Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

38th Annual Progress Report
June 2017

Chapter 3
Implementing DETAW in Modeling Hydrodynamics and Water Quality in the Sacramento-San Joaquin Delta

Authors: **Lan Liang and Bob Suits**
Delta Modeling Section
Bay-Delta Office
California Department of Water Resources

DEPARTMENT OF WATER RESOURCES • STATE OF CALIFORNIA

Contents

Figures

Tables

3 Implementing DETAW in Modeling Hydrodynamics and Water Quality in the Sacramento-San Joaquin Delta

3.1 Introduction

Numerical modeling of the hydrodynamics and water quality in the Sacramento-San Joaquin Delta (Delta) channels requires accounting for in-Delta net channel depletion, because of agricultural diversions including seasonal leaching, seepage from channels to Delta lowland islands, riparian and native vegetation evapotranspiration, and evaporation from free-water surfaces. The California Department of Water Resources (DWR) has recently developed a new model, the Delta Evapotranspiration of Applied Water Model (DETAW v2.0), which is a significant improvement over current methods for estimating Delta consumptive use and net channel depletion. This report presents the key aspects of DETAW v2.0 and its implementation in the detailed modeling of Delta conditions.

3.2 Background

Diversions of water to agricultural lands for irrigation are not metered and are difficult to measure, because the diversions are made through siphons, pumps, and floodgates operating under continuously fluctuating water levels in Delta channels. These diversions are withdrawn at more than 1,800 locations in the Delta. Some areas of the Delta, namely the Delta lowlands (areas of the Delta below the 5 feet mean sea-level contour), receive seepage from adjacent channels. This seepage to islands in the Delta lowlands contributes to net channel depletion, but it is not directly measureable. For these reasons, most estimates of Delta net channel depletion are based on estimates of crop-water demands (crop evapotranspiration [ET]) and the sources of water to meet these demands. The main sources consist of: applied water (I_A), soil moisture (SM) and precipitation (PPT). Within the Delta lowlands, seepage of water from adjacent Delta channels is also a source. Also common in the lowlands is the leaching of salts from the root zone through large irrigation applications. Typically, applied leach water (LW_A) is applied from October through December and drained (LW_D) from January through April. Excess water is also pumped from the Delta islands back into the Delta. This water consists of excess irrigation water (ID), drained leach water (LW_D), and surface runoff (RO) from precipitation.

Net channel depletion equals total diversions (DIV) plus total seepages (S) minus total drainages or return flows (RET). These relationships are defined by Equations 1 through 5 and graphically shown in Figure 3-1.

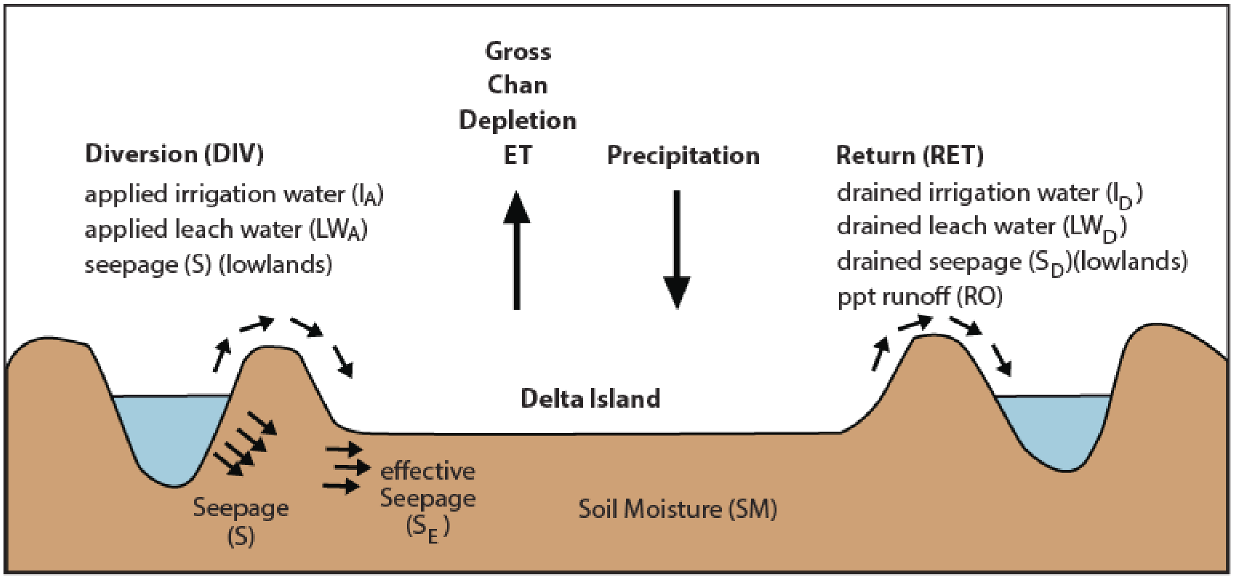

Figure 3-1 Schematic Showing the Water Balance for a Delta Island

Notes: Chan = channel, ET = evapotranspiration, ppt = precipitation

Where

$DIV = I_A + LW_A$. (1)

$RET = I_D + LW_D + RO + S_D$. (2)

$S = S_E + S_D$. (3)

Net channel depletion = DIV – RET + S. (4)

Net channel depletion = $IA-I_D + LW_A-LW_D – RO + S_E$. (5)

The models for estimating Delta net channel depletion vary in the degree in which key factors are simplified. These assumptions will affect any estimation of Delta outflow based, in part, on simulated net channel depletion. These models, discussed below, are DAYFLOW (a computer program designed to estimate daily average Delta outflow), the Consumptive Use (CU) Model and the Delta Island Consumptive Use (DICU) Model.

The current models estimating net channel depletion assume Delta channels are not hydraulically connected to groundwater. Accordingly, seepage is assumed to directly deplete adjacent channels and does not replenish ground water.

3.2.1 Current DWR Models

DWR currently uses three models to estimate Delta net channel depletion. These models, DAYFLOW, CU, and DICU base estimates of net channel depletion on estimates of Delta island consumptive use of water, which are, in turn, based upon crop acreage, crop-unit water demands, and some indicator of evapotranspiration potential. These models vary in the extent to which key factors are simplified. DAYFLOW is an accounting tool for determining historical Delta boundary hydrology. Monthly gross Delta depletions are based on land-use surveys that were completed in 1957, 1958, and 1961 and are repeated each year. This corresponds to the assumption that both Delta land use and factors, which determine monthly patterns of crop evapotranspiration, are constant for all years. Delta net channel depletion is calculated by applying precipitation measured at Stockton Fire Station No. 4 to the entire Delta and then assuming that all of the precipitation is available to meet Delta consumptive-use demands. Implementing DAYFLOW in Delta modeling requires extensive assumptions of how Delta-wide net channel depletion is distributed among Delta islands.

DICU is the model currently used by DWR to generate Delta agricultural diversions and drainage needed for simulation of Delta hydrodynamics and water quality. DICU is based on DWR's earlier consumptive use model, CU, which provides the Delta uplands and lowlands net channel depletion used by DWR's water resources planning model, which is currently CALSIM II. DICU estimates, on a monthly basis, the water that enters, leaves, or is stored in each of 142 Delta subareas. Factors considered in tracking water are land use, plant-rooting depths, seepage, soil moisture, the irrigation season, ET, and precipitation. Land use is categorized according to 20 types, and acreage is based on historical surveys. DICU tracks subarea soil moisture and estimates the amount of water in the soil that is available to plants. Soil moisture limits in DICU are based on extensive DWR neutron probe measurements of Delta islands that occurred during the 1960s. Month-end minimum soil moisture levels are assumed to force an observed yearly pattern, which is Delta soil moisture being at near-capacity at the beginning of each irrigation season. The moisture in the soil is then mined before approaching the wilting point at the end of the irrigation season. Crop-root depths vary by crop and by whether an island is in the uplands or lowlands.

Delta ET, estimated by DICU, is based on pan evaporation and monthly unit ET by crop. Long-term ET values by crop and month are based on various studies that were done during the 1970s and 1980s. Pan evaporation is determined by measuring the evaporation in a standardized evaporation pan holding water at a given location. Long-term average pan evaporation by month is based on data from two sites in Davis during 1956–1984. Pan evaporation for any given historical month and year, since Water Year (WY) 1991, comes from reported pan evaporation from Manteca.

For subareas in Delta lowlands, the DICU model simulates the practice of applying water during winter months to leach salts from the root zone. Timing and volume of leach water are based on a 1981 DWR study. Monthly Delta-wide leach volumes and later drainage are proportionally distributed among subareas, based on subarea acreage.

Precipitation in each of the 142 subareas is determined by weighting the precipitation of five Delta stations by using a Theissen polygon interpolation routine.

DICU has two significant limitations. The first is calculating Delta crop ET for the monthly averaged pan evaporation at one location, the long-term average crop ET, and pan evaporation. The calculated ET at a particular location is difficult to represent ET spatial variations in the Delta. The second limitation is DICU uses a monthly time step instead of a daily time step for precipitation.

The implementation of DICU in Delta modeling requires estimating the sources of water used to meet water demands and the drainage from Delta islands because of excess seepage, rainfall, and applied water.

3.2.2 DETAW v1.0

In 2006, DETAW v1.0 was developed by the University of California, Davis, to better estimate consumptive water demands within the Delta. (See Snyder 2006 for full documentation.)

DETAW v1.0 estimates consumptive water demands for 168 subareas within the Delta Service Area (Figure 3-2). As in DICU, daily precipitation for each subarea is estimated from seven precipitation gaging stations in and adjacent to the Delta and areal weighting factors calculated from Thiessen polygons.

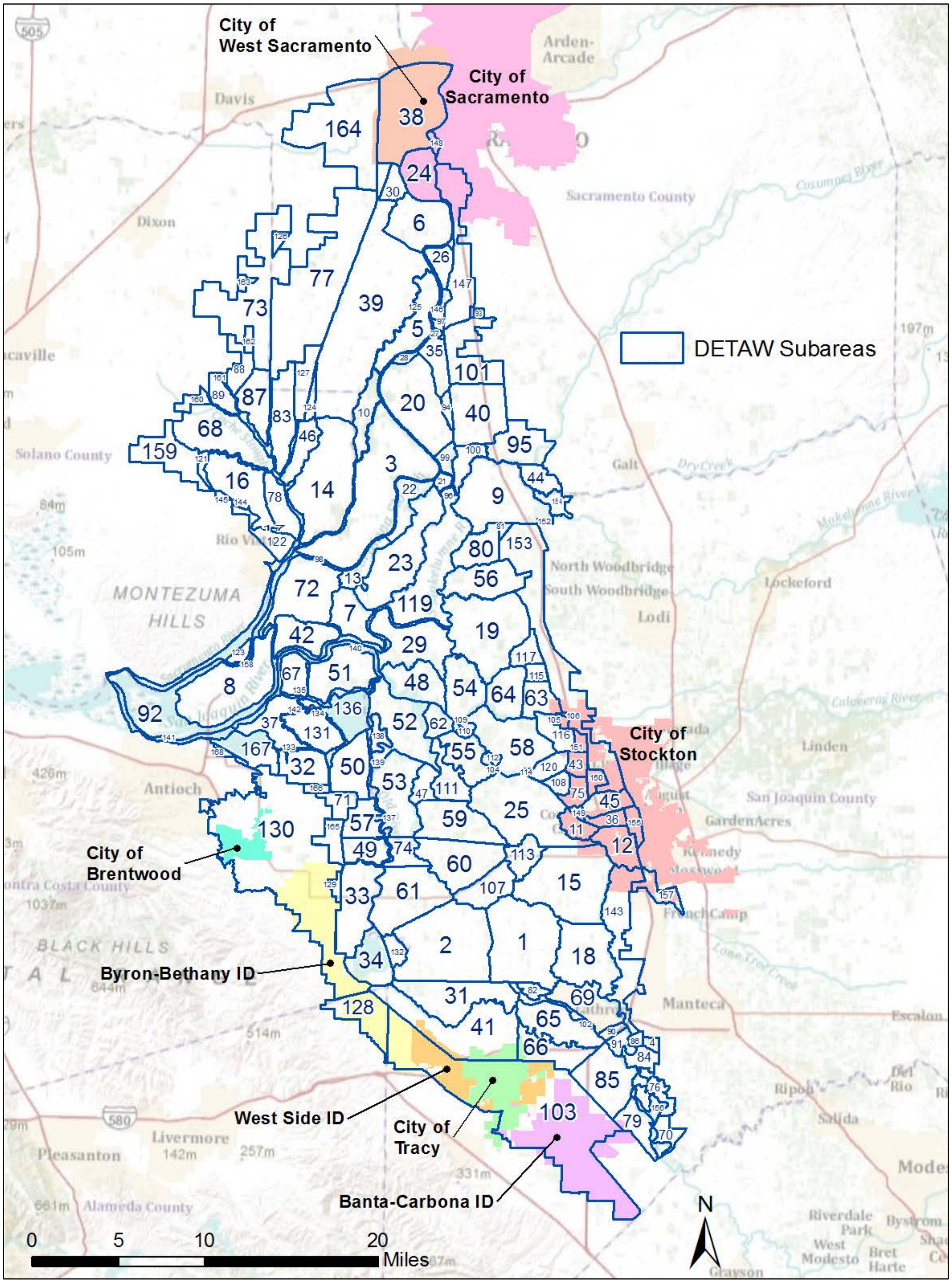

Figure 3-2 DETAW Consumptive Use Subareas

Notes: DETAW = Delta Evapotranspiration of Applied Water, ID = irrigation district

By using the Hargreaves Samani (HS) equation, the reference evapotranspiration (ETo) at the California Irrigation Management Information System (CIMIS) Lodi station was calculated; and by using the Penman-Monteith (PM) equation from nine CIMIS stations, including Lodi, isolines of correction factors to estimate Delta subareas ETo from the Lodi HS ETo were developed. Note that the PM equation uses more meteorological variables (mean temperature, wind speed, relative humidity, and solar radiation) than the HS equation, which uses minimum and maximum temperature and solar radiation. The Lodi CIMIS station is the only station that has the long-term daily temperature data to support the HS ETo simulation from 1922 to recent years. The previously mentioned nine CIMIS stations lack sufficient long-term climate data needed for PM equation, so their data were applied to determine the spatial correction factors of ETo.

Then geographic information system (GIS) contouring was used to estimate correction factors for each subarea within the Delta. In this way, DETAW v1.0 estimates daily Delta ETo, which varies spatially. Daily crop ET-unit rates are computed by using seasonal crop coefficient curves. Daily water balances are used to estimate daily ET of applied water by subarea. Irrigations (diversions from Delta adjacent channels) are triggered when island soil moisture content drops below a specified threshold after accounting for effective precipitation and seepage.

In contrast to DICU, DETAW v1.0 uses daily values of unit consumptive use and precipitation. Because of this daily time step, DETAW v1.0 can reproduce large, sporadic runoff events, both in terms of runoff volume and constituent response, which is not available in DICU. This can be important for modeling water quality in the south Delta, when relatively large spring storms generate significant island runoff to channels with lesser circulation.

3.3 DETAW v2.0: Implementing DETAW in the Modeling of Delta Hydrodynamics and Water Quality

In order to use DETAW-based information in Delta modeling, additional development has been required. This consists of rewriting the program in Python script; updating seepage assumptions; calibrating crop coefficients based on satellite image-based estimates of consumptive use; estimating actual net channel depletion by estimating island diversions, seepages, and drainages; and assigning island diversions, seepages, and returns to model nodes. These activities are presented below. Together, the measures define a new version of DETAW, which is DETAW v2.0.

3.3.1 Rewriting DETAW v1.0

DETAW v1.0, written in C++ language, was rewritten in Python script in order to make some minor changes to some algorithms, provide more control over input and output, increase efficiency of calculations and storage of interim results, and enable easier future development of code necessary for full implementation of model results. DETAW v1.0 generates separate Comma Separated Values(CSV) output files, including the daily output file, the monthly output file, and the yearly output file for each Delta subarea and each crop category. This results in enormous output for long simulations. In order to reduce the time to run DETAW, the program interface was modified and output was shifted to two Data Storage System (DSS) files, one for daily values and one for monthly values, and each contained data for all 168 subareas and 15 land-use categories.

3.3.2 Updating Seepage Rate Assumptions

Both DICU and DETAW v1.0 assume that seepage available for plants in Delta lowlands is 0.3 inches per foot of crop-rooting depth per month. This value was determined from studies conducted to calibrate soil moisture storage by adjusting the seepage (California Department of Water Resources 1995). But under this seepage rate, the estimated amount of seepage to native and riparian vegetation falls far below their water requirements. Since these two crop categories do not receive any applied water, seepage is the major water source besides precipitation. DETAW v2.0 assumes that the seepage rate for these two crops increases to 1.8 inches per ft of crop-rooting depth per month, which intends on balancing the water requirements.

3.3.3 Updating Crop Coefficients for Field Crops and Native Vegetation

Crop coefficients are needed as a way to properly adjust the ETo to more realistically represent actual Delta crop ET. Referring to Anderson et al. (2009), Richard L. Snyder and Morteza N. Orang in 2012 suggested changing the crop coefficients of field and native vegetation. This suggestion was based on lower crop production in the Sacramento-San Joaquin Delta as compared with crop production in the Sacramento Valley. The crop coefficient for field crops was lowered from 1.04 (critical and dry years) and 1.02 (noncritical/dry years) to 0.9. The crop coefficient for native vegetation in DETAW v2.0 was raised from 0.3 to 0.5.

3.3.4 Calibrating Crop Stress Coefficients

The total Delta consumptive use calculated by DETAW v1.0 is approximately 60 percent higher than that calculated by DICU. Such higher consumptive-use estimates will result in much higher net channel depletion estimates and this raises a concern whether all the crop coefficients in DETAW v1.0 were appropriate for the Delta environment. The crop coefficients in DETAW v1.0, based on the Doorenbos and Pruitt (1977) method, were developed to simulate the potential crop ET (ETc) under the ideal conditions. With consideration of the effect of local conditions and agricultural practices, it is better to adjust the potential ETc to the actual ETc, which the hydrodynamic and water quality models need to simulate the historical condition.

In DETAW v1.0, the crop coefficients of each crop category in every year are separated into four growth stages: initial, rapid, mid-season, and late season (Figure 3-3). During the off-season and initial growth stage with less than 10 percent canopy ground cover, the crop coefficient mainly reflects bare soil evaporation. During the mid-season growth stage, the peak crop coefficient of the actual ETc in DETAW v2.0 (Kc) is reached when the canopy ground cover is above 70–80 percent, which is a time when the interception of radiation by the foliage increases and transpiration, rather than soil evaporation, dominates ETc. During the rapid-growth period and late-season, crop coefficient is assumed to linearly change between the crop coefficient in the initial growth period and peak crop coefficient. Two sets of crop coefficients are used in DETAW v1.0; one set is used for critical and dry years and one set is used for wetter years.

Potential ETc is calculated as the product of the ETo and the crop coefficient for each crop category. Crop coefficient values were determined under standard field conditions without crop stress. The actual ETc, to some extent, will be lower than the potential ETc calculated by DETAW v1.0. The actual ETc is calculated by the product of the potential ETc and a stress coefficient (Ks) for each crop category. Kc and the actual ETc are defined below.

$$Kc = Kco * Ks \quad (6)$$

$$ETc = Ks*ETco = Kc * ETo \quad (7)$$

Where

Kc is the crop coefficient of the actual ETc in DETAW v2.0,
Kco is the original crop coefficient in DETAW v1.0 to calculate the potential ETc,
Ks is the stress coefficient,
ETc is the actual ETc DETAW v2.0 generates,
ETco is the potential ETc DETAW v1.0 generates, and
ETo is the reference ET.

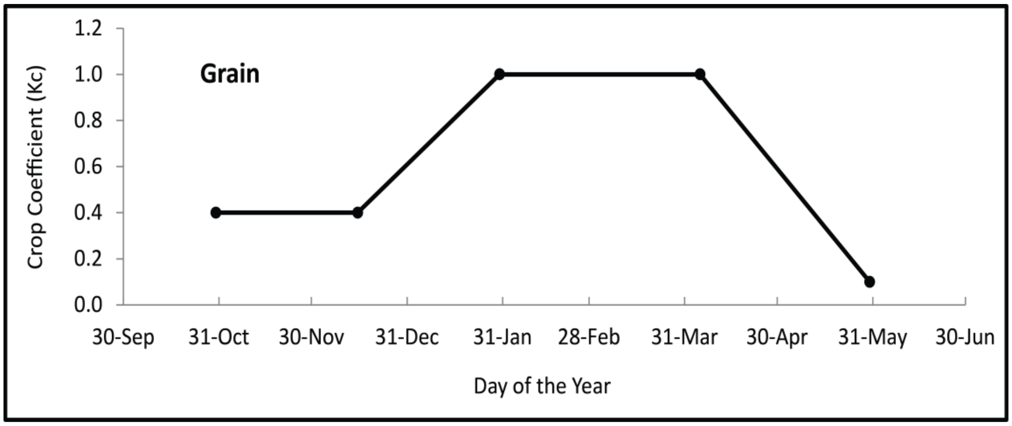

Figure 3-3 Variation in Grain Crop Coefficient (Kc) During A Year

The stress coefficient accounts for factors such as water temperature, air temperature, wind, salinity, soil saturation-reduced root-zone oxygen O_2, and low soil-moisture-induced wilt. Once the stress coefficient is determined, the actual ETc can be estimated.

Anderson et al (pers. comm. 2010) studied the energy balance and crop coefficient of rice, weeds, and bare soil on Twitchell Island. They found that rice production in the Delta is lower than that in the Sacramento Valley, which is a phenomenon they attributed to the Delta's lower water and air temperatures, compared with those in the Sacramento Valley. But developing Delta stress coefficients for the 15 crop categories, based on field studies, is not possible at this time because of a lack of data. Instead, an approach based on the Surface Energy Balance Algorithm for Land (SEBAL)-based Delta consumptive-use estimates was used.

SEBAL computes a land-surface energy balance and actual ETc, based on satellite images and weather data. The ETc in SEBAL equals the "residual" energy flux found by subtracting the soil heat flux and sensible heat flux from the net radiation at the surface. SEBAL has been tested and applied successfully since the 1990s. Bastiaanssen (1998) reports that SEBAL's estimates of consumptive use are within approximately 90 percent of estimates based on field-water models, depending on the scale of study and other factors. When used alongside land use by crop type, SEBAL can provide estimates of monthly net Delta-wide consumptive use and ETc per crop category.

SEBAL was used to estimate ETc from March through September, 2007 in order to calibrate crop stress coefficients and from March through September, 2009 in order to validate them. Satellite images for other months, when crop coefficients are lower, are generally obstructed by cloud cover to be of use. Stress coefficients are applied to only peak crop coefficient for each crop category. Crop coefficients during the initial and the late-season stages are unaffected by stress coefficients. Table 3-1 presents the stress coefficients and potential and actual crop coefficients as calibrated for DETAW's 15 crop categories. The stress coefficient of each crop category equals the 2007 SEBAL Delta ETc divided by

DETAW v1.0-generated Delta ETc. Not all DETAW v1.0-generated ETc values were adjusted through stress coefficients after incorporating SEBAL results. Some did not need an adjustment. As mentioned before, crop coefficient values for native vegetation and urban were determined from field observation and are already indicated as actual ETc. For some crop categories, the total Delta ETc produced by SEBAL and DETAW v1.0 were significantly different, reflecting issues beyond the difference between potential and actual crop coefficients.

Crop Categories	Original potential crop coefficients in DETAW v1.0		Adjusted crop coefficient based on field studies	Calibrated coefficients based on 2004 SEBAL Study	
	Critical, dry years	Non-critical/dry years		Stress coefficient	Updated crop coefficient
	Kco	**Kco**	**Kco**	**Ks**	**Kc**
Alfalfa	1	1	--	0.77	0.77
Dry grain	0.9	0.9	--	1.00	0.9
Field	1.04	1.02	0.9	1.00	0.9
Grain	1.1	1.1	--	1.00	1.1
Native vegetation	0.3	0.3	0.5	1.00	0.5
Orchard	1.05	1.04	--	0.71	0.75
Pasture	0.95	0.95	--	0.79	0.75
Rice	1.05	1.05	--	0.76	0.8
Riparian vegetation	1	0.97	--	0.85	0.85
Sugar beets	1.15	1.15	--	0.70	0.8
Tomato	1.1	1.1	--	0.64	0.7
Truck	1.01	1	--	0.59	0.6
Urban	0.35	0.35	--	1.00	0.35
Vineyard	0.8	0.8	--	0.56	0.45
Water	1.1	1.1	--	1.00	1.1

Table 3-1 Stress Coefficients and Adjusted Peak Crop Coefficients Generated from SEBAL Analysis

Notes: DETAW = Delta Evapotranspiration of Applied Water Model, Kc = crop coefficient of the actual ETc in DETAW v2.0, Kco = original crop coefficient in DETAW v1.0 to calculate the potential ETc, Ks = stress coefficient, SEBAL = Surface Energy Balance Algorithm for Land

Table 3-2 and Figure 3-4 show the estimates of total Delta consumptive use in 2007 from SEBAL, DETAW v1.0, and DETAW v2.0 with calibrated crop stress coefficients. The total Delta consumptive use (DCU) from March through September, 2007 calibrated by using DETAW v2.0, is within 2 percent of that by SEBAL. But the total DCU of these two models in June, 2007 differs by 94 thousand acre-feet (TAF), which is approximately 30 percent of the DCU. Generally, the yearly highest consumptive use occurs in July, which indicates SEBAL's DCU in June is suspect. Monthly ETc by SEBAL is based on two or three satellite images each month, and the samples from June, 2007 possibly caught non-representative conditions at the beginning or the end of the month. The total DCU during several months should be more meaningful. Davids Engineering produced the 2007 actual ETc estimates by using SEBAL. After a meeting with Davids Engineering in 2012, DETAW v1.0 and v2.0 developers agreed on considering cumulative values to calibrate stress coefficients for DETAW v2.0 based on SEBAL. Bastiaanssen(1998) also reported that the accuracy of SEBAL depended on the areal and time scales. For these reasons, stress coefficients were calibrated based on the summation of ETc values during March through September, 2007.

Month	DICU	DETAW v1.0	DETAW v2.0	SEBAL
March	89	167	163	123
April	143	221	210	134
May	174	254	223	229
June	243	316	274	368
July	256	358	312	296
August	193	331	292	285
September	102	216	193	209
Total	1,200	1,862	1,667	1,644
Rate to DICU	100%	155%	139%	137%

Table 3-2 Total Delta Consumptive Use from March through September 2007 (TAF) by DICU, DETAW v1.0, DETAW v2.0, and SEBAL

Notes: DETAW = Delta Evapotranspiration of Applied Water Model, DICU = Delta Island Consumptive Use Model, SEBAL = Surface Energy Balance Algorithm for Land

Numbers are in thousand acre-feet (TAF).

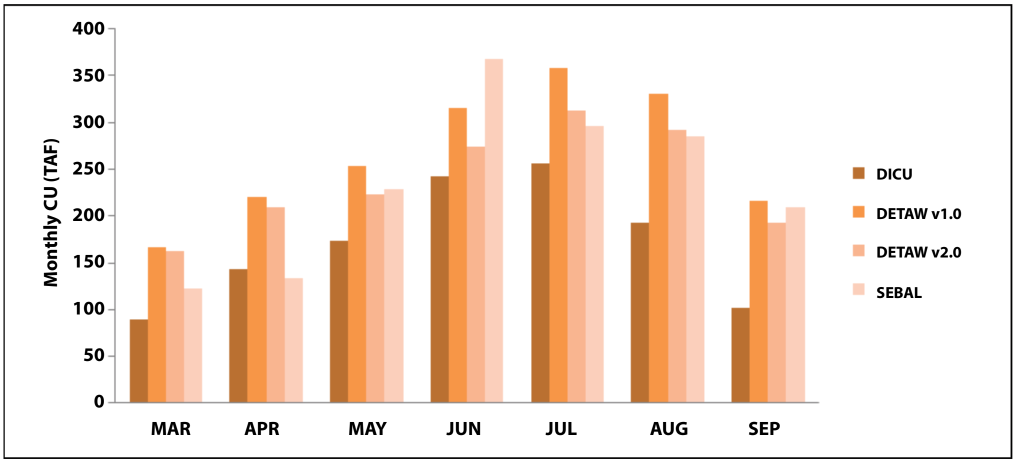

Figure 3-4 The Total Delta Consumptive Use in 2007 by Four Models

Notes: CU = consumptive use, DETAW = Delta Evapotranspiration of Applied Water Model, DICU = Delta Island Consumptive Use Model, SEBAL = Surface Energy Balance Algorithm for Land, TAF = thousand acre-feet

By using the calibrated set of stress coefficients, DETAW v2.0 was validated by comparing ETc to SEBAL-generated ETc for 2009. Table 3-3 and Figure 3-5 show a 3 percent difference in ETc between the two models from March through September 2009, which is a similar amount to that in the 2007 calibration. Moreover, the ETc of each month in 2009, calibrated by DETAW v2.0 and SEBAL, matches the SEBAL monthly consumptive use better than in the 2007 calibration. Compared with the consumptive use difference between DETAW v2.0 and SEBAL in June 2007, the difference for each month in 2009 seems much slighter. DETAW v2.0 simulates the trend and magnitude of the actual ETc for the Delta as a whole reasonably well.

Month	DICU	DETAW v1.0	DETAW v2.0	SEBAL
March	101	158	154	167
April	115	205	191	185
May	156	277	245	263
June	220	314	272	266
July	264	366	315	292
August	186	321	280	264
September	107	245	218	211
Total	1,149	1,886	1,675	1,648
Rate to DICU	100%	164%	146%	143%

Table 3-3 The Total Delta Consumptive Use from March through September 2009

Notes: DICU = Delta Island Consumptive Use Model, DETAW = Delta Evapotranspiration of Applied Water Model, SEBAL = Surface Energy Balance Algorithm for Land

Numbers are in thousand acre-feet (TAF).

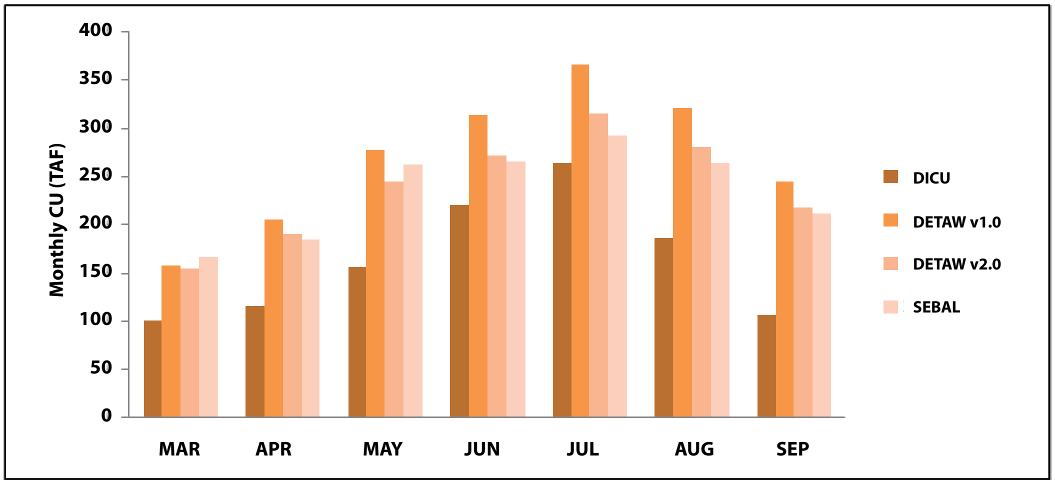

Figure 3-5 Total Delta Consumptive Use in 2009 by Four Models

Notes: CU = consumptive use, DICU = Delta Island Consumptive Use Model, DETAW = Delta Evapotranspiration of Applied Water Model, SEBAL = Surface Energy Balance Algorithm for Land
TAF = thousand acre-feet

3.3.5 Estimating Net Channel Depletion for DETAW v2.0

DETAW v1.0 only considers water demands and supplies in tracking the ground surface-water balance (i.e., the root-zone water balance — the water balance on the top layer of the ground). But some activities related to Delta islands, while not directly satisfying crop water needs, affect the water transfer between channels and Delta islands and influence the river hydrodynamics, water quality, and salinity intrusion in the Delta. These factors include excess applied water associated with irrigation efficiency, island runoff, drained seepage, and diversion and drainage of leach water. Although these water activities do not affect the ground surface-water balance, they need to be accounted for in modeling Delta conditions. The methodology used in DICU has been mostly adopted to do this for DETAW v2.0.

An important component missing in the current modeling of Delta conditions is the role of groundwater as a source for recharging soil moisture and as a sink for deep percolation. Field studies within Delta lowlands are needed to help understand this complex issue. Work is currently underway in the DWR Delta Modeling Support Branch to enable better modeling of subsurface water in the Delta. Future work is expected to generate similar consumptive-use estimates to those estimated by DETAW v2.0, but net channel-depletion estimates could significantly change at times to better reflect the understanding of how subsurface water is involved with the hydrology of the Delta.

Figure 3-1 shows the components of net channel depletion and Equations 1–5 present how net channel depletion is conceptually calculated. Crop consumptive use is the driving force behind estimating applied irrigation water, but several key components of net channel depletion have to be assumed. These components are seepage rate and proportion that is drained for lowlands, soil-moisture limits and crop-rooting depths, precipitation spatial distribution and timing of runoff and proportion that is lost to deep percolation, timing and amount of leaching diversions and drainages, and irrigation efficiency. Together, these assumptions, along with estimated consumptive use, determine the timing and amount of water diverted to Delta islands through applied water and seepage and the water that is drained to adjacent Delta channels.

For a given DETAW v2.0 subarea, once the amount of applied irrigation water is estimated, total diversion from channels and total drainage can be calculated and the resulting net channel depletion is known. The sequence of calculations includes:

1. Finding the amount of crop water needs on subarea (consumptive use).
2. Finding the amount of current day seepage available to meet water demand.
3. Finding the amount of precipitation available to meet water demand.
4. Finding the amount of soil moisture contributing to water demand.
5. Finding the amount of applied irrigation water needed.
6. Finding the total amount of irrigation water diverted from channels.
7. Finding the total amount of water drained to channels.

The actual calculations are shown in Equations 8–11.

$$DIV = I_{AN} / \eta + LW_A \quad (8)$$

$$RET = RO + (1-\eta)*I_{AN}/\eta + LW_D + S_D \quad (9)$$

$$S = S_E + S_D \text{ (lowlands)} \quad (10)$$

$$RO = (1-DP)*(PPT-PPT_E) \quad (11)$$

Where

DIV is the total diversion;

LW_A is the applied leach water;

S is the total seepages;

S_E is the effective seepage;

S_D is the drained seepage;

RET is the return flows;

RO is the surface runoff;

I_{AN} is the amount of irrigated applied water needed by crops as calculated by DETAW v2.0,

PPT is the precipitation,

PPT_E is the effective precipitation, the amount that is used to replenish the soil moisture,

DP is the deep percolation rate, assumed to be 0.25. This is a new term in DETAW v2.0, and

η is the irrigation efficiency factor and is assumed to be 0.7 for the majority of islands.

DETAW v2.0 adopts the same practice as in DAYFLOW of distributing precipitation during four days, starting on the first day of rainfall. It adopts the same drained seepage rates as are used in DICU (California Department of Water Resources 1995) and assigns the same amount as DICU of leach-applied water and leach-drained water.

After the irrigation, drainage, and seepage of each subarea in the Delta are estimated, DETAW v2.0 then inherits the same Delta Simulation Model 2 (DSM2) node allocation factors as in DICU in order to distribute the subarea values into DSM2 node values.

3.4 Data Input for DETAW v2.0

Input data to DETAW v2.0 includes land use, plant-rooting depths, seepage rates, soil-moisture limits, irrigation season, precipitation, DSM2 node allocation factors for diversions and drainages, lowlands leaching volumes and monthly schedule, and irrigation efficiency. Most input structures were borrowed from those used in DETAW v1.0 and DICU; some were modified for DETAW v2.0. These inputs are the annual land use for 168 subareas, the daily precipitation at seven stations, specified in section 3.4.2, on the periphery of the Delta, and daily maximum and minimum temperature at Lodi.

3.4.1 Land Use

DETAW v2.0 will be used for both historical and projected simulations of Delta hydrodynamic and water quality conditions. Projections use two sets of land use; one set is used for the wet and normal years and the other set is used for dry and critical dry years. These are based on past Delta land surveys done in 1976 and the 1980s. Historical simulations are based as much as possible on actual land-use surveys. As in DETAW v1.0, DETAW v2.0 also depicts the Delta as having 168 subareas. Acreage of each subarea is assigned as much as 15 crop categories and land-use identifiers (Table 3-4).

Land-use data for the 15 land-use categories by subarea for Water Years 1922–2003 were developed for DETAW v1.0 by the DWR Bay-Delta Office Modeling Support Branch. In 2007, crop acreages for each of the 168 subareas were developed based on land surveys placed in GIS format. Land use from 2004 through 2007 was assumed to be the same as that based on the 2007 survey. Land use in 2008 was estimated by averaging the data from 2007 and 2009. From 2009 through 2015, DETAW v2.0 land-use

	Crop Category	Land-Use Identifier
1	Urban	UR
2	Pasture	PA
3	Alfalfa	AL
4	Field crops	FI
5	Sugar beets	SB
6	Grain	GR
7	Rice	RI
8	Trucks	TR
9	Tomatoes	TO
10	Orchards	OR
11	Vineyards	VI
12	Riparian vegetation	RV
13	Native vegetation	NV
14	Non-irrigated grain	DGR
15	Water surfaces	WS

Table 3-4 DETAW v2.0 Crop Categories and Land-Use Identifiers

Note: DETAW = Delta Evapotranspiration of Applied Water Model

acreage was based on data from United States Department of Agriculture, National Agricultural Statistics Service.

3.4.2 Precipitation

Precipitation data is retrieved from the California weather database maintained by the Statewide Integrated Pest Management Program at University of California (UC IPM). This database includes data from CIMIS and the National Climatic Data Center (NCDC), which is part of the National Oceanic and Atmospheric Administration (NOAA). Generally, DETAW uses NOAA data. If national climate data is not available, CIMIS data is substituted.

The precipitation data comes from seven NOAA cooperative observer stations: Brentwood, Davis, Galt, Lodi, Rio Vista, Stockton, and Tracy. Currently, NOAA only provides the precipitation data at the Davis, Lodi, Stockton, and Tracy stations. Data for recent years are missing at the other three stations. Correlations to other stations for DETAW v1.0 were developed to estimate precipitation at Brentwood, Galt, and Rio Vista. These are listed in Equations 12, 13, and 14.

PPT at Brentwood = 1.37 * (PPT at Tracy) (12)

PPT at Galt = 1.01 * PPT at Lodi (13)

PPT at Rio Vista = 0.98 * PPT at Davis (14)

3.4.3 Air Temperature

The air temperature data is downloaded from UC IPM. The daily air temperature at Lodi is the required temperature input for DETAW v2.0. UC IPM collects temperature from two Lodi stations, LODI.C from NCDC and LODI_WEST.A from CIMIS. DETAW v2.0 gives priority to LODI.C as the source since all the precipitation data in DETAW v2.0 comes from NCDC. Data from LODI_WEST.A are used in case of missing data or errors.

3.5 DETAW v2.0 Results as Compared with DETAW v1.0, DICU, and DAYFLOW

DETAW v2.0 has been applied for historical Water Years 1975–2010 in order to compare results with those computed by DICU and DAYFLOW. From the perspective of modeling Delta water quality, simulated net channel depletion, which incorporate assumptions of the sources of water to meet Delta consumptive use demands, are directly related to estimated Delta outflow and accompanying salinity intrusion. And so, average monthly Delta-wide net channel depletion, distribution of monthly Delta-wide net channel depletion, and distribution of monthly Delta outflow are presented from the three models.

3.5.1 Delta Net Channel Depletion

DETAW v2.0 generates the applied water, drainage, and seepage of each subarea and then assigns flows to DSM2 nodes. The net channel depletion reflects the water transfer between channels and islands and can be found through combining applied water, drainage, and seepage (Equation 15).

Net channel depletion = applied water + seepage - drainage (15)

Delta-wide net channel depletion can be found by adding all the net channel depletion assigned to DSM2 nodes. Since DICU estimates the monthly irrigation, drainage, and seepage of DSM2 nodes, the monthly Delta net channel depletion can be calculated by using the same method as DETAW v2.0.

DAYFLOW provides estimates of net channel depletion, which equals the gross channel depletion plus miscellaneous water transfers minus Delta precipitation runoff. The same daily gross channel depletion is used for all water years. Miscellaneous water transfers are those diversions or transfers other than gross channel depletion, precipitation, and exports.

The averages of the monthly Delta net channel depletion for WYs 1975–2010 by DAYFLOW, DICU, and DETAW v2.0 are shown in Figure 3-6. The years are chosen because DSM2 historical simulation is available for these years. The monthly Delta net channel depletion calculated by DETAW v2.0 is generally several hundred cubic feet per second (cfs) higher than that by the other two models for most months, except the winter months. Delta net channel depletion calculated by DETAW v2.0 is based on the SEBAL-calibrated crop ET. If the original crop ET calculated by DETAW v1.0 is applied, the net Delta net channel depletion would be increased by another several hundred cfs. The relatively large difference between DETAW v2.0 and DAYFLOW calculations exist during February–May, while that difference between DETAW v2.0 and DICU calculations exists for almost all the irrigation season, March–September.

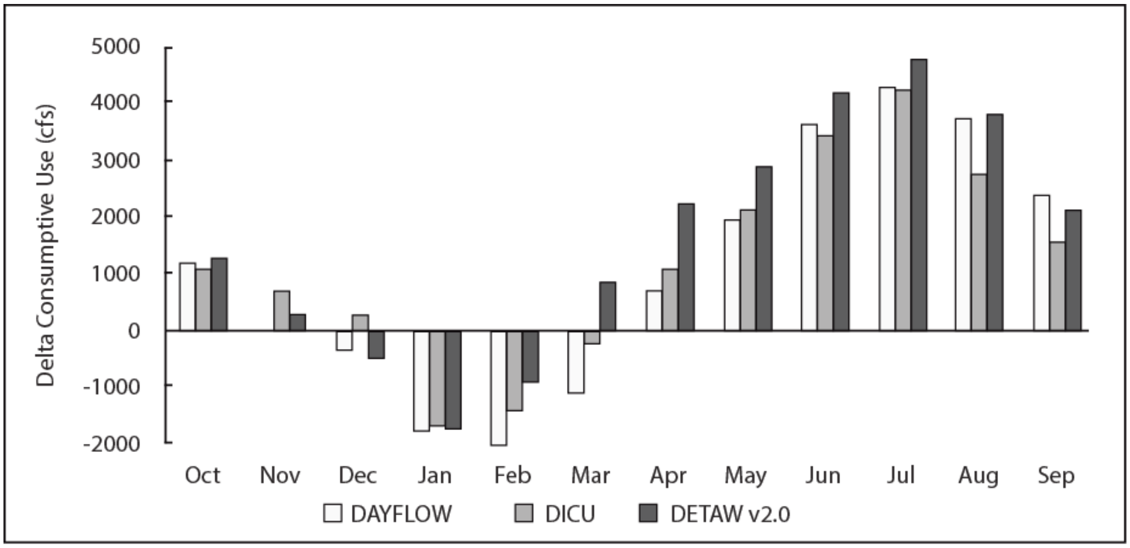

Figure 3-6 Average Delta Net Channel Depletion for WYs 1975–2010 as Modeled by DAYFLOW, DICU, and DETAW v2.0

Notes: cfs = cubic feet per second, DAYFLOW = program designed to estimate daily average Delta outflow, DICU = Delta Island Consumptive Use Model, DETAW = Delta Evapotranspiration of Applied Water Model, WY = water year

Figure 3-7 presents distributions of monthly net channel depletion for the same period through box-and-whisker plots. During the winter and spring months, the monthly Delta net channel depletion can vary widely because of the variability in precipitation. During the summer and fall, Delta net channel depletion is fairly consistent because of the relatively consistent ETc. DETAW v2.0 generally generates higher Delta net channel depletion than the other two models. Figure 3-7 shows that the variation in each month of DETAW v2.0 is similar to that of DAYFLOW, especially in November, December, May, and June.

3.5.2 Net Delta Outflow

Net Delta Outflow (NDO) is computed by using Equation 16.

NDO = Delta inflows – Delta exports – Delta net channel depletion (16)

Delta inflows and exports from DAYFLOW have been assumed in order to compare calculated NDO from DAYFLOW, DICU, and DETAW v2.0. The differences in NDO between any two models of DICU and DETAW v2.0 and DAYFLOW are the same as the differences in Delta net channel depletion. Since DETAW v2.0 estimates summer net channel depletion to be several hundred cfs higher than for DAYFLOW and DICU, NDO under DETAW v2.0 is lower by the same amount compared with the NDO under DAYFLOW and DICU.

Figure 3-8 shows the distribution of monthly Delta outflows for WYs 1975–2010 falling below 25,000 cfs. The magnitude and duration of lower Delta outflow indicate the potential for significant yearly salinity intrusion into the Delta in late summer and fall. Figure 3-9 shows the average Delta outflow during July-October for WYs October, 1975–September, 2010. These months usually have the lowest average Delta outflow during any year. Average outflow under DETAW v2.0 is lower than both DAYFLOW- and DICU-assumed net channel depletion, particularly in July and August.

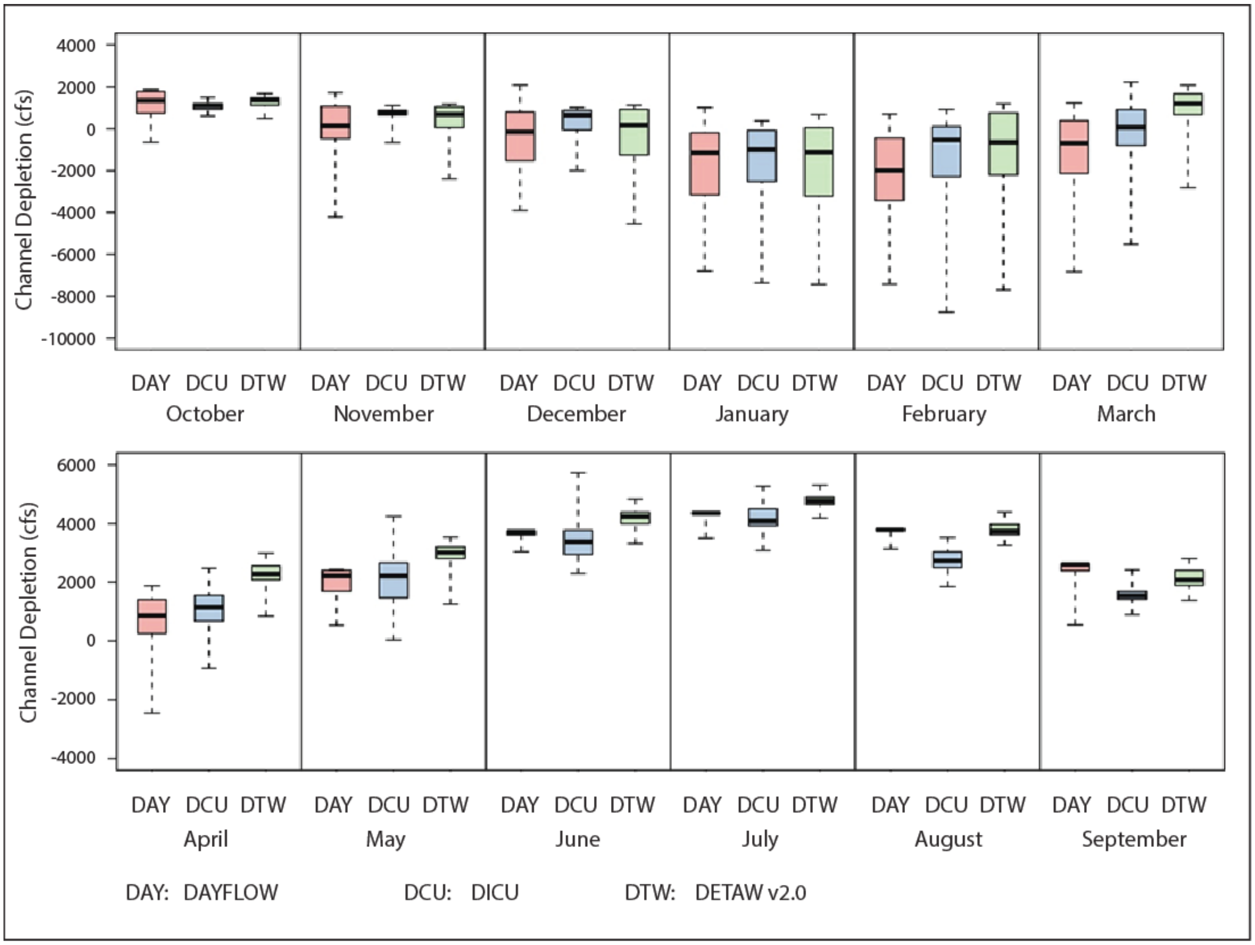

Figure 3-7 The Distribution of Monthly Delta Net Channel Depletion for WYs 1975–2010

Notes: cfs = cubic feet per second, DAYFLOW = program designed to estimate daily average Delta outflow, DETAW = Delta Evapotranspiration of Applied Water Model, DICU = Delta Island Consumptive Use Model, WY = water year

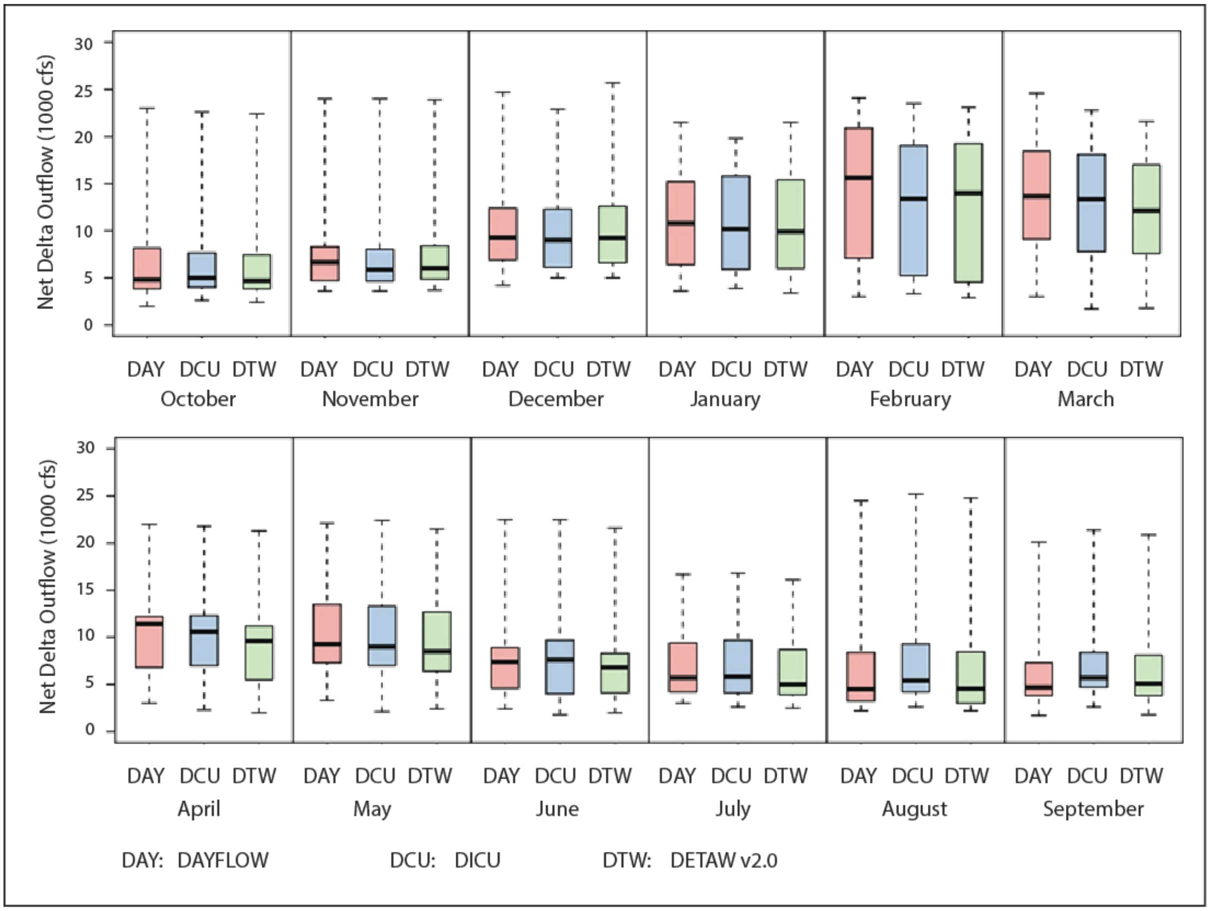

Figure 3-8 Distribution of Monthly Delta Outflows of Less Than 2,5000 cfs for WYs 1975–2010

Notes: cfs = cubic feet per second, DAYFLOW = program designed to estimate daily average Delta outflow, DETAW = Delta Evapotranspiration of Applied Water Model, DICU = Delta Island Consumptive Use Model, WY = water year

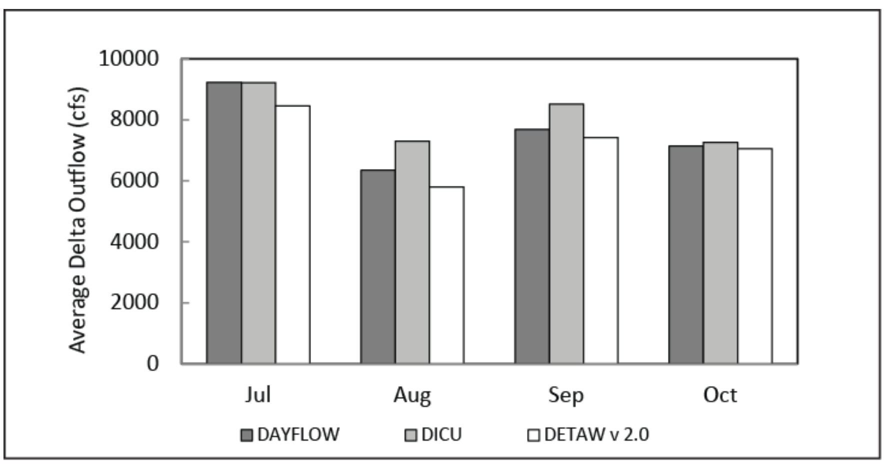

Figure 3-9 Monthly Average Delta Outflow During July–October, WYs 1975–2010

Notes: cfs = cubic feet per second, DAYFLOW = program designed to estimate daily average Delta outflow, DETAW = Delta Evapotranspiration of Applied Water Model, DICU = Delta Island Consumptive Use Model, WY = water year

3.5.3 Simulation of Delta Electrical Conductivity with DSM2

Estimates of Delta consumptive use, net channel depletion, and island drainage affect simulated Delta salinity in two ways. First, as indicated above, estimates of Delta net channel depletion directly affect estimates of Delta outflow. Current understanding of historical Delta outflow is based partly on the consumptive use reported by DAYFLOW. State Water Resources Control Board Decision D-1641 relies on the Net Delta Outflow Index as determined by DAYFLOW, which includes net Delta consumptive use as part of its calculations. Observed electrical conductivity (EC) in the Carquinez Strait at Martinez (DSM2's downstream boundary) is understood to be related to DAYFLOW-based Delta outflow estimates. Yet, the water quality module of the current version of DSM2 was calibrated based on DICU-derived net channel depletion. Computing DSM2 historical simulations under different net channel depletion estimates (i.e., DICU and DETAW v2.0) will result in different salinity intrusion scenarios. This will affect modeled EC in the west and central Delta and up Old River toward project export locations.

In addition, in areas of relatively low circulation, such as the south Delta when temporary barriers are installed, simulated island diversions and drainage — the magnitude of total applied water and the amount, timing, and water quality of drainage — can strongly affect simulated water quality in local channels.

DSM2 simulations with DICU-based net channel depletion show a pattern of somewhat overestimating EC in the summer and underestimating EC in the winter. A DWR report (Thein and Nader-Tehrani 2006) about a DSM2-DICU simulation of historical 1975–1989 conditions found that large discrepancies between observed and DSM2-simulated EC occurred during the summer of very dry years when the estimated net Delta outflow was particularly low. Overall, the calibration of DICU-based DSM2 resulted in the latest released version of DSM2, which performs well in most years.

The accuracy of localized modeling of the water quality impacts, because of nearby diversions and drainage, is limited to the extent that relevant information is known. Hundreds of pumps are located in the Delta that irrigate and drain the islands. Actual pumping rates are unknown. Unmeasurable seepage is continual all along channel banks. A fairly extensive drainage water quality sampling study was conducted by DWR's Municipal Water Quality Investigations section in the 1990s, but the variation found in the data, both spatially and temporally, prevented insightful interpretation; instead, data were averaged to generate a table of monthly agricultural drainage EC for each of three Delta regions (Jung and Associates 2000). These values repeat for all years.

In order to show how DETAW v2.0 affects simulated EC, historical Delta conditions of 1990–2009 were simulated by using net channel depletion and island drainage based on DICU and DETAW v2.0. Delta inflows and exports and the EC boundary at Martinez were identical in the two simulations, but because net channel depletions differed, Delta outflow also differed. The current version of DSM2's water quality module was calibrated and verified by using DICU-generated net channel depletion. Accordingly, DICU-based DSM2 simulations are expected to match observed EC better than DETAW-based calculations, with respect to salt intrusion from the west Delta boundary.

As shown in Figures 3-10–3-13, Delta outflow by using DETAW v2.0 can be 1,000 cfs less than by using DICU during the time of year when EC is highest, which is late summer and fall. This reduction can cause significant additional salinity intrusion in the DSM2 simulation and lead to significant overestimation of EC. This happened in 1992, 1994, 2001, 2002, 2008, and 2009. However, at other times, large decreases in Delta outflow, caused by using DETAW v2.0 instead of DICU, results in little change in EC at Antioch, Jersey Point, and Emmaton. Figure 3-14 shows the sensitivity of salinity to Delta outflow at Antioch, Jersey Point, and Emmaton, as indicated by DSM2 simulations. At monthly average Delta outflows of less than approximately 6,000 cfs, salinity sharply increases for even small decreases in outflow. This can be inferred that DETAW v2.0-based net channel depletion and also Delta outflow in DSM2 simulations of historical conditions increases the incidents of low outflow and higher EC at all three locations. That is, DSM2 simulations of Delta conditions under DETAW v2.0 result in an increase in the occasions when simulated EC in the west Delta is highly sensitive to outflow.

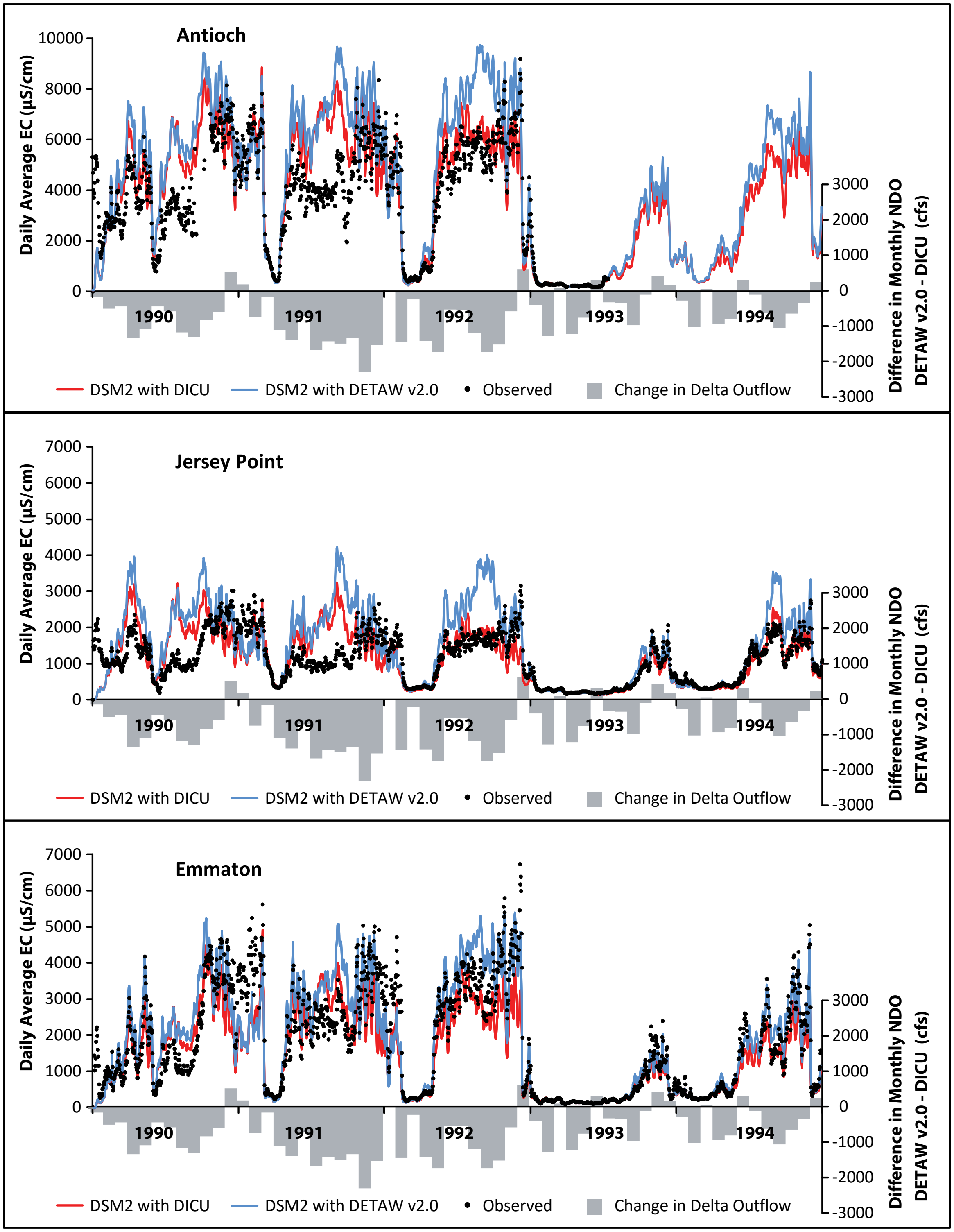

Figure 3-10 DSM2 Simulation of Historical EC under DICU and DETAW v2.0 Compared with Observed EC, 1990–1994

Notes: µS/cm = microSiemens per centimeter, cfs = cubic feet per second, DETAW = Delta Evapotranspiration of Applied Water Model, DICU = Delta Island Consumptive Use Model, DSM2 = Delta Simulation Model 2, EC = electrical conductivity, NDO = Net Delta Outflow

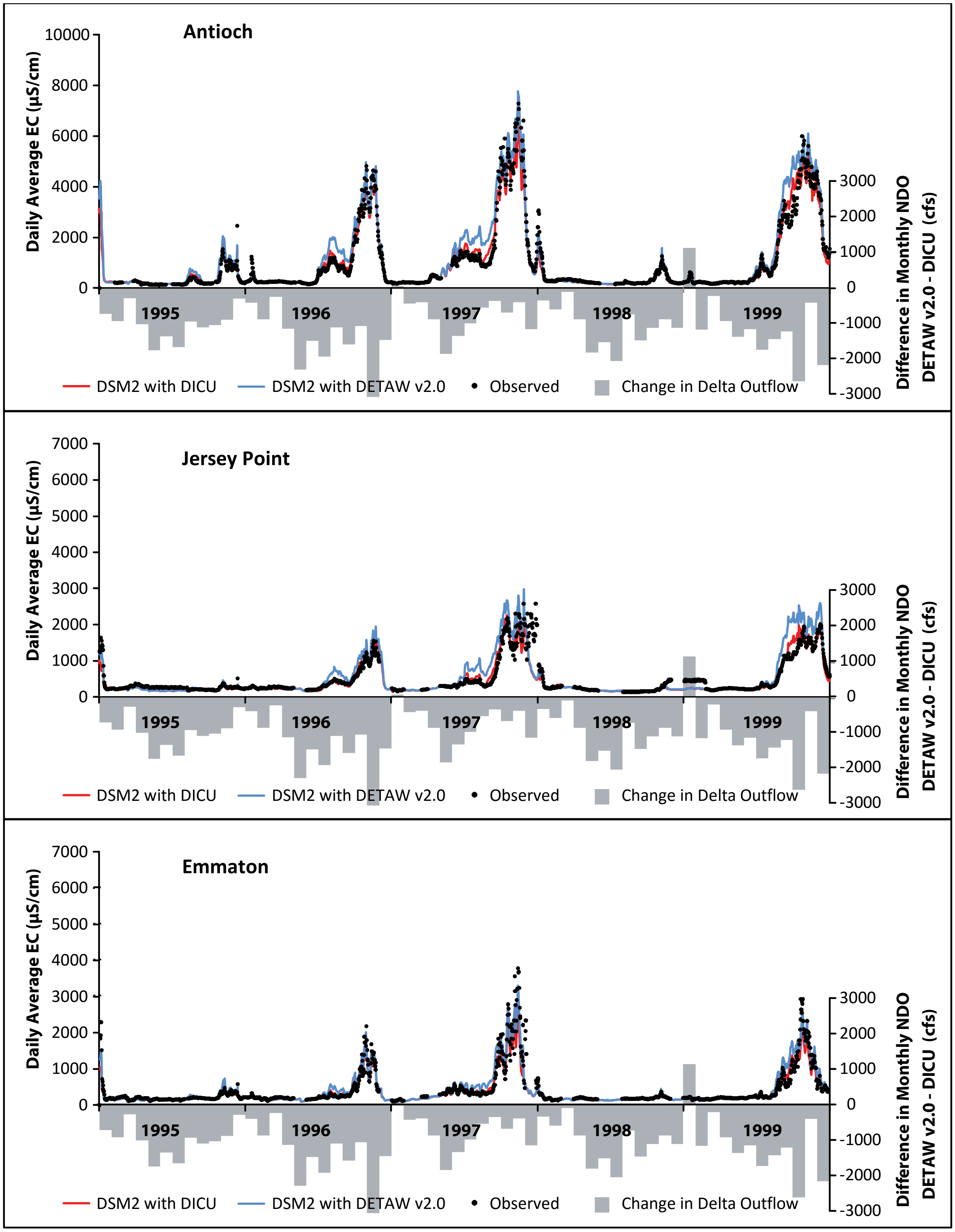

Figure 3-11 DSM2 Simulation of Historical EC under DICU and DETAW v2.0 Compared with Observed EC, 1995–1999

Notes: µS/cm = microSiemens per centimeter, cfs = cubic feet per second, DETAW = Delta Evapotranspiration of Applied Water Model, DICU = Delta Island Consumptive Use Model, DSM2 = Delta Simulation Model 2, EC = electrical conductivity, NDO = Net Delta Outflow

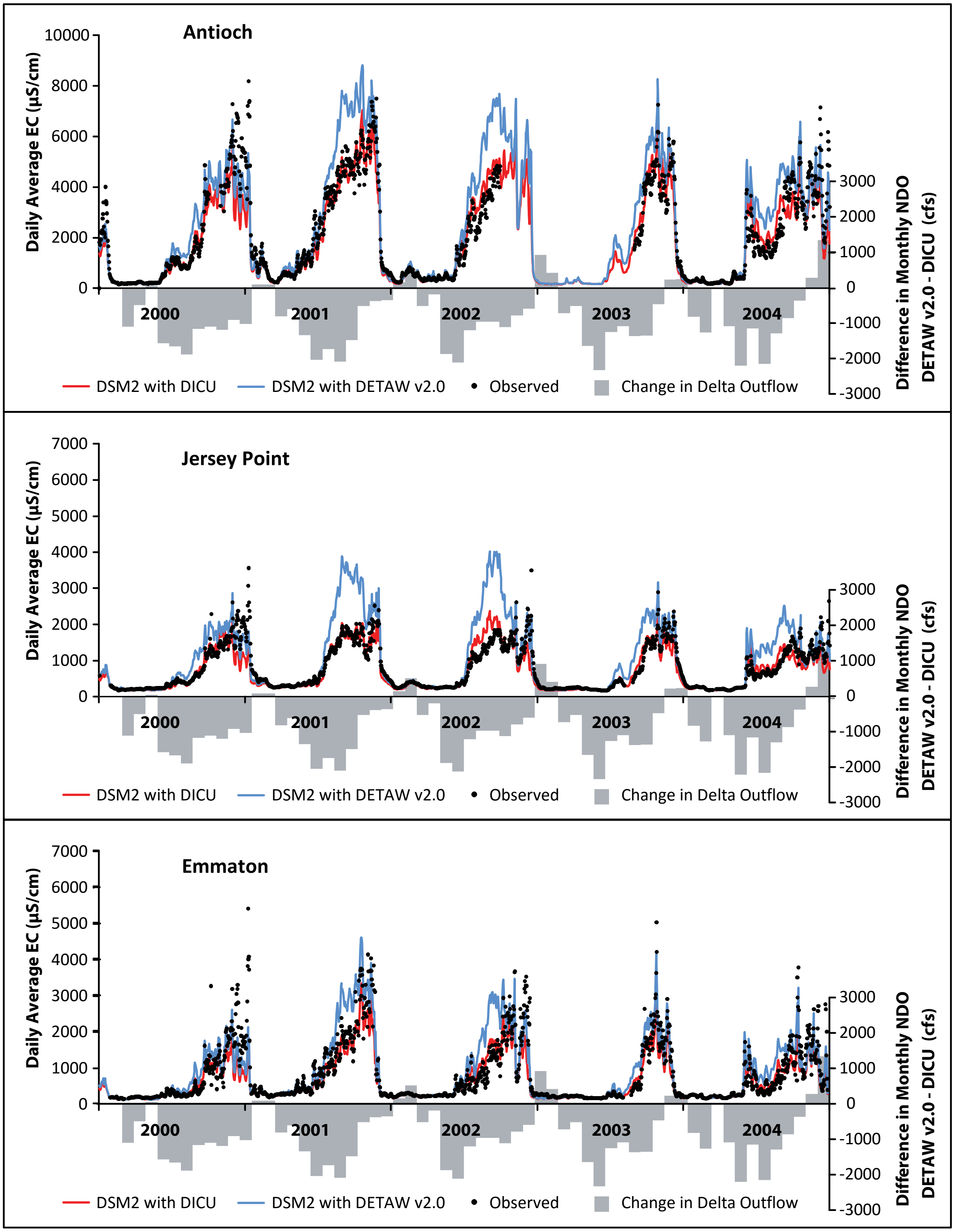

Figure 3-62 DSM2 Simulation of Historical EC under DICU and DETAW v2.0 Compared with Observed EC, 2000–2004

Notes: µS/cm = microSiemens per centimeter, cfs = cubic feet per second, DETAW = Delta Evapotranspiration of Applied Water Model, DICU = Delta Island Consumptive Use Model, DSM2 = Delta Simulation Model 2, EC = electrical conductivity, NDO = Net Delta Outflow

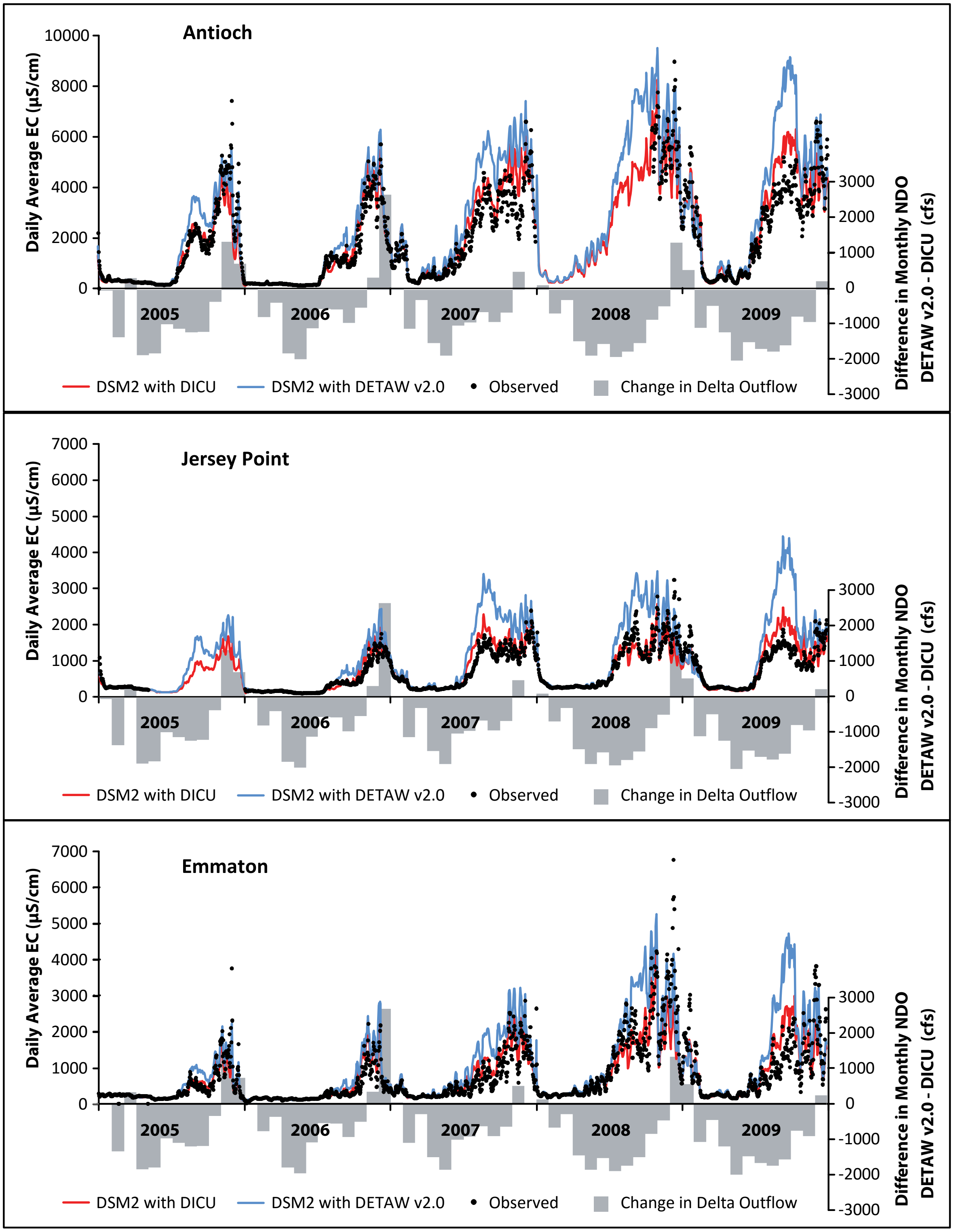

Figure 3-13 DSM2 Simulation of Historical EC under DICU and DETAW v2.0 Compared with Observed EC, 2004–2009

Notes: µS/cm = microSiemens per centimeter, cfs = cubic feet per second, DETAW = Delta Evapotranspiration of Applied Water Model, DICU = Delta Island Consumptive Use Model, DSM2 = Delta Simulation Model 2, EC = electrical conductivity, NDO = Net Delta Outflow

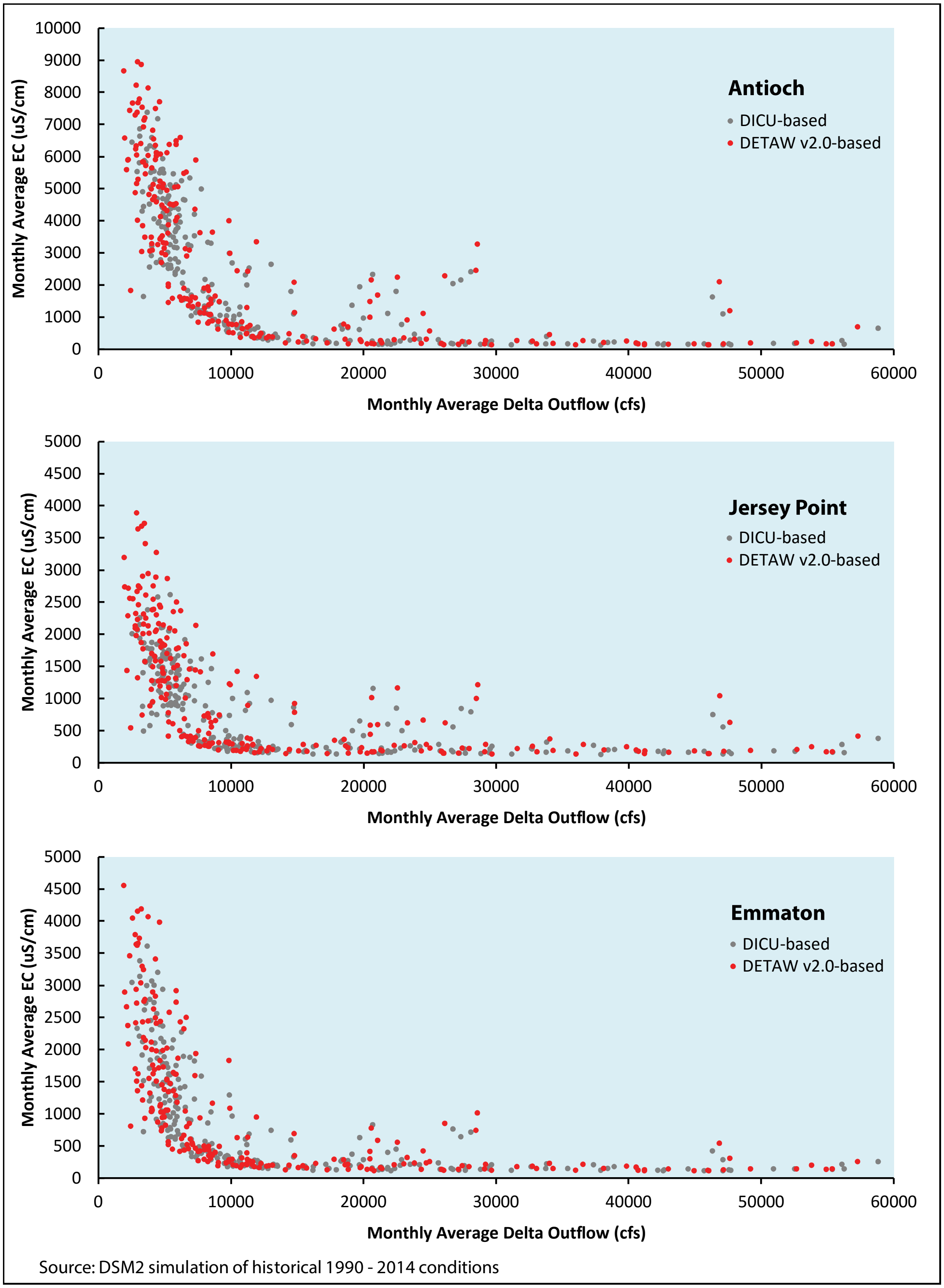

Figure 3-14 DSM2-Simulated EC and Delta Outflow under DICU and DETAW v2.0 for Historical 1990–2014 Conditions

Notes: µS/cm = microSiemens per centimeter, cfs = cubic feet per second, DETAW = Delta Evapotranspiration of Applied Water Model, DICU = Delta Island Consumptive Use Model, DSM2 = Delta Simulation Model 2, EC = electrical conductivity

3.6 Conclusion

DETAW v2.0 code has been developed to link a ground surface-water balance model to DSM2 and other surface-water models. A method for employing crop-consumed water (consumptive use) in estimating the amount of water transferred between Delta islands and channels has been built and a preliminary model output has been analyzed. The analysis concludes that a recalibration of QUAL, the water quality module of DSM2, and DETAW v2.0 are required.

Many factors need to be considered in a DETAW v2.0 calibration, because net channel depletion is determined by crop ET, leach water, seepage, applied water, irrigation efficiency, and so on. Since the Delta crop ET has been calibrated with SEBAL data, the crop-consumed water should be reliable enough for further application.

A challenge to calibrating the net channel depletion model is the unmeasurable or unknown agricultural activities, which do not relate to the water to satisfy crop ET, but affect the movement of water from channels to islands and from islands back into channels.

The processes of leaching, seepage, irrigation efficiencies, and deep percolation vary spatially and temporally. Investigations are needed to determine how to represent these dynamic processes in the model and how to calibrate the parameters. For example, deep percolation in this model has been simplified as part of precipitation that does not supply the crop ET. It might be more reasonable to consider it in the calculation of the root-zone water balance.

Some of the unknowns have not been included in the model, such as island drainage required, because of subsidence in the lowlands. On some islands, groundwater levels can be above the ground surface and farmers need to continuously drain water to maintain the groundwater levels that are deep enough for crops to grow.

Since many unknowns exist in DETAW v2.0, it is difficult to calibrate the model, itself. As pointed out above, simulated EC can be very sensitive to Delta outflow and accordingly net channel depletion. EC could be taken as an indicator to simultaneously calibrate both DETAW v2.0 and DSM2.

For example, both DETAW v2.0 and DSM2 could be calibrated to observed EC in the west Delta. Delta surface water is a comprehensive system. The internal water movement in the system includes the water balance in root zones, the water transfer between root zones and channels, and the hydrodynamics and the transport of salinity or other substances in channels. If all the components can be simulated reasonably well for a long period, the major movement of water in the system should be captured by DETAW v2.0 and DSM2. The Sacramento-San Joaquin River confluence area is the key region where Delta outflow and salinity intrusion are highly correlated. If EC in this region is simulated rationally, the estimated total Delta net channel depletion should be meaningful.

Once DETAW v2.0 and DSM2 at the confluence area have been calibrated, calibrating DSM2 upstream of the confluence area is the next step. This seems more complicated and might include both calibrating DSM2 for the whole Delta and modifying the assumptions of the distribution and water quality of island drainages.

3.7 References Cited

Anderson, FE, Detto M, Verfailie J, Baldocchi D, Snyder RL. 2009. “Variations in the surface energy balance for rice grown in the Sacramento-San Joaquin Delta and the Sacramento Valley.” Poster sent to Lan Liang.

Bastiaanssen WGM et al. 1998. “A remote sensing surface energy balance algorithm for land (SEBAL) 2. validation.” Journal of Hydrology. pp. 213-229. [Journal article].

California Department of Water Resources. 1995. *Estimation of Delta island diversion and return flows*. Sacramento (CA): Division of Planning. 144 pp. Viewed online at: http://www.calwater.ca.gov/Admin_Record/C-032892.pdf.

Doorenbos J. and Pruitt WO. 1977. *Guidelines for predicting crop water requirements*. Rome (IT): Food and Agriculture Organization of the United Nations. Irrigation and Drainage Paper 24. 154 pp. Viewed online at: http://www.fao.org/3/a-f2430e.pdf.

Marvin Jung and Associates, Inc. 2000. *Revision of representative Delta island return flow quality for DSM2 and DICU model runs*. Sacramento (CA): Report prepared for the California Department of Water Resources. Division of Planning and Local Assistance. 191 pp. Viewed online at: http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dicu/DICU_Dec2000.pdf.

Myint T and Nader-Tehrani P. 2006. "Chapter 9: DSM2 Simulation of Historical Delta Conditions over the 1975-1990 Period." In: *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 27th Annual Progress Report to the State Water Resources Control Board*. Sacramento(CA): California Department of Water Resources. Bay-Delta Office.

Snyder RL et al. 2006. *Final report, Delta evapotranspiration of applied water (DETAW) Version 1.0*. California Department of Water Resources. Department of Land, Air, and Water Resources. University of California, Davis.

3.7.1 Personal Communications

Anderson FE. 2010 — email correspondence between Anderson FE and Liang L, California Department of Water Resources — comments about energy balance and crop coefficient of rice, weeds, and bare soil on Twitchell Island.