go into a climate change analysis approach and this specific approach works well for the purposes of BDCP, it may not be appropriate for the SWRCB's purposes. For instance, the BDCP approach looks at two distinct future periods centered around 2025 and 2060. Other types of approaches provide a continuous projection of climatology and hydrology spanning from current conditions out to the future, such an approach would allow the SWRCB to look at projected impacts in any future period.

The complexity and importance of addressing climate change in the modeling work and estimations that the SWRCB may undertake while updating the Bay-Delta Plan warrant focused discussions with experts in the field to determine the appropriate level of analysis, select from existing methodologies, or develop a customized methodology. The considerations in this determination are not only technical but include issues of risk tolerance and dealing with irreducible uncertainty. As DWR mentioned in its presentation to the SWRCB at the first Bay-Delta Plan workshop, DWR has assembled a group of the leading experts in the field to discuss these topics and help us address our climate change challenges. DWR invites you to bring this matter to the DWR Climate Change Technical Advisory Group for additional focused discussions and more detailed guidance and recommendations.

6- Measured, Estimated, Natural, and Unimpaired Streamflows

Streamflow, or simply flow, is the volume of water flowing past a fixed point on a stream or on a river in a fixed unit of time. Several terminologies including measured flow, estimated flow, natural flow and unimpaired flow, have been used to describe streamflows for various purposes. Brief descriptions for each of these terminologies have been compiled to help differentiate these flows for better understanding by professionals as well as the general public.

Measured Flow vs. Estimated Flow

A widely used method of quantifying the flow of a stream is by installing streamflow gages at selected locations, presumed to be geometrically and hydraulically stable, such as at a bridge. The stage (the distance of the water surface from a specified reference datum) of the streamflow and its associated flow velocity measurement are used to compute the flow. The flow so quantified is known by various names such as measured flow, gage flow, recorded flow and observed flow.

Many times, gage flow data for a given watershed may not be available for the entire span of time period for which hydrological data is necessary for water resources planning. Some watersheds may not have measured data at all. In such situations, estimating flow is the recourse often taken. There are various methods that may be used for the flow estimations depending on the situation. For example, a statistical correlation method is most commonly used to extend shorter flow record for a watershed where a nearby watershed with longer measured flow record can be found and has similar hydrologic characteristics. Whatever the process used to estimate the flow, the flow so obtained is called estimated flow.

Natural Flow vs. Unimpaired Flow

Natural flow, which is sometimes also called full natural flow, at a certain location in a watershed is the streamflow that would have occurred naturally if the watershed hadn't been altered by any human activities including water storage and flood control structures, water imports and exports, water diversions, channel improvements. The word natural connotes that the watershed landscape is in a pre-historical or virgin state.

Unimpaired flow is an estimate of the flow that would have occurred had water flow remained unaltered in rivers and streams instead of stored in reservoirs, imported, exported, or diverted. It is a measure of the total water supply of a watershed available for all uses after removing the impacts of upstream alterations, as they occurred historically. The word unimpaired here implies only that certain items in the measured flows have been adjusted. Unimpaired flow could be synonymous with natural flow if all of the items in the unimpaired computation matched the natural flow computation. However, in reality, this is not usually the case. It is customary to include only those items in the unimpaired flow computation for which either reliable data are readily available or reasonable estimates can be made.

In California Central Valley rim watersheds where no significant human activities may exist, the magnitudes of unimpaired flow and natural flow are assumed to be very close and their uses are interchangeable. In the valley floor area, natural flows are impossible to compute reliably due to unknown nature of impairments caused by human alterations such as channel improvements, levees, and flood bypasses.

The following two examples may further graphically demonstrate how the terminologies of measured flow, natural flow, and unimpaired flow can be used under different circumstances within the Sacramento Valley.

Streamflow below Shasta Dam: An example where Unimpaired Flow can be assumed to be Natural Flow

Shasta Lake on the Sacramento River was built in early 1940s and started regulating streamflow in November of 1942. The storage space in Shasta Lake has altered the streamflow below the Shasta dam by both storing and releasing water from the storage since then. As shown in Figure 8, the line with squares and the line with diamonds represent the measured Sacramento River flow below Shasta dam before and after the reservoir was built; the line with asterisks is the estimated unimpaired flow, obtained by removing the impact of the reservoir from the measured flow (the line with diamonds).

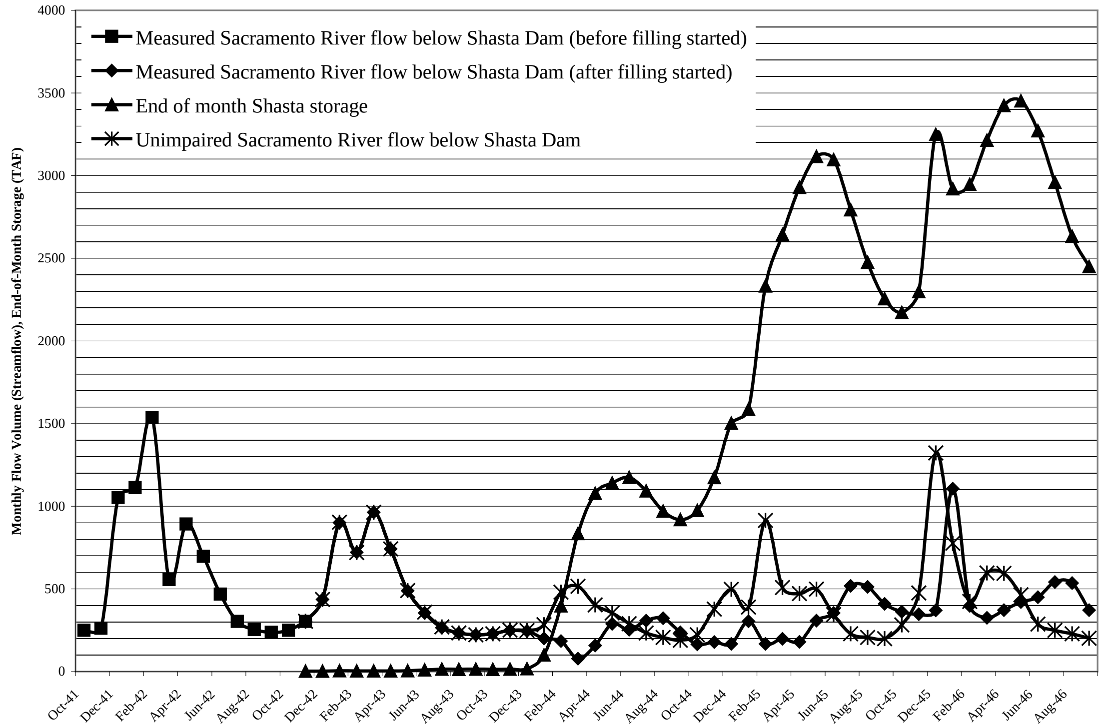


Figure 8: Measured and unimpaired flows below Shasta Dam

Since the Sacramento River watershed above Shasta Dam has generally been assumed to exist in natural state and Shasta dam is considered the only significant human alteration to the river, both terminologies of natural flow and unimpaired flow can be used to describe the measured flow before the reservoir was built (the line with squares) and the estimated unimpaired flow after the reservoir was built (the line with asterisks). The line with triangles is the end of month Shasta storage. It is the main component used in the unimpaired flow estimation. Reservoir evaporation was also used in the unimpaired flow estimation but has been omitted from the figure due to its insignificant magnitude.

Streamflow at Freeport: An example where Unimpaired Flow cannot be assumed to be Natural Flow

Figure 9 shows a comparison of the gage flow at the United States Geological Survey (USGS) gage on the Sacramento River at Freeport (the line with diamonds) with the estimated unimpaired Sacramento River flow at the same location (the line with squares). Due to the numerous upstream human alterations of water storage and flood control structures, water imports and exports, water diversions, channel improvements and other factors, this USGS gage flow gives an impaired flow (in contrast to unimpaired flow). The unimpaired flow data used in the comparison is taken from the draft DWR report titled California Central Valley Unimpaired Flow Data, Fourth Edition, Bay-Delta Office, May 2007 and it was estimated by removing impacts of upstream water storages, diversions, imports and exports, and other adjustments that may be reasonably quantified or measured from USGS gage flow. Since the impacts of upstream channel improvements, levees, and flood bypasses impacts are difficult to remove from the gage flow, the unimpaired flow so estimated can not be called natural flow. The differences between the two lines in Figure 9 represent the impairments removed.

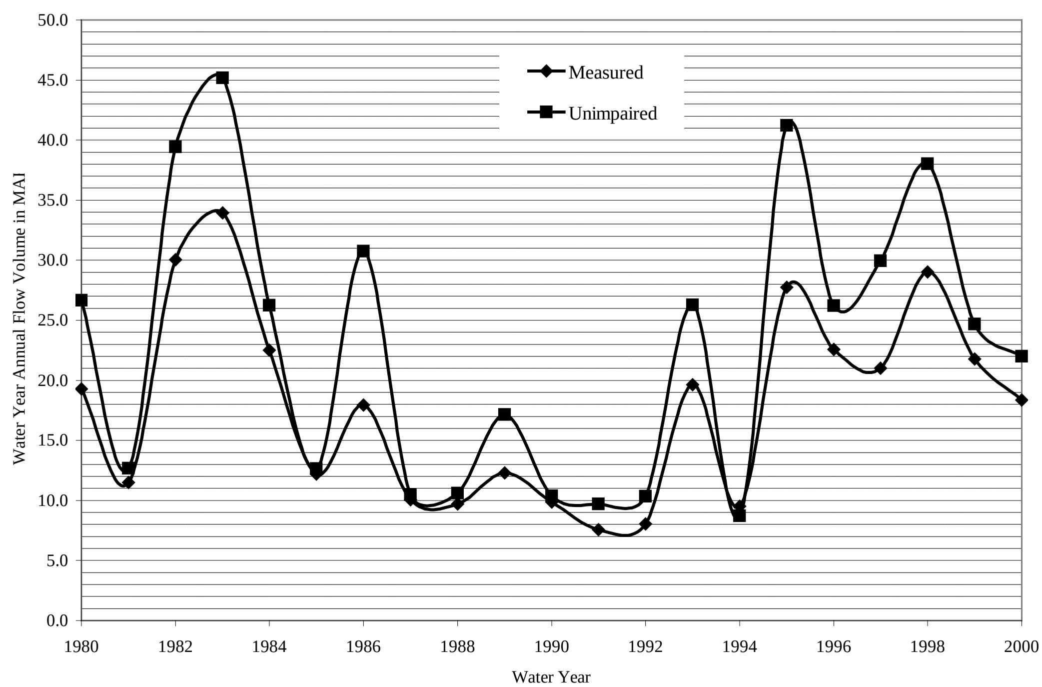


Figure 9: Sample USGS gage flow and unimpaired flow of Sacramento River at Freeport.

We would like to remind the Board that DWR gave a presentation called “Estimating California Central Valley Unimpaired Flows" on January 6, 2011 at the SWRCB workshop on " Presentation and Discussion of Draft Technical Report on the Scientific Basis for Alternative San Joaquin River Flow and Southern Delta Salinity Objectives." The purpose of the presentation was to give an overview of DWR Unimpaired Flows calculations, weaknesses, issues and pitfalls in using Unimpaired Flows for use as a basis for setting Flow objectives in the Delta.

This presentation is available at SWRCB's website at:

http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/sds_srjf/sjr/docs/dwr_uf010611.pdf

For your convenience, a copy of the presentation is attached at the end of this submittal.

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ATTACHMENTS

BDCP Appendix 5A

BDCP EIR/EIS Modeling Technical Appendix

BDCP EIR/EIS Modeling Technical Appendix

This appendix provides information about the assumptions, modeling tools and the methods used for Bay Delta Conservation Plan Environmental Impact Report/Environmental Impact Statement (BDCP EIR/EIS) Alternatives analyses including information for Existing Conditions and No Action Alternative simulations. The Appendix also provides model results obtained from the BDCP EIR/EIS Alternatives analyses; and additional modeling information such as model limitations, limitations in climate change modeling, and extreme operating conditions.

The Appendix consists of four main sections that are briefly described below:

- Section A: Modeling Methodology
- Section B: CALSIM II and DSM2 Modeling Simulations and Assumptions
- Section C: CALSIM II and DSM2 Modeling Results
- Section D: Additional Modeling Information

Section A: Modeling Methodology

Several models are used to assess and quantify the effects of BDCP Alternatives on the long-term operations and the environment. This section provides information about the overall analytical framework explaining how the modeling information obtained from different models fit together; and descriptions of the key analytical tools that were part of the analytical framework. It also summarizes the modifications to the key analytical tools used in this process.

Section B: CALSIM II and DSM2 Modeling Simulations and Assumptions

This section describes the assumptions for the CALSIM II (Hydrology and System Operations) and DSM2 (Delta Hydrodynamics, Water Quality, and Delta Particle Tracking) model simulations of the Existing Conditions, No Action Alternative and with action Alternatives.

Section C: CALSIM II and DSM2 Modeling Results

This section provides CALSIM II and DSM2 model simulation results for alternatives evaluated for the BDCP EIR/EIS. Key parameters are selected for display; and several different formats of presentations are provided for each parameter to enable the reader to do different kinds of analyses.

Section D: Additional Modeling Information

This section is still being completed. It is planned to be included in a subsequent version of this appendix. This section will provide additional details on the analytical tools and their development and background information on modeling of climate change. In addition, it will also provide information on the model limitations, uncertainty and any sensitivity analyses performed in support of the overall analysis. Furthermore, it will include information on the appropriate use of the modeling results presented in Section C.

Section A: Modeling Methodology

Outline

A.1. Introduction

This section summarizes the modeling methodology used for the Bay Delta Conservation Plan Environmental Impact Report/Environmental Impact Statement (BDCP EIR/EIS) Existing Conditions, No Action Alternative and otherAlternatives. It describes the overall analytical framework and contains descriptions of the key analytical tools and approaches used in the quantitative evaluation of the Alternatives.

BDCP includes several main components that will have significant effects on SWP and CVP operations and the hydrologic response of the system. Most of the Alternatives include construction and operation of new north Delta intakes and associated conveyance, modifications to the Fremont Weir, large scale tidal marsh restoration in the Delta and changes in the operation of the existing south Delta export facilities can significantly influence the hydrologic response of the system.

For the purposes of the modeling, the Alternatives are simulated at three phases in time: Near-Term (NT), representing a point in time 5-10 years into the permit (~2015), Early Long-Term (ELT) representing a point in time 15 years into the permit (~2025), and Late Long-Term (LLT) representing the end of the 50-year permit (~2060).

In the Alternatives including the new north Delta intakes and isolated conveyance facility, the facility is assumed not to be functional until the ELT phase. All the Alternatives, except for Existing Conditions and No Action Alternative, include the tidal marsh restoration. The acreages of the tidal marsh restoration incrementally increase with each phase. NT includes 14,000 acres, ELT includes 25,000 acres and LLT includes 65,000 acres of tidal marsh restoration.

In the evaluation of the No Action Alternative and the other Alternatives at the ELT and LLT phases, sea level rise was assumed to be inherent. ELT assumes 15cm and LLT assumes 45cm sea level rise to exist. The analytical framework and the tools described in this are developed to evaluate these complex, inter-dependent, large-scale changes to the system. The full modeling assumptions for all the alternatives are provided in Section B.

For the purpose of BDCP EIR/EIS impacts evaluation, Alternatives' modeling results at LLT phase are considered.

A.2. Overview of the Modeling Approach

To support the impact analysis of the Alternatives, modeling of the physical variables (or "physical modeling") such as flows is required to evaluate changes to conditions affecting resources within the Delta as well as effects to upstream and downstream resources. A framework of integrated analyses including hydrologic, operations, hydrodynamics, water quality, and particle tracking analysis are required to provide baseline and comparative information for water supply, surface water, aquatic resources and water quality assessments. This analytical framework is also useful to assess changes in the function of the alternatives under varying assumptions of future, non-project conditions such as climate change, future demands, and changes in Delta morphology.

The Alternatives include complex changes to internal forcings such as Delta conveyance, SWP/CVP water project operations, floodplains and tidal marsh, and Delta channel structure/gates. Both these internal forcings and external forcings such as climate and sea level changes influence the future conditions of reservoir storage, river flow, Delta flows, exports, water quality, and tidal dynamics. Evaluation of these conditions is the primary focus of the physical modeling analyses. The interaction between many of the elements proposed under the Alternatives necessitated modifications to existing analytical tools or application of new analytical tools to account for these dynamic relationships.

Figure A-1 shows the analytical tools applied in these assessments and the relationship between these tools. Each model included in Figure A-1 provides information to the next "downstream" model in order to provide various results to support the impact analyses. Changes to the historical hydrology related to the future climate are applied in the CALSIM II model and combined with the assumed operations for each Alternative. The CALSIM II model simulates the operation of the major SWP and CVP facilities in the Central Valley and generates estimates of river flows, exports, reservoir storage, deliveries, and other parameters. The Delta boundary flows and exports from CALSIM II are then used to drive the DSM2 Delta hydrodynamic and water quality models for estimating tidally-based flows, stage, velocity, and salt transport within the estuary. Particle tracking modeling uses the velocity fields generated under the hydrodynamics to emulate movement of particles throughout the Delta system. River and temperature models for the primary river systems use the CALSIM II reservoir storage, reservoir releases, river flows, and meteorological conditions to estimate reservoir and river temperatures under each scenario. The results from this suite of physical models are used to inform the understanding of effects of each individual scenario considered in the BDCP.

A.2.1. Analytical Tools

A brief description of the hydrologic, hydrodynamic, water quality, particle transport, reservoir and river temperature modeling tools used in the analytical framework is provided below.

CALSIM II

The California Department of Water Resources (DWR)/U.S. Bureau of Reclamation (Reclamation) CALSIM II planning model was used to simulate the operation of the CVP and SWP over a range of hydrologic conditions. CALSIM II is a generalized reservoir-river basin simulation model that allows for specification and achievement of user-specified allocation targets, or goals (Draper et al. 2002). CALSIM II represents the best available planning model for the SWP and CVP system operations and has been used in previous system-wide evaluations of SWP and CVP operations (USBR, 1994, 2004, 2008).

Inputs to CALSIM II include water diversion requirements (demands), stream accretions and depletions, rim basin inflows, irrigation efficiencies, return flows, non-recoverable losses, and groundwater operations. Sacramento Valley and tributary rim basin hydrologies are developed using a process designed to adjust the historical sequence of monthly stream flows over an 82-year period (1922 to 2003) to represent a sequence of flows at a future level of development.

Adjustments to historic water supplies are determined by imposing future level land use on historical meteorological and hydrologic conditions. The resulting hydrology represents the water supply available from Central Valley streams to the CVP and SWP at a future level of development.

CALSIM II produces outputs for river flows and diversions, reservoir storage, Delta flows and exports, Delta inflow and outflow, Deliveries to project and non-project users, and controls on project operations. Reclamation's 2008 Operations Criteria and Plan (OCAP) Biological

Assessment (BA) Appendix D provides more information about CALSIM II (USBR, 2008a).CALSIM II output provides the basis for multiple other hydrologic, hydrodynamic, and biological models and analyses. CALSIM II results are used to determine water quality, hydrodynamics, and particle tracking in the DSM2 model. The outputs feed into temperature models including the Upper Sacramento River Water Quality Model (USRWQM), the Reclamation Temperature Model, and other habitat and biological models.

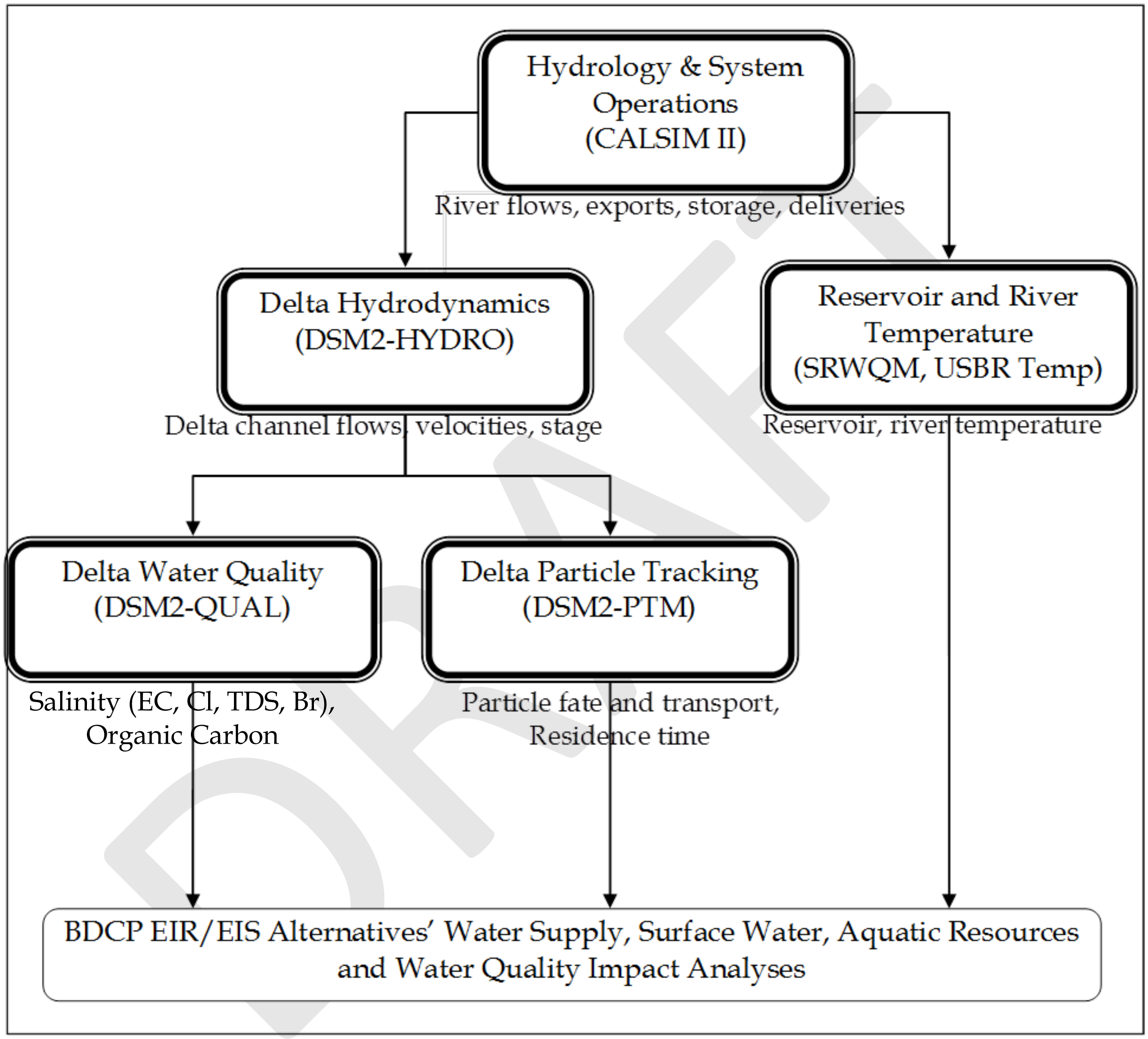


Figure A-1: Analytical Framework used to Evaluate Impacts of the Alternatives

Artificial Neural Network (ANN) for Flow-Salinity Relationships

An Artificial Neural Network (ANN) has been developed (Sandhu et al. 1999, Seneviratne and Wu, 2007) that attempts to faithfully mimic the flow-salinity relationships as modeled in DSM2, but provide a rapid transformation of this information into a form usable by the statewide CALSIM II model. The ANN is implemented in CALSIM II to constrain the operations of the upstream reservoirs and the Delta export pumps in order to satisfy particular salinity requirements. The current ANN predicts salinity at various locations in the Delta using the following parameters as input: Sacramento River inflow, San Joaquin River inflow, Delta Cross Channel gate position, and total exports and diversions. Sacramento River inflow includes Sacramento River flow, Yolo Bypass flow, and combined flow from the Mokelumne, Cosumnes, and Calaveras rivers (East Side Streams) minus North Bay Aqueduct and Vallejo exports. Total exports and diversions include State Water Project (SWP) Banks Pumping Plant, Central Valley Project (CVP) Tracy Pumping Plant, Contra Costa Water District (CCWD) diversions including diversion to Los Vaqueros Reservoir. The ANN model approximates DSM2 model-generated salinity at the following key locations for the purpose of modeling Delta water quality standards: X2, Sacramento River at Emmaton, San Joaquin River at Jersey Point, Sacramento River at Collinsville, and Old River at Rock Slough. In addition, the ANN is capable of providing salinity estimates for Clifton Court Forebay, CCWD Alternate Intake Project (AIP) and Los Vaqueros diversion locations. A more detailed description of the ANNs and their use in the CALSIM II model is provided in Wilbur and Munévar (2001). In addition, the DWR Modeling Support Branch website (http://modeling.water.ca.gov/) provides ANN documentation.

Upper Sacramento River Water Quality Model (USRWQM)

The Upper Sacramento River Water Quality Model (USRWQM) was used to simulate the effects of operations on water temperature in the Sacramento River and Shasta and Keswick reservoirs. The USRWQM was developed using the HEC-5Q model to simulate mean daily (using 6-hour meteorology) reservoir and river temperatures at key locations on the Sacramento River. The timestep of the model is daily and provides water temperature each day for the 82 year hydrologic period used in CALSIM II. The model has been used in the previous CVP and SWP system operational performance evaluation (USBR, 2008c). Monthly flows from CALSIM II for an 82 year period (WY 1922-2003) are used as input into the USRWQM after being temporally downsized to daily average flows. Temporal downscaling is performed on the CALSIM II monthly average tributary flows to convert them to daily average flows for HEC5Q input. Monthly average flows are converted to daily tributary inflows based on 1921 through 1994 daily historical record for the following aggregated inflows:

1. Trinity River above Lewiston;

2. Sacramento River above Keswick; and

3. Incremental inflow between Keswick and Bend Bridge (Seven day trailing average for inflows below Butte City).

Each of the total monthly inflows specified by CALSIM II is scaled proportionally to one of these three historical records. Reservoir inflows were proportioned as defined above. Outflows and diversions are smoothed for a better transition at the end of the month without regard for reservoir volume constraints or downstream minimum flows. As flows are redistributed within the month, the minimum flow constraint at Keswick, Red Bluff and Knights Landing may be violated. In such cases, operation modifications are required for daily flow simulation to satisfy minimum flow requirements. A utility program is included in SRWQM to convert the monthly CALSIM II flows and releases into daily operations. More detailed description SRWQM and the temporal downscaling process is included in an RMA calibration report (RMA 2003). For more information on the USRWQM, see Appendix H of the Reclamation’s 2008 OCAP BA (USBR, 2008c).

Reclamation Temperature Model

The Reclamation Temperature Model was used to predict the effects of operations on water temperatures in the Trinity, Feather, American, and Stanislaus river basins and upstream reservoirs. The model is a reservoir and stream temperature model, which simulates monthly reservoir and stream temperatures used for evaluating the effects of CVP/SWP project operations on mean monthly water temperatures in the basin based on hydrologic and climatic input data. It has been applied to past CVP and SWP system operational performance evaluations (USBR, 2008c).

The model uses CALSIM II output to simulate mean monthly vertical temperature profiles and release temperatures for five major reservoirs (Trinity, Whiskeytown, Shasta, Oroville and Folsom), four downstream regulating reservoirs (Lewiston, Keswick, Goodwin and Natoma), and three main river systems (Sacramento, Feather and American), although the model is not be applied to the Sacramento River because the USRWQM was deemed superior as a result of its daily time step. For more information on the Reclamation Temperature Model, see Appendix H of the Reclamation's 2008 OCAP BA (USBR, 2008c).

DSM2

DSM2 is a one-dimensional hydrodynamic and water quality simulation model used to simulate hydrodynamics, water quality, and particle tracking in the Sacramento-San Joaquin Delta (DWR, 2002). DSM2 represents the best available planning model for Delta tidal hydraulic and salinity modeling. It is appropriate for describing the existing conditions in the Delta, as well as performing simulations for the assessment of incremental environmental impacts caused by future facilities and operations.

The DSM2 model has three separate components: HYDRO, QUAL, and PTM. HYDRO simulates velocities and water surface elevations and provides the flow input for QUAL and PTM. DSM2-HYDRO outputs are used to predict changes in flow rates and depths, and their effects on covered species, as a result of the BDCP and climate change.

The QUAL module simulates fate and transport of conservative and non-conservative water quality constituents, including salts, given a flow field simulated by HYDRO. Outputs are used to estimate changes in salinity, and their effects on covered species, as a result of the BDCP and climate change. Reclamation's 2008 OCAP BA Appendix F provides more information about DSM2 (USBR, 2008b).

DSM2-PTM simulates pseudo 3-D transport of neutrally buoyant particles based on the flow field simulated by HYDRO. It simulates the transport and fate of individual particles traveling throughout the Delta. The model uses velocity, flow, and stage output from the HYDRO module to monitor the location of each individual particle using assumed vertical and lateral velocity profiles and specified random movement to simulate mixing. PTM has multiple applications ranging from visualization of flow patterns to simulation of discrete organisms such as fish eggs and larvae. Additional information on DSM2 can be found on the DWR Modeling Support Branch website at http://modeling.water.ca.gov/.

A.2.2. Key Components of the Analytical Framework

Major components of the BDCP physical modeling, including Hydrology and Systems Operations Modeling, Reservoir and River Temperature Modeling, Delta Hydrodynamics and

Water Quality Modeling and Delta Particle Transport and Fate Modeling are described in separate sections. Each section describes in detail the key tools used for modeling, data inter-dependencies and limitations. It also includes description of the process of how the tools are applied in a long-term planning analysis such as evaluating the Alternatives and describe any improvements or modifications performed for application in BDCP modeling.

Section A.3. *Hydrology and Systems Operations Modeling* describes the application of the CALSIM II model to evaluate the effects of hydrology and system operations on river flows, reservoir storage, Delta flows and exports, and water deliveries. Section A.4. *Reservoir and River Temperature Modeling* includes a description of the Sacramento River Water Quality Model for analysis of temperature in the Shasta-Whiskeytown complex and the Sacramento River. Section A.5. *Delta Hydrodynamics and Water Quality* section describes the application of the DSM2 model to implement new elements of the BDCP and resulting effects to tidal stage, velocity, flows, and salinity. Finally, Section A.6. *Delta Particle Transport and Fate Modeling* describes the methodology and application of the DSM2-PTM model for simulating particle transport in the Delta.

A.2.3. Climate Change and Sea Level Rise

The physical modeling approach applied for the BDCP integrates a suite of analytical tools in a unique manner to characterize changes to the system from "atmosphere to ocean". Figure A-2 illustrates the general flow of information for incorporating climate and sea level change in the physical modeling analyses. Climate and sea level can be considered the most upstream and most downstream boundary forcings on the system analyzed in the physical modeling for the BDCP. However, these forcings are outside of the influence of the BDCP and are considered external forcings. The effects of these forcings are incorporated into the key models used in the analytical framework.

The selection of the future climate and the sea level rise scenarios is described in Section A.7. *Climate and Sea Level Change Scenarios* section along with the process of science review, incorporation of uncertainty, and analytical methods for selecting appropriate scenarios. For all the selected future climate scenarios, regional hydrologic modeling was performed with the Variable Infiltration Capacity (VIC) hydrology model using temperature and precipitation projections of future climate. In addition to a range of hydrologic process information, the VIC model generates natural streamflows under each assumed climate condition. Section A.8. *Regional Hydrologic Modeling* describes the application of the macro-scale VIC hydrology model that translates the effects of future climate conditions on watershed processes ultimately affecting the timing and volume of runoff.

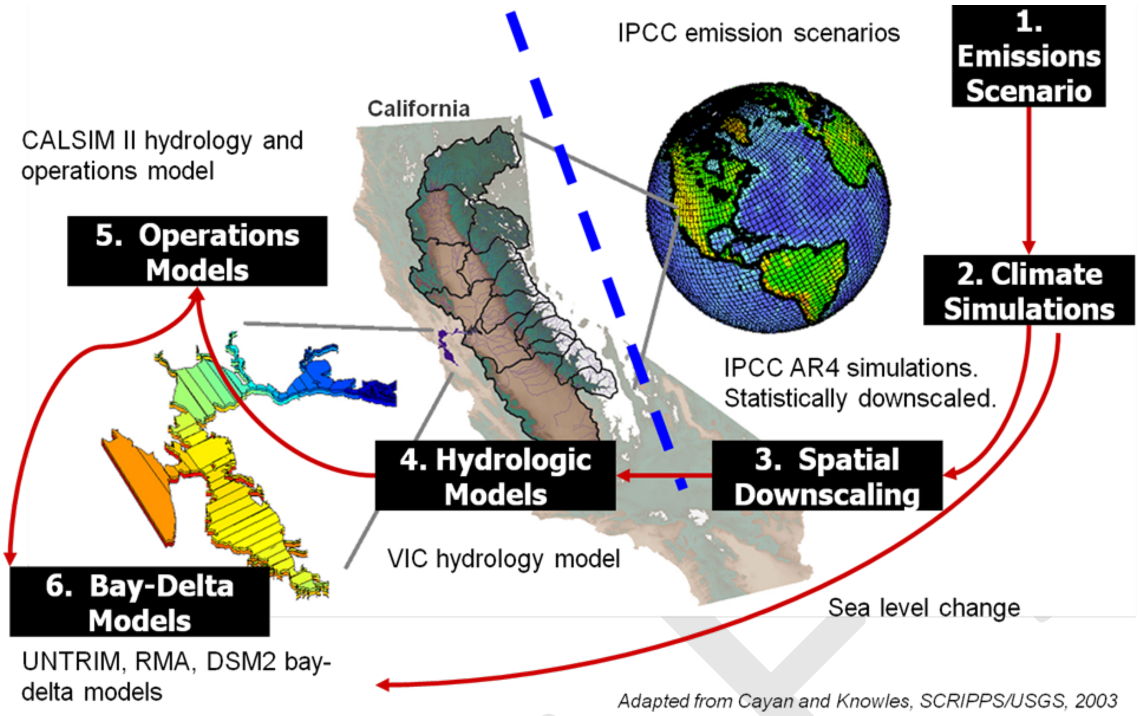


Figure A-2: Characterizing Climate Impacts from Atmosphere to Oceans

A.3. Hydrology and System Operations

The hydrology of the Central Valley and operation of the CVP and SWP systems is a critical element toward any assessment of changed conditions in the Delta. Changes to conveyance, flow patterns, demands, regulations, and/or Delta configuration will influence the operation of the SWP and CVP reservoirs and export facilities. The operations of these facilities, in turn, influence Delta flows, water quality, river flows, and reservoir storage. The interaction between hydrology, operations, and regulations is not always intuitive and detailed analysis of this interaction often results in new understanding of system responses. Modeling tools are required to approximate these complex interactions under future conditions.

The Bay Delta Conservation Plan (BDCP) includes several main components that will have significant effects on SWP and CVP operations and the hydrologic response of the system. The proposed construction and operation of new north Delta intakes and associated conveyance, modifications to the Fremont Weir, large scale tidal marsh restoration in the Delta, and changes in the operation of the existing south Delta export facilities can significantly influence the hydrologic response of the system.

This section describes in detail the methodology used to simulate hydrology and system operations for evaluating the effects of the BDCP. It discusses the primary tool (CALSIM II) used in this process and improvements made to the model to better simulate key components of the BDCP.

A.3.1 CALSIM II

The DWR/USBR CALSIM II planning model was used to simulate the operation of the CVP and SWP over a range of hydrologic conditions. CALSIM II is a generalized reservoir-river basin simulation model that allows for specification and achievement of user-specified allocation targets, or goals (Draper et. al., 2004). The current application to the Central Valley system is called CALSIM II and represents the best available planning model for the SWP and CVP system operations. CALSIM II includes major reservoirs in the Central Valley of the California including Trinity, Lewiston, Whiskeytown, Shasta, Keswick, Folsom, Oroville, San Luis, New Melones and Millerton located along the Sacramento and San Joaquin Rivers and their tributaries. CALSIM II also includes all the major CVP and SWP facilities including Clear Creek Tunnel, Tehama Colusa Canal, Corning Canal, Jones Pumping Plant, Delta Mendota Canal, Mendota Pool, Banks Pumping Plant, California Aqueduct, South Bay Aqueduct, North Bay Aqueduct, Coastal Aqueduct and East Branch Extension. In addition, it also includes some locally managed facilities such as the Glenn Colusa Canal, Contra Costa Canal and the Los Vaqueros Reservoir. Figure A-3 shows the major reservoirs, streams and facilities included in the CALSIM II model.

The CALSIM II simulation model uses single time-step optimization techniques to route water through a network of storage nodes and flow arcs based on a series of user-specified relative priorities for water allocation and storage. Physical capacities and specific regulatory and contractual requirements are input as linear constraints to the system operation using the water resources simulation language (WRESL). The process of routing water through the channels and storing water in reservoirs is performed by a mixed integer linear programming solver. For each time step, the solver maximizes the objective function to determine a solution that delivers or stores water according to the specified priorities and satisfies all system constraints. The sequence of solved linear programming problems represents the simulation of the system over the period of analysis.

Figure A-3: Major Reservoirs, Streams and Facilities (both CVP and SWP) Included in the CALSIM II Model

CALSIM II includes an 82-year modified historical hydrology (water years 1922-2003) developed jointly by DWR and USBR. Water diversion requirements (demands), stream accretions and depletions, rim basin inflows, irrigation efficiencies, return flows, non-recoverable losses, and groundwater operations are components that make up the hydrology used in CALSIM II. Sacramento Valley and tributary rim basin hydrologies are developed using a process designed to adjust the historical observed sequence of monthly stream flows to represent a sequence of flows at a future level of development. Adjustments to historic water supplies are determined by imposing future level land use on historical meteorological and hydrologic conditions. The resulting hydrology represents the water supply available from Central Valley streams to the system at a future level of development. Figure A-4 shows the valley floor depletion regions, which represent the spatial resolution at which the hydrologic analysis is performed in the model.

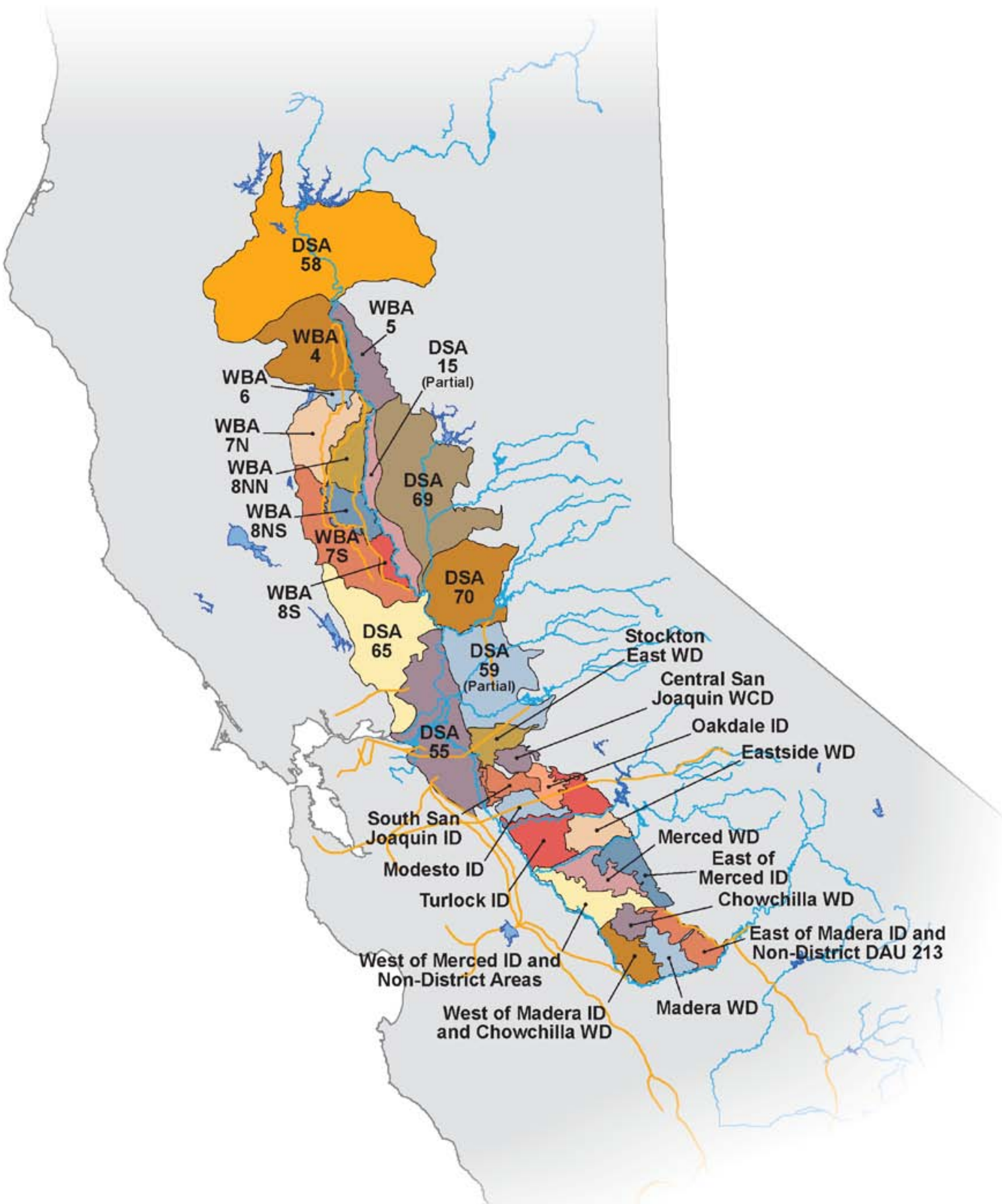


Figure A-4: CALSIM II Depletion Analysis Regions

CALSIM II uses rule-based algorithms for determining deliveries to north-of-Delta and south-of-Delta CVP and SWP contractors. This delivery logic uses runoff forecast information, which incorporates uncertainty and standardized rule curves. The rule curves relate storage levels and forecasted water supplies to project delivery capability for the upcoming year. The delivery capability is then translated into SWP and CVP contractor allocations which are satisfied through coordinated reservoir-export operations.

The CALSIM II model utilizes a monthly time-step to route flows throughout the river-reservoir system of the Central Valley. While monthly time steps are reasonable for long-term planning analyses of water operations, two major components of the BDCP conveyance and conservation strategy include operations that are sensitive to flow variability at scales less than monthly: the operation of the modified Fremont Weir and the diversion/bypass rules associated with the proposed north Delta intakes. Initial comparisons of monthly versus daily operations at these facilities indicated that weir spills were likely underestimated and diversion potential was likely overstated using a monthly time step. For these reasons, a monthly to daily flow disaggregation technique was included in the CALSIM II model for the Fremont Weir, Sacramento Weir, and north Delta intakes. The technique applies historical daily patterns, based on the hydrology of the year, to transform the monthly volumes into daily flows. The procedure is described in more detail further in this document. Reclamation's 2008 OCAP BA Appendix D provides more information about CALSIM II (USBR, 2008a).

A.3.2. Artificial Neural Network for Flow-Salinity Relationship

Determination of flow-salinity relationships in the Sacramento-San Joaquin Delta is critical to both project and ecosystem management. Operation of the SWP/CVP facilities and management of Delta flows is often dependent on Delta flow needs for salinity standards. Salinity in the Delta cannot be simulated accurately by the simple mass balance routing and coarse timestep used in CALSIM II. Likewise, the upstream reservoirs and operational constraints cannot be modeled in the DSM2 model. An Artificial Neural Network (ANN) has been developed (Sandhu et al. 1999) that attempts to mimic the flow-salinity relationships as simulated in DSM2, but provide a rapid transformation of this information into a form usable by the CALSIM II operations model. The ANN is implemented in CALSIM II to constrain the operations of the upstream reservoirs and the Delta export pumps in order to satisfy particular salinity requirements. A more detailed description of the use of ANNs in the CALSIM II model is provided in Wilbur and Munévar (2001).

The ANN developed by DWR (Sandhu et al. 1999, Seneviratne and Wu, 2007) attempts to statistically correlate the salinity results from a particular DSM2 model run to the various peripheral flows (Delta inflows, exports and diversions), gate operations and an indicator of tidal energy. The ANN is calibrated or trained on DSM2 results that may represent historical or future conditions using a full circle analysis (Seneviratne and Wu, 2007). For example, a future reconfiguration of the Delta channels to improve conveyance may significantly affect the hydrodynamics of the system. The ANN would be able to represent this new configuration by being retrained on DSM2 model results that included the new configuration.

The current ANN predicts salinity at various locations in the Delta using the following parameters as input: Northern flows, San Joaquin River inflow, Delta Cross Channel gate position, total exports and diversions, Net Delta Consumptive Use, an indicator of the tidal energy and San Joaquin River at Vernalis salinity. Northern flows include Sacramento River flow, Yolo Bypass flow, and combined flow from the Mokelumne, Cosumnes, and Calaveras rivers (East Side Streams) minus North Bay Aqueduct and Vallejo exports. Total exports and diversions include State Water Project (SWP) Banks Pumping Plant, Central Valley Project (CVP) Jones Pumping Plant, and CCWD diversions including diversions to Los Vaqueros Reservoir. A total of 148 days of values of each of these parameters is included in the correlation, representing an estimate of the length of memory of antecedent conditions in the Delta. The ANN model approximates DSM2 model-generated salinity at the following key locations for the purpose of modeling Delta water quality standards: X2, Sacramento River at Emmaton, San Joaquin River at Jersey Point, Sacramento River at Collinsville, and Old River at Rock Slough. In addition, the ANN is capable of providing salinity estimates for Clifton Court Forebay, CCWD Alternate Intake Project (AIP) and Los Vaqueros diversion locations.

The ANN may not fully capture the dynamics of the Delta under conditions other than those for which it was trained. It is possible that the ANN will exhibit errors in flow regimes beyond those for which it was trained. Therefore, a new ANN is needed for any new Delta configuration or under sea level rise conditions which may result in changed flow – salinity relationships in the Delta.

A.3.3. Application of CALSIM II to Evaluate BDCP Alternatives

Typical long-term planning analyses of the Central Valley system and operations of the CVP and SWP have applied the CALSIM II model for analysis of system responses. CALSIM II simulates future SWP/CVP project operations based on a 82-year monthly hydrology derived from the observed 1922-2003 period. Future land use and demands are projected for the appropriate future period. The system configuration consisting of facilities, operations, and regulations are input to the model and define the limits or preferences on operation. The configuration of the Delta, while not simulated directly in CALSIM II, informs the flow-salinity relationships and several flow-related regressions for interior Delta conditions (i.e. X2 and OMR) included in the model. For each set of hydrologic, facility, operations, regulations, and Delta configuration conditions, the CALSIM II model is simulated. Some refinement of the SWP/CVP operations related to delivery allocations and San Luis target storage levels is generally necessary to have the model reflect suitable north-south reservoir balancing under future conditions. These refinements are generally made by experienced modelers in conjunction with project operators.

The CALSIM II model produces outputs of river flows, exports, water deliveries, reservoir storage, water quality, and several derived variables such as X2, Delta salinity, OMR, and QWEST. The CALSIM II model is most appropriately applied for comparing one alternative to another and drawing comparisons between the results. This is the method in which CALSIM II is applied for the BDCP. For each phase of the Alternatives a companion No Action Alternative simulation has been prepared. The No Action simulation includes the existing infrastructure, existing regulatory restrictions including the recent biological opinions, but may include future demands, climate, and sea level rise depending on the time frame. The Alternative is compared to the No Action Alternative to evaluate areas in which the project changes conditions and the seasonality and magnitude of such changes. The change in hydrologic response or system conditions is important information that informs the effects analysis related to water-dependent resources in Sacramento-San Joaquin watersheds.

There are a number of areas in which the CALSIM II model has been improved or is applied differently for the BDCP analyses. This section briefly describes these key changes.

Changes to the CALSIM II Model Network

The main feature of the Alternatives that necessitated changes to the CALSIM II model network was the proposed diversion intakes in the north Delta along the Sacramento River. The intakes and associated conveyance allow for SWP and CVP diversions on the Sacramento River between Freeport and Courtland. Some of the Alternatives include up to 5 intakes in this reach of the river with individual diversion capacity up to 3,000 cfs. Since there are relatively small existing diversions and negligible inflows occurring in this reach of the Sacramento River, the CALSIM II aggregates all proposed diversions into a single diversion arc (Figure A-5) near Hood. This diversion arc (D400) conveys water diverted by the SWP and CVP to their respective pumping plants (either Banks PP or Jones PP) in the south Delta. Since dual conveyance – diverting from either or both north and south facilities -- is being considered, the model comingles the water at the pumping plant. Water for each project is tracked separately.

Additional changes were made to the CALSIM II network in the south Delta to allow for better estimation of the Combined Old and Middle River (OMR) flow.

The Delta island consumptive use (DICU) is applied in CALSIM II at five nodes representing regions in the north, west, central, south, and San Joaquin regions of the Delta. A review of the DICU was performed in 2009 to discern if any adjustments would be necessary to best reflect the flow available at the points of diversion. The DICU was disaggregated further, into a total of seven parts, including to split out the DICU upstream and downstream of the proposed north Delta diversion, and portion of the DICU in the south Delta to improve estimates of the OMR flow.

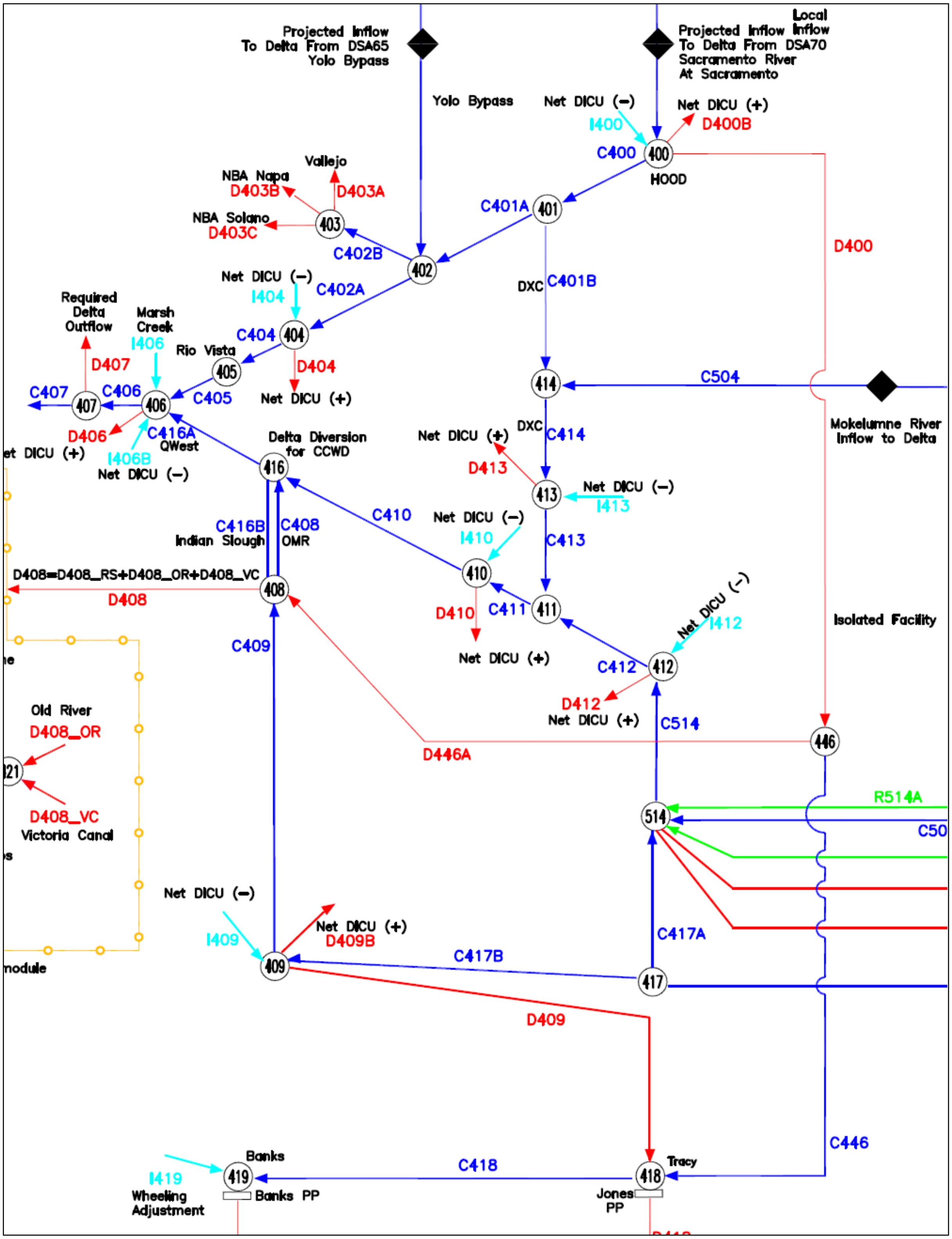


Figure A-5: Updated CALSIM II network for the inclusion of north Delta diversion (D400)

Incorporation of Sacramento River Daily Variability

As described above, the operation of the modified Fremont Weir and the diversion/bypass rules associated with the proposed north Delta intakes are sensitive to the daily variability of flows. Short duration, highly variable storms are likely to cause Fremont Weir spills. However, if flows are averaged for the month, as is done in a monthly model, it is possible to not identify any spill. Similarly, the operating criteria for the north Delta intakes include variable bypass flows and pulse protection criteria. Storms as described above may permit significant diversion but only for a short period of time. Initial comparisons of monthly versus daily operations at these facilities indicated that weir spills were likely underestimated and diversion potential was likely overstated using a monthly time step.

Figure A-6 shows a comparison of observed monthly averaged Sacramento River flow at Freeport and corresponding daily flow as an example. The figure shows that the daily flow exhibits significant variability around the monthly mean in the winter and spring period while remaining fairly constant in summer and fall months. Figure A-7 shows the daily historical patterns by water year type. It shows that daily variability is significant in the winter-spring while the summer flows are holding fairly constant in the most water year types. The winter-spring daily variability is deemed important to species of concern.

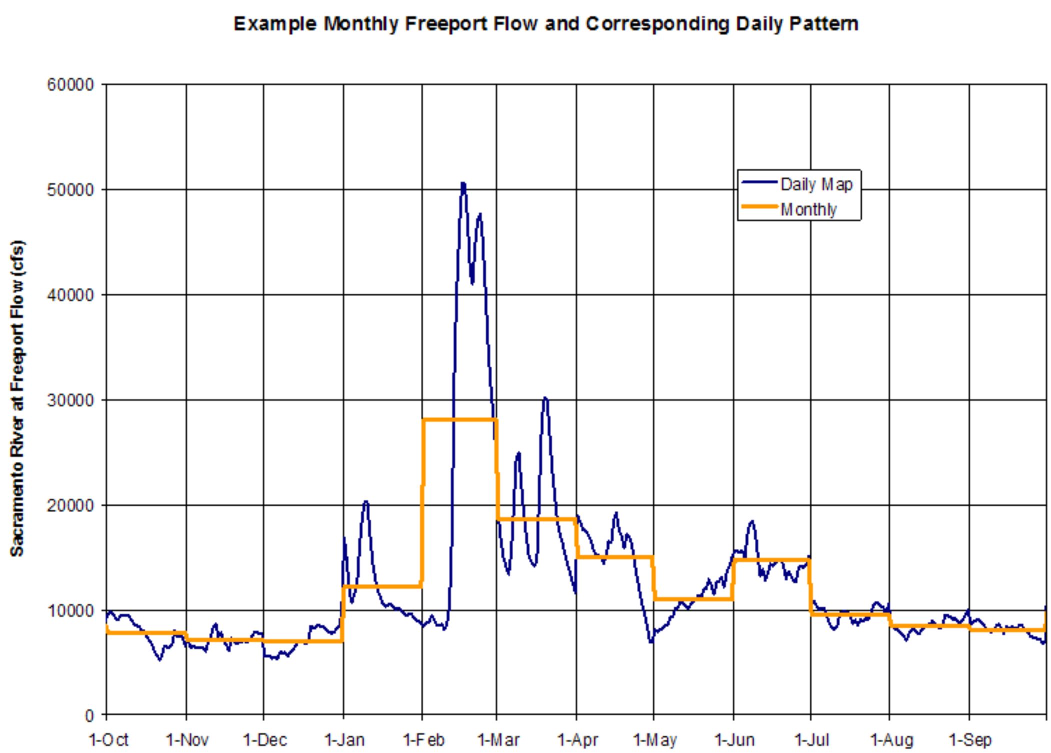


Figure A-6: Example monthly-averaged and daily-averaged flow for Sacramento River at Freeport

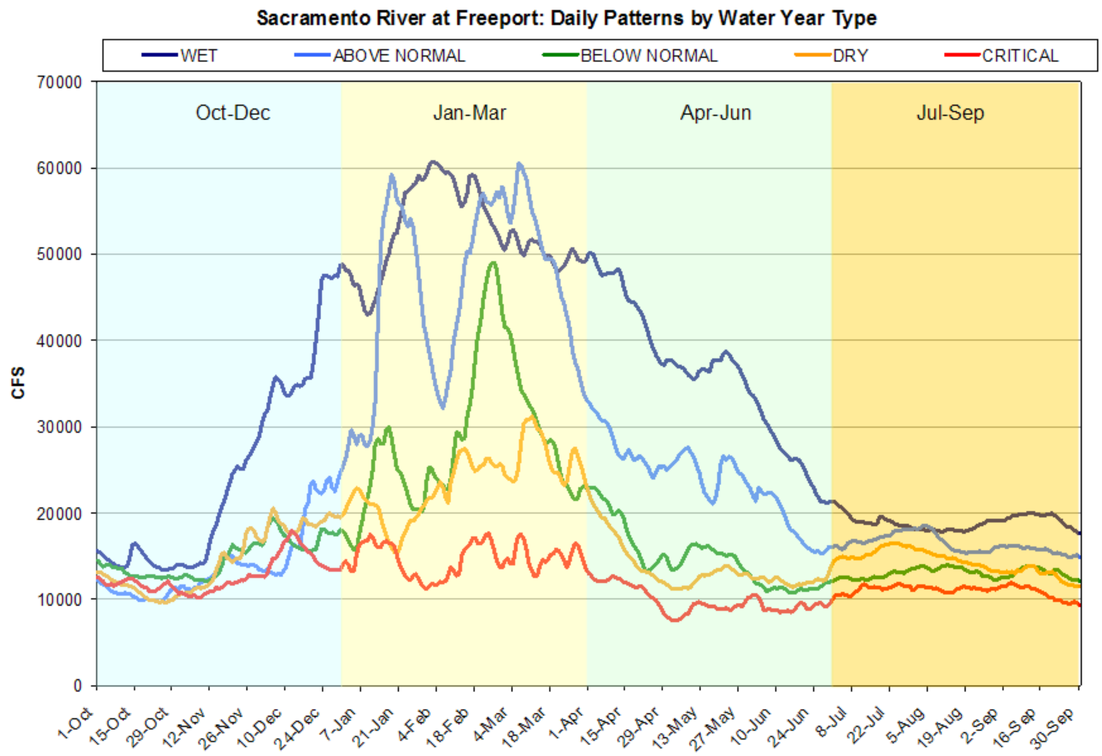


Figure A-7: Mean daily flows by Water Year Type for Sacramento River at Freeport

In an effort to better represent the sub-monthly flow variability, particularly in early winter, a monthly-to-daily flow mapping technique is applied directly in CALSIM II for the Fremont Weir, Sacramento Weir, and the north Delta intakes. The technique applies historical daily patterns, based on the hydrology of the year, to transform the monthly volumes into daily flows. Daily flow patterns are obtained from the observed DAYFLOW period of 1956-2008. In all cases, the monthly volumes are preserved between the daily and monthly flows. It is important to note that this daily mapping approach does not in any way represent the flows resulting from operational responses on a daily time step. It is simply a technique to incorporate representative daily variability into the flows resulting from CALSIM II's monthly operational decisions. It helps in refining the monthly CALSIM II operations by providing a better estimate of the Fremont and Sacramento weir spills which are sensitive to the daily flow patterns and allows in providing the upper bound of the available north Delta diversion in the Alternatives.

Observed Daily Patterns

CALSIM II hydrology is derived from historical monthly gauged flows for 1922-2003. This is the source data for monthly flow variability. DAYFLOW provides a database of daily historical Delta inflows from WY 1956 to present. This database is aligned with the current Delta infrastructure setting. Despite including the historical operational responses to various regulatory regimes existed over this period, in most winter and spring periods the reservoir operations and releases are governed by the inflows to the reservoirs.

Daily patterns from DAYFLOW used directly for mapping CALSIM II flows for water years 1956 to 2003. For water years 1922 to 1955 with missing daily flows, daily patterns are selected from water years 1956 to 2003 based on similar total annual unimpaired Delta inflow. The daily pattern for the water year with missing daily flows is assumed to be the same as the daily pattern of the identified water year. Correlation among the various hydrologic basins is preserved by selecting same pattern year for all rivers flowing into the Delta, for a given year in the 1922-1955 period. Table A-1 lists the selected pattern years for the water years 1922 to 1955 along with the total unimpaired annual Delta inflow.

Thus, for each month in the 82-year CALSIM II simulation period, the monthly flow is mapped onto a daily pattern for computation of spills over the Fremont Weir and Sacramento Weir and for computing water available for diversions through the north Delta intakes. A preprocessed timeseries of daily volume fractions, based on Sacramento River at Freeport observed flows, is input into CALSIM II. The monthly volume as determined dynamically from CALSIM II then is multiplied by the fractions to arrive at a daily flow sequence. The calculation of daily spills and daily diversions are thus obtained. In the subsequent cycle (but still the same month), adjustments are made to the daily river flow upstream of the Sacramento Weir and the north Delta intakes to account for differences between the monthly flows assumed in the first cycle and the daily flows calculated in subsequent cycles. For example, if no spill over Fremont was simulated using a monthly flow, but when applying a daily pattern spill does occur, then the River flow at the Sacramento Weir is reduced by this amount. In this fashion, daily balance and monthly balance is preserved while adding more realism to the operation of these facilities.

TABLE A-1
Identified "Pattern" Water Year for the Water Years 1922 to 1955 with Missing Daily Historical Flows

Water Year	Total Annual Unimpaired Delta Inflow (TAF)	Selected "Pattern" Water Year	Total Annual Unimpaired Delta Inflow (TAF)
1922	32,975	1975	31,884
1923	23,799	2002	23,760
1924	8,174	1977	6,801
1925	26,893	1962	25,211
1926	18,534	1959	17,967
1927	38,636	1984	38,188
1928	26,363	1962	25,211
1929	12,899	1994	12,456
1930	20,326	1972	19,863
1931	8,734	1977	6,801
1932	24,179	2002	23,760
1933	14,126	1988	14,019
1934	12,895	1994	12,456
1935	28,486	2003	28,228
1936	30,698	2003	28,228
1937	25,448	1962	25,211
1938	56,949	1998	56,482
1939	12,743	1994	12,456
1940	37,185	1963	36,724
1941	46,746	1986	46,602
1942	42,301	1980	41,246
1943	36,870	1963	36,724
1944	17,158	1981	17,131
1945	26,757	1962	25,211
1946	28,823	2003	28,228
1947	16,206	2001	15,460
1948	23,741	1979	22,973

TABLE A-1
Identified "Pattern" Water Year for the Water Years 1922 to 1955 with Missing Daily Historical Flows

Water Year	Total Annual Unimpaired Delta Inflow (TAF)	Selected "Pattern" Water Year	Total Annual Unimpaired Delta Inflow (TAF)
1949	19,176	1960	19,143
1950	23,272	1979	22,973
1951	39,110	1984	38,188
1952	49,270	1986	46,602
1953	30,155	2003	28,228
1954	26,563	1962	25,211
1955	17,235	1981	17,131

Fremont Weir Operations

All the Alternatives, except for Existing Conditions and No Action Alternative, include the measure for modifying the current Fremont Weir by notching it to allow for more frequent inundation in the Yolo Bypass. Details of the Fremont Weir and Yolo Bypass Hydraulics are described in Section D. The HEC-RAS modeling included in that section provides modified rating curves of the Fremont Weir for use in CALSIM II. CALSIM II simply includes two sets of rating curves, one with the "notch" and one without the notch. Input tables allow specification of when the notch is assumed to be operated. The amount of spill over the Fremont Weir or the notch is computed using the daily patterned Sacramento River flow at Verona and the rating curves included in the model.

North Delta Diversion Operations

Several of the Alternatives include new intakes (1 to 5 intakes depending on the Alternative) on Sacramento River upstream of Sutter Slough, in the north Delta. Each intake is proposed to have 3,000 cfs maximum pumping capacity. It is also proposed that the intakes will be screened using positive barrier fish screens to eliminate entrainment at the pumps. Water diverted at the five intakes is conveyed to a new forebay in the south Delta via a new isolated conveyance facility capable of conveying up to a maximum flow of 15,000 cfs (the conveyance capacity depends on the Alternative). Detailed assumptions for each Alternative are provided in Section B.

The BDCP proposes bypass (in-river) rules, which govern the amount of water required to remain in the river before any diversion can occur. Bypass rules are designed with the intent to avoid increased upstream tidal transport from downstream channels, to maintain flow supporting the migration of the salmonid and transport of pelagic species to regions of suitable habitat, to preserve shape of the natural hydrograph which may act as cue to important biological functions, to lower potential for increased tidal reversals that may occur because of the reduced net flow in the river and to provide flows to minimize predation effects downstream. The bypass rules include three important components:

- An initial pulse protection during the Nov – Jan period,
- A post-pulse operations that permit a percentage of river flow above a certain threshold to be diverted (and transitioning from Level I to Level II to Level III), and
- Consideration of a constant low level pumping of up to 300 cfs at each intake depending on the flow in the Sacramento River during the Dec – Jun period.

The bypass rules are simulated in CALSIM II using daily mapped Sacramento River flows as described above to determine the maximum potential diversion that can occur in the north Delta for each day. The simulation identifies which of the three criteria is governing, based on antecedent daily flows and season. An example of the north Delta flows and diversion is illustrated in Figure A-8. As can be seen in this figure, bypass rules begin at Level I in October until the Sacramento River pulse flow develops. During the pulse flow, the constant low level pumping (Level 0) is permitted, but is limited to a certain percentage of river flow. After longer periods of high bypass flows, the bypass flow requirements moves to Level II and eventually Level III which permit greater potential diversion. CALSIM II uses the monthly average of this daily potential diversion as one of the constraints in determining the final monthly north Delta diversion.

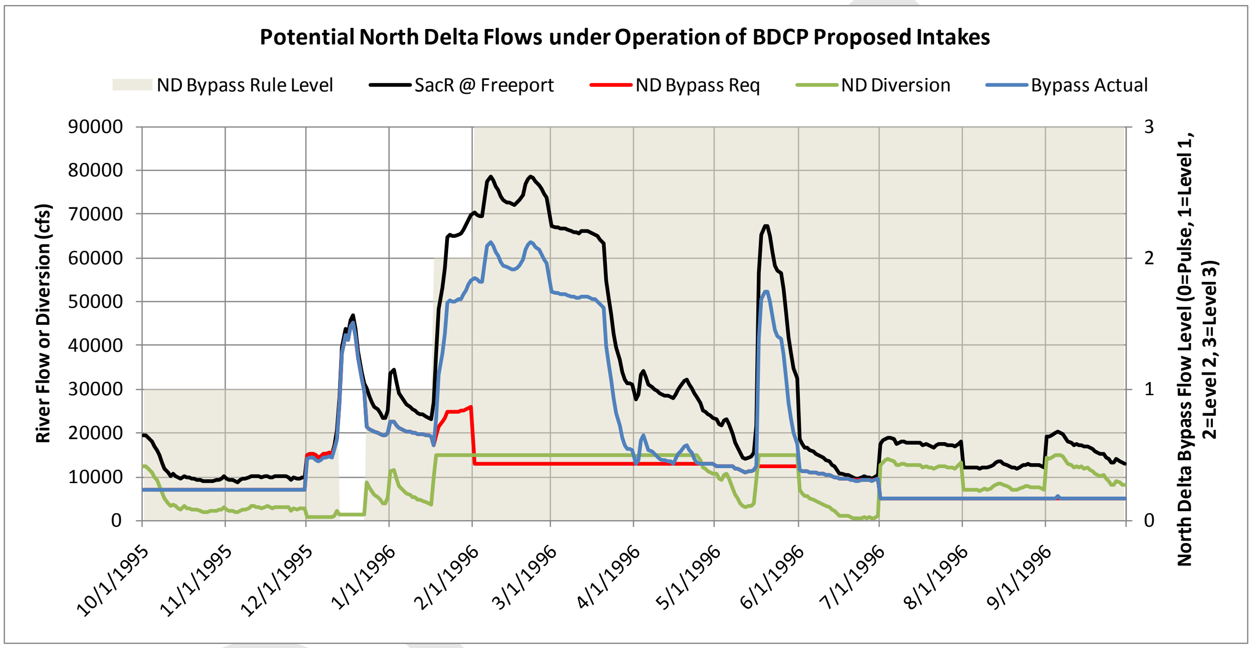


Figure A-8: Example year daily patterns and operation of the north Delta intakes. Note: the grey shading indicates the active bypass rule (0=pulse/low level pumping, 1=level I, 2=level II, and 3=level III).

ANN Retraining

ANNs are used for flow-salinity relationships in CALSIM II. They are trained on DSM2 outputs and therefore, emulate DSM2 results. ANN requires retraining whenever the flow – salinity relationship in the Delta changes. As mentioned earlier, BDCP analysis assumes different tidal marsh restoration acreages at NT, ELT and LLT phases and 15cm and 45cm sea level rise at ELT and LLT, respectively. Each combination of restoration and sea level condition results in a different flow – salinity relationship in the Delta and therefore require a new ANN. New ANNs have been developed by DWR for each new proposed combination of tidal marsh and sea level. ANN retraining process is described in Section A.5.3.

Incorporation of Climate Change

Climate and sea level change are incorporated into the CALSIM II model in two ways. As described in Section A.8., changes in runoff and streamflow are simulated through VIC modeling under representative climate scenarios. These simulated changes in runoff are applied to the CALSIM II inflows as a fractional change from the observed inflow patterns (simulated future runoff divided by historical runoff). These fraction changes are first applied for every month of the 82-year period consistent with the VIC simulated patterns. A second order correction is then applied to ensure that the annual shifts in runoff at each location are consistent with that generated from the VIC modeling. A spreadsheet tool has been prepared to process this information and generate adjusted inflow time series records for CALSIM II. Once the changes in flows have been resolved, water year types and other hydrologic indices that govern water operations or compliance are adjusted to be consistent with the new hydrologic regime.

Sea level rise and restored tidal marsh effects on the flow-salinity response is incorporated in the new ANNs. CALSIM II model simulations require the modeler to select which hydrology should be paired with which sea level/tidal marsh ANN.

The following input parameters are adjusted in CALSIM II to incorporate the effects of climate change:

- Inflow time series records for all major and minor streams in the Central Valley
- Sacramento and San Joaquin Valley water year types
- Runoff forecasts used reservoir operations and allocation decisions
- Delta water temperature as used in triggering biological opinion smelt criteria
- Modified ANNs to reflect the flow-salinity response under sea level change scenarios

The CALSIM II simulations do not consider future climate change adaptation which may manage the SWP and CVP system in a different manner than today to reduce climate impacts. For example, future changes in reservoir flood control reservation to better accommodate a seasonally changing hydrograph may be considered under future programs, but are not considered under the BDCP. Thus, the CALSIM II BDCP results represent the risks to operations, water users, and the environment in the absence of dynamic adaptation for climate change.

A.3.4. Output Parameters

The Hydrology and System Operations models produce the following key parameters on a monthly time-step:

- River flows and diversions
- Reservoir storage
- Delta flows and exports
- Delta inflow and outflow

- Deliveries to project and non-project users
- Controls on project operations

Some operations have been informed by the daily variability included in the CALSIM II model for the BDCP, and where appropriate, these results are presented. However, it should be noted that CALSIM II remains a monthly model. The daily variability in the CALSIM II model to better represent certain operational aspects, but the monthly results are utilized for water balance.

A.3.5. Linkages to Other Physical Models

The Hydrology and System Operations models generally require input assumptions relating to hydrology, demands, regulations, and flow-salinity responses. DWR and USBR have prepared hydrologic inputs and demand assumptions for various levels of development (future land use and development assumptions) based on historical hydroclimatic conditions. Regulations and associated operations are translated into operational requirements. The flow-salinity ANN, representing appropriate Delta configuration, is embedded into the system operations model. The river flows and Delta exports from the CALSIM II model are used as input to the Delta Hydrodynamics and Water Quality models and reservoir storage and releases are used as input to the River and Reservoir Temperature models.

A.4. Reservoir and River Temperature

The CVP and SWP are required to operate the reservoirs and releases such that specific temperature compliance objectives are met downstream in the rivers, to protect habitat for the anadramous fish. Models are necessary to study the impacts of operational changes on the river and reservoir temperatures. Several models are available to study the impacts to the water temperatures on various river systems in the Central Valley. These models in general are capable of simulating mean monthly and mean daily downstream temperatures for long-term operational scenarios taking into consideration the selective withdrawal capabilities at the reservoirs. 2008 OCAP BA Technical Appendix H (USBR, 2008c) provides a good summary of the temperature modeling tools used in this section.

This section briefly describes the tools used to model the reservoir and river temperatures as part of the BDCP physical modeling.

A.4.1. SRWQM

Sacramento River Water Quality Model (SRWQM) was developed by Reclamation to simulate temperature in the upstream CVP reservoirs and the upper Sacramento River. It was developed using integrated HEC-5 and HEC-5Q models. The HEC-5 component of SRWQM simulates daily flow operations in the upper Sacramento River. The HEC-5Q component of SRWQM simulates mean daily reservoir and river temperatures at Shasta, Trinity, Lewiston, Whiskeytown, Keswick and Black Butte Reservoirs and the Trinity River, Clear Creek, the upper Sacramento River from Shasta to Knights Landing, and Stony Creek based on the flow and meteorological parameters on a 6-hour time step. Figure A-9 shows the model schematic for HEC-5 component of the SRWQM. HEC-5Q is a cross-section based model and has a higher spatial resolution in comparison to the HEC-5 component of SRWQM. The HEC-5Q was customized to simulate the operations of the temperature control device at Shasta Dam.

SRWQM was successfully calibrated based on the observed temperatures in the reservoirs and the upper Sacramento River. More detailed description SRWQM and the calibration performance is included in the calibration report (RMA, 2003).

A.4.2. Reclamation Temperature Model

Reclamation Temperature Model includes reservoir and stream temperature models, which simulate monthly reservoir and stream temperatures used for evaluating the effects of CVP/SWP project operations on mean monthly water temperatures in the basin. The model simulates temperatures in seven major reservoirs (Trinity, Whiskeytown, Shasta, Oroville, Folsom, New Melones and Tulloch), four downstream regulating reservoirs (Lewiston, Keswick, Goodwin and Natoma), and five main river systems (Trinity, Sacramento, Feather, American and Stanislaus). The river component of the Reclamation Temperature model calculates temperature changes in the regulating reservoirs, below the main reservoirs. With regulating reservoir release temperature as the initial river temperature, the river model computes temperatures at several locations along the rivers. The calculation points for river temperatures generally coincide with tributary inflow locations. The model is one-dimensional in the longitudinal direction and assumes fully mixed river cross sections. The effect of tributary inflow on river temperature is computed by mass balance calculation. The river temperature calculations are based on regulating reservoir release temperatures, river flows, and climatic data.

A.4.3. Application of Temperature Models to Evaluate BDCP Alternatives

The temperature modeling for planning analysis is driven by the long term operations modeled using CALSIM II. The objective is to find temperature variability in the reservoirs and streams, given CVP/SWP operations, and compare between existing and assumed future scenarios. This section briefly describes the general temperature modeling approach used in a planning analysis and any changes to the approach as part of the BDCP.

SRWQM

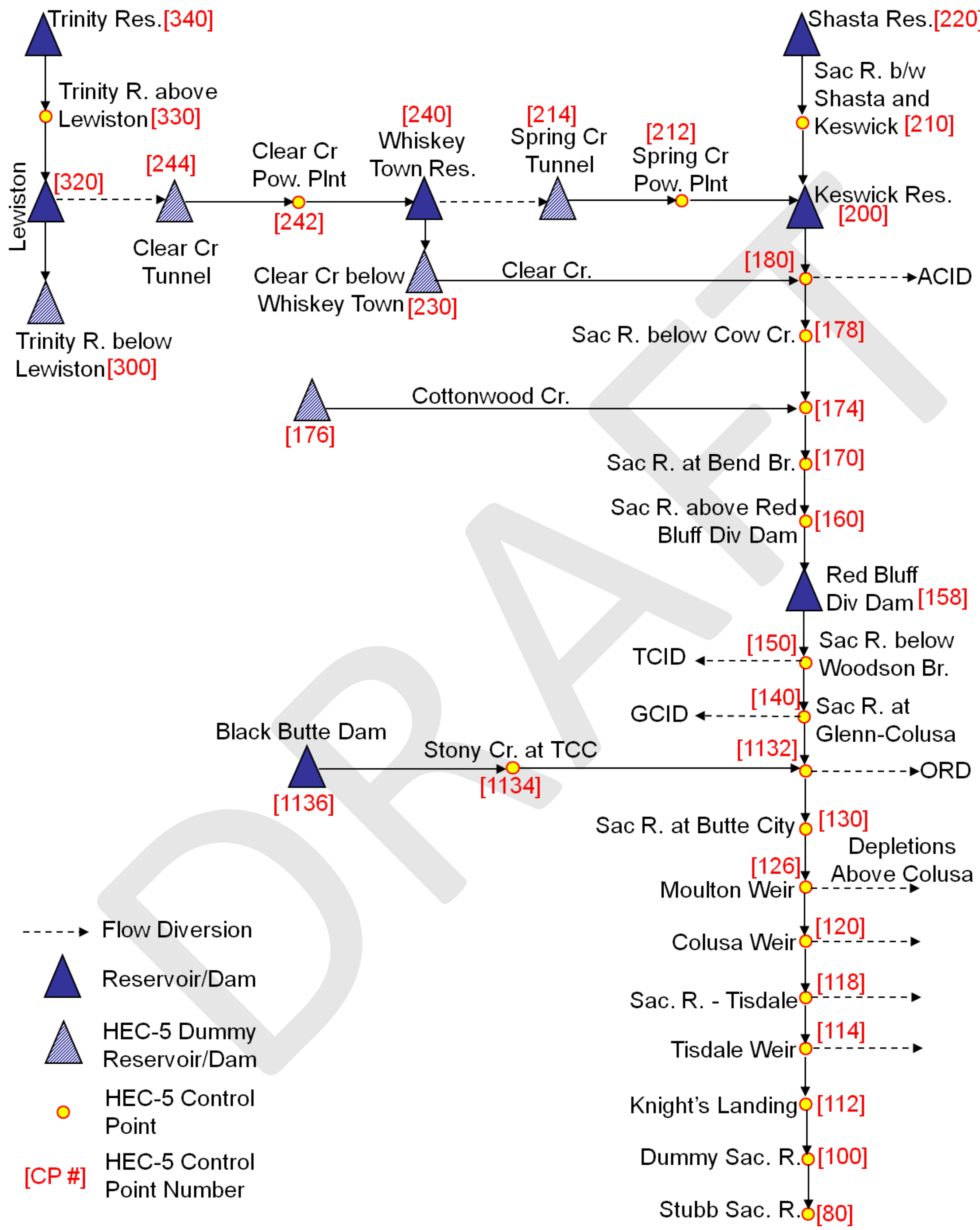
SRWQM is designed for long-term planning simulation of temperature at key locations on the Sacramento River at a mean daily time step that captures diurnal fluctuations and is sensitive to fishery management objectives. The geographical scope of the model ranges from Shasta Dam and Trinity Dam to Knights Landing. Monthly flows, simulated by the CALSIM II model for an 82 year period (WY 1922-2003), are used as input to the SRWQM. Temporal downscaling is performed on the CALSIM II monthly average tributary flows to convert them to daily average flows for SRWQM input. Monthly average flows are converted to daily tributary inflows based on 1921 through 1994 daily historical record for the following aggregated inflows:

- Trinity River above Lewiston.
- Sacramento River above Keswick.
- Incremental inflow between Keswick and Bend Bridge (Seven day trailing average for inflows below Butte City).

Each of the total monthly inflows specified by CALSIM II is scaled proportional to one of these three historical records. Outflows and diversions are smoothed for a better transition at the end of the month without regard for reservoir volume constraints or downstream minimum flows. As flows are redistributed within the month, the minimum flow constraint at Keswick, Red Bluff and Knights Landing may be violated. In such cases, operation modifications are required for daily flow simulation to satisfy minimum flow requirements. A utility program is included in SRWQM to convert the monthly CALSIM II flows and releases into daily operations. More detailed description of SRWQM and the temporal downscaling process is included in calibration report (RMA, 2003). The boundary conditions required for simulating SRWQM planning run are listed in Table A-2.

Reclamation Temperature Models

The Reclamation temperature model suite is a monthly time-step model. It was applied to estimate temperatures in the Trinity, Feather, American, and Stanislaus River systems. Monthly flows, simulated by the CALSIM II model for an 82 year period (WY 1922-2003), are used as input to the model. Because of the CALSIM II model's complex structure, where applicable, flow arcs were combined at the appropriate temperature nodes to insure compatibility with the temperature model (see Table A-3). Monthly mean historical air temperatures for the 82-year period and other long-term average climatic data for Trinity, Shasta, Whiskeytown, Redding, Red Bluff, Colusa, Marysville, Folsom, Sacramento, New Melones, and Stockton were obtained from National Weather Service records and used to represent climatic conditions for the four river systems.



SRWQM HEC-5 Schematic

Figure A-9: SRWQM HEC-5 Model Schematic

A.4.4. Incorporating Climate Change Inputs

When simulating alternatives with climate change, some of the inputs to the temperature models are required to be modified. This section states the assumptions and approaches used for modifying meteorological and inflow temperatures in the temperature models.

SRWQM

SRWQM requires meteorological inputs specified in the form of equilibrium temperatures, exchange rates, shortwave radiation and wind speed. The exchange rates and equilibrium temperatures are computed from hourly observed data at Gerber gauging station. Considering the uncertainties associated with climate change impacts, it was assumed that the equilibrium temperature inputs derived from observed data would be modified by the change in daily average air temperature in the climate change scenarios.

The inflow temperatures in SRWQM are specified as seasonal curve fit values with diurnal variations superimposed as a function of heat exchange parameters. The seasonal temperature values are derived based on the observed flows and temperatures for each inflow. SRWQM superimposes diurnal variations on the seasonal values specified using the heat exchange parameter inputs. The diurnal variations are superimposed by adjusting the equilibrium temperature to reflect the inflow location environment and scaling it based on the heat exchange rate scaling factor and the weighting factor for emphasis on the seasonal values specified (RMA, 1998). In this fashion, any changes in the equilibrium temperature are translated to the inflow temperatures in the SRWQM. Therefore, for the climate change scenarios, the equilibrium temperatures were adjusted for the projected change in temperature, and these influence the inflow temperature, but independent inflow temperature inputs were not changed.

Reclamation Temperature Models

The Reclamation temperature models require mean monthly meteorological inputs of air and equilibrium temperature, and heat exchange rates. The heat exchange rates and equilibrium temperatures are computed from the mean monthly air temperature data and long-term estimates of solar radiation, relative humidity, wind speed, cloud cover, solar reflectivity and river shading. Considering the uncertainties associated with climate change impacts, it was assumed that the equilibrium temperature and heat exchange rate inputs would be modified by the change in mean monthly air temperature in the climate change scenarios.

Reservoir inflow temperatures were derived from the available record of observed data and averaged by month. The mean monthly inflow temperatures are then repeated for each study year. The inflow temperatures were further modified based on the computed change in mean annual air temperature, by climate-change scenario.

A.4.5. Output Parameters

SRWQM results in daily averaged temperature results. The Reclamation Temperature Models provide monthly averaged results. In general, the following outputs are generated from the temperature models:

- Reservoir temperature thermocline used to compute cold water pool volume in the reservoirs
- River temperature at locations along the streams

TABLE A-2
Inputs Required for SRWQM Planning Analysis

Input Type	Location	Description of the Input
Initial Storage	Trinity Lake	End-of-day storage to initialize reservoir storage condition at the start of the SRWQM run
	Whiskeytown Lake	
	Shasta Lake	
	Black Butte Reservoir	
Reservoir Inflows	Trinity Lake	Daily net inflow to reservoirs computed based on the reservoir inflow and the evaporation
	Lewiston Reservoir	
	Whiskeytown Lake	
	Shasta Lake	
	Black Butte Reservoir	
Tributary Inflows	Cottonwood Creek	Local unregulated tributary inflows
	Thomes Creek	
	Colusa Drain	
Distributed flows	Bend Bridge	Net inflows, accretions and depletions along the Sacramento River distributed along the River
	Lower River	
Outflow	Trinity Lake	Daily reservoir release specification
	Whiskeytown Lake	
	Shasta Lake	
	Black Butte Reservoir	
Diversions	Clear Creek Tunnel from Lewiston Reservoir	Inter-basin transfer reservoir releases
	Spring Creek Tunnel from Whiskeytown Lake	
	Anderson Cottonwood Irrigation District Canal	Lumped diversions along various reach of the River specified at point locations
	Tehama Colusa Canal	

TABLE A-2
Inputs Required for SRWQM Planning Analysis

Input Type	Location	Description of the Input
	Glenn Colusa Canal	
	Miscellaneous Diversions above Ord	
	West Banks Diversions	
	Diversions near Colusa Weir	
	Lower River Diversions	
Meteorological Inputs including Equilibrium Temperature, Exchange Rate, Shortwave Radiation and Wind Speed	Entire Spatial Domain	Meteorological inputs on 6-hour time step derived primarily from Gerber gauging station. Calibration report provides more details (RMA, 2003). This dataset remains unchanged as long as the climate conditions are the same across the alternatives.
Inflow Temperatures	Reservoir and tributary inflows included in the model	Seasonal temperatures based on historical flows and temperatures. These inputs remain unchanged for all alternatives
Target Temperatures	Shasta Lake Tail Water	Seasonal temperature targets specified based on the end-of-May Shasta storage conditions

TABLE A-3
Reclamation Temperature Model Nodes

River or Creek System	Location
Trinity River	Lewiston Dam
	Douglas City
	North Fork
Feather River	Oroville Dam
	Fish Barrier Dam
	Upstream of Thermalito Afterbay
	Thermalito Afterbay Release
	Downstream of Thermalito Afterbay
	Gridley
	Honcut Creek
	Yuba River

TABLE A-3
Reclamation Temperature Model Nodes

River or Creek System	Location
	Bear River
	Nicolaus
	Nelson Slough
	Confluence
American River	Folsom Dam
	Nimbus Dam
	Sunrise Bridge
	Cordova Park
	Arden Rapids
	Watt Avenue Bridge
	American River Filtration Plant
	H Street
	16th Street
	Confluence
Stanislaus River	New Melones Dam
	Tulloch Dam
	Goodwin Dam
	Knights Ferry
	Orange Blossom
	Oakdale
	Riverbank
	McHenry Bridge
	Ripon
	Confluence

A.4.6. Use of Model Results

Since the temperature models are driven by the operations simulated in CALSIM II on a monthly time step, typically the temperature results are presented on a monthly time step from both SRWQM and the Reclamation Temperature Models. Monthly flows and temperatures are unlikely to address the daily variability in the river temperatures, but reflect changes in the mean. The daily variability, around a changed mean, could be added to the monthly temperature results by scaling the historical daily temperature patterns to reflect the monthly means. However, this approach of incorporating daily variability does not account for the uncertainty associated with the daily flow conditions which are not included in the boundary flows used by the temperature models. Thus, while the models generate daily results they need to be interpreted with the understanding that the monthly changes are the most appropriate use of the modeling results.

A.4.7. Modeling Limitations

The Reclamation temperature models operate on a monthly time-step. Mean monthly flows and temperatures do not define daily variations that could occur in the rivers due to dynamic flow and climatic conditions. It is important to note that even though SRWQM runs on a daily time step, it adheres to the CALSIM II in terms of the reservoir releases and other operations. Neither SRWQM nor the Reclamation temperature models alter operations to meet a temperature requirement downstream in the River. There is no feedback to CALSIM II to alter the operations, either. Using the daily results from SRWQM to check the compliance includes some uncertainty. Both SRWQM and the Reclamation temperature models perform selective temperature withdrawal based on the tail water temperature target and this may or may not meet the temperature requirement downstream in the River.

A.4.8. Linkages to Other Physical Models

The Reservoir and River Temperature models require inputs for representative meteorological conditions, reservoir storage, reservoir release rates, tributary flows, and channel morphology. The output from the Reservoir and River Temperature models are sometimes used to evaluate performance of satisfying temperature requirements and refine the simulated project operation in CALSIM II. The temperature outputs are commonly used in the biological assessments of salmonid mortality.

A.5. Delta Hydrodynamics and Water Quality

Hydrodynamics and water quality modeling is essential to understand the impact of proposed modifications to the morphology of the Delta and the operations of the CVP and SWP. Changes to the configuration of the Delta, restoration of tidal marsh, and project operations will influence the hydrodynamics and water quality conditions in the Delta. The analysis and understanding of the hydrodynamics and water quality changes as a result of these complex changes are critical in understanding the impacts to habitat, species and water users that depend on the Delta.

Large scale tidal marsh restoration and a north Delta diversion are two main components of the BDCP that can significantly alter the hydrodynamics in the Delta, along with the external forcing, sea level rise.

This document describes in detail the methodology used for simulating Delta hydrodynamics and water quality for evaluating the alternatives. It discusses the primary tool (DSM2) used in this process and any improvements to it briefly. Any additional detail is included in Section D and appropriate references are provided in here. The portions of the modeling that were performed by elsewhere are only described briefly in this document with appropriate references included.

A.5.1. Overview of Hydrodynamics and Water Quality Modeling Approach

Some of the Alternatives assume changes to the existing Delta morphology through the restoration of large acreages of tidal marshes in the Delta. Also, changes in sea level are assumed in the analysis of the future scenarios. These changes result in modified hydrodynamics and salinity transport in the Sacramento – San Joaquin Delta.

There are several tools available to simulate hydrodynamics and water quality in the Delta. Some tools simulate detailed processes, however are computationally intensive and have long runtimes. Other tools approximate certain processes and have short runtimes, while only compromising slightly on the accuracy of the results. For a planning analysis it is ideal to understand the resulting changes over several years such that it covers a range of hydrologic conditions. So, a tool which can simulate the changed hydrodynamics and water quality in the Delta accurately and that has short runtimes is desired. Delta Simulation Model (DSM2), a one-dimensional hydrodynamics and water quality model serves this purpose.

DSM2 has a limited ability to simulate two-dimensional features such as tidal marshes and three-dimensional processes such as gravitational circulation which is known to increase with sea level rise in the estuaries. Therefore, it is imperative that DSM2 be recalibrated or corroborated based on a dataset that accurately represents the conditions in the Delta under restoration and sea level rise. Since the proposed conditions are hypothetical, the best available approach to estimate the Delta hydrodynamics would be to simulate higher dimensional models which can resolve the two- and three-dimensional processes well. These models would generate the data sets needed to corroborate or recalibrate DSM2 under the proposed conditions so that it can simulate the hydrodynamics and salinity transport with reasonable accuracy.

Figure A-10 shows a schematic of how the hydrodynamics and water quality modeling is formulated for BDCP. UnTRIM Bay-Delta Model (MacWilliams et al., 2009), a three-dimensional hydrodynamics and water quality model was used to simulate the sea level rise effects on hydrodynamics and salinity transport under the historical operations in the Delta. RMA Bay-Delta Model (RMA, 2005), a two-dimensional hydrodynamics and water quality model was used to simulate tidal marsh restoration effects with and without sea level rise on hydrodynamics and salinity transport under the historic operations. The results from the UnTRIM model were used to corroborate RMA and DSM2 models so that they simulate the effect of sea level rise accurately. The results from the RMA model were used to corroborate DSM2 so that it can simulate the effect of tidal marsh restoration with and without sea level rise accurately.

The corroborated DSM2 was used to simulate hydrodynamics and water quality in the Delta by integrating the tidal marsh restoration and sea level rise effects over a 16-year period (WY 1976 – 1991), using the hydrological inputs and exports determined by CALSIM II under the projected operations. It was also used to retrain ANNs that can emulate modified flow-salinity relationship.

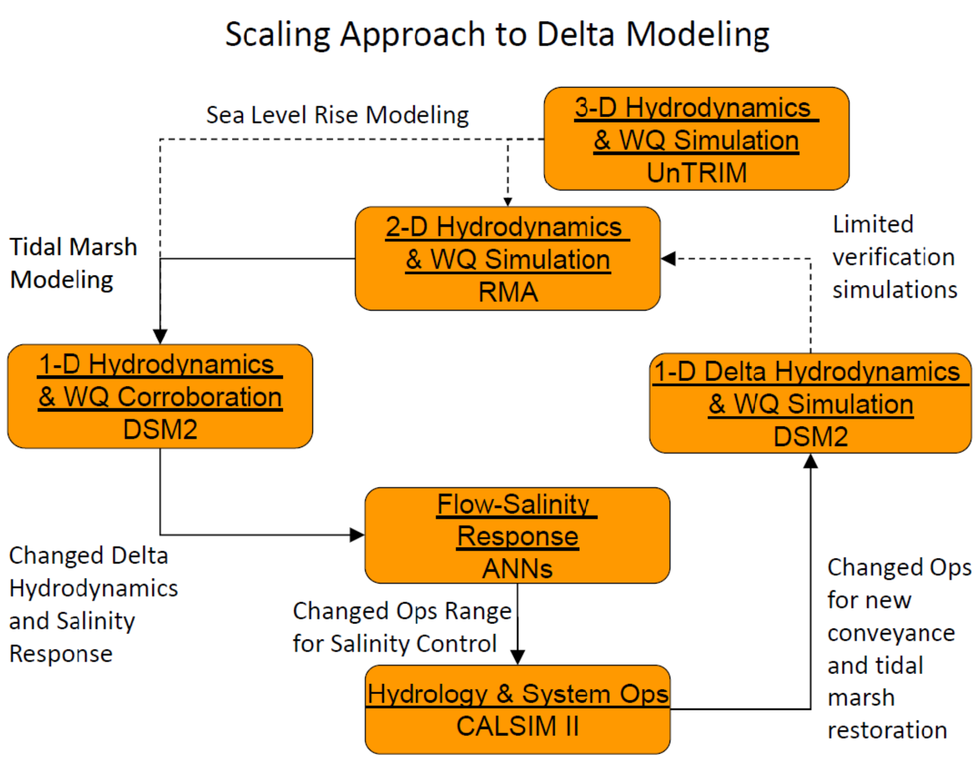


Figure A-10: Hydrodynamics and Water Quality Modeling Approach used in the BDCP

A.5.2. Delta Simulation Model (DSM2)

DSM2 is a one-dimensional hydrodynamics, water quality and particle tracking simulation model used to simulate hydrodynamics, water quality, and particle tracking in the Sacramento-San Joaquin Delta (Anderson and Mierzwa, 2002). DSM2 represents the best available planning model for Delta tidal hydraulics and salinity modeling. It is appropriate for describing the existing conditions in the Delta, as well as performing simulations for the assessment of incremental environmental impacts caused by future facilities and operations. The DSM2 model has three separate components: HYDRO, QUAL, and PTM. HYDRO simulates one-dimensional hydrodynamics including flows, velocities, depth, and water surface elevations. HYDRO provides the flow input for QUAL and PTM. QUAL simulates one-dimensional fate and transport of conservative and non-conservative water quality constituents given a flow field simulated by HYDRO. PTM simulates pseudo 3-D transport of neutrally buoyant particles based on the flow field simulated by HYDRO.

DSM2 v8.0.4 was used in modeling of the BDCP Existing Conditions, No Action Alternative and the other Alternatives. The v8 of the DSM2 includes several enhancements compared to the v6 such as improved data management, increased speed and robustness, ability to simulate gates with multiple structures and the ability to specify Operating Rules in the HYDRO module. The Operating Rules form a powerful tool which triggers changes in gate operations or source/sink flow boundaries while model is running, based on the current value of a state variable (flow, stage or velocity), pre-specified timeseries or the simulation timestep.

DSM2 hydrodynamics and salinity (EC) were initially calibrated in 1997(DWR, 1997). In 2000, a group of agencies, water users, and stakeholders recalibrated and validated DSM2 in an open process resulting in a model that could replicate the observed data more closely than the 1997 version (DSM2PWT, 2001). In 2009, CH2M HILL performed a calibration and validation of DSM2 by including the flooded Liberty Island in the DSM2 grid, which allowed for an improved simulation of tidal hydraulics and EC transport in DSM2 (CH2M HILL, 2009). The model used for evaluating the BDCP scenarios was based on this latest calibration.

Simulation of Dissolved Organic Carbon (DOC) transport in DSM2 was successfully validated in 2001 by DWR (Pandey, 2001). The temperature and Dissolved Oxygen calibration was initially performed in 2003 by DWR (Rajbhandari, 2003). Recent effort by RMA in 2009 allowed for improved calibration of temperature, DO and the nutrients transport in DSM2.

DSM2-HYDRO

The HYDRO module is a one-dimensional, implicit, unsteady, open channel flow model that DWR developed from FOURPT, a four-point finite difference model originally developed by the USGS in Reston, Virginia. DWR adapted the model to the Delta by revising the input-output system, including open water elements, and incorporating water project facilities, such as gates, barriers, and the Clifton Court Forebay. HYDRO simulates water surface elevations, velocities and flows in the Delta channels (Nader-Tehrani, 1998). HYDRO provides the flow input necessary for QUAL and PTM modules.

The HYDRO module solves the continuity and momentum equations fully implicitly. These partial differential equations are solved using a finite difference scheme requiring four points of computation. The equations are integrated in time and space, which leads to a solution of stage and flow at the computational points. HYDRO enforces an "equal stage" boundary condition for all the channels connected to a junction. The model can handle both irregular cross-sections derived from the bathymetric surveys and trapezoidal cross-sections. Even though, the model formulation includes a baroclinic term, the density is held constant, generally, in the HYDRO simulations.

HYDRO allows the simulation of hydraulic gates in the channels. A gate may have a number of associated hydraulic structures such as radial gates, flash boards, boat ramps etc., each of which may be operated independently to control flow. Gates can be placed either at the upstream or downstream end of a channel. Once the location of a gate is defined, the boundary condition for the gated channel is modified from "equal stage" to "known flow," with the calculated flow. The gates can be opened or closed in one or both directions by specifying a coefficient of zero or one.

Reservoirs are used to represent open bodies of water that store flow. Reservoirs are treated as vertical walled tanks in DSM2, with a known surface area and bottom elevation and are considered instantly well-mixed. The flow interaction between the open water area and one or more of the connecting channels is determined using the general orifice formula. The flow in and out of the reservoir is controlled using the flow coefficient in the orifice equation, which can be different in each direction. DSM2 does not allow the cross-sectional area of the inlet to vary with the water level.

DSM2v8 includes a new feature called "operating rules" using which the gate operations or the flow boundaries can be modified dynamically when the model is running based on the current value of a state variable (flow, stage or velocity). The change can also be triggered based on a timeseries that's not currently simulated in the model (e.g. daily averaged EC) or based on the current timestep of the simulation (e.g. a change can occur at the end of the day or end of the season). The operating rules include many functions which allow derivation of the quantities to be used as trigger, from the model data or outside timeseries data. Operating rules allow a change or an action to occur when the trigger value changes from false to true.

DSM2-QUAL

The QUAL module is a one-dimensional water quality transport model that DWR adapted from the Branched Lagrangian Transport Model originally developed by the USGS in Reston, Virginia. DWR added many enhancements to the QUAL module, such as open water areas and gates. A Lagrangian feature in the formulation eliminates the numerical dispersion that is inherently in other segmented formulations, although the tidal dispersion coefficients must still be specified. QUAL simulates fate and transport of conservative and non-conservative water quality constituents given a flow field simulated by HYDRO. It can calculate mass transport processes for conservative and non-conservative constituents including salts, water temperature, nutrients, dissolved oxygen, and trihalomethane formation potential.

The main processes contributing to the fate and transport of the constituents include flow dependent advection and tidal dispersion in the longitudinal direction. Mass balance equations are solved for all quality constituents in each parcel of water using the tidal flows and volumes calculated by the HYDRO module. Additional information and the equations used are specified in the 19^{th} annual progress report by DWR (Rajbhandari, 1998).

The QUAL module is also used to simulate source water finger printing which allows determining the relative contributions of water sources to the volume at any specified location. It is also used to simulate constituent finger printing which determines the relative contributions of conservative constituent sources to the concentration at any specified location. For fingerprinting studies, six main sources are typically tracked: Sacramento River, San Joaquin River, Martinez, eastside streams (Mokelumne, Cosumnes and Calaveras combined), agricultural drains (all combined), and Yolo Bypass. For source water fingerprinting a tracer with constant concentration is assumed for each source tracked, while keeping the concentrations at other inflows as zero. For constituent (e.g., EC) fingerprinting analysis, the concentrations of the desired constituent is specified at each tracked source, while keeping the concentrations at other inflows as zero (Anderson, 2003).

DSM2 Input Requirements

DSM2 requires input assumptions relating to physical description of the system (e.g. Delta channel, marsh, and island configuration), description of flow control structures such as gates, initial estimates for stage, flow and EC throughout the Delta, and time-varying input for all boundary river flows and exports, tidal boundary conditions, gate operations, and constituent concentrations at each inflow. Figure A-11 illustrates the hydrodynamic and water quality boundary conditions required in DSM2. For long-term planning simulations, output from the CALSIM II model generally provides the necessary input for the river flows and exports.

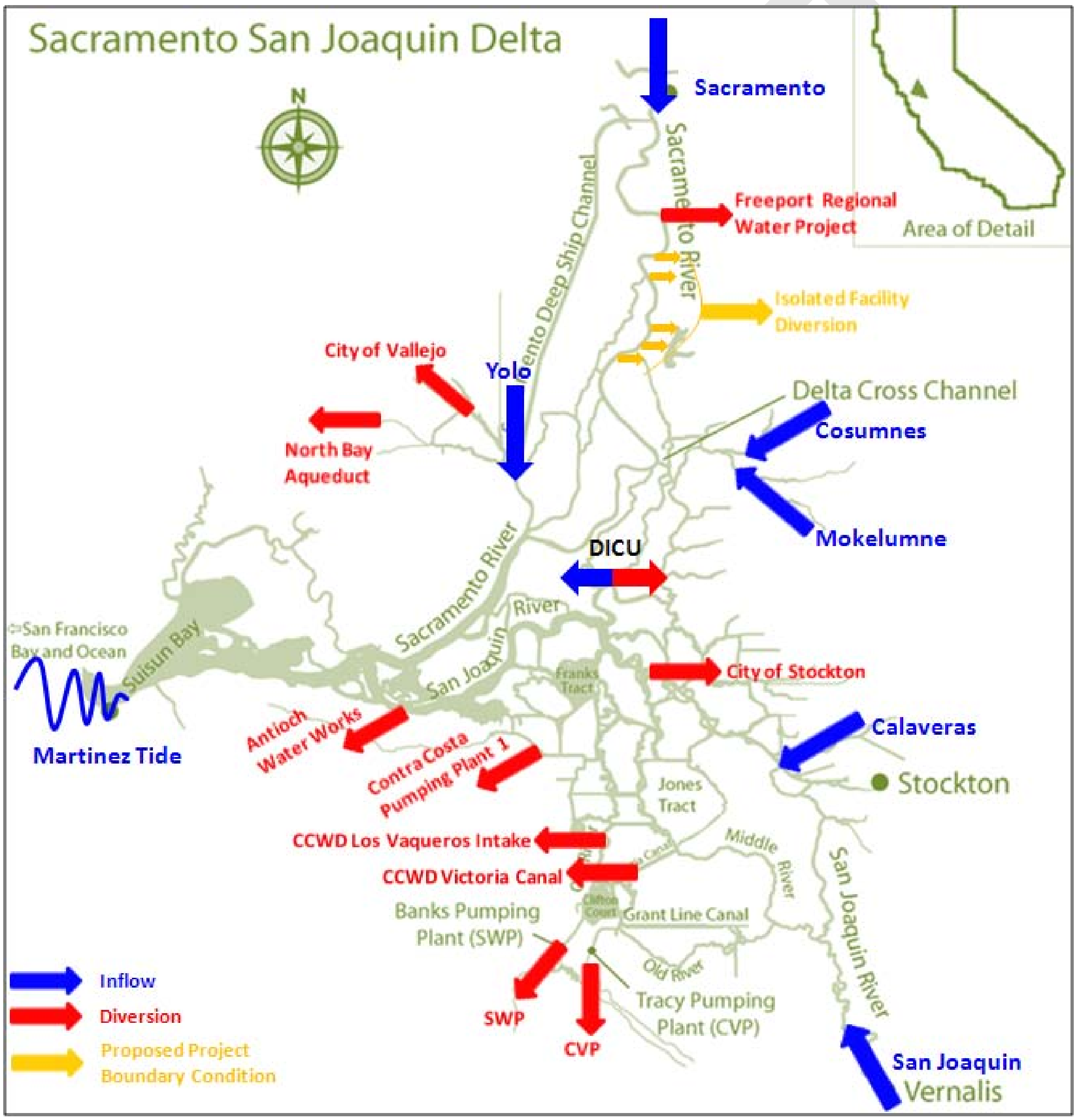


Figure A-11: Hydrodynamic and Water Quality Boundary Conditions in DSM2

For long-term planning simulations, output from the CALSIM II model generally provides the necessary input for the river flows and exports. Assumptions relating to Delta configuration and gate operations are directly input into the hydrodynamic models. Adjusted astronomical tide (Ateljevich, 2001a) normalized for sea level rise (Ateljevich and Yu, 2007) is forced at Martinez boundary. Constituent concentrations are specified at the inflow boundaries, which are either estimated from historical information or CALSIM II results. EC boundary condition at Vernalis location is derived from the CALSIM II results. Martinez EC boundary condition is derived based on the simulated net Delta outflow from CALSIM II and using a modified G-model (Atljevich, 2001b).

The major hydrodynamic boundary conditions are listed in Table A-4 and the locations at which constituent concentrations are specified for the water quality model are listed in Table A-5.

TABLE A-4
DSM2 HYDRO Boundary Conditions

Boundary Condition	Location/Control Structure	Typical Temporal Resolution
Tide	Martinez	15min
Delta Inflows	Sacramento River at Freeport	1day
	San Joaquin River at Vernalis	1day
	Eastside Streams (Mokelumne and Cosumnes Rivers)	1day
	Calaveras River	1day
	Yolo Bypass	1day
Delta Exports/Diversions	Banks Pumping Plant (SWP)	1day
	Jones Pumping Plant (CVP)	1day
	Contra Costa Water District Diversions at Rock Slough, Old River at Highway 4 and Victoria Canal	1day
	North Bay Aqueduct	1day
	City of Vallejo	1day
	Antioch Water Works	1day
	Freeport Regional Water Project	1day
	City of Stockton	1day
	Isolated Facility Diversion	1day
Delta Island Consumptive Use	Diversion	1mon
	Seepage	1mon

TABLE A-4
DSM2 HYDRO Boundary Conditions

Boundary Condition	Location/Control Structure	Typical Temporal Resolution
	Drainage	1mon
Gate Operations	Delta Cross Channel	Irregular Timeseries
	South Delta Temporary Barriers	dynamically operated on 15min
	Montezuma Salinity Control Gate	dynamically operated on 15min

TABLE A-5
DSM2 QUAL Boundary Conditions Typically used in a Salinity Simulation

Boundary Condition	Location/Control Structure	Typical Temporal Resolution
Ocean Salinity	Martinez	15min
Delta Inflows	Sacramento River at Freeport	Constant
	San Joaquin River at Vernalis	1mon
	Eastside Streams (Mokelumne and Cosumnes Rivers)	Constant
	Calaveras River	Constant
	Yolo Bypass	Constant
Delta Island Consumptive Use	Drainage	1mon (repeated each year)

Notes: For other water quality constituents, concentrations are required at the same locations

A.5.3. Application of DSM2 to Evaluate BDCP Alternatives

Several long-term planning analyses used DSM2 to evaluate Delta hydrodynamics and water quality, in the past. In those studies, DSM2 was run for a 16-year period from WY1976 to WY1991, on a 15-min timestep. Typically the inputs needed for DSM2 – inflows, exports, and Delta Cross Channel (DCC) gate operations were provided by the 82-year CALSIM II simulations. The tidal boundary condition at Martinez was provided by an adjusted astronomical tide (Ateljevich and Yu, 2007). Monthly Delta channel depletions (i.e., diversions, seepage and drainage) were estimated using DWR's Delta Island Consumptive Use (DICU) model (Mahadevan, 1995).

CALSIM II provides monthly inflows and exports in the Delta. Traditionally, the Sacramento and San Joaquin River inflows are disaggregated to a daily time step for use in DSM2 either by applying rational histosplines, or by assuming that the monthly average flow as constant over the whole month. The splines allow a smooth transition between the months. The smoothing reduces sharp transitions at the start of the month, but still results in constant flows for most of the month. Other inflows, exports and diversions were assumed to be constant over the month.

Delta Cross Channel gate operation input in DSM2 is based on CALSIM II output. For each month, DSM2 assumes the DCC gates are open for the "number of the days open" simulated in CALSIM II, from the start of the month.

The operation of the south Delta Temporary Barriers, if included in the model is determined dynamically in using the operating rules feature in DSM2. These operations generally depend on the season, San Joaquin River flow at Vernalis and tidal condition in the south Delta. Similarly, the Montezuma Slough Salinity Control Gate operations are determined using an operating rule that sets the operations based on the season, Martinez salinity and tidal condition in the Montezuma Slough.

For salinity, EC at Martinez is estimated using the G-model on a 15-min timestep, based on the Delta outflow simulated in CALSIM II and the pure astronomical tide at Martinez (Ateljevich, 2001a). The monthly averaged EC for the San Joaquin River at Vernalis estimated in CALSIM II for the 82-year period is used in DSM2. For other river flows, which have low salinity, constant values are assumed. Monthly average values of the EC associated with Delta agricultural drainage and return flows was estimated for three regions in the Delta based on observed data identifying the seasonal trend. These values are repeated for each year of the simulation.

For BDCP, several enhancements were incorporated in the planning analysis approach traditionally used for DSM2. Some of the changes were to address the assumptions for BDCP while the others are improvements which make the DSM2 planning simulations more realistic.

The changes that are based on the BDCP assumptions include modifications to DSM2 to capture the effect of sea level rise, tidal marsh restoration with and without sea level rise, and north Delta diversion intakes. The DSM2 models incorporating above changes were used in developing new ANNs for CALSIM II.

The other enhancement is with regard to the flow boundary conditions used in DSM2. As described above, traditional approach does not represent the variability that would exist in the Delta inflows within a month. Since CALSIM II, from which the boundary flows are derived is a monthly time step model, a new approach was developed to incorporate daily variability in the DSM2 boundary flows using the monthly results from CALSIM II.

The following sections describe in detail various enhancements and changes made to the DSM2 hydrodynamics, salinity and nutrient modeling methods as part of the BDCP analyses.

Changes to the DSM2 Grid

DSM2 model grid from the 2009 recalibration (CH2M HILL, 2009) was further modified in the north Delta to locate the DSM2 nodes at the proposed north Delta diversion intake locations as agreed on January 29th BDCP Steering Committee meeting. Two new nodes and two new channels are added to the grid and several existing nodes were relocated and channel lengths were modified in the reach upstream of Delta Cross Channel. Figure A-12 shows the grid used in the baseline models for BDCP. The DSM2 grid includes several other changes related to the north Delta diversion intakes and the tidal marsh restoration.

Incorporation of Daily Hydrologic Inputs to DSM2

DSM2 is simulated on a 15-minute time step to address the changing tidal dynamics of the Delta system. However, the boundary flows are typically provided from monthly CALSIM II results. In all previous planning-level evaluations, the DSM2 boundary flow inputs were applied on a daily time step but used constant flows equivalent to the monthly average CALSIM II flows except at month transitions.

As shown in Figures A-6 and A-7, Sacramento River flow at Freeport exhibits significant daily variability around the monthly mean in the winter and spring period in the most water year types. The winter-spring daily variability is deemed important to species of concern. In an effort to better represent the sub-monthly flow variability, particularly in early winter, a monthly-to-daily flow mapping technique is applied to the boundary flow inputs to DSM2. The daily mapping approach used in CALSIM II and DSM2 are consistent. The incorporation of daily mapping in CALSIM II is described in the Section A.3.3. A detailed description of the implementation of the daily variability in DSM2 boundary conditions is provided in Section D.

It is important to note that this daily mapping approach does not in any way represent the flows that would result from any operational responses on a daily time step. It is simply a technique to incorporate representative daily variability into the flows resulting from CALSIM II's monthly operational decisions.

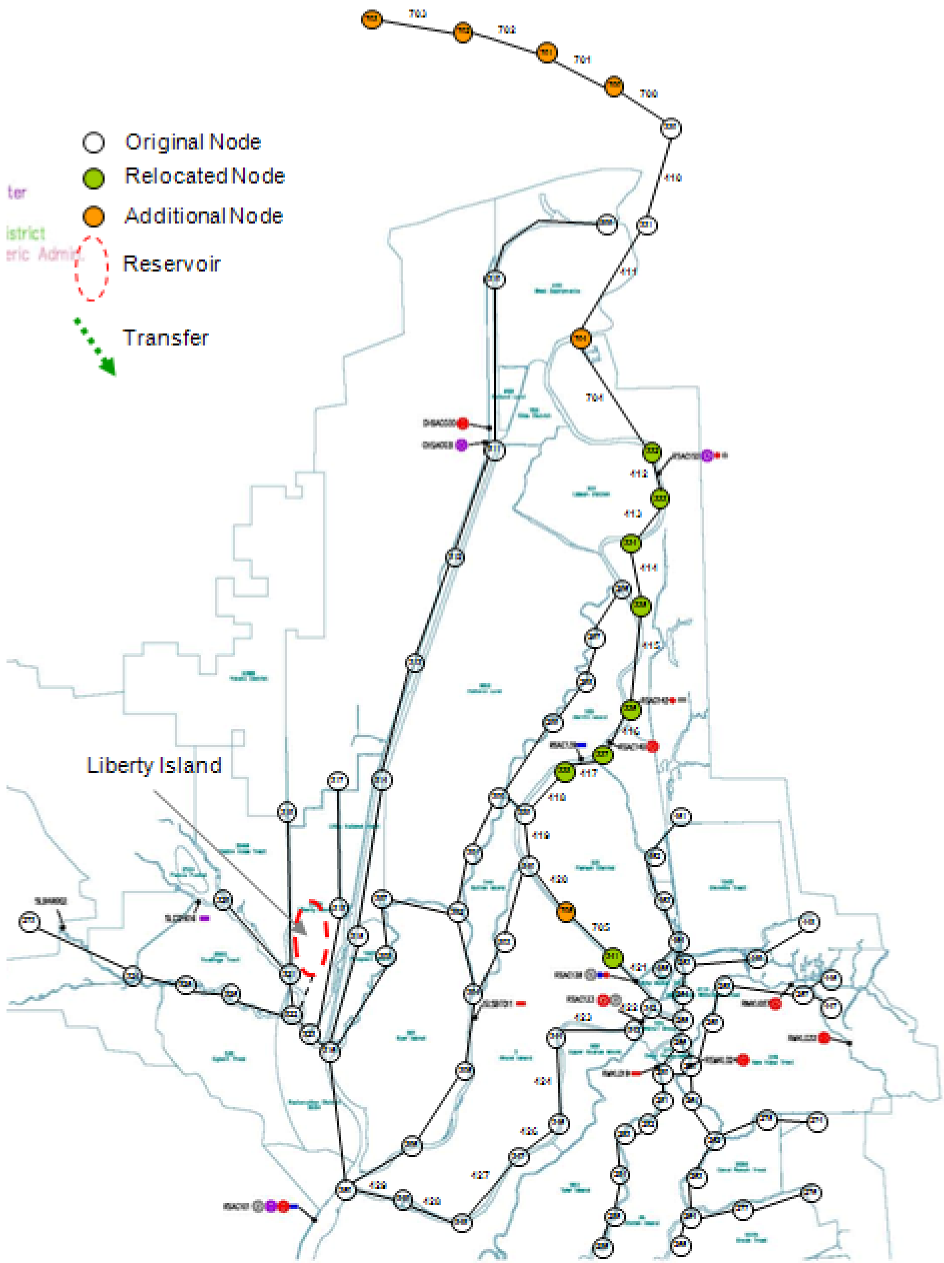


Figure A-12: North Delta DSM2 grid used in the BDCP Modeling

Incorporation of Tidal Marsh Restoration and Sea Level Rise Effects in DSM2 Planning Simulations

Using the corroboration described above described, seven (7) separate DSM2 grid configurations and model setups were prepared for use in the planning simulations for the Alternatives. Each configuration corresponds to one combination of sea level rise and restoration scenario.

Using the results from the RMA current conditions and tidal marsh models, three sets of regression relationships were developed to estimate the stage and EC at Martinez location for the 14,000ac (NT), 25,000ac (ELT) and 65,000ac (LLT) restoration scenarios based on the baseline stage and EC at Martinez. Similarly, using the results from the UnTRIM models, two sets of correlations were developed to compute the resulting stage and EC at Martinez location for the 15cm (ELT) and 45cm (LLT) sea level rise scenarios.

Based on the RMA integrated tidal marsh and sea level rise scenarios, two sets of correlations were developed for estimating Martinez stage and EC resulting for the 25,000ac restoration under 15cm sea level rise (ELT) and for the 65,000ac restoration under 45cm sea level rise (LLT) scenarios.

Table A-6 shows the Martinez stage and EC correlations for these seven (7) scenarios described above. It also shows the lag in minutes between the baseline stage or EC and the resulting stage or EC under the scenario with sea level rise and/or restoration. The regressed baseline stage or EC timeseries needs to be shifted by the lag time noted in the Table A-6.

Accurate effects of the tidal marsh restoration and sea level rise are incorporated in DSM2 simulations for the Alternatives in two ways. First, by incorporating consistent grid configuration and model setup identified in corroboration process into the DSM2 model for the selected Alternative, based on the tidal marsh restoration acreage and sea level rise assumptions selected for the Alternative. Second, by modifying the downstream stage and EC boundary conditions at Martinez in the DSM2 model inputs using the regression relationships identified in the corroboration process for the selected restoration and sea level rise assumptions.

As noted earlier, adjusted astronomical tide at Martinez is used as the downstream stage boundary in the DSM2 planning simulation representing current Delta configuration without any sea level rise or tidal marsh restoration. This stage timeseries is modified using one of the stage correlation equations identified in Table A-6 for use in a planning simulation with either restoration or sea level rise or both.

The EC boundary condition in a DSM2 planning simulation is estimated using the G-model based on the monthly net Delta outflow simulated in CALSIM II and the pure astronomical tide (Ateljevich, 2001b). Even though the rim flows and exports are patterned on a daily step in DSM2, the operational decisions are still on a monthly timestep. This means that the net Delta outflow may or may not meets the standards on a daily timestep. Therefore, to estimate the EC boundary condition at Martinez, monthly net Delta outflow simulated in CALSIM II is used. For a planning simulation with either restoration or sea level rise or both, EC timeseries from the G-model is regressed using one of the EC correlations listed in Table A-6 to account for the anticipated changes at Martinez.

TABLE A-6
Correlations to Transform Baseline Martinez Stage and EC for use in DSM2 BDCP Planning Runs with Tidal Marsh Restoration, Sea Level Rise or both Restoration and Sea Level Rise

Scenario	Martinez Stage (ft NGVD 29)		Martinez EC (µS/cm)	
	Correlation	Lag (min)	Correlation	Lag (min)
NT (14,000ac)	Y = 0.966 * X + 0.04	-3	Y = 1.001 * X + 191.5	8
ELT (25,000ac)	Y = 0.964 * X + 0.04	-4	Y = 0.999 * X + 114.7	10
LLT (65,000ac)	Y = 0.943 * X + 0.06	-3	Y = 0.996 * X + 68.2	13
15cm SLR	Y = 1.0033*X + .47	-1	Y = 0.9954* X + 556.3	0
45cm SLR	Y = 1.0113*X + 1.4	-2	Y = 0.98* X + 1778.9	-2
ELT (25,000ac &15cm SLR)	Y = 0.968 * X + 0.5	-5	Y = 0.999 * X + 357.78	9
LLT (65,000ac & 45cm SLR)	Y = 0.958 * X + 1.49	-9	Y = 1.002 * X + 1046.3	11

Notes: X = Baseline Martinez stage or EC and Y = Scenario Martinez stage or EC

ANN Retraining

ANNs are used for flow-salinity relationships in CALSIM II. They are trained on DSM2 outputs and therefore, emulate DSM2 results. ANN requires retraining whenever the flow – salinity relationship in the Delta changes. BDCP analysis assumes different restoration acreages at NT, ELT and LLT phases. In addition it includes 15cm and 45cm sea level rise at ELT and LLT, respectively. Each combination of restoration and sea level condition results in a different flow – salinity relationship in the Delta and therefore require a new ANN. Table A-7 lists the ANNs developed and used as part of the BDCP analysis.

DWR Bay-Delta Modeling staff has retrained the ANNs for each scenario. ANN retraining process involved following steps:

- Corroboration of the DSM2 model for each scenario as described above
- Range of example long-term CALSIM II scenarios to provide range of boundary conditions for DSM2 models
- Using the grid configuration and the correlations from the corroboration process several 16-year planning runs are simulated based on the boundary conditions from the identified CALSIM II scenarios to create a training dataset for each new ANN
- ANNs are trained using the Delta flows and DCC operations from CALSIM II, EC results from DSM2and the Martinez tide
- The training dataset is divided into two parts. One is used for training the ANN and the other to validate
- Once the ANN is ready a full circle analysis is performed to assess the performance of the ANN

Detailed description of the ANN training procedure and the full circle analysis is provided in DWR's 2007 annual report (Seneviratne and Wu, 2007).

TABLE A-7
List of ANNs Developed and Used in the BDCP Modeling

ANN	Description	Reference DSM2 Model
BST_noSLR_111709	Represents current Delta configuration with no sea level rise	2009 DSM2 Recalibration
BDCP_ROA0ac_SLR15cm_16Mar2010	Represents current Delta configuration with 15cm sea level rise	DSM2 model corroborated with UnTRIM results for 15cm sea level rise case
BDCP_ROA0ac_SLR45cm_18Mar2010	Represents current Delta configuration with 45cm sea level rise	DSM2 model corroborated with UnTRIM results for 45cm sea level rise case
BDCP_ROA14Kac_SLR0cm_22Dec2009	Represents 14000ac tidal marsh restoration assumed, with no sea level rise	DSM2 model corroborated with RMA results for 14,000ac restoration proposed for NT phase
BDCP_ROA25Kac_SLR0cm_29Dec2009	Represents 25000ac tidal marsh restoration assumed, with no sea level rise	DSM2 model corroborated with RMA results for 25,000ac restoration proposed for ELT phase
BDCP_ROA65Kac_SLR0cm_30Mar2010	Represents 65000ac tidal marsh restoration assumed, with no sea level rise	DSM2 model corroborated with RMA results for 65,000ac restoration proposed for LLT phase
BDCP_ROA25Kac_SLR15cm_14Apr2010	Represents 25000ac tidal marsh restoration assumed, with 15cm sea level rise	DSM2 model corroborated with RMA results for 25,000ac restoration proposed for ELT phase under 15cm sea level rise
BDCP_ROA65Kac_SLR45cm_30Mar2010	Represents 65000ac tidal marsh restoration assumed, with 45cm sea level rise	DSM2 model corroborated with RMA results for 65,000ac restoration proposed for LLT phase under 45cm sea level rise

North Delta Diversion Operations

As described in Section A.3.3, several Alternatives include new intakes on Sacramento River upstream of Sutter Slough, in the north Delta. The diversions at the intakes are governed by the bypass rules. The bypass rules are simulated in CALSIM II using daily mapped Sacramento River flow, which provides the maximum potential diversion that can occur in the north Delta for each day. CALSIM II uses the monthly average of this daily potential diversion as one of the constraints in determining the final monthly north Delta diversion. For use in DSM2, the monthly diversion output for the north Delta intakes is mapped onto the daily pattern of the potential diversion estimated in CALSIM II.

In DSM2 diversion at each intake is determined on a 15 min timestep, subject to sweeping velocity criteria so that the fish migrating past the fish screens do not impinge on them. For BDCP, Delta Smelt criterion of 0.4fps, required by DFG (DFG, 2009) is used in determining whether or not water can be diverted at an intake. The intake operations are also subjected to ramping rates that are required to shut off or start the pumps. The current design allows ramping up or down the pumps between 0 and 3,000cfs in less than an hour. These criteria cannot be simulated in CALSIM II. They are dynamically simulated using the operating rules feature in DSM2.

The north Delta diversion operating rule in the DSM2 allows diverting up to the amount specified by CALSIM II each day while subjecting each intake to the sweeping velocity and the ramping criteria. The intakes are operated as long as the daily diversion volume specified by CALSIM II is not met. Once the specified volume is diverted for the day, the pumps are shut off until next day.

The volume corresponding to first 100cfs per intake (for five intakes 500 cfs) of the daily north Delta diversion specified by CALSIM II is diverted equally at all the intakes included for the Alternative. The remaining volume for the day will be diverted such that operation of the upstream intakes is prioritized over the downstream intakes. Intake diversions are ramped over an hour to allow smooth transitions when they are turned on and off.

In the current modeling of the Alternatives, the diversion flow at an intake for each time step is estimated assuming that the remaining diversion volume in a day would have to be diverted in one time step at the upstream-most intake first and immediate downstream one next and so on until the daily specified total is diverted. However, the estimated amount of diversion at each intake is only diverted when the velocity measured just downstream of the DSM2 diversion node is greater than or equal to 0.4fps. If in any time step this criteria is violated then the diversion occurs in a future time step when the velocity is above 0.4fps or may occur at a different intake. The sweeping velocity criterion is measured at 1000ft downstream from the diversion node in DSM2 to minimize potential instabilities in the model. Even though DSM2 produces a cross-sectional averaged velocity, it is not corrected for the velocity profile across the cross-section as the actual screen location is still uncertain.

New channels, transfers and a reservoir are added to the DSM2 grid to simulate up to five (5) north Delta diversion intakes as shown in the Figure A-13. Five channels, 601 – 605, divert water off the Sacramento River and transfer to channel 607 and 608, from where the total diverted water is transferred to a new reservoir (IF_FOREBAY). Figure A-14 shows an example timeseries of sweeping velocities and the diversions at each intake. The plot shows how the intakes are ramped up and down when the velocity falls below 0.4 ft/s.

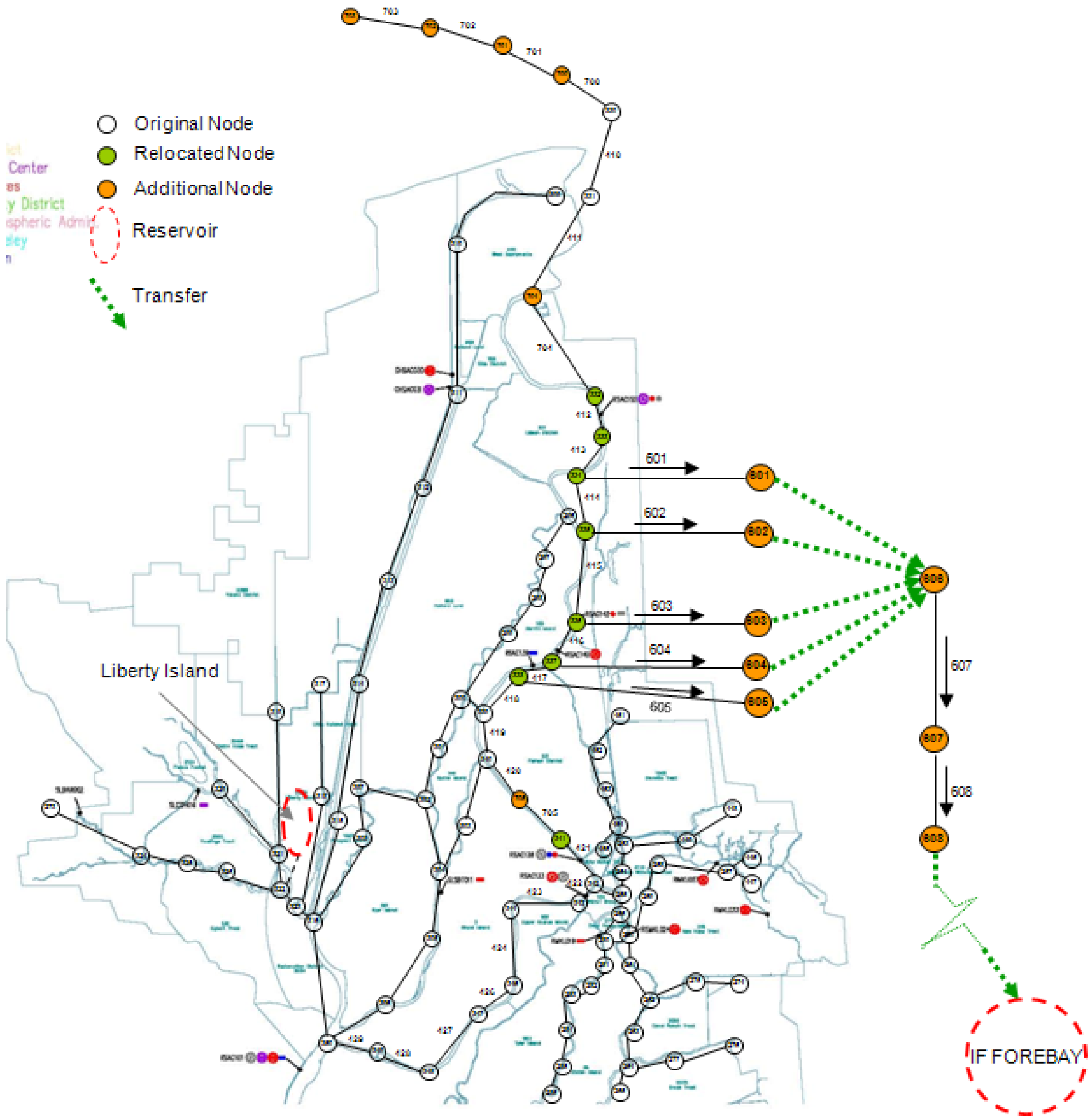


Figure A-13: North Delta DSM2 Grid Modifications for Simulating North Delta Diversions

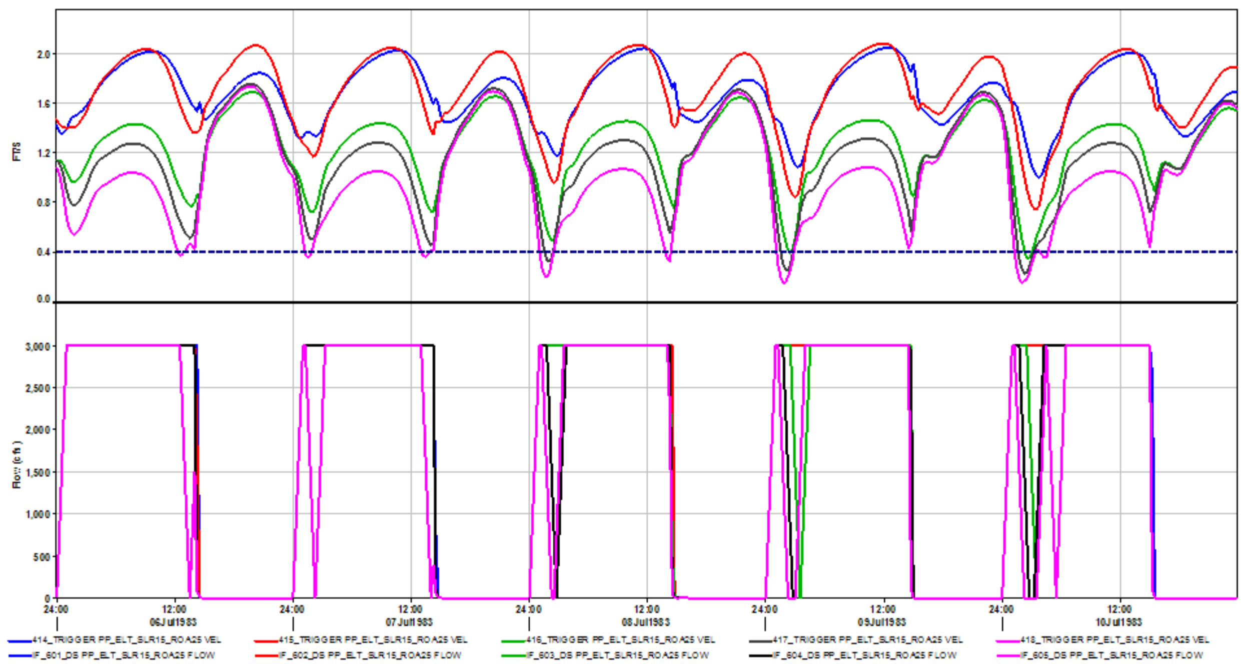


Figure A-14: An Example of Sweeping Velocity and the Diversion at the Five Intakes Simulated in DSM2

A.5.4. Output Parameters

DSM2 HYDRO provides the following outputs on a 15-minute time step:

- Tidal flow
- Tidal stage
- Tidal velocity

Following variables can be derived from the above outputs:

- Net flows
- Mean sea level, mean higher high water, mean lower low water and tidal range
- Water depth
- Tidal reversals
- Flow splits, etc.

DSM2 QUAL provides the following outputs on a 15-minute time step:

- Salinity (EC)
- DOC
- Source water and constituent fingerprinting

Following variables can be derived from the above QUAL outputs:

- Bromide, chloride, and total dissolved solids
- Selenium and mercury

In a planning analysis, the flow boundary conditions that drive DSM2 are obtained from the monthly CALSIM II model. The agricultural diversions, return flows and corresponding salinities used in DSM2 are on a monthly time step. The implementation of Delta Cross Channel gate operations in DSM2 assumes that the gates are open from the beginning of a month, irrespective of the water quality needs in the south Delta.

The input assumptions stated above should be considered when DSM2 EC results are used to evaluate performance of a baseline or an alternative against the standards. Even though CALSIM II releases sufficient flow to meet the standards on a monthly average basis, the resulting EC from DSM2 may be over the standard for part of a month and under the standard for part of the month, depending on the spring/neap tide and other factors (e.g. simplification of operations). It is recommended that the results are presented on a monthly basis. Frequency of compliance with a criterion should be computed based on monthly average results. Averaging on a sub-monthly (14-day or more) scale may be appropriate as long as the limitations with respect to the compliance of the baseline model are described in detail and the alternative results are presented as an incremental change from the baseline model. A detailed discussion is required in this case.

In general, it is appropriate to present DSM2 QUAL results including EC, DOC, volumetric fingerprinting and constituent fingerprinting on a monthly time step. When comparing results from two scenarios, computing differences based on these mean monthly statistics would be appropriate.

A.5.5. Modeling Limitations

DSM2 is a 1D model with inherent limitations in simulating hydrodynamic and transport processes in a complex estuarine environment such as the Sacramento – San Joaquin Delta. DSM2 assumes that velocity in a channel can be adequately represented by a single average velocity over the channel cross-section, meaning that variations both across the width of the channel and through the water column are negligible. DSM2 does not have the ability to model short-circuiting of flow through a reach, where a majority of the flow in a cross-section is confined to a small portion of the cross-section. DSM2 does not conserve momentum at the channel junctions and does not model the secondary currents in a channel. DSM2 also does not explicitly account for dispersion due to flow accelerating through channel bends. It cannot model the vertical salinity stratification in the channels.

It has inherent limitations in simulating the hydrodynamics related to the open water areas. Since a reservoir surface area is constant in DSM2, it impacts the stage in the reservoir and thereby impacting the flow exchange with the adjoining channel. Due to the inability to change the cross-sectional area of the reservoir inlets with changing water surface elevation, the final entrance and exit coefficients were fine tuned to match a median flow range. This causes errors in the flow exchange at breaches during the extreme spring and neap tides. Using an arbitrary bottom elevation value for the reservoirs representing the proposed marsh areas to get around the wetting-drying limitation of DSM2 may increase the dilution of salinity in the reservoirs. Accurate representation of RMA's tidal marsh areas, bottom elevations, location of breaches, breach widths, cross-sections, and boundary conditions in DSM2 is critical to the agreement of corroboration results.

For open water bodies DSM2 assumes uniform and instantaneous mixing over entire open water area. Thus it does not account for the any salinity gradients that may exist within the open water bodies. Significant uncertainty exists in flow and EC input data related to in-Delta agriculture, which leads to uncertainty in the simulated EC values. Caution needs to be exercised when using EC outputs on a sub-monthly scale. Water quality results inside the water bodies representing the tidal marsh areas were not validated specifically and because of the bottom elevation assumptions, preferably do not use it for analysis.

A.6. Delta Particle Tracking Modeling

Particle tracking models (PTM) are excellent tools to visualize and summarize the impacts of modified hydrodynamics in the Delta. These tools can simulate the movement of passive particles or particles with behavior representing either larval or adult fish through the Delta. The PTM tools can provide important information relating hydrodynamic results to the analysis needs of biologists that are essential in assessing the impacts to the habitat in the Delta.

A.6.1. DSM2-PTM

DSM2-PTM simulates pseudo 3-D transport of neutrally buoyant particles based on the flow field simulated by HYDRO. The PTM module simulates the transport and fate of individual particles traveling throughout the Delta. The model uses geometry files, velocity, flow, and stage output from the HYDRO module to monitor the location of each individual particle using assumed vertical and lateral velocity profiles and specified random movement to simulate mixing. The location of a particle in a channel is determined as the distance from the downstream end of the channel segment (x), the distance from the centerline of the channel (y), and the distance above the channel bottom (z).PTM has multiple applications ranging from visualization of flow patterns to simulation of discrete organisms such as fish eggs and larvae.

The longitudinal distance traveled by a particle is determined from a combination of the lateral and vertical velocity profiles in each channel. The transverse velocity profile simulates the effects of channel shear that occurs along the sides of a channel. The result is varying velocities across the width of the channel. The average cross-sectional velocity is multiplied by a factor based on the particle's transverse location in the channel. The model uses a fourth order polynomial to represent the velocity profile. The vertical velocity profile shows that particles located near the bottom of the channel move more slowly than particles located near the surface. The model uses the Von Karman logarithmic profile to create the velocity profile. Particles also move because of random mixing. The mixing rates (i.e., distances) are a function of the water depth and the velocity in the channel. High velocities and deeper water result in greater mixing.

At a junction the path of a particle is determined randomly based on the proportion of flow. The proportion of flow determines the probability of movement into each reach. A random number based on this determined probability then determines where the particle will go. A particle that moves into an open water area, such as a reservoir, no longer retains its position information. A DSM2 open water area is considered a fully mixed reactor. The path out of the open water area is a decision based on the volume in the open water area, the time step, and the flow out of the area. At the beginning of a time step the volume of the open water area the volume of water leaving at each opening of the open water area is determined. From that the probability of the particle leaving the open water area is calculated. Particles entering exports or agricultural diversions are considered "lost" from the system. Their final destination is recorded. Once particles pass the Martinez boundary, they have no opportunity to return to the Delta. (Smith, 1998, Wilbur, 2001, Miller, 2002)

A.6.2. DSM2-PTM Metrics

The particle transport and fate metrics resulting from DSM2 PTM are outlined below.

1. Fate Mapping – an indicator of entrainment. It is the percent of particles that go past various exit points in the system at the end of a given number of days after insertion.
2. Delta-wide Residence Time – an indicator of transport of larval fish and plankton. It is the time taken for 75% of the particles inserted to leave the system via all the exit points.

A.6.3. PTM Period Selection

PTM simulation periods for the residence time and fate computations were selected based on the simulated Delta inflows and the exports from the No Action Alternative CALSIM II results. A two-pronged approach was used to identify the particle insertion periods such that the selected periods cover the entire range of hydrology and also represent full range of export operations that occurred in the 82-year simulation period. Representative periods with various combinations of total inflow and exports were identified over the whole range of simulated values.

Briefly, the process included sorting all the months in the 82-year period into 25 hydrology bins based on the percent ranks of monthly Sacramento and San Joaquin inflows as shown in Figure A-15. The 984 months were then sorted based on the monthly total Delta inflow and the monthly exports as shown in Figure A-16. Several months falling on the 0.1, 0.2, 0.3, 0.4, 0.5 and 0.6 EI ratio isopleths were manually identified such that they cover all the hydrology bins. Figures A-17 and A-18 show the selected periods plotted on the hydrology binning plot and the EI ratio plot, respectively. Both the plots show that the selected periods cover the full range of hydrology and export operations. Figure A-19 shows number of selected periods in each month. The selected periods were reviewed to ensure representation of all the seasons. The selection was biased to include more periods in the Dec – Jun period. The variability captured in the selected periods, in terms of the hydrology and the operations, is mostly sustained for both the early long-term and late long-term conditions.

A.6.4. PTM Simulations

PTM simulations are performed to derive the metrics described above. PTM model can track flux at twenty locations in one simulation. The particles are inserted at the 39 locations shown in Figure A-20. These locations are listed in Table A-8. The locations were identified based on the 20mm Delta Smelt Survey Stations. They also include special interest stations such as Mokelumne River and Cache Complex.

A total of 39 PTM simulations are performed in a batch mode for each insertion period. For each insertion period, 4000 particles are inserted at the identified locations over a 24.75-hour period, starting on the 1st of the selected month. The fate of the inserted particles is tracked continuously over a 120-day simulation period. The particle flux is tracked at the key exit locations – exports, Delta agricultural intakes, past Chipps Island, to Suisun Marsh and past Martinez and at several internal tracking locations as shown in Figure A-20. Generally, the fate of particles at the end of 30 days, 60 days, 90 days and 120 days after insertion is computed for the fate mapping analysis. For the Delta-wide residence time analysis, the number of days taken for 25%, 50%, 75% of the total inserted particles to be removed via all the exit points in the Delta are computed.

Table A-8: List of Particle Insertion Locations for Residence Time and Fate Computations

Location	DSM2 Node
San Joaquin River at Vernalis	1
San Joaquin River at Mossdale	7
San Joaquin River D/S of Rough and Ready Island	21
San Joaquin River at Buckley Cove	25
San Joaquin River near Medford Island	34
San Joaquin River at Potato Slough	39
San Joaquin River at Twitchell Island	41
Old River near Victoria Canal	75
Old River at Railroad Cut	86
Old River near Quimby Island	99
Middle River at Victoria Canal	113
Middle River u/s of Mildred Island	145
Grant Line Canal	174
Frank's Tract East	232
Threemile Slough	240
Little Potato Slough	249
Mokelumne River d/s of Cosumnes confluence	258
South Fork Mokelumne	261
Mokelumne River d/s of Georgiana confluence	272
North Fork Mokelumne	281
Georgiana Slough	291
Miner Slough	307
Sacramento Deep Water Ship Channel	314
Cache Slough at Shag Slough	321
Cache Slough at Liberty Island	323
Lindsey slough at Barker Slough	324
Sacramento River at Sacramento	330
Sacramento River at Sutter Slough	339
Sacramento River at Ryde	344
Sacramento River near Cache Slough confluence	350
Sacramento River at Rio Vista	351
Sacramento River d/s of Decker Island	353
Sacramento River at Sherman Lake	354
Sacramento River at Port Chicago	359
Montezuma Slough at Head	418
Montezuma Slough at Suisun Slough	428
San Joaquin River d/s of Dutch Slough	461
Sacramento River at Pittsburg	465
San Joaquin River near Jersey Point	469

A.6.5. Output Parameters

The particle tracking models can be used to assist in understanding passive fate and transport, or through consideration of behavior or residence time. In, general the following outputs are generated:

- Fate of particles and cut lines or regions
- Time of travel breakthrough curves
- Residence time

Spatial plots of fate and residence time can be prepared as shown in the Figure A-21 and A-22. Scatter plots of entrainment with a hydrologic variable as shown in Figure A-23 can be helpful in assessing the correlation between hydraulics and entrainment, as well as the spatial extent over which such correlations hold.

A.6.6. Limitations

PTM results are most often used to understand the potential movement of eggs and larval fish with flow changes. Similarly, the PTM is also used to study the changes in the residence time (residence time being a surrogate of the water quality conditions in the Delta) in the Delta associated with flow changes. However, the PTM only approximates movement of neutrally-buoyant particles based on the hydraulics of flow. They do not include elements of fish behavior such as active swimming or tidal surfing which may be important for certain species and life stages. The version of the PTM model used in this analysis does not have a capability to simulate fish behavior. The PTM model requires input of channel velocity fields from HYDRO model, which leads to the translation of the limitations inherent to HDYRO to the PTM model. The partitioning of the particles at a junction is simplistic and is based on the flow split into different branches at a junction. Information related to higher order hydraulics such as acceleration around the bend and secondary are not simulated in the PTM, despite its use of an approximate 3D velocity field. Use of the PTM results to analyze certain species and life stages with significant active behavior responses should be used with caution. The PTM model used for this analysis is incapable of simulating fish screens and blocking the particles from entering small sump pumps in the Delta channels. While some uncertainty exists in the PTM results, the model is a reasonable tool to compare the movement and fate of particles across various scenarios, if results are interpreted within the context of these limitations.

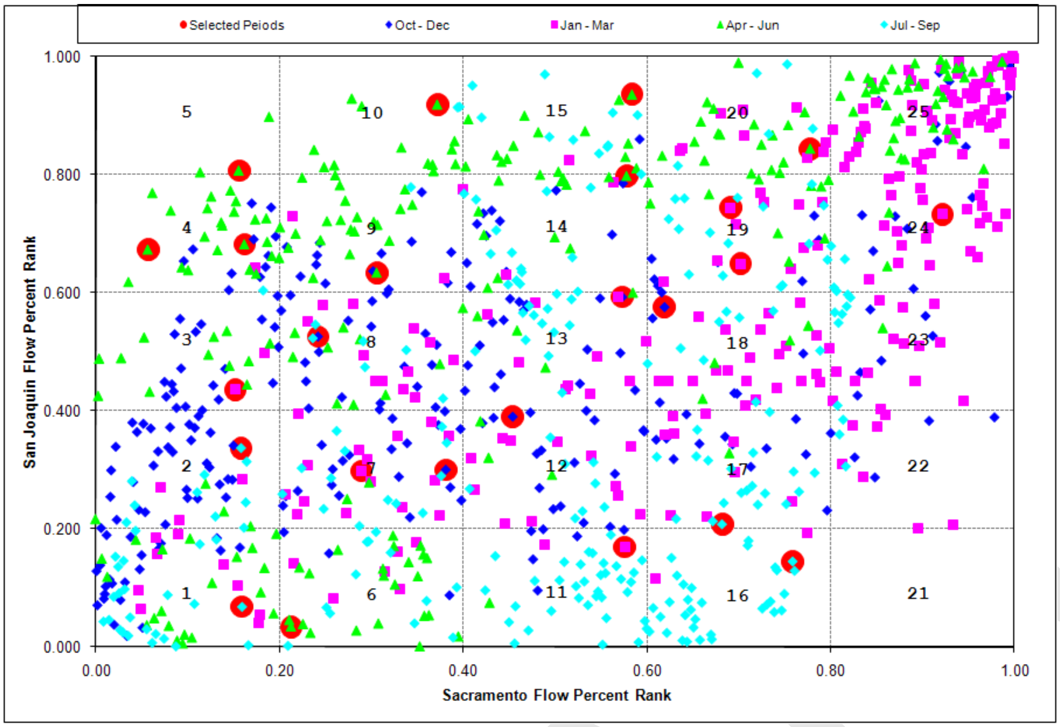


Figure A-15: Sorting of the 984 months (82-years) into 25 hydrology bins based on the percent rank of Sacramento River inflow and San Joaquin River inflow

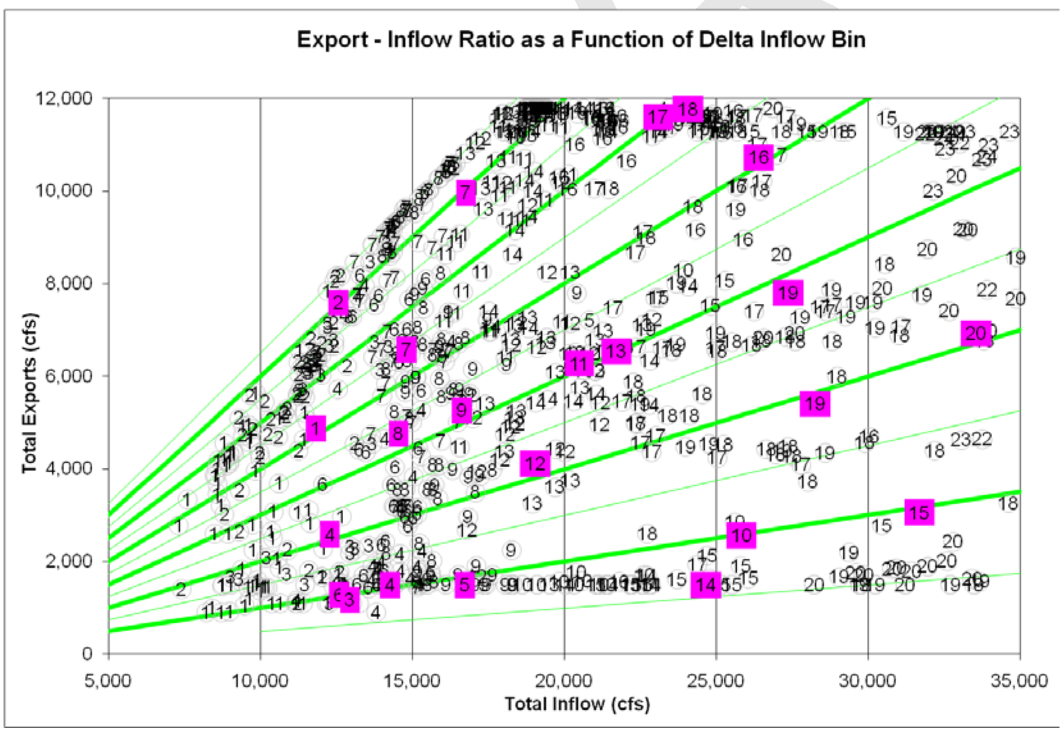


Figure A-16: Identification of months falling on the 0.1, 0.2, 0.3, 0.4, 0.5 and 0.6 EI ratio isopleths while covering the full range of hydrology bins (Numeric labels indicate hydrology bin)

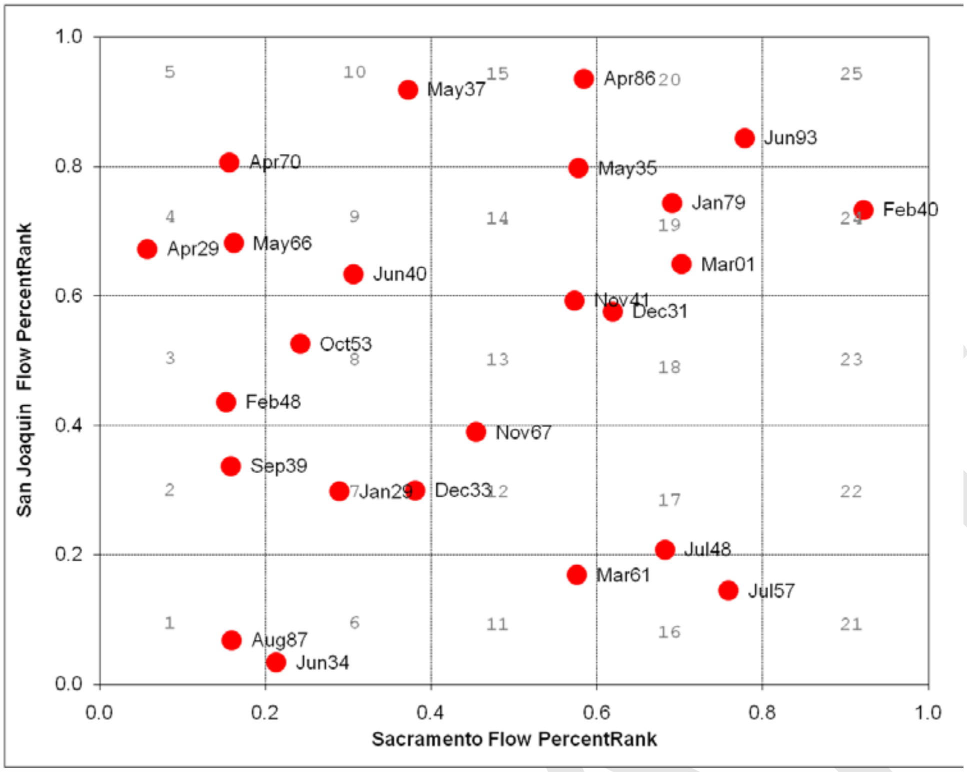


Figure A-17: Selected PTM insertion periods plotted on the Sacramento River and San Joaquin River inflow hydrology bins with month and year identified for each insertion period

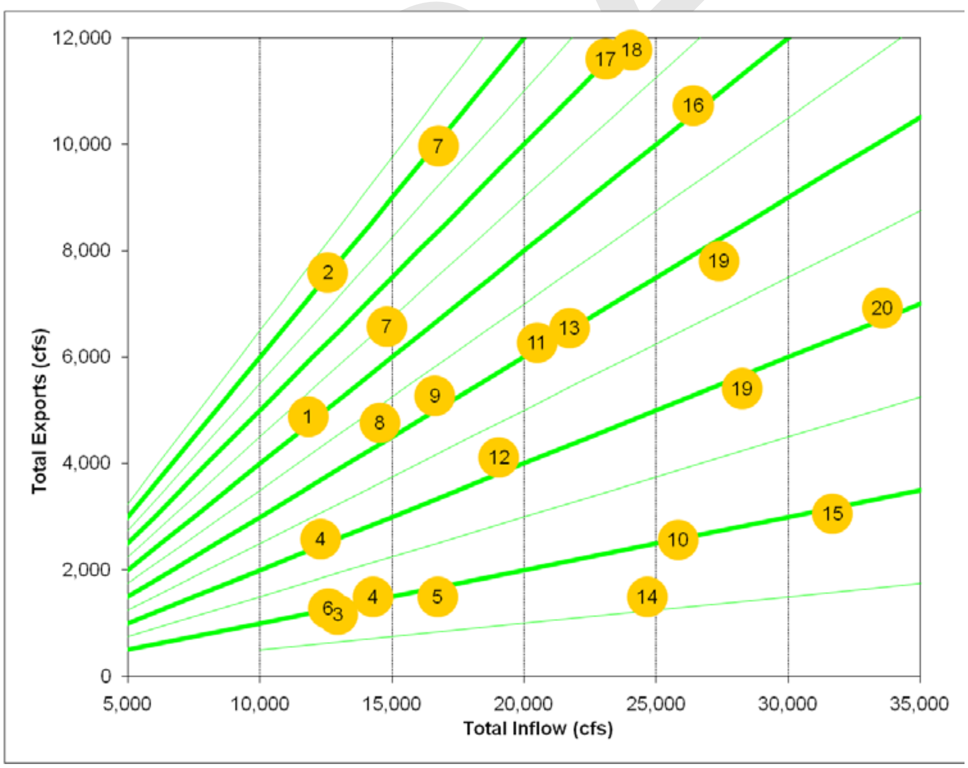


Figure A-18: Selected PTM insertion periods plotted on the EI ratio plot with the hydrology bin for each period identified

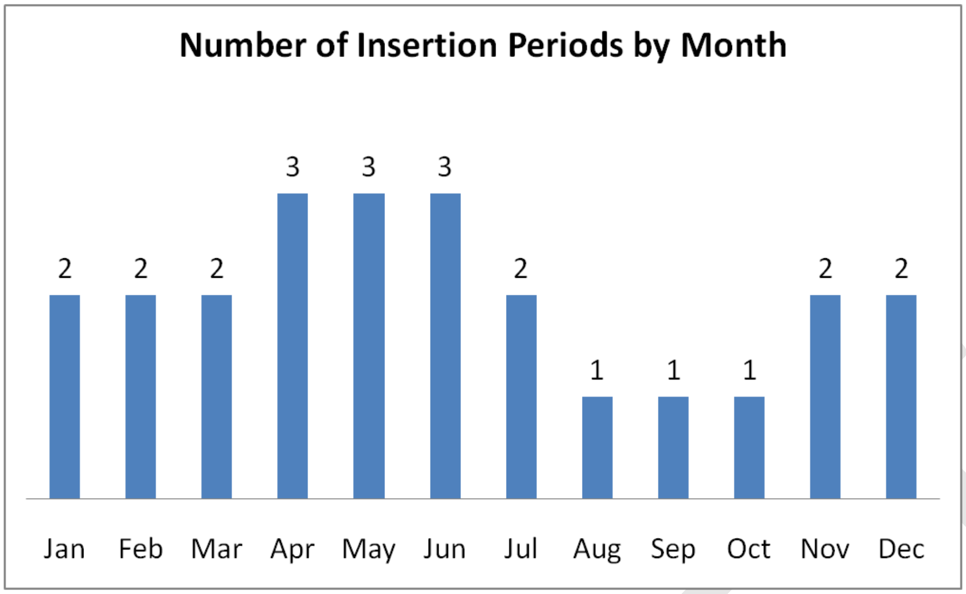


Figure A-19: Number of selected PTM insertion periods in each Month

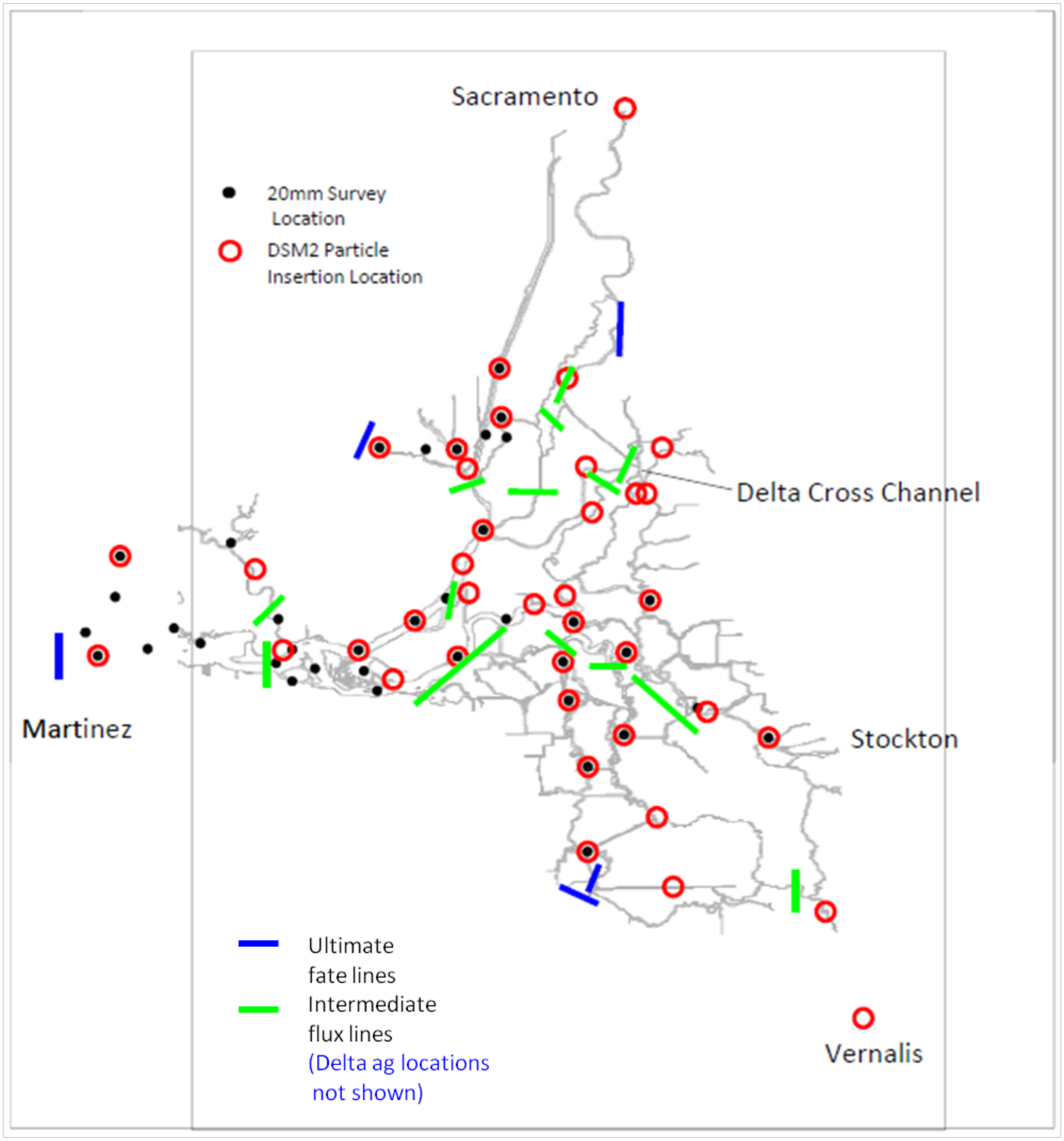


Figure A-20: Particle insertion and tracking locations for residence time and fate computations

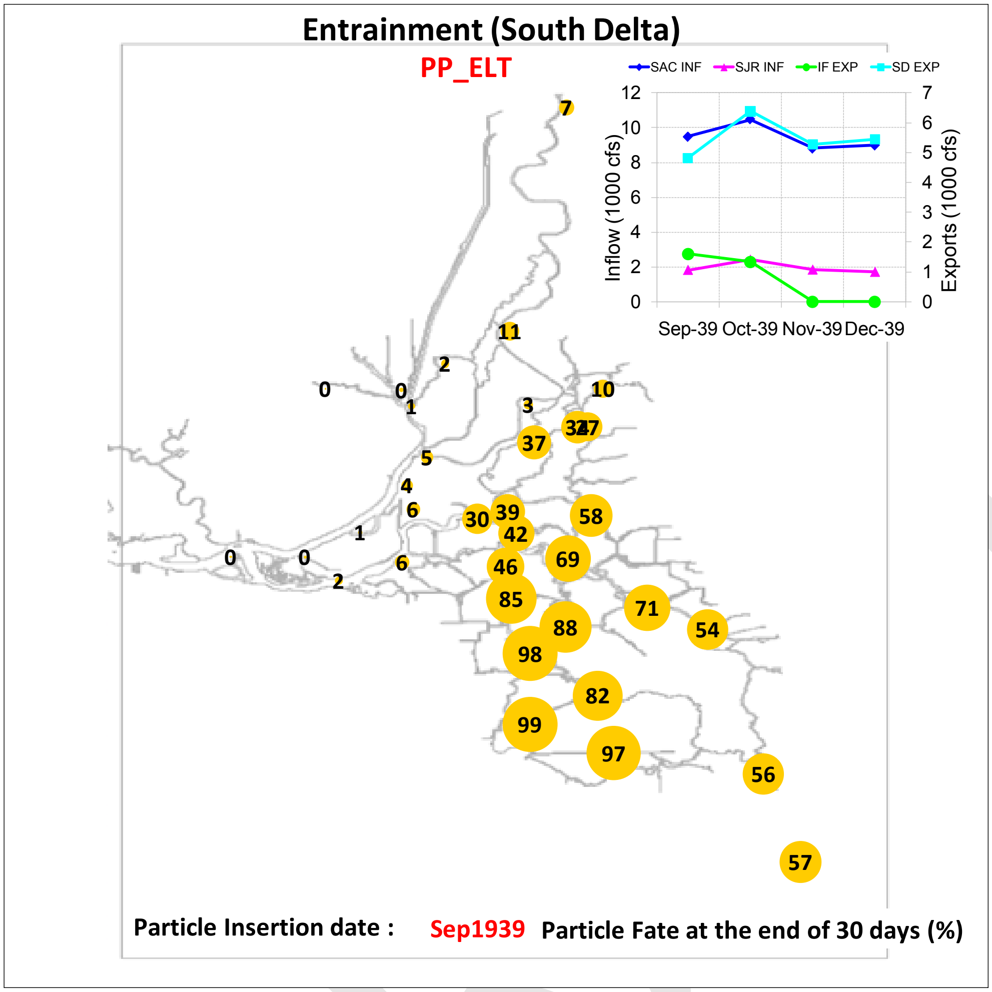


Figure A-21: An example spatial plot showing the percent entrainment for particles released at various locations in the Delta at the end of 30 days after insertion

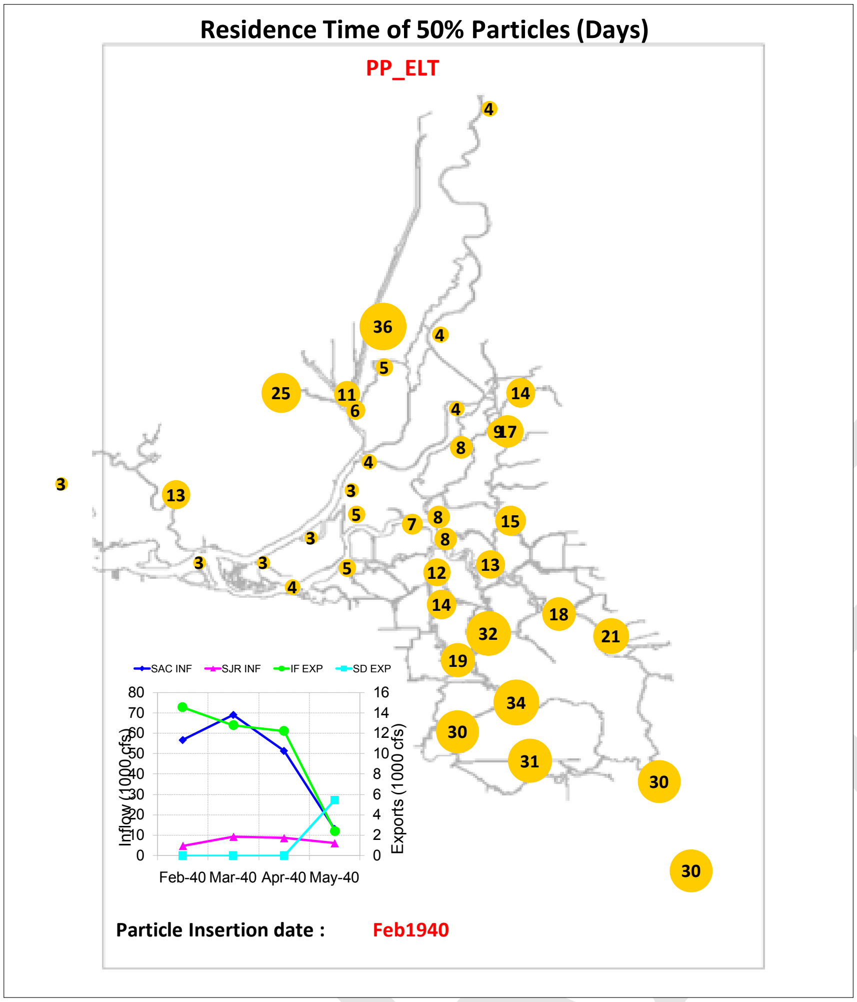


Figure A-22: An example spatial plot showing the residence time for 50 percent particles to exit the Delta

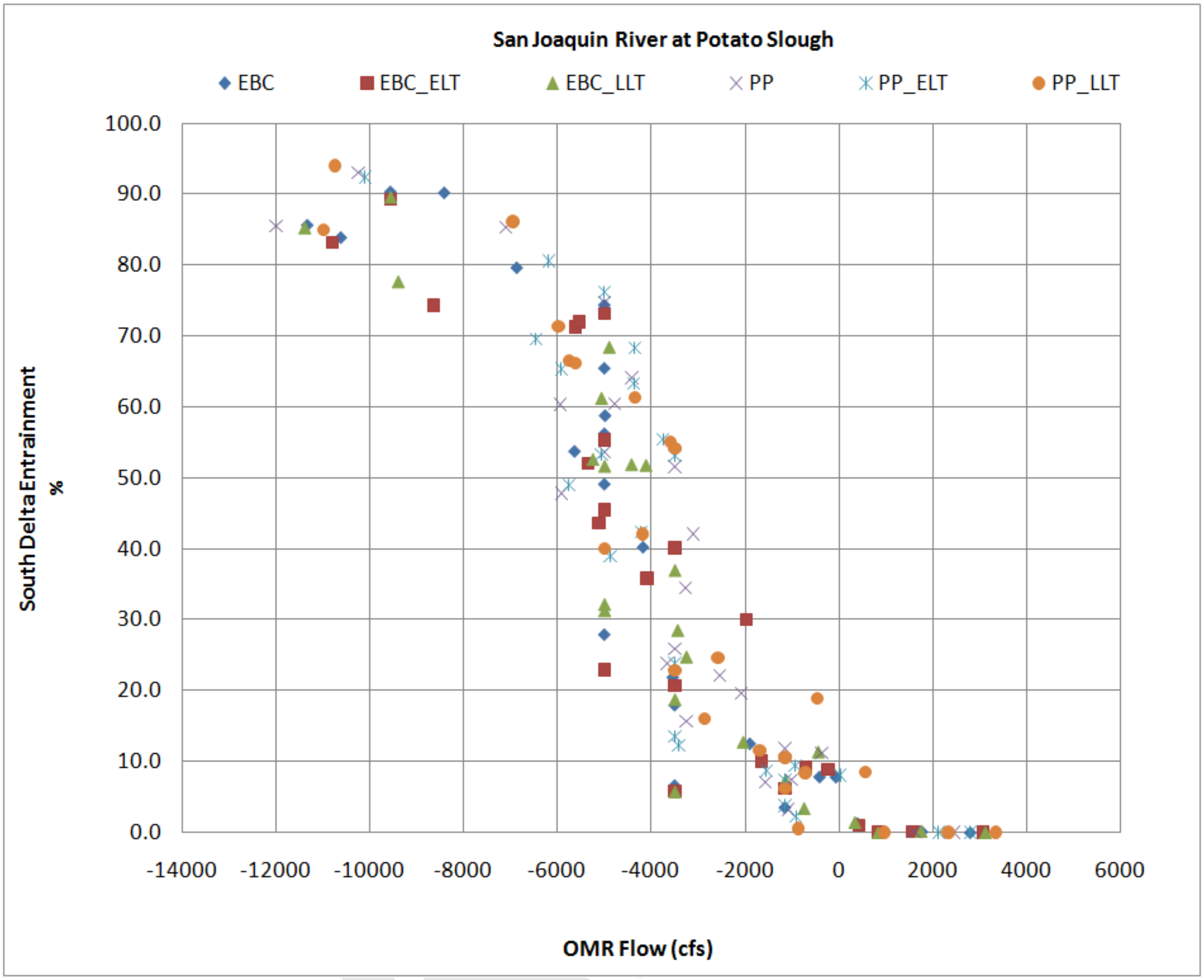


Figure A-23: An example scatter plot showing the percent entrainment of particles at south Delta pumps inserted at San Joaquin River at Potato Slough location and OMR flow, 60 days after the particles were inserted

A.7. Climate Change Scenarios

A.7.1. Selection of BDCP Climate Scenarios

A technical subgroup was formed with representatives from DWR, Reclamation, USFWS, and NMFS to review the technical merits of several approaches for incorporating climate change into BDCP analytical processes. The issues of multi-decadal variability in the sampling of any one GCM projection and the superiority of multi-model projections over any one single projection were emphasized by the group members. These and other comments received from the group members led to the recommendation of the following criteria to guide the selection of climate scenarios:

- Select a range of scenarios to reflect the uncertainty with GCM projections and emission scenarios;
- Select scenarios that reduce the "noise" inherent with any particular GCM projection due to multi-decadal variability that often does not preserve relative rank for different locations and time periods;
- Select an approach that incorporates both the mean climate change trend and changes in variability; and
- Select time periods that are consistent with the major phases used in BDCP planning.
- The selected approach for development of climate scenarios for the BDCP incorporates three fundamental elements. First, it relies on sampling of the ensemble of GCM projections rather than one single realization or a handful of individual realizations. Second, it includes scenarios that both represent the range of projections as well as the central tendency of the projections. Third, it applies a method that incorporates both changes to the mean climate as well as to the variability in climate. These elements are described further in the sections below.

A.7.2. Downscaled Climate Projections

A total of 112 future climate projections used in the IPCC AR4, subsequently bias-corrected and statistically downscaled (BCSD), were obtained from Lawrence Livermore National Laboratory (LLNL) under the World Climate Research Program's (WCRP) Coupled Model Intercomparison Project Phase 3 (CMIP3). This archive of contains climate projections generated from 16 different GCMs developed by national climate centers (Table A-9) and for SRES emission scenarios A2, A1b, and B1. Many of the GCMs were simulated multiple times for the same emission scenario due to differences in starting climate system state, thus the number of available projections is greater than simply the product of GCMs and emission scenarios. These projections have been bias corrected and spatially downscaled to 1/8th degree (~12km) resolution over the contiguous United States through methods described in detail in Wood et al. 2002, Wood et al. 2004, and Maurer 2007.

TABLE A-9
General Circulation Models used in the World Climate Research Program's (WCRP) Coupled Model Intercomparison Project Phase 3 (CMIP3) Database

Modeling Group, Country	WCRP CMIP3 I.D.
Bjerknes Centre for Climate Research	BCCR-BCM2.0
Canadian Centre for Climate Modeling & Analysis	CGCM3.1 (T47)
Meteo-France / Centre National de Recherches Meteorologiques, France	CNRM-CM3
CSIRO Atmospheric Research, Australia	CSIRO-Mk3.0
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM2.0
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM2.1
NASA / Goddard Institute for Space Studies, USA	GISS-ER
Institute for Numerical Mathematics, Russia	INM-CM3.0
Institut Pierre Simon Laplace, France	IPSL-CM4
Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan	MIROC3.2 (medres)
Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA	ECHO-G
Max Planck Institute for Meteorology, Germany	ECHAM5/ MPI-OM
Meteorological Research Institute, Japan	MRI-CGCM2.3.2
National Center for Atmospheric Research, USA	CCSM3
National Center for Atmospheric Research, USA	PCM
Hadley Centre for Climate Prediction and Research / Met Office, UK	UKMO-HadCM3

A.7.3. Climate Periods

Climate change is commonly measured over a 30-year period. Changes in temperature and precipitation for any particular scenario are compared to a historical period. The historical period of 1971-2000 is selected as the reference climate since it is the currently established climate normal used by NOAA and represents the most recent time period. Corresponding to the long-term timelines of the BDCP analysis, in which climate change is likely to be relevant, future climate periods are identified as approximately 2025 (2011-2040) [early long-term] and 2060 (2046-2075) [late long-term]. The difference in mean annual temperature and precipitation among the two future periods and historic period were identified as the climate change metric.

A.7.4. Multi-Model Ensemble and Sub-Ensembles

The recommended approach makes use of all 112 downscaled climate projections of future climate change described in the previous section. The group of multi-model, multi-emission scenario projections is termed the ensemble. Individual model-emission scenario projections are termed “members” of the ensemble. It is often useful to characterize climate change projections in terms of the simulated change in annual temperature and precipitation compared to an historical reference period. At any selected 30-yr future climatological period, each projection represents one point of change amongst the others. This is graphically depicted in Figure A-24 for a region in Feather River watershed.

Since the ensemble is made up of many projections, it is useful to identify the median (50th percentile) change of both annual temperature and annual precipitation (dashed blue lines). In doing so, the state of climate change at this point in time can be broken into quadrants representing (1) drier, less warming, (2) drier, more warming, (3) wetter, more warming, and (4) wetter, less warming than the ensemble median. These quadrants are labeled Q1-Q4 in Figure A-24. In addition, a fifth region (Q5) can be described that samples from inner-quartiles (25th to 75th percentile) of the ensemble and represents a central region of climate change. In each of the five regions the sub-ensemble of climate change projections, made up of those contained within the region bounds, is identified. The Q5 scenario is derived from the central tending climate projections and thus favors the consensus of the ensemble.

Through extensive coordination with the State and Federal teams involved in the BDCP, the bounding scenarios Q1-Q4 were refined in April 2010 to reduce the attenuation of climate projection variability that comes about through the use of larger ensembles. A sensitivity analysis was prepared for the bounding scenarios (Q1-Q4) using sub-ensembles made up of different numbers of downscaled climate projections. The sensitivity analysis was prepared using a “nearest neighbor” (k-NN) approach. In this approach, a certain joint projection probability is selected based on the annual temperature change-precipitation change (i.e. 90th percentile of temperature and 90th percentile of precipitation change). From this statistical point, the “k” nearest neighbors (after normalizing temperature and precipitation changes) of projections are selected and climate change statistics are derived. Consistent with the approach applied in OCAP, the 90th and 10th percentile of annual temperature and precipitation change were selected as the bounding points. The sensitivity analysis considered using the 1-NN (single projection), 5-NN (5 projections), and 10-NN (10 projections) sub-ensemble of projections. These were compared to the original quadrant scenarios which commonly are made up of 25-35 projections and are based on the direction of change from 50th percentile statistic.

The very small ensemble sample sizes exhibited month by month changes that were sometimes dramatically different than that produced by adding a few more projections to the ensemble. The 1-NN approach was found to be inferior to all other methods for this reason. The original quadrant method produced a consensus direction of change of the projections, and thus produced seasonal trends that were more realistic, but exhibited a slightly smaller range due to the inclusion of several central tending projections. The 5-NN and 10-NN methods exhibited slightly wider range of variability than the quadrant method which was desirable from the "bounding" approach. In most cases the 5-NN and 10-NN projections were similar, although they differed at some locations in representation of season trend. The 10-NN approach (Figure A-24) was found to be preferable in that it best represented the seasonal trends of larger ensembles, retained much of the "range" of the smaller ensembles, and was guaranteed to include projections from at least two GCM-emission scenario combinations (in the CMIP3 projection archive, up to 5 projections – multiple simulations – could come from one GCM-emission scenario combination). The State and Federal representatives agreed to utilize the following climate scenario selection process for BDCP:

(1) the use of the original quadrant approach for Q5 (projections within the 25th to 75th percentile bounding box) as it provides the best estimate of the consensus of climate projections and
(2) the use of the 10-NN method to developing the Q1-Q4 bounding scenarios.

An automated process has been developed that generates the monthly and annual statistics for every grid cell within the Central Valley domain and identifies the members of the sub-ensemble for consideration in each of the five scenarios.

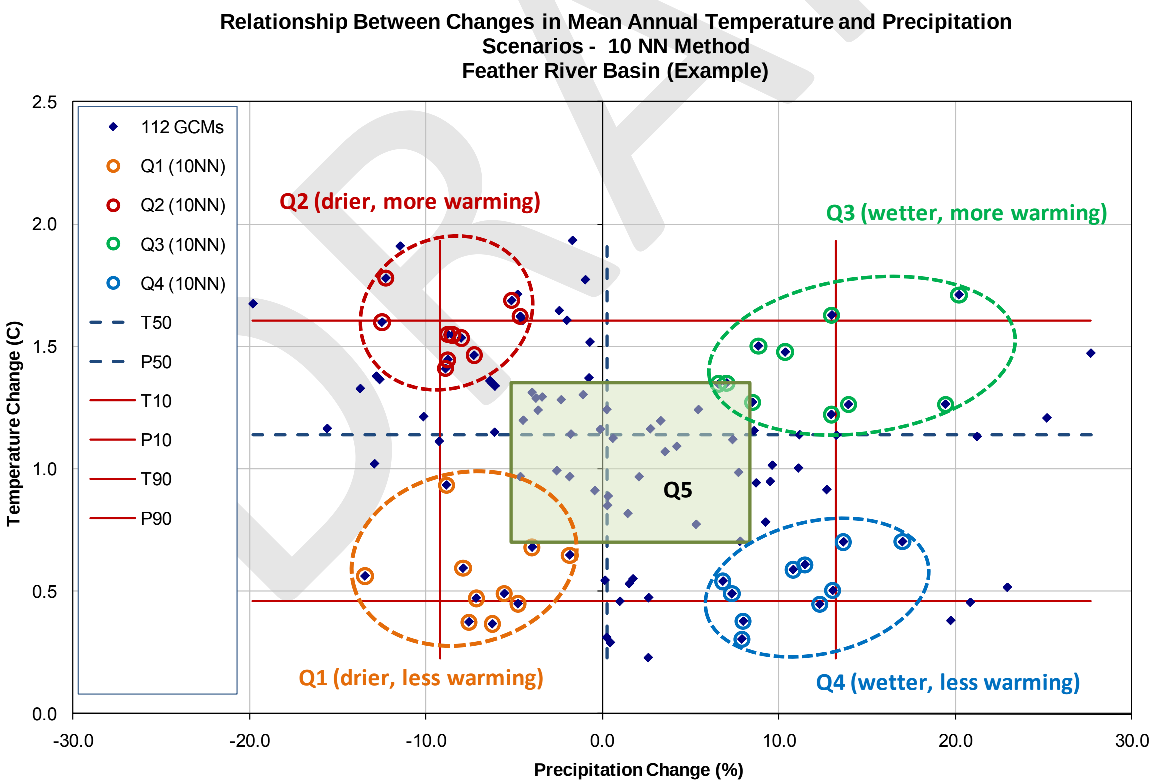


Figure A-24. Example downscaled climate projections and sub-ensembles used for deriving climate scenarios (Q1-Q5), Feather River Basin at 2025. The Q5 scenario is bounded by the 25th and 75th percentile joint temperature-precipitation change. Scenarios Q1-Q4 are selected to reflect the results of the 10 projections nearest each of 10th and 90th joint temperature-precipitation change bounds. Note: the temperature and precipitation changes are normalized before determining the nearest neighbors.

A.7.5. Incorporating Changes in Mean Climate and Climate Variability

Climate is usually defined as the "average" condition of weather over a period of time. More rigorously, climate can be defined as the "statistical description" in terms of mean and variability of the relevant quantities over a period of time ranging from months to millions of years (IPCC TAR). The standard averaging period defined by the World Meteorological Organization (WMO) is 30 years. The parameters that are most often associated with the description of climate state are temperature, precipitation, and wind speed. Thus, climate change refers to a shift in the statistical properties of climate variables over extended periods of time.

One difficulty that arises in implementing climate change into long-term water resources planning is that the natural variability is often greater than the magnitude of change expected over several decades. In many water resource management areas, it is the extreme events (droughts and floods) that drive the decision-making and long-range planning efforts. Thus, there is a need to combine the climate change signal with the range of natural variability observed in the historical record.

In many current climate change analyses, only the mean state of climate change is analyzed through the use of the "delta" method. In this method, temperature and/or precipitation are adjusted by the mean shift from one future 30-year period to a historical 30-year period. However, climate change is unlikely to manifest itself in a uniform change in values. In fact, the climate projections indicate that the changes are nonlinear and shifts in the probability distributions are likely, not just the mean values. In other analyses, a transient 30-year depiction of climate is used and compared against a similar 30-year historical period. Hydrologic analyses are performed and summarized as the "mean" change between the future and base periods. This latter approach is roughly what has been applied in the OCAP and CAT processes. The difficulty with this approach is that the natural observed variability may be large and not fully present in the 30-year period, resulting in truncated variability. Also, because the sequence of variability is different under each period it is difficult to make comparisons between the resulting hydrologic variables beyond the mean response.

In order to incorporate both the climate change signal and the natural variability in the longer-term observed record, the recommended approach is to create an expanded time series which allows use of the long-term observed records. The approach is similar to that applied by the Climate Impacts Group for development of hydrologic scenarios for water planning in the Pacific Northwest (Wood et al 2002, Salathe et al 2007, Hamlet et al 2009), applied in the Lower Colorado River, Texas studies (CH2M HILL 2008), and recent Reclamation planning (USBR, 2010). The approach uses a technique called "quantile mapping" which maps the statistical properties of climate variables from one data subset with the time series of events from a different subset. In this fashion, the approach allows the use of a shorter period to define the climate state, yet maintains the variability of the longer historic record. The quantile mapping approach involves the following steps:

1. Extract a 30-year slice of downscaled climate projections based on the ensemble subset for the quadrant of interest and centered on the year of investigation (i.e. 2025 or 2060)
2. For each calendar month (i.e. January) of the future period, determine the statistical properties (cumulative distribution function, CDF) of temperature and precipitation at each grid cell
3. For each calendar month of the historical period (1971-2000 in our case), determine the statistical properties (CDFs) of temperature and precipitation at each grid cell
4. Develop quantile maps between the historic observed CDFs and the future downscaled climate CDFs, such that the entire probability distribution (including means, variance, skew, etc) at the monthly scale is transformed to reflect the climate scenario
5. Using the quantile maps, redevelop a monthly time series of temperature and precipitation over the observed period (1915 -2003) that incorporates the climate shift of the future period
6. Convert monthly time series to a daily time series by scaling monthly values to daily sequence found in the observed record

The result of the quantile mapping approach is a daily time series of temperature and precipitation that has the range of variability observed in the historic record, but also contains the shift in climate properties (both mean and expanded variability) found in the downscaled climate projection. Figure A-25 provides an example of this process a grid cell in the Feather River watershed. As shown in this figure, the precipitation change quantities are not expected to shift uniformly across all percentiles. For example, in this wetting climate scenario, the median (50^{th} percentile) January precipitation is projected to exhibit almost no change from baseline conditions. However, for large precipitation events (i.e. the 90^{th} percentile) January precipitation is projected to increase by almost 2 mm/day (more than 2 inches/month). That is, the climate shift is larger at higher precipitation events and lower at low precipitation events. While this may be different for each climate scenario, future period, spatial location, and month, the need to map the full range of statistic climate shift is important to characterize the projected effects of climate change.

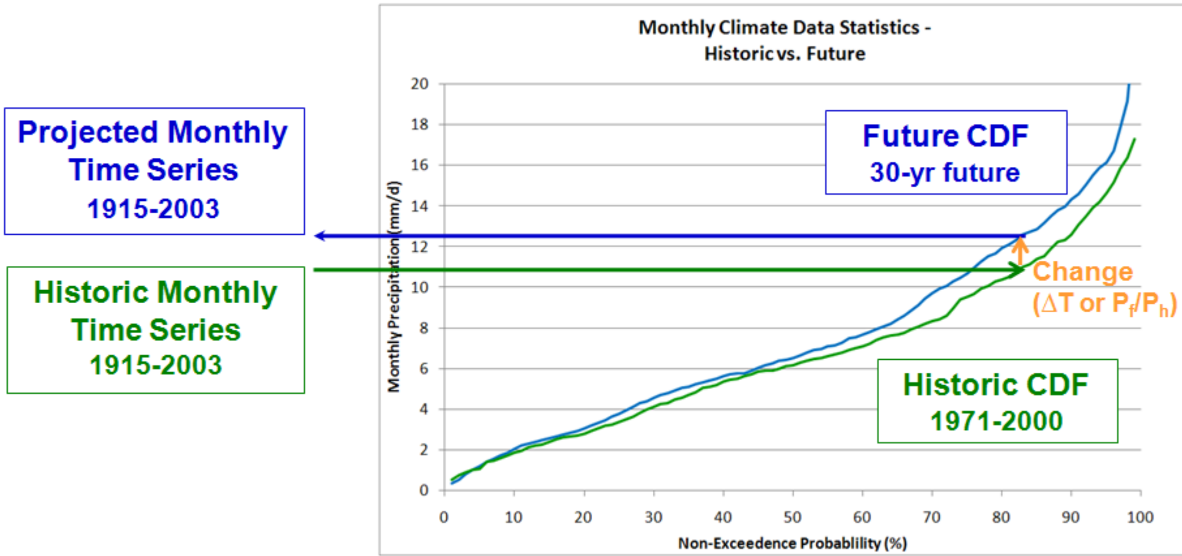


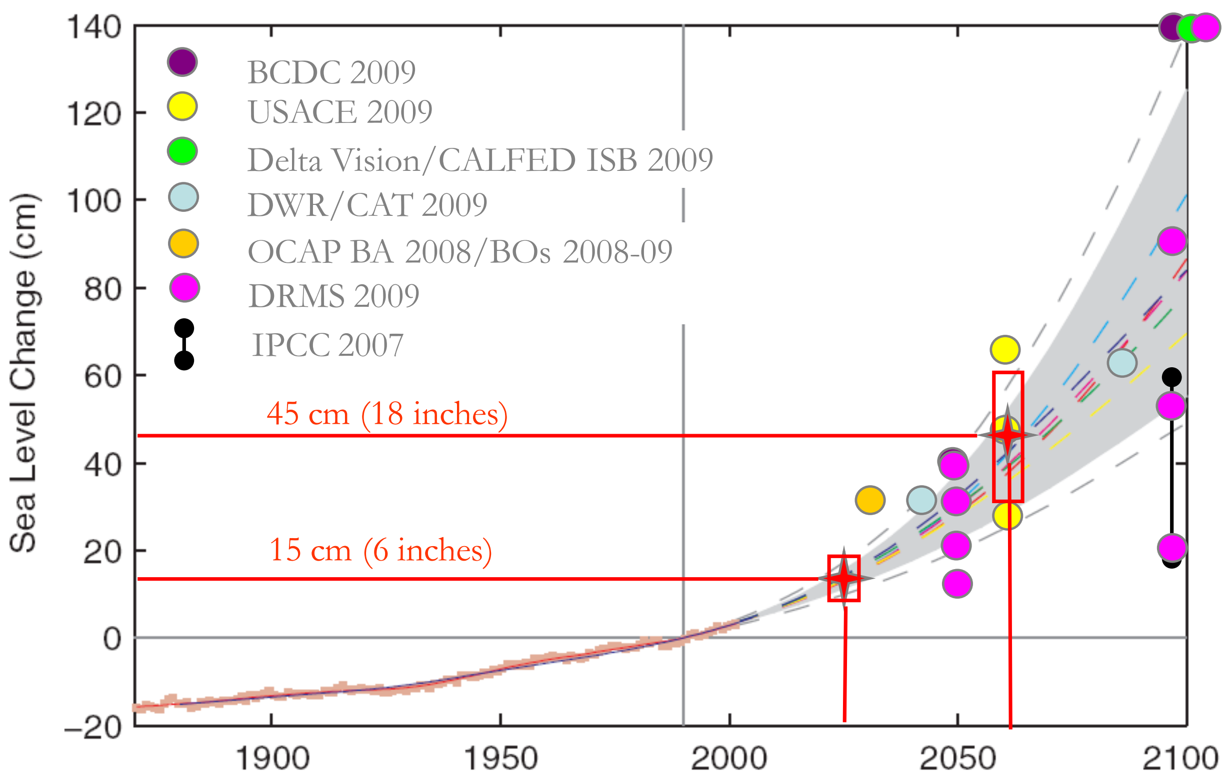
FIGURE A-25:
Historical Monthly Precipitation Statistics for a Grid Cell in Feather River Basin (January - EXAMPLE ONLY)

A.7.6. Sea Level Rise Scenarios

In early 2007, the IPCC released their latest assessment of the scientific assessment for projections of future climate. Included in the IPCC AR4 were revised estimates of global mean sea level rise. The IPCC estimates are based on physical models that attempt to account for thermal expansion of oceans and storage changes associated with melt of land-based ice and snowfields (Healy 2007). Since their release, the IPCC AR4 sea level rise estimates have been widely criticized for their failure to include dynamic instability in the ice sheets of Greenland and Antarctica, and for their under-prediction of recent observed increases in sea level.

Due to the limitations with the current state of physical models for assessing future sea level rise, several scientific groups, including the CALFED Independent Science Board (ISB) (Healy 2007), recommend the use of empirical models for short to medium term planning purposes. Both the CALFED ISB and CAT 2009 assessments have utilized the empirical approach developed by Ramsdorf (2007) that projects future sea level rise rates based on the degree of global warming. This method better reproduces historical sea levels and generally produces larger estimates of sea level rise than those indicated by the IPCC (2007). When evaluating all projections of global air temperature, Ramsdorf projects a mid-range sea level rise of 70 – 100 cm (28 – 40 inches) by the end of the century, and when factoring the full range of uncertainty the projected rise is 50 - 140 cm (20 – 55 inches). The CAT scenarios utilized an identical empirical approach, but limited the sea level rise estimates to the degree of warming range from 12 GCM projections selected for that study.

Using the work conducted by Ramsdorf, the projected sea level rise at the early long-term timeline for the BDCP analysis (2025) is approximately 12 - 18 cm (5 - 7 inches). At the late long-term timeline (2060), the projected sea level rise is approximately 30 – 60 cm (12 – 24 inches). These sea level rise estimates are also consistent with those outlined in the recent USACE guidance circular for incorporating sea-level changes in civil works programs (USACE 2009). Due to the considerable uncertainty in these projections and the state of sea level rise science, it is proposed to use the mid-range of the estimates for each BDCP timeline: 15 cm (6 inches) by 2025 and 45 cm (18 inches) by 2060. In addition, sensitivity scenarios will be prepared to consider sea level rise of up to 60 cm by 2060.



A.7.7. Changes in Tidal Amplitude

As discussed previously, mean sea level has been increasing across the globe and is exhibited on all U.S. coasts and almost all long-term stations. Tidal amplitude appears to be increasing, particulary in the eastern Pacific but the trend is not consistent for all stations on the West Coast. Tidal amplitude can be significantly affected by physical changes in coasts, harbors, bays, and estuaries. At long-term open-ocean stations along the California coast (La Jolla, Los Angeles, San Francisco, and Crescent City), which are less influenced by the physical changes, Flick et al. (2003) found a statistically significant increase in tidal amplitude (MHHW - MLLW), except at Crescent City which showed a slight decreasing trend. At San Francisco, the trend in tidal amplitude was found to be around 3-5% increase per century. Jay (2009) recently completed research into changes in tidal constituents, using long-term stations. Results indicated that on average tidal amplitude along the West Coast increased by about 2.2% per century. San Francisco indicated higher increases, while some stations (Alaska/Canada) were relatively constant. Jay hypothesized that global sea level rise may be influencing the location of the amphidrominc points (locations in the ocean where there are no tides) and thus affecting tidal range. However, Jay notes that it remains unclear whether rapid evolution of tidal amplitudes can be described as a symptom of global climate change.

Inland stations such Alameda and Port Chicago showed larger increases in tidal amplitudes than open ocean stations (9% and 26%, respectively). These inland stations have both short records and may be influenced by physical changes in the Bay. The importance of long-term tide records and open-ocean stations is stressed by both Flick et al and Jay for identifying trends in tidal amplitude due to the 18.6-year periodicity and influence of physical changes. Flick et al discounts the use of these inland stations for trends in tidal amplitude. In addition, Flick et al found that other nearby stations exhibited a decreased tidal amplitude trend (Point Reyes at -12% per century and Monterey at -14% per century).

Due to the considerable uncertainty associated with the tidal amplitude increase and the evolving science relating these changes to climate change and mean sea level rise, it is recommended to include a sensitivity analysis of increased tidal amplitude. The recommendation is to evaluate the effect of an amplitude increase of 5% per century, relying on the published observed trends of Flick et al and Jay and assuming that they would continue in the future. We do not propose using the inland stations trends, adhering to guidance from Flick et al. Thus, it is proposed to include one sensitivity simulation with the UNTRIM model, which incorporates an open-ocean tidal boundary, with increased tidal amplitude of 5% per century to contribute to understanding of the relative effect of amplitude increase in comparison to mean sea level increase.

A.7.8. Analytical Process for Incorporating Climate Change

The analytical process for incorporation of climate change effects in BDCP planning includes the use of several sequenced analytical tools (Figure A-2). The GCM downscaled climate projections (DCP), developed through the process described above, are used to create modified temperature and precipitation inputs for the Variable Infiltration Capacity (VIC) hydrology model. The VIC model simulates hydrologic processes on the 1/8th degree scale to produce watershed runoff (and other hydrologic variables) for the major rivers and streams in the Central Valley. The changes in reservoir inflows and downstream accretions/depletions are translated into modified input time series for the CALSIM II model. The CALSIM II simulates the response of the river-reservoir-conveyance system to the climate change derived hydrologic patterns. The CALSIM II model, in turn, provides monthly flows for all major inflow sources to the Delta, as well as the Delta exports, for input to the DSM2 hydrodynamic model. DSM2 also incorporates the assumptions of sea level rise for an integrated assessment of climate change effects on the estuary.

At each long-term BDCP analysis timeline (Early Long-Term: 2025 and Late Long-Term: 2060), five regional climate change projections are considered for the 30-year climatological period centered on the analysis year (i.e. 2011-2040 to represent 2025 timeline). DSM2 model simulations have been developed for each habitat condition and sea level rise scenario that is coincident with the BDCP timeline. New Artificial Neural Networks (ANNs) have been developed based on the flow-salinity response simulated by the DSM2 model. These sea level rise-habitat ANNs are subsequently included in CALSIM II models. The CALSIM II model has been simulated with each of the five climate change hydrologic conditions in addition to the historical hydrologic conditions.

The CALSIM II simulations have been developed for all alternatives and Future No Project/No Action Alternatives only for the mid-range climate change scenario (Q5).

A.8. Regional Hydrologic Modeling

Regional hydrologic modeling is necessary to understand the watershed-scale impacts of historical and projected climate patterns on the processes of rainfall, snowpack development and snowmelt, soil moisture depletion, evapotranspiration, and ultimately changes in streamflow patterns. Future projected climate change, downscaled from global climate models (GCMs), suggests substantial warming throughout California and changes in precipitation. The effect of these changes in critical to future water management. In most prior analyses of the water resources of the Central Valley, the assumptions of hydroclimatic “stationarity”, the concept that variability extends about relatively unchanging mean, have been made. Under the stationarity assumption, the observed streamflow record provides a reasonable estimate of the hydroclimatic variability. However, recent observations and future projections indicate that the climate will not be stationary, thus magnifying the need to understand the direct linkages between climate and watershed processes. Hydrologic models, especially those with strong, directly linkages to climate, enable these processes to be effectively characterized and provide estimates of changes in magnitude and timing of basin runoff with changes in climate conditions.

A.8.1. Variable Infiltration Capacity (VIC) Model

The VIC model (Liang et al. 1994; Liang et al. 1996; Nijssen et al. 1997) is a spatially distributed hydrologic model that solves the water balance at each model grid cell. The VIC model incorporates spatially distributed parameters describing topography, soils, land use, and vegetation classes. VIC is considered a macro-scale hydrologic model in that it is designed for larger basins with fairly coarse grids. In this manner, it accepts input meteorological data directly from global or national gridded databases or from GCM projections. To compensate for the coarseness of the discretization, VIC is unique in its incorporation of subgrid variability to describe variations in the land parameters as well as precipitation distribution. Parameterization within VIC is performed primarily through adjustments to parameters describing the rates of infiltration and baseflow as a function of soil properties, as well as the soil layers depths. When simulating in water balance mode, as done for this California application, VIC is driven by daily inputs of precipitation, maximum and minimum temperature, and windspeed. The model internally calculates additional meteorological forcings such short-wave and long-wave radiation, relative humidity, vapor pressure and vapor pressure deficits. Rainfall, snow, infiltration, evapotranspiration, runoff, soil moisture, and baseflow are computed over each grid cell on a daily basis for the entire period of simulation. An offline routing tool then processes the individual cell runoff and baseflow terms and routes the flow to develop streamflow at various locations in the watershed. Figure A-26 shows the hydrologic processes included in the VIC model.

The VIC model has been applied to many major basins in the United States, including large-scale applications to California’s Central Valley (Maurer et. al 2002; Brekke et al 2007; Cayan et al. 2009), Colorado River Basin (Christensen and Lettenmaier, 2009), Columbia River Basin (Hamlet et al 2010), and for several basins in Texas (Maurer et al 2003; CH2M HILL 2008). The VIC model application for California was obtained from Dan Cayan and Tapash Das at Scripps Institute of Oceanography (SIO) and is identical to that used in the recent Climate Action Team (2009) studies. The VIC model was simulated by CH2M HILL and comparisons were performed with SIO to ensure appropriate transfer of data sets. No refinements to the existing calibration was performed for the BDCP application.

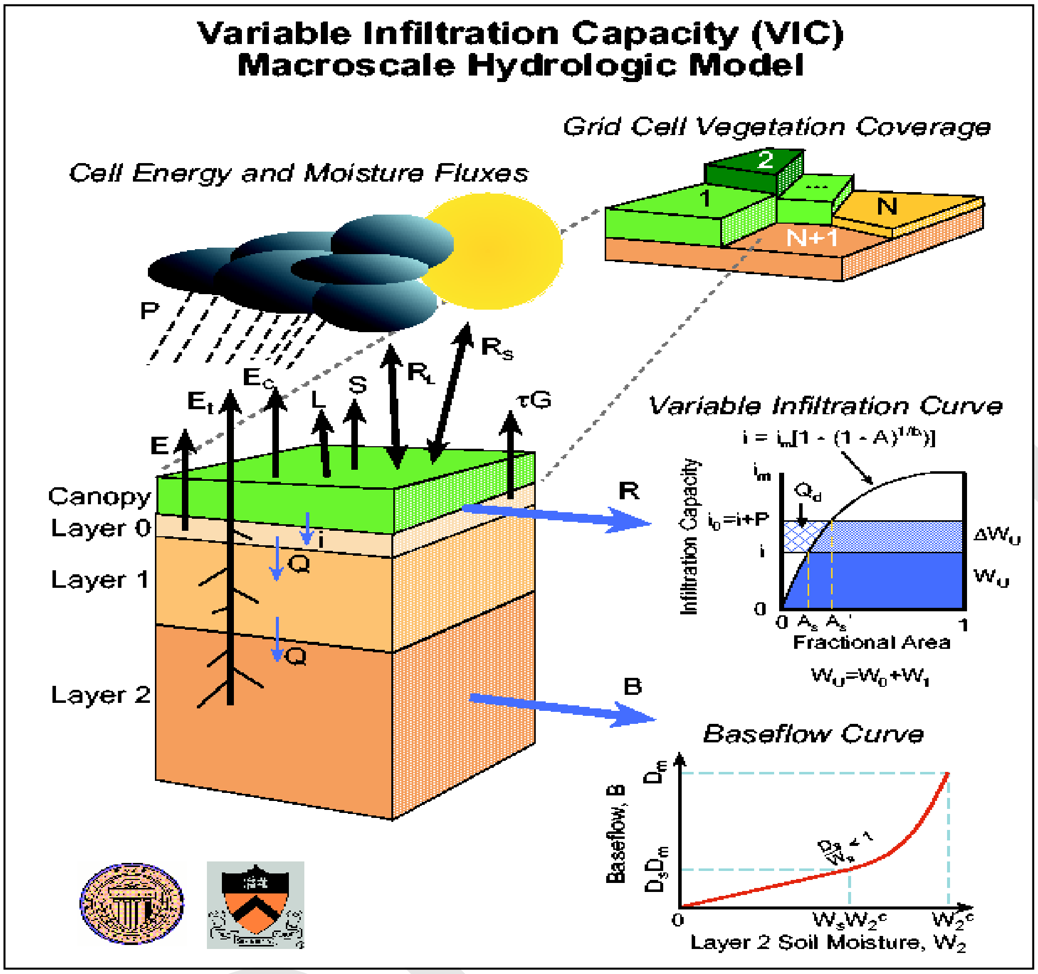


Figure A-26. Hydrologic Processes Included in the VIC Model (Source: University of Washington 2010)

A.8.2. Application of VIC Model for BDCP Evaluations

The regional hydrologic modeling is applied to support an assessment of changes in runoff associated with future projected changes in climate. These results are intended for use in comparative assessments and serve the primary purpose of adjusting inflow records in the CALSIM II long term operations model to reflect anticipated changes in climate. This section describes the regional hydrologic modeling methods used in the planning analysis for BDCP. The general flow of information is shown graphically in Figure A-2.

The GCM downscaled climate projections (DCP) are used to adjust historical California climate for the effects of climate change for each of the climate scenarios described in Section A.7. The resulting adjusted climate patterns, primarily temperature and precipitation fields are used as inputs to the VIC hydrology model. The VIC model is simulated for the each of the five climate scenarios at each BDCP long-term timeline. The VIC model simulations produce outputs of hydrologic parameters for each grid cell and daily and monthly streamflows at key locations in the Sacramento River and San Joaquin River watersheds. The changes in “natural” flow at these locations between the observed and climate scenarios are then applied to adjust historical inflows to the CALSIM II model.

Model Domain

The VIC application for California was originally developed by University of Washington (Wood et al, 2000), but has been subsequently refined by Ed Maurer and others (Maurer et al 2002). The model grid consists of approximately 3000 grid cells at a 1/8th degree latitude by longitude spatial resolution. The VIC model domain is shown in Figure A-27 and covers all major drainages in California.

Observed Meteorology

The VIC application for the BDCP is run in water balance mode with inputs consisting of daily precipitation, minimum temperature, maximum temperature, and windspeed. The model internally calculates additional meteorological forcings such short-wave and long-wave radiation, relative humidity, vapor pressure and vapor pressure deficits. Daily gridded observed meteorology was obtained from the University of Washington (Hamlet and Lettenmaier 2005) for the period of 1915-2003. This data set adjusts for station inhomeniety (station length, movement, temporal trends) and is comparable to a similar observed data set developed by Maurer et al (2002) for the 1950-99 overlapping period. The longer sequence of this observed meteorology data set allow for improved simulation techniques and integration with CALSIM II model with commensurate time coverage. In addition, this observed data set is currently being applied by Cayan et al (2010) for the recent study on Southwest drought and Hamlet et al (2010) in their study of climate change in the Pacific Northwest. To better understand the sensitivity of the VIC modeling to different observed meteorology, comparative simulations using both the Hamlet data set and the Maurer data set were performed. The resulting simulated streamflows were comparable between the two data sets with relatively minor differences in individual months and years.

Daily Meteorology for Future Climate Scenarios

Scenarios of future climate were developed through methods as described in Section A.7. These ensemble informed scenarios consist of daily time series and monthly distribution statistics of temperature and precipitation for each grid cell for the entire state of California. Historical daily time series of temperature and precipitation are converted to representative future daily series through the process of quantile mapping which applies the change in monthly statistics derived from the climate projection information onto the input time series. The result of this process (described in detail in Section A.7.) is a modified daily time series that spans the same time period as the observed meteorology (1915-2003). Daily precipitation and temperature are adjusted based on the derived monthly changes and scaled according to the daily patterns in the observed meteorology. Wind speed was not adjusted in these analyses as downscaling of this parameter was not available, nor well-translated from global climate models to local scales.

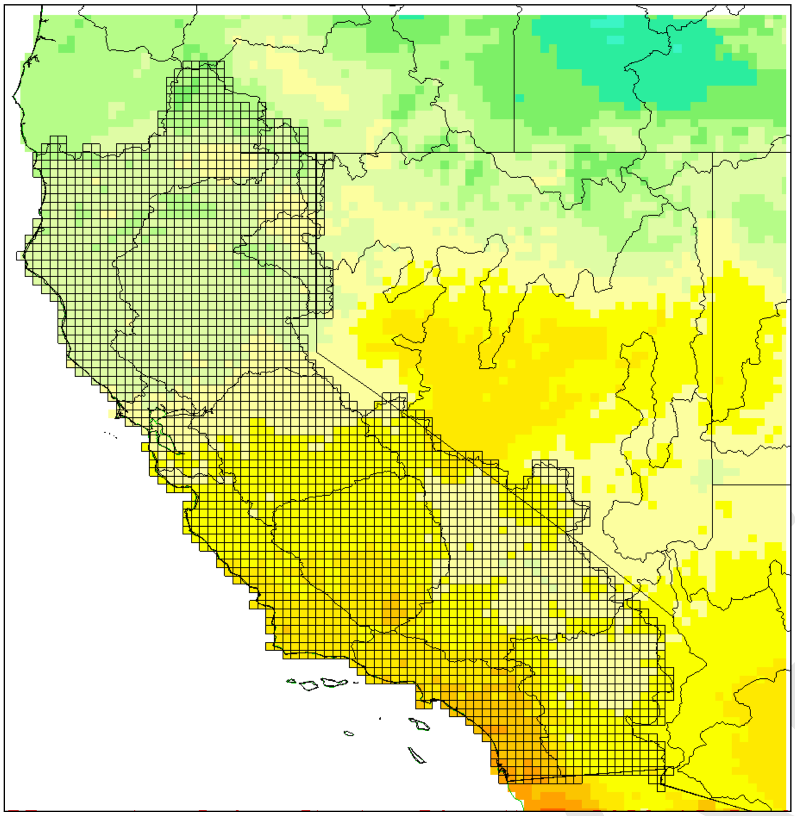


Figure A-27: VIC model domain and grid as applied for the BDCP application.

Grid Cell Characterization and Water Balance

As described previously, the VIC model was simulated in water balance mode. In this mode, a complete land surface water balance is computed for each grid cell on a daily basis for the entire model domain. Unique to the VIC model is its characterization of sub-grid variability. Sub-grid elevation bands enable more detailed characterization of snow-related processes. Five elevation bands are included for each grid cell. In addition, VIC also includes a sub-daily (1 hour) computation to resolve transients in the snow model. The soil column is represented by three soil zones extending from land surface in order to capture the vertical distribution of soil moisture. The VIC model represents multiple vegetation types as uses NASA's Land Data Assimilation System (LDAS) databases as the primary input data set.

For each grid cell, the VIC model computes the water balance over each grid cell on a daily basis for the entire period of simulation. For the simulations performed for the BDCP, water balance variables such as precipitation, evapotranspiration, runoff, baseflow, soil moisture, and snow water equivalent are included as output. In order to facilitate understanding of these watershed process results, nine locations throughout the in the watershed were selected for more detailed review. These locations are representative points within each of the following hydrologic basins: Upper Sacramento River, Feather River, Yuba River, American River, Stanislaus River, Tuolumne River, Merced River, and Upper San Joaquin River. The flow in these main rivers are included in the Eight River Index which is the broadest measure of total flow contributing to the Delta. A ninth location was selected to represent conditions within the Delta itself.

Routing of Streamflows

The runoff simulated from each grid cell is routed to various river flow locations using VIC's offline routing tool. The routing tool processes individual cell runoff and baseflow terms and routes the flow based on flow direction and flow accumulation inputs derived from digital elevation models (Figure A-28). For the simulations performed for the BDCP, streamflow was routed to 21 locations that generally align with long-term gauging stations throughout the watershed. For the VIC application for the BDCP, several additional streamflow routing locations were added to ensure that all major watersheds contributing to Delta inflow were considered. The primary additions were the smaller drainages in the upper Sacramento Valley consisting of Cottonwood Creek and Bear River and the Eastside streams consisting of Cosumnes, Mokelumne, and Calaveras Rivers. Table A-10 lists these 21 locations. The flow at these locations also allows for assessment of changes in various hydrologic indices used in water management in the Sacramento-San Joaquin Delta. Flows are output in both daily and monthly time steps. Only the monthly flows were used in subsequent analyses. It is important to note that VIC routed flows are considered "naturalized" in that they do not include effects of diversions, imports, storage, or other human management of the water resource.

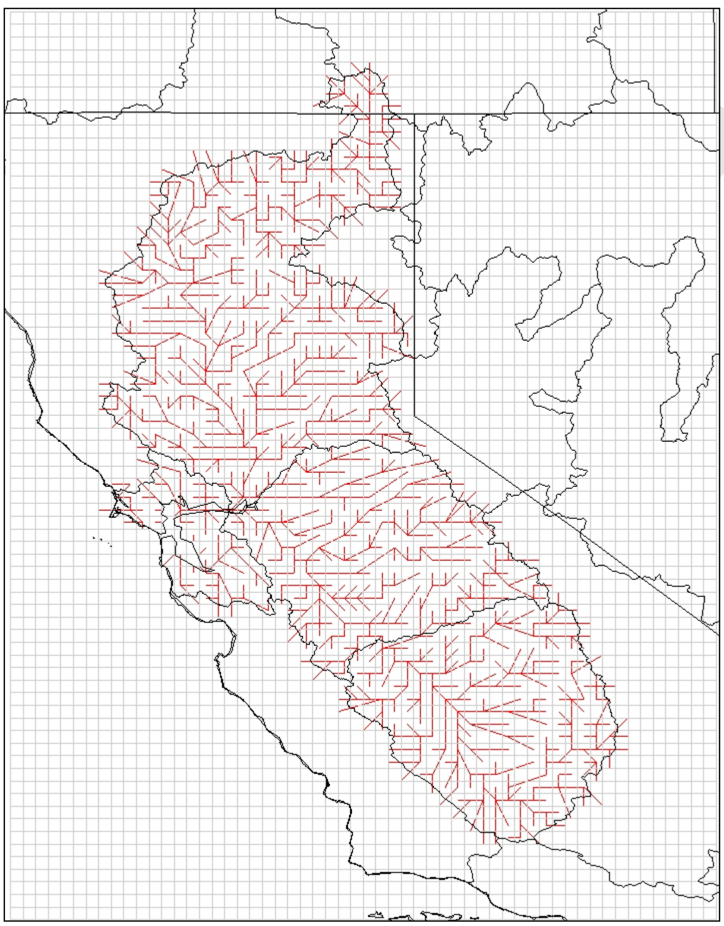


Figure A-28: VIC model routing network as applied for the BDCP application.

Table A-10: Listing of flow routing locations included in the VIC modeling.

Abbr	Name	Lat	Lon	VIC Lat	VIC Lon
SMITH	Smith River at Jed Smith SP	41.7917	-124.075	41.8125	-124.063
SACDL	Sacramento River at Delta	40.9397	-122.416	40.9375	-122.438
TRINI	Trinity River at Trinity Reservoir	40.801	-122.762	40.8125	-122.813
SHAST	Sacramento River at Shasta Dam	40.717	-122.417	40.6875	-122.438
SAC_B	Sacramento River at Bend Bridge	40.289	-122.186	40.3125	-122.188
OROVI	Feather River at Oroville	39.522	-121.547	39.5625	-121.438
SMART	Yuba River at Smartville	39.235	-121.273	39.1875	-121.313
NF_AM	North Fork American River at North Fork Dam	39.1883	-120.758	39.1875	-120.813
FOL_I	American River at Folsom Dam	38.683	-121.183	38.6875	-121.188
CONSU	Cosumnes River at Michigan Bar	38.5	-121.044	38.3125	-121.313
PRD_C	Mokelumne River at Pardee	38.313	-120.719	38.3125	-120.813
N_HOG	Calaveras River at New Hogan	38.155	-120.814	38.1875	-120.813
N_MEL	Stanislaus River at New Melones Dam	37.852	-120.637	37.9375	-120.563
MERPH	Merced River at Pohono Bridge	37.7167	-119.665	37.9375	-119.563
DPR_I	Tuolumne River at New Don Pedro	37.666	-120.441	37.6875	-120.438
LK_MC	Merced River at Lake McClure	37.522	-120.3	37.5625	-120.313
MILLE	San Joaquin River at Millerton Lake	36.984	-119.723	36.9375	-119.688
KINGS	Kings River - Pine Flat Dam	36.831	-119.335	37.1875	-119.438
COTTONWOOD	Cottonwood Creek near Cottonwood	40.387	-122.239		
CLEARCREEK	Clear Creek near Igo	40.513	-122.524		
BEARCREEK	Bear River near Wheatland	39.000	-121.407		

A.8.3. Output Parameters

As discussed previously the following key output parameters are produced on a daily and monthly time-step:

- Temperature, precipitation, runoff, baseflow, evapotranspiration, soil moisture, and snow water equivalent on grid-cell and watershed basis

- Routed streamflow at major flow locations to the Sacramento Valley and San Joaquin Valley

A.8.4. Critical Locations for Analysis

The watershed hydrologic process information can be characterized for each of the approximately 3,000 grid cells, but the nine locations described above provide a reasonable spatial coverage of the changes anticipated in Central Valley. The routed streamflows at all 21 locations identified in Table A-10 are necessary to adjust the inflow timeseries and hydrologic indices in the CALSIM II model. Analysis of flows for watersheds much smaller than what is included here should be treated with caution given the current spatial discretization of the VIC model domain. The streamflows included in this analysis and used to adjust hydrology in the CALSIM II model account for over 95% of the total natural inflow to the Delta.

A.8.5. Modeling Limitations

The regional hydrologic modeling described using the VIC model is primarily intended to generate changes in inflow magnitude and timing for use in subsequent CALSIM II modeling. While the model contains several sub-grid mechanisms, the coarse grid scale should be noted when considering results and analysis of local scale phenomenon. The VIC model is currently best applied for the regional scale hydrologic analyses. The model is only as good as its inputs. There are several limitations to long-term gridded meteorology related to spatial-temporal interpolation and bias correction that should be considered. In addition, the inputs to the model do not include any transient trends in the vegetation or water management that may affect streamflows; they should only be analyzed from a "naturalized" flow change standpoint. Finally, the VIC model includes three soil zones to capture the vertical movement of soil moisture, but does not explicitly include groundwater. The exclusion of deeper groundwater is not likely a limiting factor in the upper watersheds of the Sacramento and San Joaquin River watersheds that contribute approximately 80-90 percent of the runoff to the Delta, however, in the valley floor groundwater management and surface water regulation is considerable. Water management models such as CALSIM II should be utilized to characterize the heavily "managed" portions of the system.

A.8.6. Linkages to Other Physical Models

The VIC hydrology model requires input related to historic and future meteorological conditions. Long-term historical gridded datasets have been obtained to characterize past climate. Future estimates of meteorological forcings are derived from downscaled climate projections incorporating the effects of global warming. The changes in routed streamflows between historic and future VIC simulations are used to adjust inflows and hydrologic indices for use in the CALSIM II model.

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BDCP Chapter 4
Section 4.3

example, installation of sedimentation barriers and other stormwater protections during grading—in contrast to mitigation measures that would be necessary to be included as part of project approval to offset the environmental effects of the proposed action. The rationale behind including environmental commitments is that the BCDP proponents commit to undertake and implement these measures as part of the project in advance of impact findings and determinations in good faith to improve the quality and integrity of the project, streamline the environmental analysis, and demonstrate responsiveness and sensitivity to environmental quality. .Environmental commitments that are incorporated into the alternatives are detailed in Appendix 3B.

4.3 Overview of Tools, Analytical Methods, and Applications

Several modeling tools and analytical methods were used to characterize and analyze the operational changes in water operations in the SWP and CVP systems under each alternative. These tools represent the best available technical tools for purposes of conducting the analyses at issue. The overall flow of information between the models and the general application and use of outputs for the resource evaluations are shown in Figure 4-1. Table 4-1 provides a description of the various modeling tools and an overview of how they may be applied for the environmental consequences analyses.

The models were used to compare and contrast the effects among various operating scenarios. The models incorporated a set of base assumptions; the assumptions were then modified to reflect the operations associated with each of the alternatives. The output of the models is used to show the comparative difference in the conditions among the different alternative scenarios. The model output does not predict absolute conditions in the future; rather, the output is intended to show what type of changes would occur. This type of model is described as comparative rather than predictive. Because of the comparative nature of these models, these results are best interpreted using various statistical measures such as long-term and year-type averages and probability of exceedance.

In general, CALSIM II is used to simulate the operations of the SWP and CVP. The output of this model is then used by the DSM2 model to simulate the hydrodynamics, water quality, and particle tracking. With the information generated from these models, the water supply, flows, and water quality can be compared under different operating scenarios. The output from these models are then used by a variety of other models to support the comparative analysis of various other resources, such as land use, economics, energy, temperature, and other water quality characteristics. Additional detailed discussions of the modeling tools and assumptions are provided in Appendix 4B, *Modeling Tools* .

[*Note to Lead Agencies: Table 4-1 in preparation*]

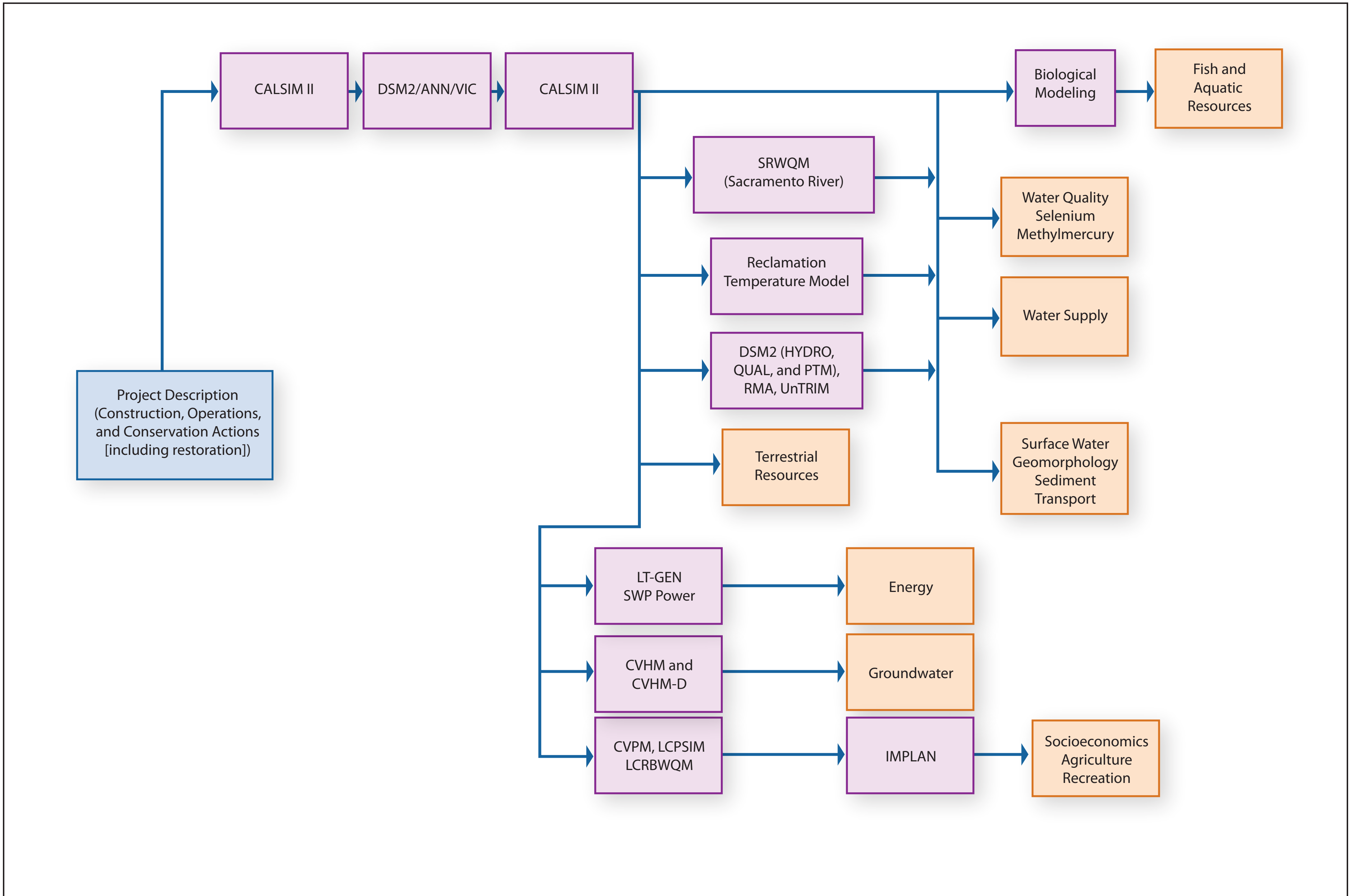
Table 4-1. Overview of BDCP EIR/EIS Modeling Tools

Model Name	Description of Model
Artificial Neural Network (ANN)	ANN mimics the flow-salinity relationships as modeled in DSM2, and provides a rapid transformation of this information into a form usable by the Statewide CALSIM II model. ANN is implemented in CALSIM II to inform the operations of the upstream reservoirs and the Delta export pumps to satisfy particular salinity requirements.
CALSIM II	CALSIM II simulates operations of the SWP, CVP, and other facilities in the Central Valley and approximates changes in river flows and exports from the Delta. The principal results of interest for this phase of evaluation are changes to: (1) Sacramento River flows, (2) exports and south Delta flows, and (3) reservoir storage conditions associated with the assumed operation of the BDCP simulated scenarios.
Central Valley Hydrologic Model (CVHM)	CVHM is a three-dimensional numerical groundwater flow model that simulates subsurface and limited surface hydrologic processes over the entire Central Valley at a uniform grid-cell spacing of 1 mile.
Central Valley Hydrologic Model - Delta (CVHM-D)	CVHM-D simulates hydrologic processes in the Delta region at a more refined grid-cell spacing of 0.25 mile (compared to the grid-cell spacing of 1 mile with CVHM).
Central Valley Production Model (CVPM)	CVPM is a multi-regional model of irrigated agricultural production and economics that simulates the decisions of agricultural producers in California's Central Valley. The model includes up to 22 crop production regions in the Central Valley and 26 categories of crops. Surface water supplies are estimated by hydrologic models and groundwater use and pumping lift are estimated iteratively with a groundwater simulation model. CVPM model versions consider responses under average hydrologic conditions and responses during drought. The model maximizes the producer and consumer surplus to determine an optimal market solution. Output from CALSIM II surface water and groundwater models provide key modeling inputs to the CVPM agricultural production model.
Delta Simulation Model II (DSM2)	DSM2 is a one-dimensional hydrodynamic and water quality simulation model used to simulate hydrodynamics, water quality, and particle tracking. It describes the existing conditions in the Delta, as well as performs simulations for the assessment of incremental environmental impacts caused by facilities and operations. DSM2 uses flow data generated from CALSIM II outputs. DSM2 is simulated on a 15-minute time step to address the changing tidal dynamics of the Delta system.
IMPLAN	IMPLAN develops input-output estimates of the economic impacts of various activities. For water resources planning, IMPLAN estimates the income and employment effects upon local communities from water project construction and the regional effects of water transfers. Key modeling inputs for IMPLAN include output from the recreation economics analysis, CVPM, LCPSIM, and LCRBWQM.
Least Cost Planning SIMulation (LCPSIM)	LCPSIM is a simulation/optimization model that assesses the economic benefits and costs of increasing urban water service reliability at the regional level. The primary objective of LCPSIM is to develop a regional water management plan based on the principle of least-cost planning.

Model Name	Description of Model
Lower Colorado River Basin Water Quality Model (LCRBWQM)	LCRBWQM covers nearly the entire urban coastal region of southern California and assesses the regional economic effects of water salinity within the SWP system and Colorado River Aqueduct. The LCRBWQM salinity model assesses the average annual regional salinity benefits or costs based on demographic data; water deliveries; TDS concentration; and costs for typical household, agricultural, industrial, and commercial water uses. LCRBWQM uses mathematical functions that define the relationship between TDS and items in each affected category, such as the useful life of appliances, specific crop yields, and costs to industrial and commercial customers. The key model inputs into LCRBWQM are CALSIM II and DSM2 estimates of SWP East and West Branch deliveries and the concentration of TDS in these deliveries.
Reclamation Long Term-GEN (LT_GEN)	LT-GEN is a CVP power model that estimates the CVP power generation, capacity, and project use based on the operations defined by a CALSIM II simulation. The LT-GEN Model computes monthly power generation, capacity, and project use (pumping plant demand) for each CVP power facility for each month of the CALSIM II simulation.
Particle Tracking Model (PTM) (DSM2)	DSM2 PTM generates a weighted average entrainment risk of smelt from stations throughout the Delta based on an assumed starting distribution of smelt within the Delta and PTM results. This weighting is performed through post-processing of the PTM results to represent the proportion of fish that would occur in different parts of the Delta or starting distributions. The analysis focuses on the total proportion or percent of the population that would move to the different endpoints after 30 or 60 days under a project relative to existing conditions.
Reclamation Monthly Temperature Model - Sacramento River Basin (Reclamation Temperature)	This model predicts the effects of operations on water temperatures in the Sacramento, Feather, Stanislaus, and American river basins and upstream reservoirs. The model simulates monthly reservoir and stream temperatures used for evaluating the effects of SWP and CVP operations on mean monthly water temperatures in the basin based on hydrologic and climatic input data. The model uses CALSIM II output to simulate mean monthly vertical temperature profiles and release temperatures for five major reservoirs (Trinity, Whiskeytown, Shasta, Oroville, Folsom, and New Melones), four downstream regulating reservoirs (Lewiston, Keswick, , Natoma, and Goodwin), and four main river systems (Sacramento, Feather, American, and Stanislaus).
RMA	RMA2 is a surface hydrodynamic model that computes two-dimensional depth-averaged velocity and water surface elevation. RMA11 is a two-dimensional depth-averaged water quality model that computes a temporal and spatial description of conservative and non-conservative water quality parameters. RMA11 uses the results from RMA2 to describe the flow field. The model uses a depth-averaged approximation in the western Delta and Suisun Bay where substantial vertical gradients in salinity are often present. The model uses CALSIM outputs as inputs and produces results at a 15-minute time step.
State Water Project Power Model (SWP POWER)	SWP Power is an SWP power model that estimates the SWP power generation, capacity, and project use based on the operations defined by a CALSIM II simulation. The SWP Power Model computes monthly power generation, capacity, and project use (pumping plant demand) for each SWP power facility for each month of the CALSIM II simulation.
UnTRIM San Francisco Bay Delta Model (UnTRIM)	UnTRIM assesses the effects of sea level rise on Bay-Delta hydrodynamics and water quality. UnTRIM is a three-dimensional hydrodynamic model of the San Francisco Bay and Delta. Model outputs from UnTRIM are used to retrain ANN models with climate change and are corroborated with CALSIM II and DSM2.

Model Name	Description of Model
Upper Sacramento River Water Quality Model (SRWQM)	SRWQM predicts the effects of operations to water temperature in the Sacramento River and Shasta and Keswick reservoirs. The model is a daily time step and provides water temperatures for each day of the 82-year hydrologic period used in CALSIM II.
Variable Infiltration Capacity (VIC)	VIC is a spatially distributed hydrologic model that solves water balance. Changes in routed stream flows from VIC simulations adjust inflows to the CALSIM II model. VIC incorporates spatially distributed parameters describing topography, soils, land use, and vegetation classes. The VIC model is driven by daily inputs of precipitation, maximum and minimum temperature, and wind speed.
CCHE2D	CCHE2D model is a two-dimensional depth-averaged, unsteady, flow and sediment transport model. The flow model is based on depth-averaged Navier-Stokes equations. The sediment transport module is used to simulate non-uniform sediment (both non-cohesive and cohesive) using non-equilibrium transport models.
Land Evaluation Site Assessment Model (LESA)	In the LESA system, the land evaluation rating is combined with the site assessment rating to determine the total rating of a specific site. The higher the total value of a site, the more likely the site is suited for long term agricultural production.
Other Municipal Water Economics Model (OMWEM)	
Statewide Agricultural Production Model (SWAP)	SWAP is an optimization model for major crops and agricultural regions in California and uses Positive Mathematical Programming (or PMP). SWAP has been used to estimate economic losses due to salinity in the Central Valley and economic losses to agriculture in the San Joaquin Delta
Bay Area Water Quality Economics Model (BAWQEM)	
OFFROAD2007	The OFFROAD Model estimates the relative contribution of gasoline, diesel, compressed natural gas, and liquefied petroleum gas powered vehicles to the overall emissions inventory of the state.
Emissions & Generation Resource Integrated Database (eGRID)	The eGRID is a comprehensive source of data on the environmental characteristics of almost all electric power generated in the United States. These environmental characteristics include air emissions for nitrogen oxides, sulfur dioxide, carbon dioxide, methane, and nitrous oxide; emissions rates; net generation; resource mix; and many other attributes.
URBan EMISsions (URBEMIS 2007)	URBEMIS 2007 estimates air pollution emissions from a wide variety of land use projects. The model uses the California Air Resources Board's EMFAC2007 model for on-road vehicle emissions and the OFFROAD2007 model for off-road vehicle emissions.
EMission FACtors (EMFAC 2007)	The EMFAC model is used to calculate emission rates from all motor vehicles, such as passenger cars to heavy-duty trucks, operating on highways, freeways and local roads in California
AERMOD Modeling System	A steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain.

BDCP Figure 4-1



SOURCE: HDR 2010

DRAFT

Note: this figure will be updated for the public draft.

Figure 4-1
Use of Modeling Tools and Results in Analysis of BDCP Alternatives

BDCP Table 1

Table 1. Model Utilization in BDCP Effects Analysis

Model	Description	Applicable Effects Analysis Appendix								
		A	B	C	D	E	F	G	H	I
Conceptual Models	Conceptual models organize factors and relationships to explain phenomena. They are a starting point for development of quantitative models and stand on their own as a way to structure discussion and analyses.	X	X	X	X	X	X	X	X	
CALSIM II	The CALSIM II planning model simulates the operation of the CVP and SWP over a range of hydrologic conditions. CALSIM II produces key outputs that include river flows and diversions, reservoir storage, Delta flows and exports, Delta inflow and outflow, deliveries to project and non-project users, and controls on project operations.		X	X	X	X	X	X		
DSM 2	DSM2 is a one-dimensional hydrodynamic and water quality simulation model used to simulate hydrodynamics, water quality, and particle tracking in the Sacramento-San Joaquin Delta. The DSM2 model has three separate components, or modules: HYDRO, QUAL, and PTM.		X	X	X		X			
DSM 2 Hydro	DSM2-HYDRO predicts changes in flow rates and depths as a result of the BDCP and climate change. Outputs are used to determine the effects of these hydrodynamic parameters on covered terrestrial and fish species and as inputs to other biological models.			X	X					
DSM 2 Qual	The DSM-QUAL module simulates fate and transport of conservative and non-conservative water quality constituents, including salts, given a flow field simulated by HYDRO. Outputs are used to estimate changes in salinity and their effects on covered species as a result of the BDCP and climate change.			X			X			
DSM 2 PTM	The DSM-PTM module simulates fate and transport of neutrally buoyant particles through space and time. Outputs are used to estimate the effect of hydrodynamic changes on the fate and transport of larval fish and toxics through the Delta, as well as entrainment of larval fish at various locations.		X	X	X		X			
RMA	The RMA model output is used to evaluate the effects of tidal habitat restoration on flows throughout the Delta and the subsequent effects on covered species, aquatic and terrestrial. It is also used to calibrate CALSIM II and DSM 2.						X		X	
SRWQM	Output from the Sacramento River Water Quality Model is used as an input to a number of biological models for upstream lifestages of salmonids and sturgeon.			X	X					

Key to Appendices:

A: Conceptual Foundation and Analytical Framework	B: Entrainment	C: Flow, Salinity, Passage and Turbidity	D: Toxics	E: Habitat Restoration
F: Ecological	G: Fish Population	H: Terrestrial	I: Analyses Not Used	

Model	Description	Applicable Effects Analysis Appendix								
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
USBR Temp Model	The USBR Temp Model is used to predict the effects of operations on water temperatures in the Feather, Stanislaus, Trinity, and American river basins, which are then used as inputs to the Reclamation Salmon Mortality Model and species-specific habitat evaluations.			X	X		X			
MIKE-21	Outputs of MIKE-21 are used to predict the area of inundated habitat in the Yolo Bypass for species such as splittail and Chinook salmon			X						
DRERIP	The Delta Regional Ecosystem Restoration Implementation Plan conceptual models and scientific evaluation process were developed to aid in planning and decision making for potential ecosystem restoration actions in the Delta. The 2009 DRERIP assessment of BDCP provided qualitative rankings for the effects on covered fish species from the conservation measures proposed at that time.	X	X	X	X	X	X			
Striped Bass Bioenergetics Model	The bioenergetics model is used to estimate predation rates of striped bass on covered fish species at the proposed North Delta diversion intakes. Results of the model are also used as inputs to the Delta Passage Model and Interactive Object-Oriented Salmon Simulation (IOS) Model.			X			X			
Delta Passage Model (DPM)	The Delta Passage Model is used to predict relative reach-specific survival estimates for winter, spring, and fall-run juvenile Chinook salmon passing through the Delta, as well as estimates of salvage in the south Delta export facilities.		X	X						
IOS	The Interactive Object-Oriented Salmon Simulation model is used to evaluate the effects of multiple aspects of the BDCP on survival of winter-run Chinook salmon and population viability.							X		
OBAN	Complementary to IOS, the Oncorhynchus Bayesian Analysis (OBAN) model is used to predict the effects of multiple BDCP actions on winter-run and spring-run Chinook salmon survival and population dynamics and population viability.			X				X		
SacEFT	The Sacramento River Ecological Flows Tool (SacEFT) is used to predict the effects of flow changes in the Sacramento River on a set of physical (spawning area, juvenile rearing area, redd scour, and redd dewatering) and biological (egg survival, juvenile stranding, and juvenile growth) parameters for all races of Chinook salmon and steelhead. The model also predicts flow-based effects on green sturgeon egg survival.			X	X					

Key to Appendices:

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Model	Description	Applicable Effects Analysis Appendix								
		A	B	C	D	E	F	G	H	I
SALMOD	SALMOD is used to predict the effects of flows in the Sacramento River on habitat quality and quantity and ultimately on juvenile production of all races of Chinook salmon.			X						
USBR Salmon Mortality Model	This model is used to predict temperature-related proportional losses of eggs and fry for each race of Chinook salmon in the Trinity, Sacramento, Feather, American, and Stanislaus rivers.			X						
Fall X2 Model	Calculates surface area of water at 2 ppt salinity as related to the position of X2 during the fall (September-December).			X						
Covered Wildlife and Plant Species Habitat Models	Habitat models were developed for each of the covered wildlife and plant species based on vegetation/land cover associations that support each species' habitat type modified by parameters such as soil type, elevation, topography, spatial distribution, and proximity to aquatic habitats, as relevant.								X	
Salvage-Density Method	Uses historical salvage and flow data to predict entrainment		X							
Old and Middle River Flow Proportional Entrainment Regressions (delta smelt)	Uses linear regression (based on estimates from Kimmerer [2008], as well as estimates adjusted based on the rationale provided by Miller [2011]) and CALSIM data to estimate the proportion of delta smelt population that would be entrained		X							
Manly (2011) Salvage Estimation Equation (delta smelt)	Uses multiple regression to estimate salvage of adult delta smelt as a function of OMR flows, turbidity, and population size		X							
Effectiveness of Nonphysical Barriers	Discusses results of recent studies at Georgiana Slough and Old River as well as literature studies to determine potential effectiveness of barriers in other Delta locations		X	X						
Screening Effectiveness Analysis (North Delta Intake)	Estimate of potential for screening based on different sizes of fish approaching the north Delta intakes		X							

Key to Appendices:

A: Conceptual Foundation and Analytical Framework	B: Entrainment	C: Flow, Salinity, Passage and Turbidity	D: Toxics	E: Habitat Restoration
F: Ecological	G: Fish Population	H: Terrestrial	I: Analyses Not Used	

Model	Description	Applicable Effects Analysis Appendix								
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Origin-of-flow analyses	Estimates the number of adult anadromous fish ending up at Fremont Weir.			X						
Fry-rearing benefit for Yolo Bypass	Quantifies fry benefits			X						
Habitat Suitability Indices	Quantifies the value of habitat for a particular covered species. Variables used depend on the species and available data.					X			X	
Maunder-Deriso delta smelt life cycle model	A state-space multi-stage lifecycle model that evaluates population impacts on delta smelt by allowing density dependence and environmental factors to impact different life stages.							X		
Kimmerer et al. X2-abundance Regression (longfin smelt)	Regression relationships using X2 to estimate annual abundance indices of longfin smelt in fall midwater trawls, bay midwater trawls, and bay otter trawls.			X						
Glibert Foodweb Regression	Regressions that estimate relative change in abundance of total chlorophyll, diatoms and dinoflagellates, and several copepod and fish species based on changes in individual nutrients and nutrient ratios, the latter having been derived from DSM2-QUAL modeling.									X
Copper Loading	Uses DSM 2 and the calculated total load of the contaminant within each watershed to estimate the diluted concentration of contaminant in the Plan Area.									X
Pyrethroid/EDC Loading	Uses DSM 2 and the calculated total load of the contaminant within each watershed to estimate the diluted concentration of contaminant in the Plan Area.									X
Selenium Loading	Uses DSM 2 and the calculated total load of the contaminant within each watershed to estimate the diluted concentration of contaminant in the Plan Area.									X
Mercury/Methylmercury Loading	Uses DSM 2 and the calculated total load of the contaminant within each watershed to estimate the diluted concentration of contaminant in the Plan Area.									X
Ammonia Loading	Uses DSM 2 and the calculated total load of the contaminant within each watershed to estimate the diluted concentration of contaminant in the Plan Area.									X
	Total Models	**2**	**12**	**22**	**10**	**5**	**10**	**6**	**5**	**6**

Key to Appendices:

A: Conceptual Foundation and Analytical Framework	B: Entrainment	C: Flow, Salinity, Passage and Turbidity	D: Toxics	E: Habitat Restoration
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Estimating California Central Valley Unimpaired Flows

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Modeling Support Branch
Bay-Delta Office
Department of Water Resources

January 6, 2011

Outline

- Key Points
- Definition of Unimpaired Flow (UF)
- Assumptions
- History
- Geographic Extent
- Data Sources for Estimating UF
- Sample Estimation Procedure
- Summary of Estimated UFs
- Limitations
- Closing

2

Key Points

- The unimpaired flows (UF) can be significantly different from the natural flows.
- UF is a conceptual quantity estimated through various means.
- UF is an imprecise estimate, and will require further improvement before being used as an operational flow criterion. This improvement can be made with careful design, time, and expert effort.
- Implementing the proposed flow criteria in real time operations will require timely acquisition of field data needed to estimate the UF.
- Timely acquisition of field data, and, under certain circumstances, forecasting certain components of the UF will pose extra challenges to the project operations.

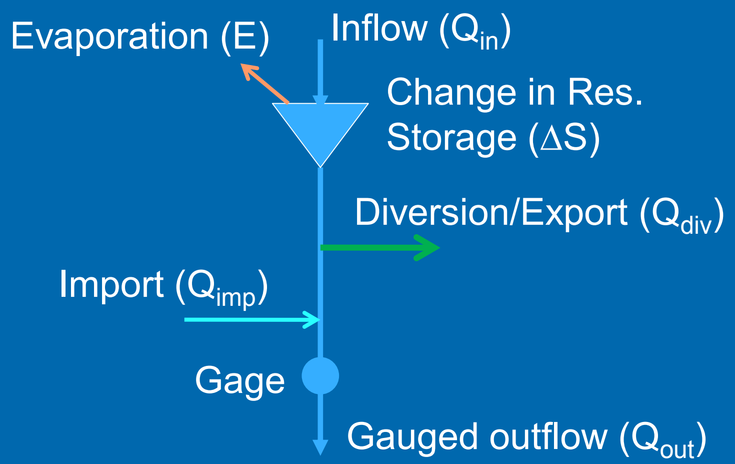
Definition of UF

- The following terms are (have been) used by DWR for UF
  - Full natural flow
  - Natural flow
  - Natural runoff
  - Unimpaired flow
  - Unimpaired runoff
- However, revised Bay-Delta Office Reports make distinctions between "Natural flow" and "Unimpaired flow"
  - Natural flow is a theoretical flow in pre-development or virgin state.
  - UF is an estimated flow for natural flow, not natural flow. The estimation assumes:
    - the existence of the current river configuration.
    - the same groundwater accretion and depletion as in historical condition.

Definition of UF (cont.)

- California Data Exchange Center (CDEC) Definition
  - "Full Natural Flow" or "Unimpaired Runoff" represents the natural water production of a river basin, unaltered by upstream diversions, storage, or by export or import of water to or from other watersheds.
- State Water Resources Control Board
  - Unimpaired flow is the total volume of water that would flow past a particular point of interest if no diversions (impairments) were taking place in the watershed above that point (taken from annual and seasonal unimpaired flow definitions).

Conceptual UF Estimation Procedure



$$UF = Q_{out} - Q_{imp} + Q_{div} + \Delta S + E$$

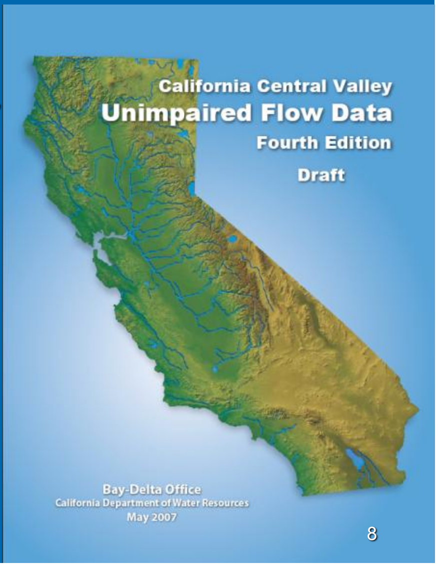
Assumptions

- Observed (gage) data is reliable.
- Change in stream groundwater interaction due to flow regulation is not included.
- Change in surface retention of precipitation (such as swamps) due to land use development is not included.
- Change in flow due to change in channel reconfiguration is not included.
- Water flow from upstream to downstream of the Sacramento and San Joaquin valleys are instantaneous (no routing).

7

History of UF Development

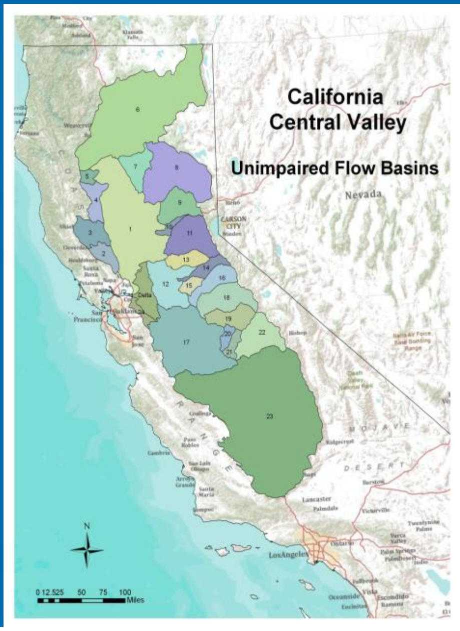
- First Edition (DWR, Apr 1980): California Central Valley Natural Flow Data
- Second Edition (DWR, Division of Planning, Feb 1987): California Central Valley Unimpaired Flow Data
  - (WY 1921 – 1983)
- Third Edition (DWR, Division of Planning, Aug 1994):
  - (Data extended to 1992)
- Fourth Edition (DWR, Bay-Delta Office, May 2007):
  - Same methodologies as those used in previous reports
  - (Data extended to 2003)



8

Geographic Extent

- Unimpaired flows are estimated for 24 river basins that are tributary to the Sacramento Valley, Eastside Streams, and San Joaquin Valley.



9

Data Sources

- USGS gages adjusted for upstream reservoir operations
- Proportionality between UF of unknown basin using UF of known basin in terms of area or precipitation
- Regression analysis (correlation between nearby watersheds)
- Depletion studies

10

Example : San Joaquin River at Millerton Reservoir (UF 22)

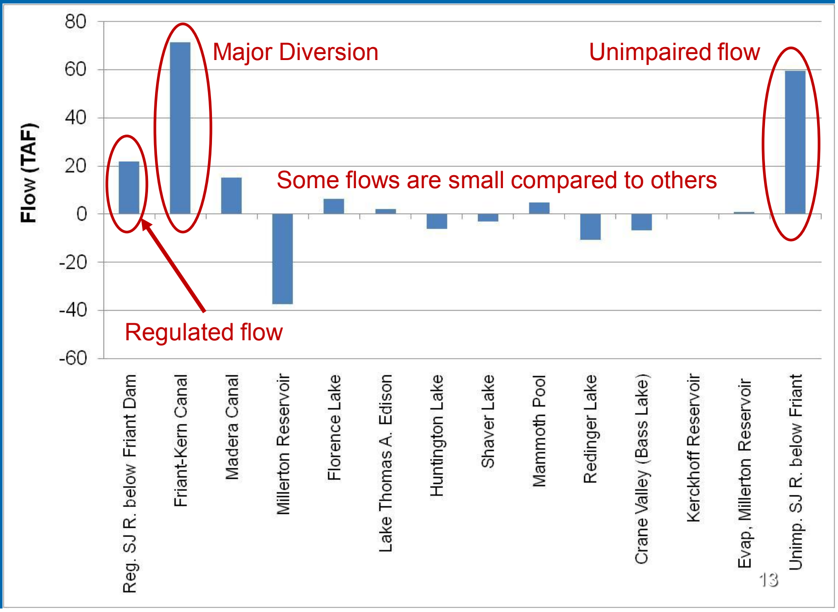
Example (cont.)

Example: San Joaquin River at Millerton Reservoir

Flow category	Adjustment	Flow description	Source
Observed flow	+	San Joaquin River below Friant Dam	USGS gage
Diversion	+	Friant-Kern Canal	MI2
	+	Madera Canal	MI1
Storage gain	+	Millerton Lake	MIL (RECL.)
	+	Florence Lake	FLR
	+	Lake Thomas A. Edison	TAE
	+	Huntington Lake	HNT
	+	Shaver Lake	SHV
	+	Mammoth Pool	MPL
	+	Redinger Lake	RDN
	+	Crane Valley (Bass Lake)	CNV
	+	Kerckhoff Reservoir	KRH
Evaporation	+	Millerton Lake	MIL (RECL.)
Unimpaired flow	Sum	San Joaquin River below Friant Dam	SJF

Example (cont.)

Example: San Joaquin River at Millerton Reservoir (October 2010 Data)



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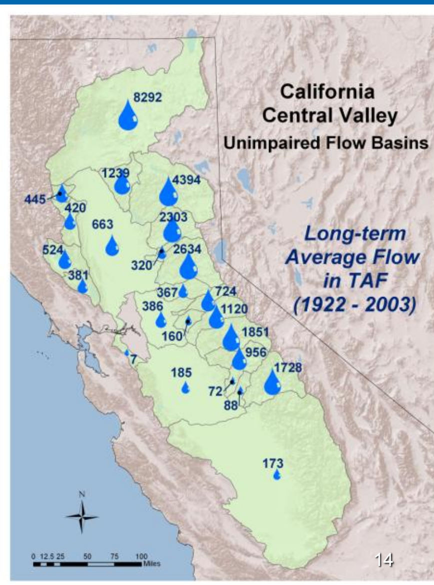
Summary of Estimated UFs in the Central Valley

Region	Long-term annual average flow volume (MAF)
Sac Valley	21.6
Eastside Streams	1.6
San Joaquin Valley	6.2
Delta Inflow	29.4



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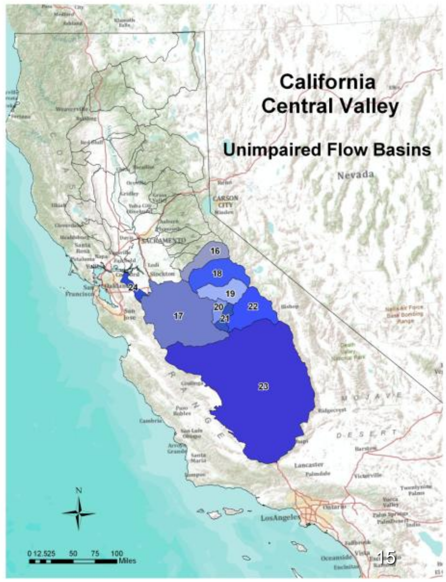
Components of the SJ Valley UF.

San Joaquin Valley outflow to the Delta

- 9 River basins (UF Basin 16 – 24)
- Contributes ~21% of flow to the Delta



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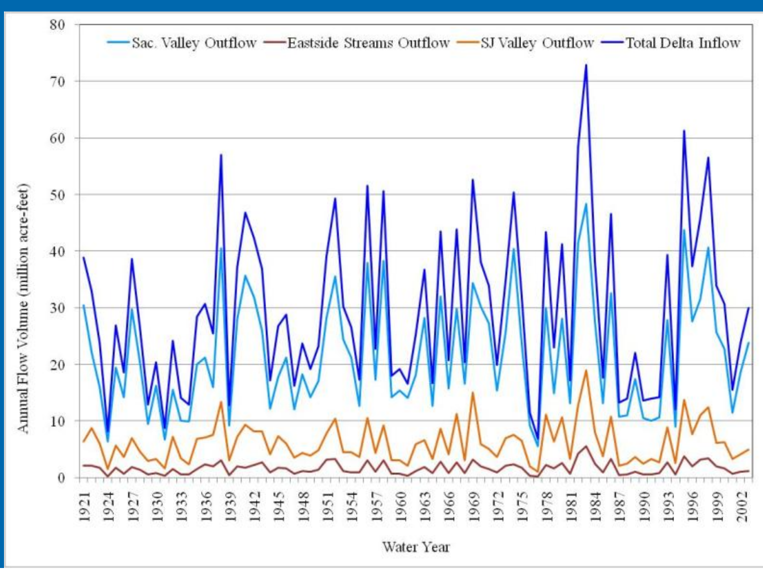
Summary of Estimated UFs to the Delta (cont.)



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Limitations

- Mixed use as natural flow
- Inconsistency of estimation approaches
- Access to proprietary data
- No flow routing
- Some estimates are based on expert judgment; hence not precise
- Data for early periods are poorly documented
- Groundwater use – recent studies show a significant level of stream-groundwater interaction shift in the Sac Valley

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In Closing …

- The UF is viewed as a close surrogate to the natural flow. These two quantities, however, must be distinguished as they can be significantly different depending on the timing and location.
- UF is a conceptual quantity estimated through various means. Direct field measurement of the UF is not possible. UF has been used as an index in D1641 year classification.
- UF is an imprecise estimate requiring further improvement before being used as an operational flow criterion. Refinement is possible given careful design, time, resources and expert effort.
- Applying the proposed flow criteria to real time operations will require timely acquisition of field data that are necessary to estimate the UF. Timely acquisition of needed field data and, under certain circumstances, forecasting certain components of the UF can pose extra challenges to the project operations.

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