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

39th Annual Progress Report
June 2018

Chapter 2
Calibrating and Validating Delta Channel Depletion Estimates

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

Contents

Tables

Figures

Acronyms and Abbreviations

BDCP	Bay-Delta Conservation Plan
cfs	cubic feet per second
CLC	Clifton Court Forebay
DCD	Delta Channel Depletion Model
Delta	Sacramento-San Joaquin Delta
DETAW	Delta Evapotranspiration of Applied Water
DICU	Delta Island Consumptive Use
DSM2	Delta Simulation Model II
DWR	California Department of Water Resources
EC	electrical conductivity
ET	evapotranspiration
GW	groundwater
LWA	applied leach water
LWD	drained leach water
NDO	net Delta outflow
SCHISM	Semi-Implicit Cross-scale Hydroscience Integrated System Model
SEBAL	Surface Energy Balance Algorithm for Land
SSW	unknown water source
QUAL	Delta Simulation Model II-Water Quality Module

Chapter 2. Calibrating and Validating Delta Channel Depletion Estimates

2.1 Introduction

This chapter details the assumptions in an extension of the Delta Evapotranspiration of Applied Water (DETAW) v2.0, Delta Channel Depletion Model (DCD) v1.0, which has been calibrated to produce what may be more accurate Sacramento-San Joaquin Delta (Delta) channel depletions in the process of yielding improved Delta simulations of historical electrical conductivity (EC). For simulating Delta hydrodynamics and water quality, Delta channel depletions and agriculture drainage, expressed as withdrawals and returns at model nodes, are the actual hydrology parameters needed rather than Delta consumptive use — consumptive use being just one step in estimating channel depletions. DCD v1.0 differs from DETAW v2.0 by considering subsurface water sources, changes to leaching amounts, flow-salinity relationships, and Delta Simulation Model II (DSM2) EC simulation results in modifying how channel depletions are estimated.

2.1.1 Estimating Delta Channel Depletions by DETAW v2.0

Appendix 1 presents schematics of the basic logic flow in DETAW v2.0. Estimating channel depletions in the Delta must consider many physical processes, such as crop evapotranspiration (ET), leaching, seepage, irrigation, drainage, and local groundwater. Implementation of the current version of DETAW, DETAW v2.0, was documented in a 2017 California Department of Water Resources (DWR) report (California Department of Water Resources 2017). DETAW v2.0 implemented three significant changes in applying DETAW to the Delta: seepage assumptions were updated, leaching was modified, and crop coefficients were calibrated based on satellite-image based estimates of consumptive use. Island diversions, seepages, and drainages were assigned to DSM2 model nodes using the same algorithm as in Delta Island Consumptive Use (DICU) and the original DETAW model.

DETAW v2.0 assumes that seepage water is available to plants in Delta lowlands at a rate of 0.3 inch per foot of crop rooting depth per month. This value was determined from studies which adjusted assumed seepage while calibrating soil moisture storage.

Based on the 1981 report, *Joint DWR and WPRS Delta Channel Depletion Analysis*, DICU and DETAW v2.0 assume that the total volume of annual leach water in Delta lowlands equals 26,800 acres of flooded area to a depth of 2 feet.

The Delta crop ET currently calculated by DETAW v2.0 is considered reasonable. DETAW v2.0 crop ET has been calibrated by the Delta consumptive use estimated by Surface Energy Balance Algorithm for Land (SEBAL) for 2007, and validated by that estimated by SEBAL for 2009. SEBAL uses satellite images to estimate consumptive use in the hydrologic cycle. In addition, the University of California, Davis, recently compared seven crop ET models, including DETAW. DETAW v2.0's crop ET generally falls within the range of the results of the six other models.

Estimating channel depletions in the Delta must consider many physical processes, such as crop ET, leaching, seepage, irrigation, drainage, and local groundwater. Based on its ET estimates, DETAW v2.0 simulates ground surface water balance on Delta islands to estimate Delta channel depletions. The *ground surface water balance* is the balance between water demands and water supplies at the ground surface. Channel depletion is the water transferred between Delta island ground surface and adjacent channels.

Delta channel depletions estimated by DETAW v2.0 tend to exceed DICU-based estimates because consumptive use estimates by DETAW v2.0 tend to be higher than DICU-based values.

2.1.2 The Need to Revise DETAW v2.0-Based Estimates of Delta Channel Depletions

When DETAW v2.0-based Delta channel depletions are used in DSM2 simulations of historical Delta EC conditions, errors in simulated EC at times deviates significantly from DICU-based DSM2 simulations of EC, particularly in the west and central Delta (California Department of Water Resources 2017 [Figure 10 through Figure 13]). Recalibrating DSM2-Water Quality Module (QUAL) dispersion coefficients fails to yield satisfactory modeled salinity profiles in the west Delta. The inaccuracy in DSM2 historical EC simulations based on DETAW v2.0 are believed to be caused by errors in modeled Delta outflow, rather than a model calibration problem. Salinity modeling errors in the west Delta result from too much or too little seawater intrusion. These modeling errors then propagate up into the central Delta.

The likely main reason for errors in Delta outflow is calculated Delta channel depletions. A DWR study of the hydrology of Twitchell Island from October 1959 through March 1961 included measured soil moisture at 60 locations on the island approximately every two months (Owen LW and Nance DH 1962). Considering the nature of organic soils in the Delta, with percent moisture common ranging from 500 percent to 2,000 percent of dry weight, an appreciable soil moisture storage above free groundwater was believed possible. The study reached three key conclusions. First, as explained below, monthly channel depletions in the Delta are not synonymous with monthly consumptive use. Second, the effect of change in soil moisture on computed Delta outflow is to increase the computed value of outflow during low-outflow months and to decrease computed outflow during higher-outflow months. Third, using the results for Twitchell Island as a rough guide, computed Delta outflow adjusted for change in soil moisture in Delta lowlands can be as much as 39 percent different from unadjusted outflow for certain months.

How to reasonably quantify the above processes for the entire Delta is a major problem for calculating Delta channel depletions. Other studies, numerous model tests, and data analysis reinforce the idea that solid estimates of subsurface flow, groundwater, and leaching may be very important in adequately simulating channel depletion. In addition, Delta land use and the extent of subsidence have changed over time. While land surveys periodically have been taken, ongoing land subsidence in the Delta lowlands and associated seepage have not been accounted for in DICU and DETAW v2.0. Farming practices in the lowlands can be such that farmers need to drain out the subsurface water in order to maintain the water table below the root zone. But, the needed extent for this type of draining is unknown. The estimation of seepage in DETAW v2.0 is likely low. DETAW v2.0 assumes that seepage water is available to plants in the lowlands at a rate of 0.3 inch per foot of crop rooting depth per month. This value was determined from studies which adjusted assumed seepage while calibrating soil moisture storage. Actual seepage could be more, some of which could be stored in the ground surface to be consumed later or passed to deep percolation. The seepage stored beneath the ground surface becomes part of the subsurface flow.

The estimation of leach water applied in Delta lowlands in DETAW v2.0 is also likely low. Based on the 1981 report, *Joint DWR and WPRS Delta Channel Depletion Analysis*, DICU and DETAW v2.0 assume that the total volume of annual leach water in Delta lowlands equals 26,800 acres of flooded area to a depth of 2 feet. Considering that the Delta lowlands, most of which are used for agriculture, cover approximately 350,000 acres, the estimate of 26,800 acres receiving leach water seems low.

Taking the above study into account, and after reviewing past studies of in-Delta water use and sources and well data from the Delta, the estimation of channel depletions in DETAW v2.0 was modified by introducing subsurface water and groundwater, and changing the assumed amount of seepage and leach water applied. By comparing modeled EC in the west Delta to observed EC, simple, repeatable patterns were studied in the amount of adjustments to channel depletions needed to bring DSM2-simulated EC in the west Delta more in line with the observed EC in the west Delta. This process is explained in detail below. The net effect of these changes is that Delta channel depletions and Delta consumptive use will always be different — perhaps sometimes may be very different. DSM2-QUAL was then recalibrated by adjusting dispersion coefficients at the Sacramento-San Joaquin rivers confluence area. In this sense, DETAW-based channel depletions and DSM2-QUAL were calibrated and validated together. This process is referred to as an “integrated model approach” and the extension of DETAW is labelled DCD v1.0.

2.2 An Integrated Model Approach: Calibrating and Validating DCD v1.0 and DSM2 Together

As implied above, accurately estimating crop ET in the Delta does not mean the subsequent estimation of channel depletion is accurate, given the complex interaction of water sources. Tables 2-1 and 2-2 list the factors behind channel depletion related to channel diversion, drainage, and seepage for two Delta islands from studies in the 1950s. Hydraulic conductivity, drainage rate, and leaching volumes and timing are difficult or impossible to measure directly, and the scarcity of this data means DCD v1.0 cannot be directly calibrated and validated. At best, available observed data can confine the parameters and the channel depletions within reasonable magnitudes of values.

While values for all the parameters related to channel depletions associated with each island may be unavailable, estimating net Delta-wide channel depletion can make use of the relationship between Delta outflow and salinity in the west Delta. Other than periods of extended high Delta outflow, the degree of Delta salinity intrusion is sensitive to Delta outflow. Delta hydrodynamic and water quality models DSM2, Semi-Implicit Cross-scale Hydroscience Integrated System Model (SCHISM), and Resource Management Associates (RMA) Bay-Delta model, as well as the G model for X2 (the distance from Golden Gate to the location within the Delta of the 2 part per thousand isopleth measured at 1 meter from the channel bottom) all show that estimated EC in the west Delta is strongly related to the net Delta outflow (NDO). Low NDO for a sufficiently long duration will cause significant salinity intrusion, while high NDO will eventually freshen the Delta.

Calculated NDO is the total Delta inflow less exports and total Delta channel depletion. Errors in modeled historical Delta channel depletion will cause errors in modeled NDO, which, in turn, cause errors in the modeled extent of salinity intrusion. When NDO is low, particularly over an extended period, the simulated location of high salinity gradient in the west Delta can vary widely with relatively small changes in estimated NDO. Currently, both DSM2 and SCHISM fail to simulate salinity intrusion well during many dry and critical years (Figures 2-10 through 2-17).

Characteristics of DSM2's simulation of historical Delta EC during dry and critical dry years have been investigated since DSM2 was developed in the 1990s. In the *2006 Bay-Delta Office Annual Report* (California Department of Water Resources 2006), DWR noted large discrepancies between observed and DSM2-simulated EC during summers of dry periods over the period of 1975–1989. In the 2015 annual report, similar accuracy concerns were noted for the period of 1990–1991 (California Department of Water Resources 2015). From 2013 to 2015, DSM2, SCHISM, and other Delta models with the Delta consumptive use generated by DICU, significantly underestimated EC during the wintertime.

Sensitivity of model parameters has been analyzed to investigate whether model parameters adjustments can reduce errors. Testing shows that model calibrations can moderate the errors but do not change the overall error trends. This implicates the accuracy of assumed model inputs as being the problem, of which Delta channel depletion is the least known — all other inputs of Delta hydrodynamics models being based on observed data of some kind. As a result, Delta channel depletion is assumed the major reason for this kind of EC bias. A better estimate of Delta channel depletion is believed necessary for producing meaningful simulations of salinity intrusion when NDO is low. This is consistent with the DWR report (Owen LW and Nance DH 1962) which found that errors in Delta channel depletion to be the most likely the cause in the lack of relationship between computed Delta outflow and observed salinity intrusion.

Some unaccounted components in DETAW v2.0, such as the groundwater and subsurface flow, are likely important sources of errors in channel depletion estimates. If this is true, then the quantity of subsurface water and groundwater of the whole Delta in DCD v1.0 can be estimated by adjusting parameters to simulate reasonable ECs in the Sacramento-San Joaquin rivers confluence area, where the salinity-NDO correlation is the most sensitive. Although the channel depletion associated with each island may not be correct, Delta channel depletion will be confined to a reasonable range and discrepancies between the observed and simulated EC will be reduced greatly. This better allows major trends in EC under the low NDO condition to be captured. Considering this, and the sensitive response of salinity intrusion to Delta channel depletion, integrating Delta channel depletion and the hydrodynamics and water quality model components of DSM2 is necessary. The resulting estimated Delta channel depletion is assumed sufficiently accurate when two conditions are met: a DCDv1.0-DSM2 integrated model simulates salinity intrusion well under most low-NDO conditions, and the adjustments to channel depletions follow simple concepts that are consistent with the literature on Delta channel depletions and can be applied to hypothetical or planning studies as well as to historical simulations since 1922.

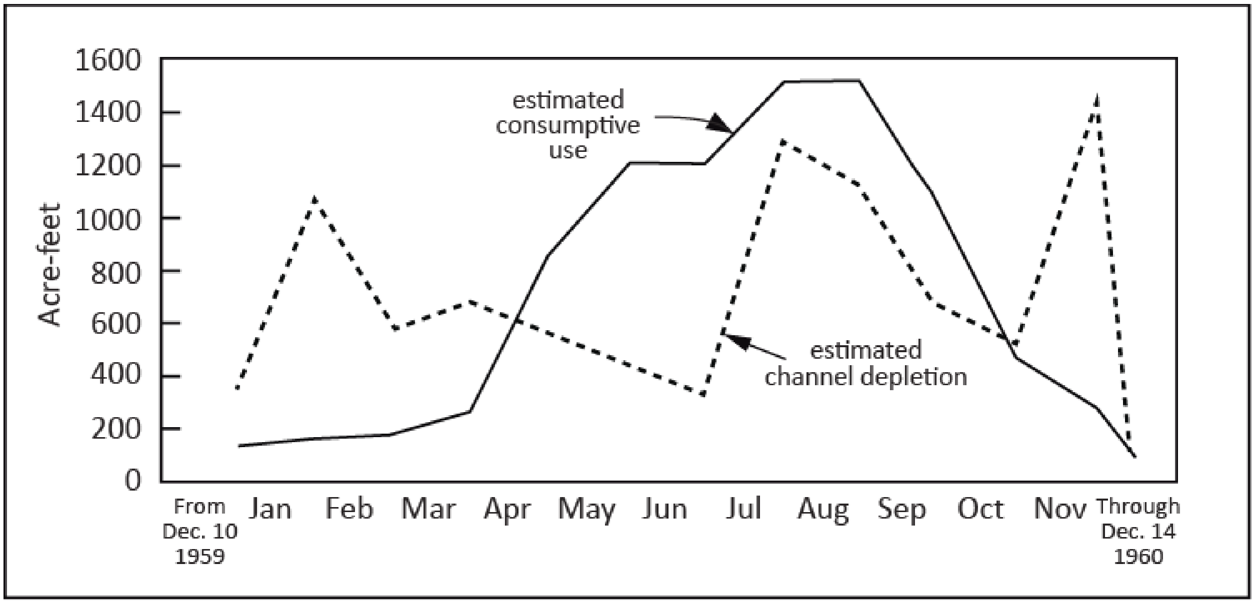
In modifying Delta channel depletion based on Delta ET demands, three parameters were considered: subsurface water as a source in Delta lowlands, groundwater as a source in Delta uplands, and applied leach water and subsequent drainage in Delta lowlands. A justification for allowing for adjusting each of these follows.

2.2.1 Considering Subsurface Water and Groundwater as Additional Water Supplies

DETAW simulates both the water balance on the ground surface of Delta islands and channel depletion. *Channel depletion* is the net amount of water transferred between Delta channels and islands and includes diversions, drainage and seepage. The components of the ground surface water balance of Delta islands include the water demand in crop ET and the water supplies, such as precipitation, seepage, and applied water. DICU and DETAW v2.0 assume that, outside of precipitation and seepage, applied water from channels is the only additional water source.

DCD v1.0 modifies DETAW v2.0 by considering subsurface water and groundwater as additional water supplies in calculating channel depletion. Specifically, it assumes that in lowlands the applied water in DETAW is a mixture of the channel diversion and the subsurface water, and in uplands it is a mixture of channel diversions and pumped groundwater. The subsurface water in lowlands is assumed to be a combination of extra seepage temporarily stored below the surface and upward-moving groundwater. The presence of stored seepage water and groundwater during the irrigation season reduce the amount of surface channel water needed to satisfy crop ET. As a result, channel depletions are assumed reduced during the irrigation season compared to those in DETAW v2.0. This is consistent with the findings of the 1962 report on Twitchell Island (Owen LW and Nance DH 1962), shown in Figure 2-1. Details justifying these changes to water supply are presented below.

Figure 2-1 Comparison of Estimated Consumptive Use with Estimated Channel Depletion on Twitchell Island



Source: *Hydrology of the Sacramento-San Joaquin Delta*, Owen LW and Nance DH 1962

The applied water calculated in the ground surface water balance is the available water (water made available) that Delta crops absorb in the root zone, excluding rainfall and seepage. Besides from surface channels, the applied water crops use may come from the subsurface area or deeper groundwater. In Delta lowlands, a source of this water is seepage from adjacent channels while in Delta uplands pumped groundwater is a source.

2.2.1.1 Subsurface Water in Delta Lowlands

Significant land subsidence has occurred in Delta lowlands because of oxidation of peat soils and wind erosion. This subsidence helps create a complex hydrological cycle in the Delta lowlands (Figure 2-2).

Ingebritsen SE, et al. (2000) reported that subsidence in the Delta has resulted in groundwater levels being close to the ground surface. They also reported that reclamation and agricultural practices have led to subsidence of the land surface on the developed islands in the central and western Delta at long-term average rates of 1 to 3 inches per year since 1930. Many islands in the central Delta are presently 10 to 25 feet below sea level. Maintaining groundwater levels below crop rooting zones is critical for successful agriculture, especially for islands that lie below sea level. Many farmers rely on an intricate network of drainage ditches and pumps to maintain groundwater levels at approximately 3 to 6 feet below ground surface. The accumulated agricultural drainage is pumped through, or over, the levees and discharged into adjoining streams and canals.

Because of this subsidence in Delta lowlands, three issues need to be considered in DCD v1.0. First, the growing head difference between surface water and groundwater year after year has increased the amount of channel actual seepage and groundwater moving upward, neither of which have been previously considered in Delta consumptive use models. Second, the actual drainage is much more than the DETAW v2.0 calculated drainage resulting from runoff and water irrigation efficiency, because some Delta lowlands farmers need to continuously pump water into their drainage channels to maintain groundwater levels below the root zone. Third, the root zone acts as a reservoir, holding both surface water and groundwater. As a result, the water in the root zone is a mixture of the water directly diverted from surface channels, seepage stored in the root zone, and groundwater (through capillary rise). Seepage from surface channels can be stored in the root zone or percolate into the groundwater. The seepage stored in the root zone would be consumed by the crops gradually. Because of this, the stored seepage can be much more than the seepage the crops actually use (i.e., the effective seepage), and it is available for crop ET that is in addition to surface diversions and rainfall and effective seepage. The subsurface water consisting of stored seepage and groundwater is this extra source, which DETAW v2.0 does not account.

DWR reports in the 1950s presented subsurface water as a significant water source for two islands in the Delta lowlands (Figure 2-2): Medford Island (Kabakov S, et al. 1956b) and McDonald Island (Kabakov S, et al. 1959). Through a combination of analyzing the anionic characteristics of Medford Island waters, assuming water sources, and referencing geochemical diagrams, DWR estimated that 10 cubic feet per second (cfs) of groundwater inflow was made up of approximately 80 percent contiguous channel water, 18 percent Mokelumne River area groundwater, and 2 percent connate water (Kabakov S, et al. 1956b). As shown in Table 2-1, siphon inflow to Medford Island was estimated to be 103 acre-feet from July to November in 1953, while subsurface inflow was estimated at 2,737 acre-feet. Considering precipitation and siphon inflow, the subsurface inflow was estimated to account for approximately 90 percent of the entire inflow to Medford Island.

The study of the sources of groundwater inflow to McDonald Island found very similar results. The estimated 37 cfs of subsurface inflow was estimated composed of approximately 80 percent San Joaquin River water, 19 percent Mokelumne River area groundwater, and 1 percent connate water (Kabakov S, et al. 1959). As shown in Table 2-2, subsurface inflow in McDonald Island was estimated to contribute approximately 40 percent of the whole inflow to the island.

Figure 2-2 Land Subsidence in the Delta

Source: *Delta Subsidence in California; The sinking heart of the State,* Ingebritsen SE, et al. 2000

Considering the significant subsidence experienced by islands in the Delta lowlands since the 1950s, seepage and groundwater today likely contribute more to subsurface water than was estimated in these past reports because of the larger differences between island land-surface elevations and adjacent channel water-surface elevations. While the amount of subsurface inflow to each Delta island varies, this source of water supply to Delta lowlands cannot be neglected. Any estimate of Delta channel depletions by DCD v1.0, or any other model, needs to reasonably account for variable subsurface flow as a source to meet water demands.

The two reports mentioned above also analyzed the spatial distribution of subsurface water. The report on Medford Island referred to an old investigation of using water table and piezometric gradients to estimate flow of groundwater in several tracts in the Delta lowlands from 1924 through 1927. Findings were

Table 2-1 **Derivation of the Subsurface Inflow to Medford Island, 1953 (in acre-feet)**

Month	Inflow			Disposal			Subsurface Inflow	
1953	Precipitation	Siphonage	Total	Drainage	Consumptive Use	Total	Excluding Ground water Storage Changes	Including Ground water Storage Changes
July	0	13	13	68	440	508	495	418
August	8	90	98	216	748	964	866	908
September	0	0	0	122	605	727	727	718
October	25	0	25	97	462	559	534	625
November	116	0	116	99	132	231	115	-
Total	149	103	252	602	2387	2,989	2,737	-

Source: Table 8 from *Investigation of the Sacramento-San Joaquin Delta, Report No. 2, water supply and water utilization on Medford island*, Kabakov S, et al. 1956.

Table 2-2 **Derivation of the Subsurface Inflow to McDonald Island, 1953 (in acre-feet)**

Month 1953	Inflow			Disposal			Subsurface Inflow
	Precipitation	Surface Diversion	Total	Drainage	Consumptive Use	Total	Excluding Groundwater Storage Changes
May	250	3,250	3,500	3,430	1,750	5,180	1,680
June	240	3,640	3,880	5,480	2,230	7,710	3,830
July	0	4,630	4,630	5,470	2,580	8,050	3,420
August	40	2,950	2,990	3,560	2,360	5,920	2,930
September	0	1,660	1,660	1,760	1,700	3,460	1,800
October	130	1,180	1,310	1,490	1,100	2,590	1,280
November	600	2,010	2,610	2,810	580	3,390	780
Total	1,260	19,320	20,580	24,000	12,300	36,300	15,720

Source: Table 10 from *Investigation of the Sacramento-San Joaquin Delta, Report No. 3, water supply and water utilization on McDonald Island*, Kabakov S, et al. 1959.

presented in a report published by the Division of Water Resources, *Irrigation Investigations in the Sacramento-San Joaquin Delta – 1927*. This study indicated that on one tract in the Delta lowlands, groundwater flowed inward from surrounding channels several hundred feet, and that in the interior of the tract there was a piezometric gradient that would cause a vertically upward movement of groundwater. It also described the spatial distribution of the two components of the subsurface flow. It appears that at Delta islands in the lowlands, seepage flows inward from the surrounding channels and some groundwater moves upward in the interior.

2.2.1.2 Groundwater Pumped from Wells in the Delta Uplands

DWR's North Central Region Office (NCRO) collects Delta groundwater wells information and records values in the DWR Water Data Library (WDL). Approximately 1,000 groundwater wells in the Delta region are included in the WDL (http://wdl.water.ca.gov/waterdatalibrary/). Among these wells, 32 have been used for irrigation. Figure 2-3 shows that most of the WDL-recorded wells are located in the Delta uplands. Figure 2-4 graphically presents examples of depth to groundwater data at four irrigation wells shown in Figure 2-3. Groundwater levels from these irrigation wells show seasonal and long-term trends: lowering during the irrigation season and rising afterward. During multiple-year droughts, such as 1976–1977 and 1985–1992, the groundwater level declined continuously, indicating that groundwater pumping exceeded recovery inflow for those years.

A Bay Delta Conservation Plan (BDCP) report (California Department of Water Resources, et al. 2016) estimated average annual groundwater pumping in the upland peripheral Delta areas to range between 100,000 and 150,000 acre-feet, for both domestic and agricultural uses. The groundwater wells database produced by the NCRO contains 456 irrigation wells in the Delta (Figure 2-5). Most wells are located in the uplands in the vicinity of Stockton, Tracy, Contra Costa Water District, and the north Delta area. The wells adjacent to rivers may be monitoring seepage instead of providing groundwater.

Brown (2004) reports that most diversions from surface channels in the Delta uplands were made by pumping with additional irrigation supplies coming from wells and diversions from internal drains. This means the water pumped from groundwater wells is another source of irrigation.

Figure 2-3 Distribution of the Groundwater Wells used by the Water Data Library to Collect Groundwater-Level Data

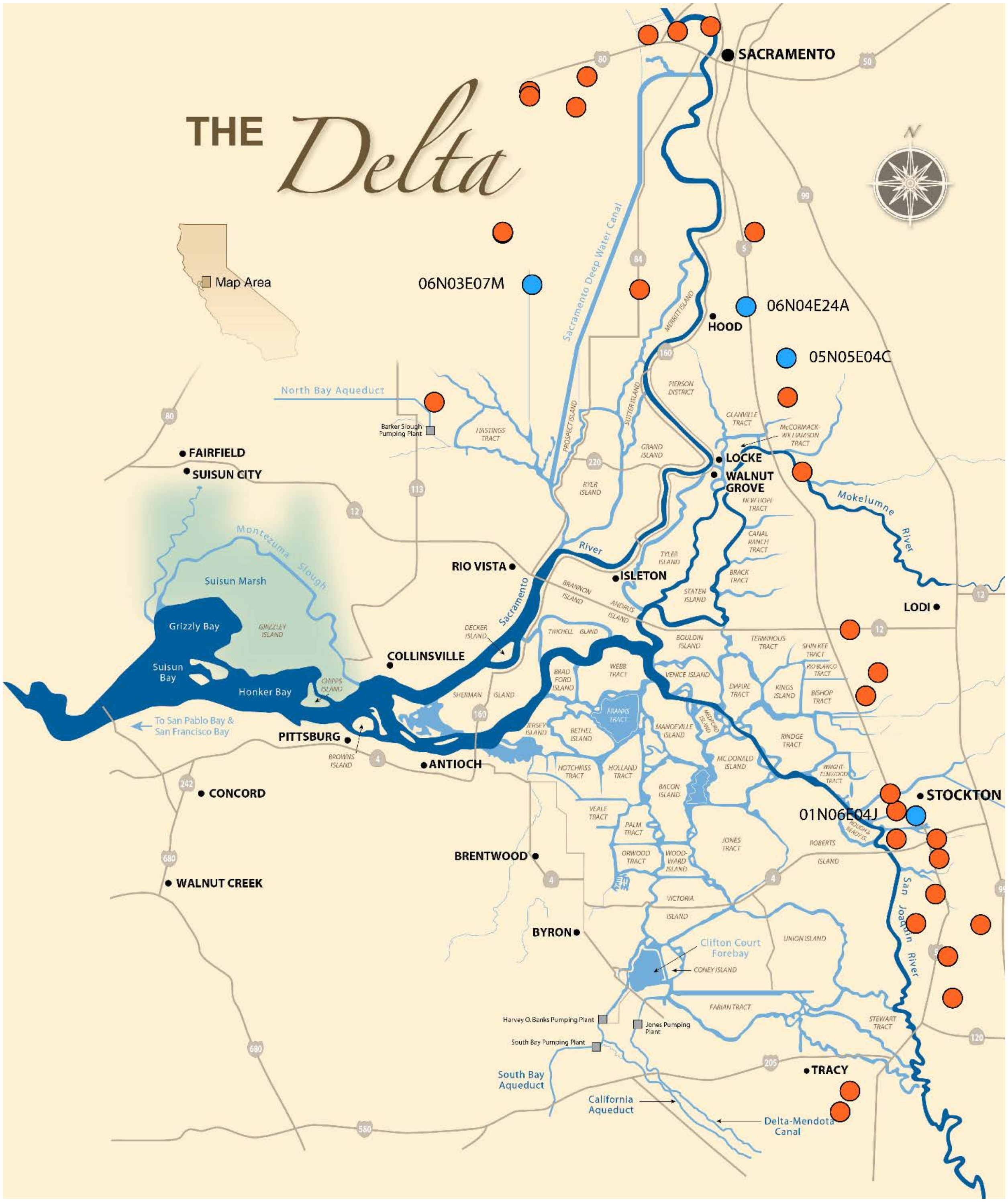
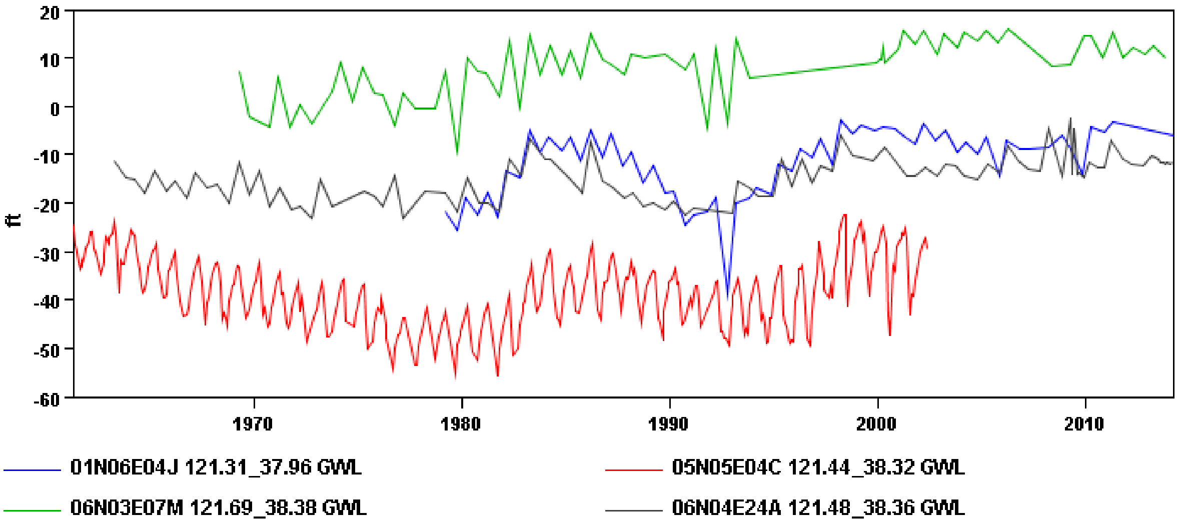
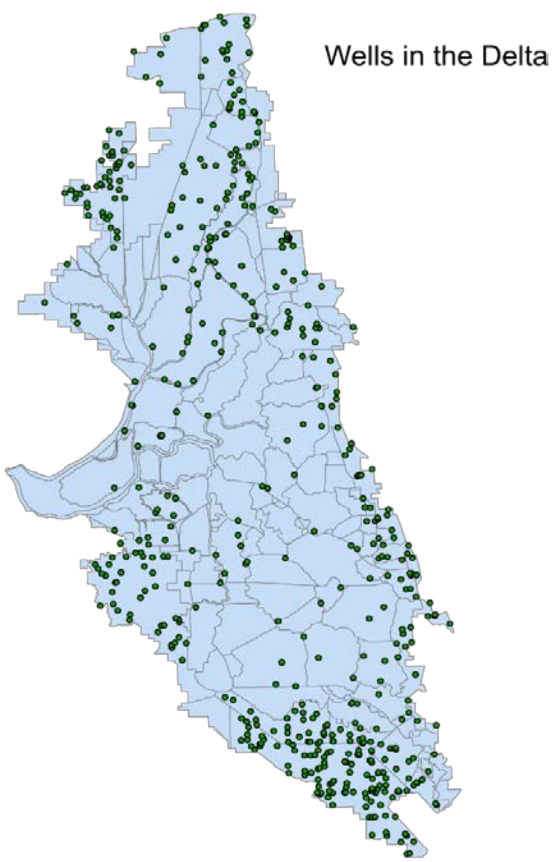


Figure 2-4 **Depth of Groundwater Levels Below Land Surface of Four Wells (locations shown in Figure 2-2)**



Source: California Department of Water Resources' Water Data Library

Figure 2-5 **Irrigation Well Locations in the Delta**



Source: California Department of Water Resources, North Central Region Office database.

2.2.2 DCD v1.0 Modifies the Amount of Applied Leach Water and Subsequent Draining of Islands

Both DETAW v2.0-based and DICU-based DSM2 EC simulations significantly underestimate EC in winter and spring of many dry and critical dry years such as 1991, 1992, 2000, 2004, 2005, 2008, as well as the recent continuously critical dry years 2013 through 2015. Similar to the consistent overestimation of EC in summers of many dry years, this pattern of error in simulated EC seems related to estimated Delta channel depletion, which appears to be too low, perhaps because of underestimating applied leach water and failing to account for the extra seepage water replenishing subsurface water. Currently, reliable data related to these two factors are not available. To determine the approximate magnitude of Delta channel depletion during the non-irrigation season, DCD v1.0 retains the same seepage assumptions as DETAW v2.0, while the leach-applied water was calibrated via the DSM2 historical EC simulation. Further investigation is needed to quantify any such seepage adding to subsurface storage.

2.2.3 Calibrating DCD v1.0 and DSM2 Together

2.2.3.1 Modifying the Calculation of Channel Depletions in Delta Lowlands and Uplands

As stated above, use of subsurface water in lowlands and groundwater in uplands to meet crop ET demands (Figure 2-6) needs to be accounted for to improve estimated Delta channel depletions. Subsequent simulated EC, DCD v1.0 assumes that the amount of the subsurface water or groundwater for crops is proportional to the water supply, excluding precipitation and effective seepage.

Figure 2-6 The Hydrology Cycle of Delta in Recent Decades

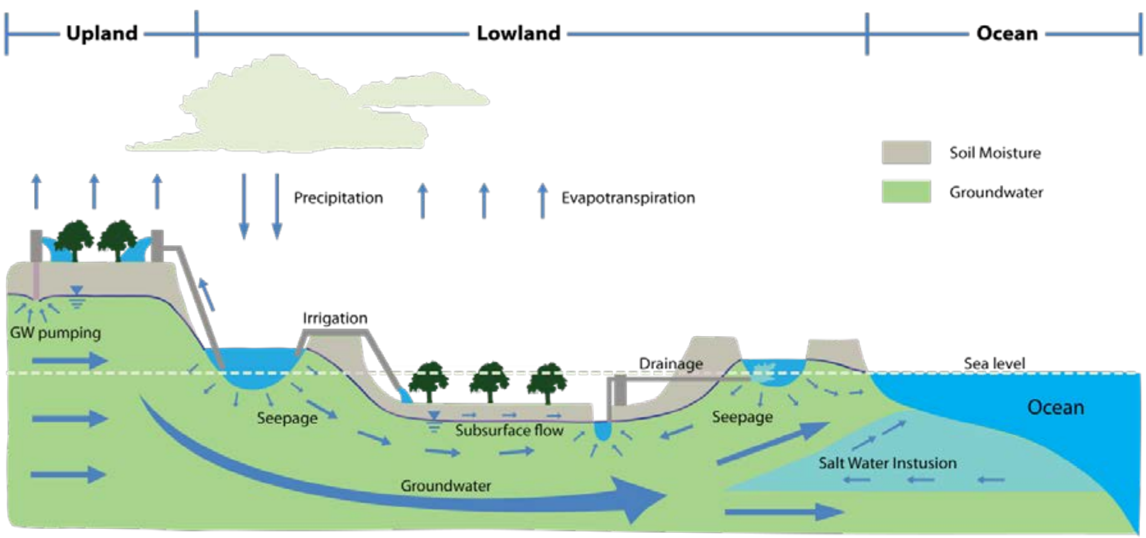
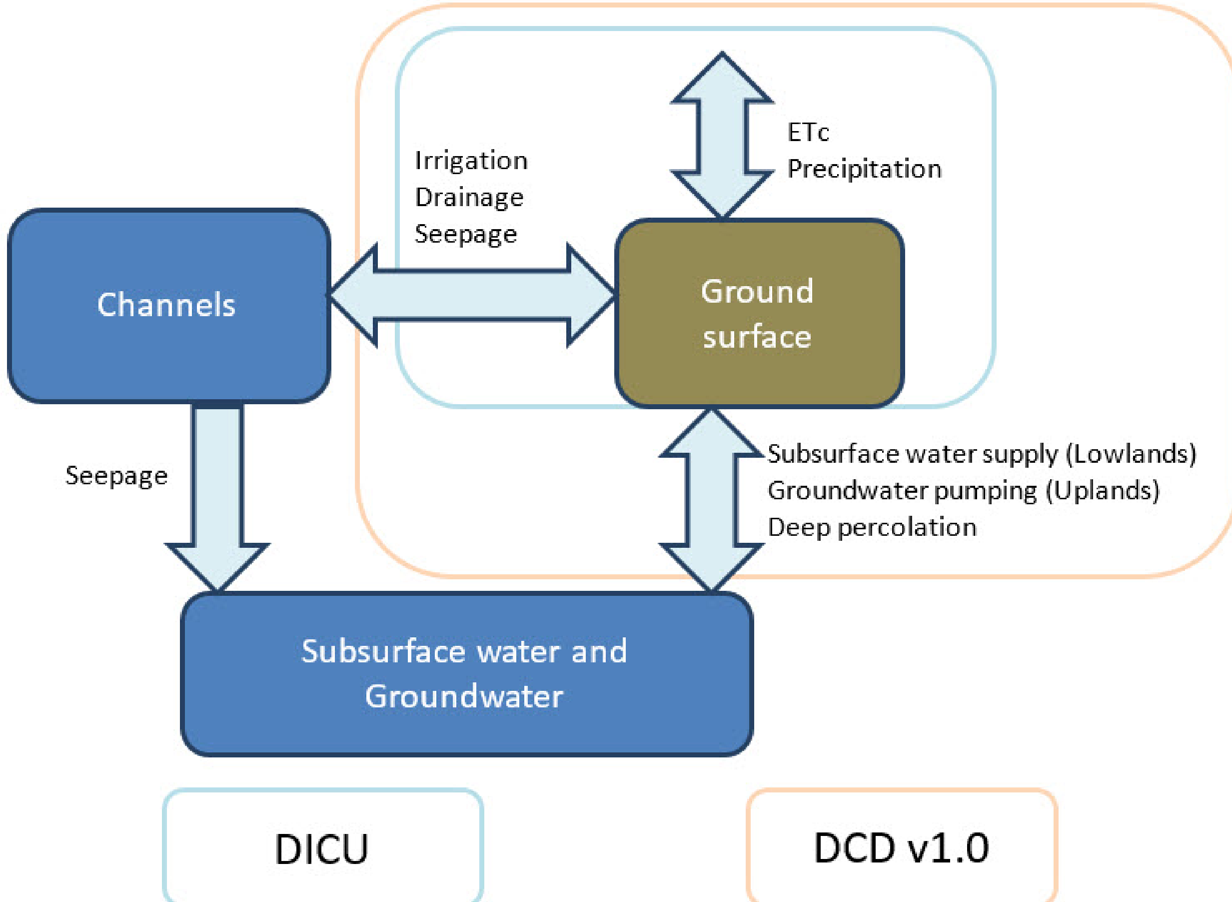


Figure 2-7 shows the difference in model framework between DICU and DCD v1.0. DCD v1.0 focuses on modifying the amount of leach water and quantifying the subsurface water in lowlands and groundwater in uplands which contribute to the crop ET. Appendix 2 shows the latest DCD v1.0 framework to calculate the channel depletion.

Figure 2-7 Differences of Water Interactions in DICU and DCD v1.0 Models



Notes: DCD = Delta Channel Depletion Model, DICU = Delta Island Consumptive Use

DCD v1.0 revises the equations [1] through [6] to calculate Delta island irrigation, drainage and seepage in lowlands and uplands.

$$\text{Channel depletion} = DIV - RET + S \quad [1]$$

$$DIV = (1\text{-}S_r)*I_{AN} / \eta + LW_A \quad [2]$$

$$RET = RO + I_{AN}*(1\text{-} \eta)/ \eta + LW_D + S_D \quad [3]$$

$$S = (1\text{-}S_r)*(S_E + S_D) \quad \text{(lowlands)} \quad [4]$$

$$S = 0,\ S_E = 0, \text{ and } S_D = 0 \text{ (uplands)} \quad [5]$$

$$RO = (1\text{-}DP)*(PPT\text{-}PPT_E) \quad [6]$$

Where:

DIV is the total diversion;

RET is the return flow;

LW_A is the applied leach water;

S is the total seepage;

RO is the runoff;

LW_D is the drained leach water;

S_D is the drained seepage;

S_E is the effective seepage;

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;

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

S_r is the contribution rate of the subsurface water (lowlands) or groundwater (uplands).

DCD v1.0 adds one coefficient, S_r, to the equations from DETAW v2.0. This term reflects the amount of subsurface water in lowlands and the groundwater contribution in uplands because DCD v1.0 assumes the subsurface water or groundwater is proportional to the calculated applied water. The applied leach water (LW_A) and the drained leach water (LW_D) also have been modified. All the terms in the equations, except for S_r, LW_A, and LW_D, remain the same as in DETAW-v2.0.

2.2.3.2 Quantifying the Subsurface Flow, Groundwater and Leach Water

The ground under Delta islands in the lowlands acts as a reservoir by storing surplus seepage, groundwater, irrigation water, and precipitation. This effective reservoir acts as a buffer and lessens the demand for surface water during the irrigation season. But, it is not possible to directly measure the amount of this subsurface water which supplies a portion of the crop water demand. Instead, old DWR reports were referenced to determine a reasonable range in subsurface water use rates. These rates were then adjusted by calibrating the integrated channel depletion-hydrodynamics-EC model. This process is described below.

2.2.3.2.1 Estimating the Amount of Subsurface Water Meeting Crop ET Demand in Delta Lowlands

In order to directly simulate water dynamics in the root zone in the Delta islands, reasonable estimates are needed for surface flows, regional and local groundwater characteristics, soil properties, climate, land use, and farming activities. With consideration of the temporal and spatial scales of DCD v1.0, the daily farming practices and local groundwater movement are full of uncertainties and difficult to simulate. Lacking most of this information, DCD v1.0 assumes that all the water sources in the root zone, such as from channel diversion, precipitation, seepage, and groundwater, are mixed. Water reaching the root zone from above, below, or laterally is assumed merged with the subsurface water. The root zone in Delta lowlands acts as a “reservoir” buffering the mismatches between the crop water demands and supplies.

When DETAW v2.0 calculates the daily ground surface-water balance, the seepage and applied water are assumed to directly come from channels. The estimated seepage is especially related to the crop rooting depletion and would be much less than the actual seepage because of Delta lowlands subsidence. The surplus seepage, more than crop needs, is assumed to be drained immediately and does not percolate into the ground. As a result, the estimation of soil moisture change in the root zone does not involve the resilience of the subsurface “reservoir.”

In DCD v1.0, the subsurface “reservoir” is assumed to temporarily store part of surplus seepage, surplus precipitation, surplus applied water, and groundwater. Because DCD v1.0 currently has not been connected to any groundwater model, a parameter, the subsurface water rate S_r, is introduced to represent the proportion of subsurface in the water supply, excluding precipitation.

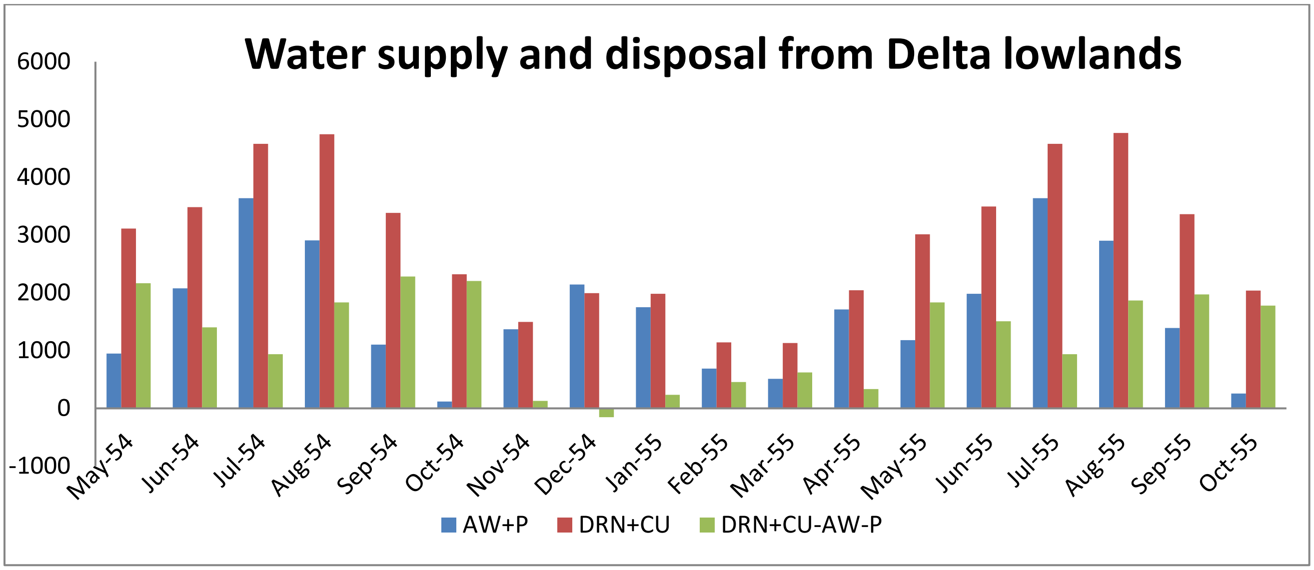
Because DCD v1.0 assumes the subsurface water is fully mixed, the subsurface water rate S_r for the seepage and applied water are assumed the same. This results in lower estimates of diversion and seepage from channels, which are now calculated as:

$$\text{Channel water depleted by irrigation} = (1-S_r)*I_{AN}/\eta \qquad [7]$$

$$\text{Channel water depleted by seepage} = (1-S_r)*(S_E + S_D) \qquad [8]$$

As presented in Report 4 (Kabakov S, et al. 1956c), a Delta island water balance based on field measurements of appropriate unit consumptive uses, drainage pumping and channel diversions of irrigated major crops, required adding significant amount of an unknown subsurface water as a source (Figure 2-8 and Table 2-3). This was because significantly more water was drained from the island than was introduced through precipitation and irrigation. Table 2-3 shows that the unknown water source (SSW) in lowlands is approximately 52 percent of the estimated water supply (AW+SSW), excluding precipitation. Report 4 proposes that this subsurface water consists of (1) groundwater storage changes, (2) stored seepage, and (3) rising water from deep-seated and remote sources. But, as mentioned above, the root zone contains not only seepage and groundwater, but also part of irrigation and precipitation. The water making up the 52 percent might include the surplus irrigation and precipitation not consumed by the crops in a short term. DETAW v2.0 already accounts for irrigation and precipitation, so the subsurface water rate in the model actually represents the portion of the surplus seepage and groundwater stored in the root zone. Based on Report 4, the subsurface water rate to provide supply for crop ET should be significant, but less than 52 percent of the estimated water supply.

Figure 2-8 **Water Supply and Disposal from Delta Lowlands (in cubic feet per second)**



Source: Based on Table 12 from *Investigation of the Sacramento-San Joaquin Delta, Report No. 4, quantity and quality of waters applied to and drained from the Delta lowlands,* Kabakov S, et al. 1956

Table 2-3 **Water Balance in Delta Lowlands, Water Year 1955 (in acre-feet)**

	Water Supply		Water Disposal		Subsurface Water (Drn+CU) – (AW+P)		
Month	**AW**	**P**	**Drn**	**CU**	**SSW**	**AW+SSW**	**SSW/(AW+SSW)**
Oct. 1954	6,560	350	46,817	91,164	131,071	13,7631	
Nov. 1954	0	81,441	46,537	42,573	7,669	7,669	
Dec. 1954	0	127,579	85,731	32,915	-8,933	-8,933	
Jan. 1955	0	104,161	95,668	22,371	13,878	13,878	
Feb. 1955	0	40,895	41,960	26,108	27,173	27,173	
March 1955	6,560	23,768	32,419	35,001	37,092	43,652	
Apr. 1955	26,240	75,499	37,628	84,015	19,904	46,144	
May 1955	45,910	24,467	49,813	129,609	109,045	154,955	
June 1955	118,060	0	71,084	136,679	89,703	207,763	
July 1955	216,450	0	80,606	191,744	55,900	272,350	
Aug. 1955	170,540	0	72,170	211,339	110,969	281,509	
Sept. 1955	65,590	17,127	43,116	156,805	117,204	182,794	
Total	655,910	495,287	703,549	1,160,323	710,675	1,366,585	52%

Source: Based on Table 12 in *Investigation of the Sacramento-San Joaquin Delta, Report No. 4, quantity and quality of waters applied to and drained from the Delta lowlands*, Kabakov S, et al. 1956.
Notes: AW = applied water, CU =consumptive use, Drn = drainage, P =precipitation, SSW = subsurface water

Within the range of 0 to 0.52, the subsurface water rate S_r in Delta lowlands has been calibrated to constant values of 0.25, 0.3, and 0.35, depending on the estimated extent of island subsidence. DCD v1.0, in accordance with DICU, assigns each constant subsurface water rate to one of three zones based on both the degree of subsidence and level of dissolved organic carbon in drainage (Marvin Jung and Associates Inc. 2000).

The integrated channel depletion-hydrodynamics-EC model is based on the linkage between Delta channel depletion and EC. Because EC in the western Delta is sensitive to NDO and DCD when NDO is relatively low, changes in estimated channel depletion can strongly affect EC simulation results. When calibrating all other parameters in the integrated model does not significantly improve simulated EC during periods of low NDO, the problem is likely that the hydrology (i.e., NDO and thus channel depletion) is in error. Modifying subsurface water rates in Delta lowlands should substantially help.

2.2.3.2.2 Estimating Groundwater as Source to Meet Crop ET Demands in Delta Uplands

Delta uplands do not have subsidence and extra water supply from subsurface water. But, based on the NCRO database and the 2016 Final BDCP/California WaterFix Environmental Impact Report/Environmental Impact Statement (California Department of Water Resources and U.S. Bureau of Reclamation 2016), groundwater does contribute to the water supply, but total Delta groundwater pumping amount is unknown. Similar to the subsurface water rate for Delta lowlands, a groundwater rate (GW) for Delta uplands is introduced in DCD v1.0 to represent the proportion of groundwater in the water supply, excluding precipitation. The model assumes the groundwater pumping is linearly correlated to the amount of irrigation wells. The NCRO database provides basic well information through 2009, including the years of drilling. The accumulated irrigation wells in the Delta starting from 1931 are shown in Table 2-4. DCD v1.0 assumes groundwater rates (the portion of groundwater which contributes to water supply, excluding precipitation) based on these well counts. The integrated model assumes a groundwater rate in 2009 of 0.4. For other years the groundwater rate per year is determined by Equation 9 which assumes that every well has the same yield:

$$GW\ (year) = N\ (year) * 0.4 / 456 \qquad [9]$$

Where:

N is the number of the accumulated irrigation wells for each year, see Table 2-4;

0.4 is the groundwater rate in 2009;

456 is the number of Delta irrigation wells in 2009.

2.2.3.2.3 Estimating Amount of Leach Water

DSM2-simulated EC based on DETAW v2.0 tends to be lower than observed EC in the winter and spring of dry years. This implies that DCD in the field is higher (and NDO is lower) than estimated in DETAW v2.0. In addressing this issue, it was first assumed that the underestimation of DCD is because of underestimating the amount of leach applied water.

Both DICU and DETAW v2.0 estimate 53,600 acre-feet of leach water is applied in the Delta each year by assuming:

- Leaching covers 26,800 acres.
- Water is applied evenly from October through December.
- Applied leach water has a depth of 1 foot of water ponded and another foot of water stored in the soil.

The volume and timing of applied leaching correspond to approximately 300 cfs over the three months. But, the U. S. Geological Survey (Ingebritsen SE, et al. 2000) reports that the drained root zone is 3 to 6 feet. Assuming the water placed in the root zone is one-half-foot per foot of soil, the depth of applied leach water in the root zone would be 1.5 to 3 feet instead of the assumed 1 foot. Then total depth of leach water would be 2.5 to 4 feet instead of 2 feet. Doubling the amount of applied leach water estimated would increase DCD 300 cfs over the three months.

But, based on the analysis of EC simulations, DCD would need to increase 1,000 to 2,000 cfs during October to December in order to bring DSM2-simulated EC in line with observed EC. DCD v1.0 assumes a maximum applied leach water that is five times higher than the previous assumed. This increases the maximum leach applied water to as much as 1,500 cfs.

DCD v1.0 also modifies applied leaching to account for precipitation. In DICU and DETAW v2.0, the assumed amount of applied leach water is constant each year. In DCD v1.0, the difference between the amount of precipitation and the target leach water volume is set as the amount of applied leach. The subsequent leach drainage is adjusted accordingly.

Table 2-4 DCD v1.0 Assumes the Groundwater Rates based on the Drilled Years of the Irrigation Wells

Year	Total Wells	Wells/Year	GW Rate		Year	Total Wells	Wells/Year	GW Rate
1931	2	2	0.00		1971	161	6	0.14
1932	2	0	0.00		1972	168	7	0.15
1933	2	0	0.00		1973	172	4	0.15
1934	2	0	0.00		1974	178	6	0.16
1935	2	0	0.00		1975	185	7	0.16
1936	2	0	0.00		1976	197	12	0.17
1937	2	0	0.00		1977	218	21	0.19
1938	2	0	0.00		1978	231	13	0.20
1939	2	0	0.00		1979	241	10	0.21
1940	2	0	0.00		1980	249	8	0.22
1941	2	0	0.00		1981	256	7	0.22
1942	2	0	0.00		1982	265	9	0.23
1943	2	0	0.00		1983	265	0	0.23
1944	4	2	0.00		1984	269	4	0.24
1945	4	0	0.00		1985	277	8	0.24
1946	4	0	0.00		1986	281	4	0.25
1947	7	3	0.01		1987	289	8	0.25
1948	10	3	0.01		1988	293	4	0.26
1949	12	2	0.01		1989	304	11	0.27
1950	23	11	0.02		1990	313	9	0.27
1951	34	11	0.03		1991	323	10	0.28
1952	36	2	0.03		1992	336	13	0.29
1953	46	10	0.04		1993	345	9	0.30
1954	56	10	0.05		1994	354	9	0.31
1955	65	9	0.06		1995	367	13	0.32
1956	77	12	0.07		1996	380	13	0.33
1957	89	12	0.08		1997	389	9	0.34
1958	100	11	0.09		1998	393	4	0.34
1959	107	7	0.09		1999	399	6	0.35
1960	115	8	0.10		2000	403	4	0.35
1961	119	4	0.10		2001	410	7	0.36
1962	123	4	0.11		2002	413	3	0.36
1963	124	1	0.11		2003	422	9	0.37
1964	130	6	0.11		2004	427	5	0.37
1965	135	5	0.12		2005	431	4	0.38
1966	138	3	0.12		2006	433	2	0.38
1967	143	5	0.13		2007	441	8	0.39
1968	148	5	0.13		2008	448	7	0.39
1969	151	3	0.13		2009	456	8	0.40
1970	155	4	0.14					

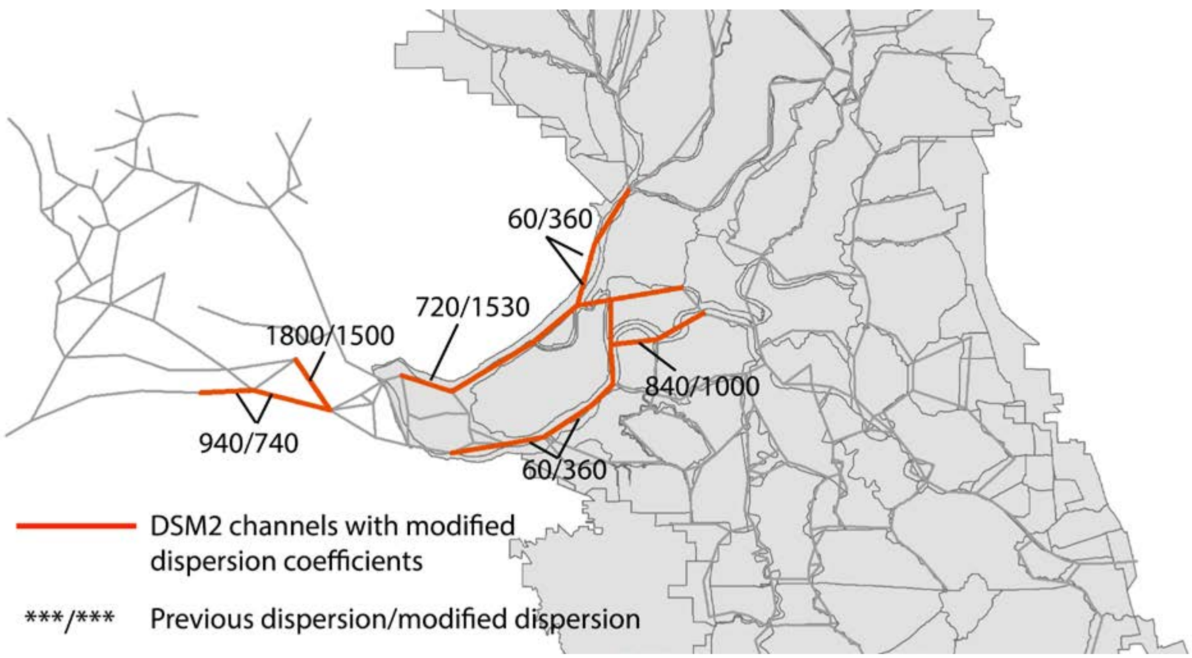
Note: DCD = Delta Channel Depletion Model, GW = groundwater

2.2.4 Preliminary Calibration of the Dispersion Coefficients in DSM2-QUAL

After the estimated historical Delta channel depletions were modified, a preliminary new calibration was done of the dispersion coefficients in DSM2-QUAL. The past DICU-based DSM2 calibration was unable to match EC at both Emmaton and Jersey Point during dry and critical dry years. If simulated EC matched observed EC at Emmaton, the simulated EC at Jersey Point would be too high. Dispersion coefficients were calibrated to make a compromise between simulating EC at Emmaton and Jersey Point, and then restraining salinity intrusion into the central Delta. The result of this approach was to generate very small dispersion coefficients in the Sacramento River and San Joaquin River confluence region. This calibration approach could cause too little salinity intrusion up Old River toward Rock Slough and Clifton Court Forebay under certain Delta outflow scenarios. In retrospect, the dispersion coefficients in the west Delta under DICU are probably partly an artifact of errors in the modeled Delta outflow because of errors in computed channel depletions.

The preliminary recalibration focused only on the Sacramento-San Joaquin rivers confluence area to determine whether simulated salinity intrusion in the western Delta would be improved. Figure 2-9 shows the DSM2 channels in orange, where the dispersion coefficients have been calibrated according to the DCD v1.0 based channel depletions. It also shows the dispersion coefficient changes of some channels before and after the preliminary recalibration. After the preliminary recalibration, the pattern of dispersion coefficients in the confluence area is more realistic than before. It is believed that any calibration based on better Delta channel depletion estimates will be more successful in the interior Delta as well.

Figure 2-9 DSM2 Channels where Dispersion Coefficients were Calibrated According to DCD v1.0-Based Channel Depletions



2.3 Comparing DSM2 with DCD v1.0 Based Simulated EC with Observed EC

Figures 2-10 through 2-17 compare observed EC to DSM2-simulated EC using DICU and DCD v1.0 from 1990 through 2009 at six locations. Figures 2-10 through 2-13 show the west Delta at Antioch (RSAN007), Emmaton (RSAC092), and Jersey Point (RSAN018). Figures 2-14 through 2-17 show the central and south Delta at Old River at Bacon Island (ROLD024), Middle River at Borden Highway (RMLD023), and Clifton Court Forebay (CLC). For reference, these figures include the monthly Delta channel depletion as calculated by DCD v1.0 and DICU. Generally, the maximum Delta channel depletion in every year calculated by DCD v1.0 is lower than that by DICU. Using lower DCD in the irrigation season as estimated by DCD v1.0, compared to DICU, lowers simulated Delta EC which substantially reduces model errors.

The observed EC from 1990 to 2009 at the six sites mentioned above were used to calibrate the integrated model. The observed EC at RSAN007, RSAC092, and RSAN018, are used to calibrate the amounts of subsurface water in lowlands and groundwater in uplands, and leach water in DCD v1.0. These three sites are sensitive to the salinity intrusion. The observed EC at ROLD024, RMID023, and CLC are used to partially calibrate dispersion coefficients in DSM2. The simulation period of 20 years captures a wide variation in Delta hydrology, including periods of low Delta outflow. The period also includes variable barrier operations and wide ranges in exports.

Overall, the figures show that EC estimated by DCD v1.0-DSM2 at these six sites has been significantly improved, except for RMID023. The simulated EC at RMID023 seems worse after calibration, although part of the overestimations at this location during the dry years have been reduced. This exception might be because of the preliminary calibration of the dispersion coefficients. If the dispersion coefficients for the entire Delta are recalibrated, the simulated EC at RMID023 could be expected to improve.

The integrated model only tried to quantify Delta channel depletion based on the correlation between Delta channel depletion and salinity intrusion. No attempt was made to refine the distribution of island-generated channel depletion to DSM2 nodes. This level of detail may affect simulated water quality in the interior Delta, including RMID023.

The calibrated DCD v1.0-DSM2 model reduces excessive underestimation and overestimation of EC by DICU-DSM2. It is not possible to consistently improve simulated EC over 20 years without studying the Delta physics, interpreting the physics into the model, and integrating DETAW and DSM2 model. Quantifying reasonable Delta channel depletion is very important to enhance the reliability of Delta surface-water models. In other words, the subsurface water and groundwater have significant impact on the river hydrodynamics and water quality in the Delta.

Figure 2-10 **Comparison of DSM2-Simulated EC and Observed EC in the Sacramento-San Joaquin Rivers Confluence Area under DCD v1.0 and DICU, 1990–1994**

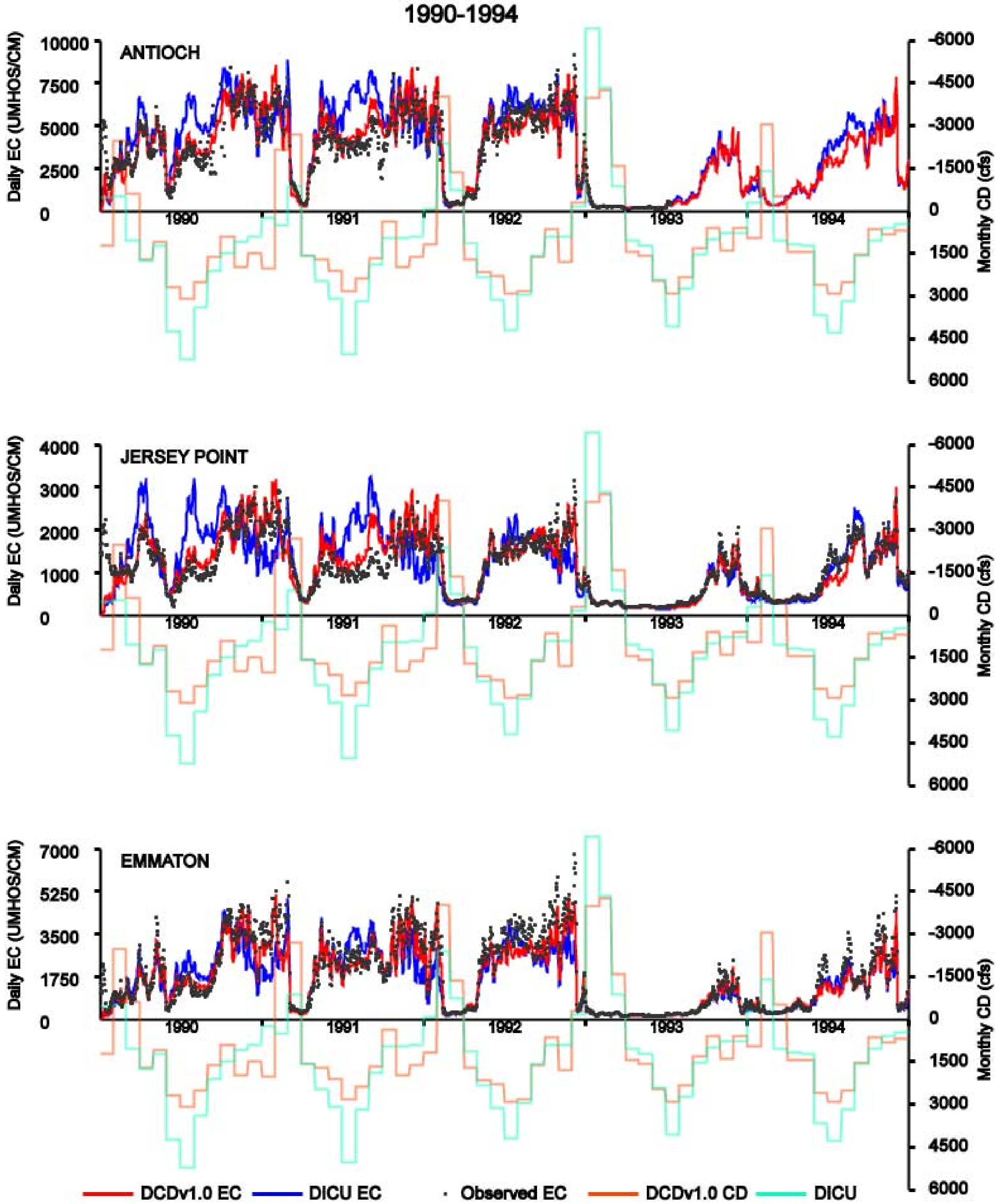


Figure 2-11 **Comparison of DSM2-Simulated EC and Observed EC in the Sacramento-San Joaquin Rivers Confluence Area under DCD v1.0 and DICU, 1995–1999**

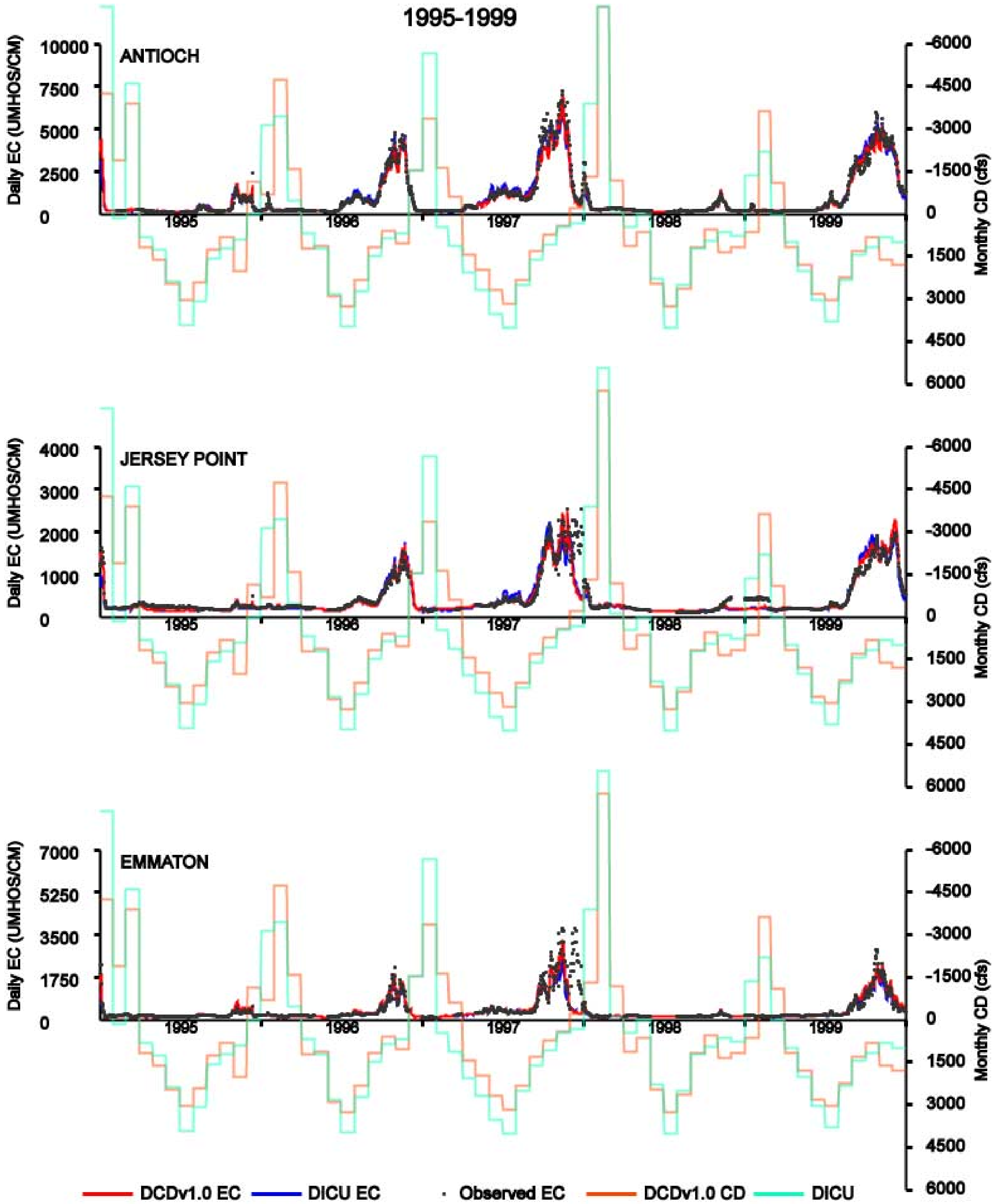


Figure 2-12 **Comparison of DSM2-Simulated EC and Observed EC in the Sacramento-San Joaquin Rivers Confluence Area under DCD v1.0 and DICU, 2000–2004**

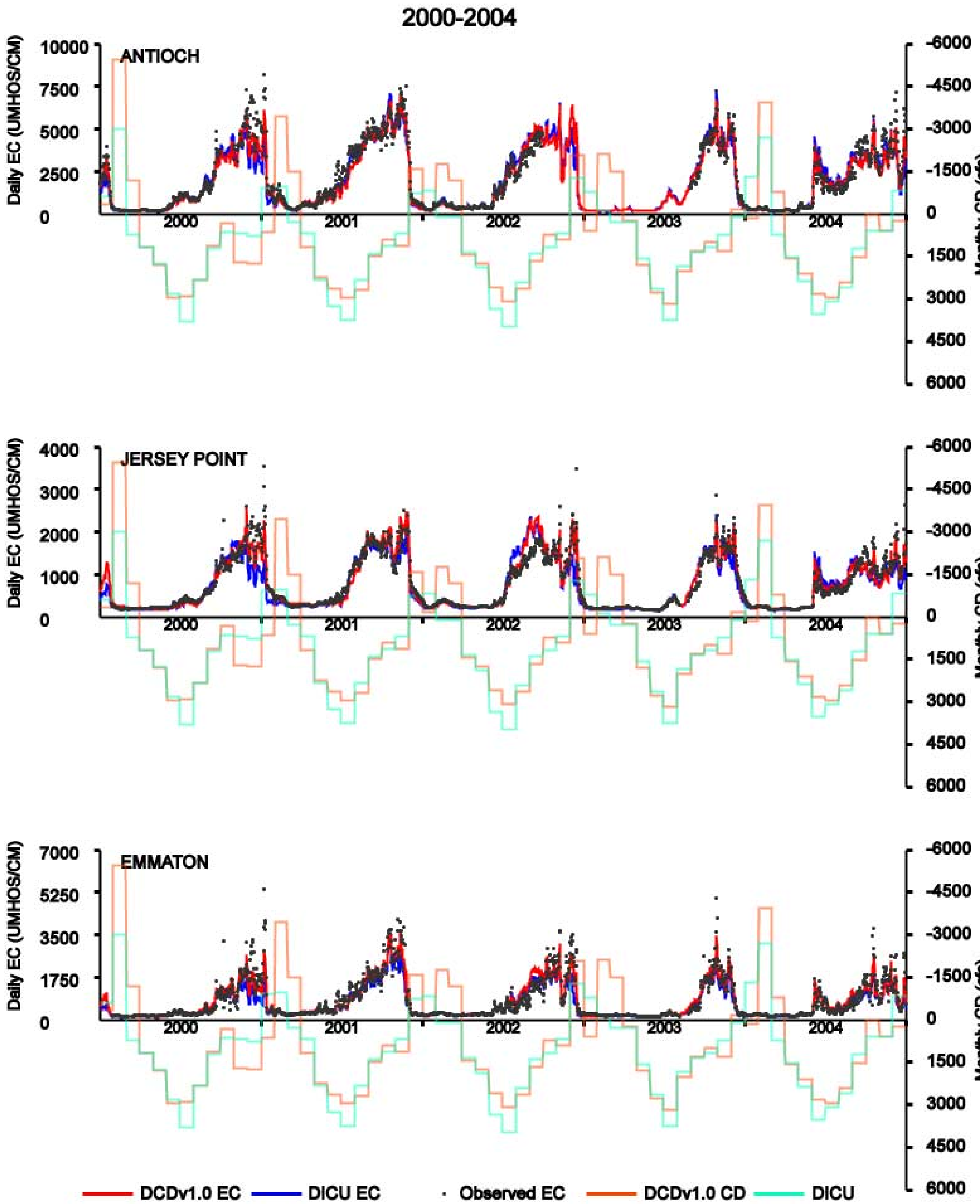


Figure 2-13 **Comparison of DSM2-Simulated EC and Observed EC in the Sacramento-San Joaquin Rivers Confluence Area under DCD v1.0 and DICU, 2005–2009**

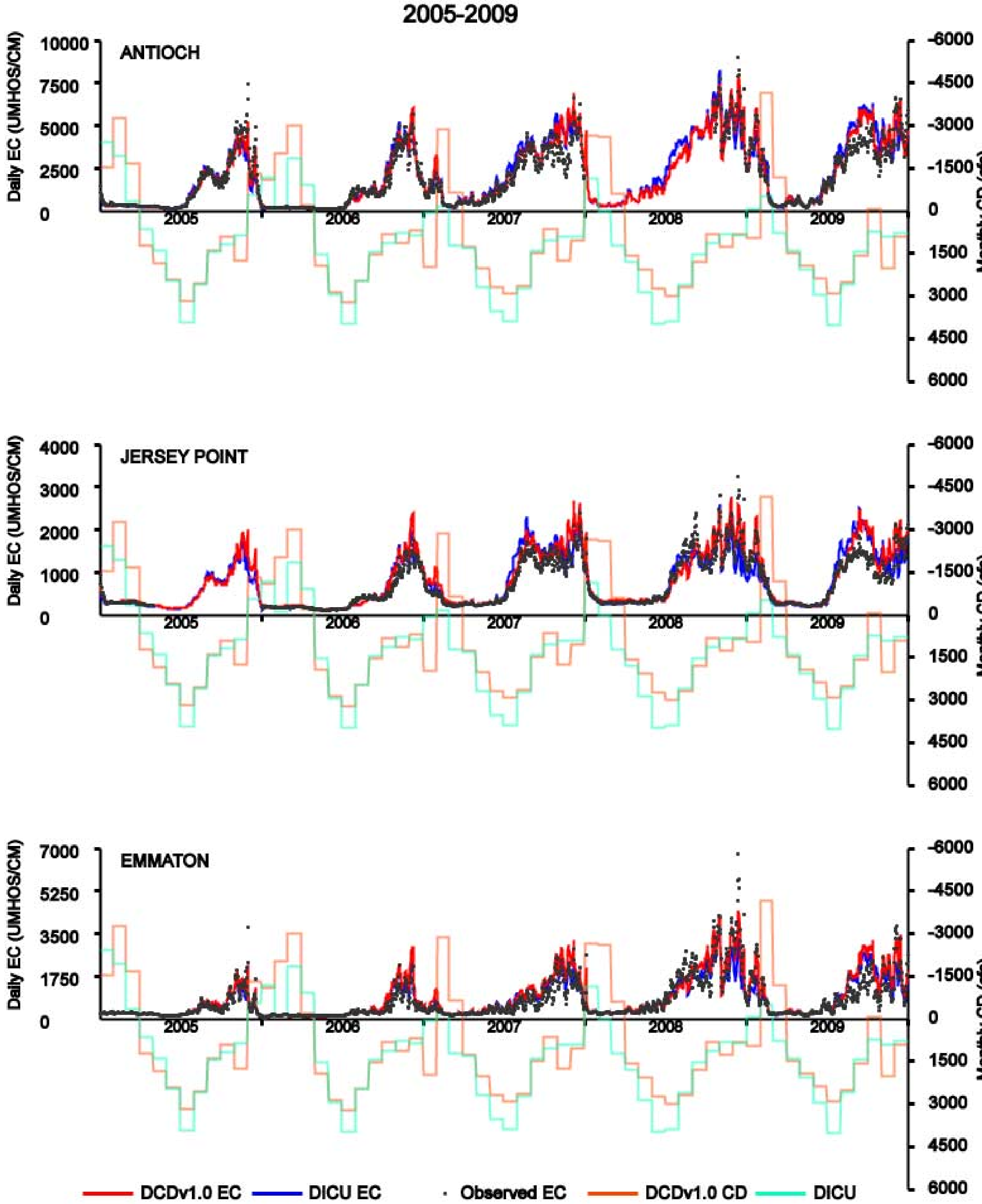


Figure 2-14 Comparison of DSM2-Simulated EC and Observed EC in the South Delta under DCD v1.0 and DICU, 1990–1994

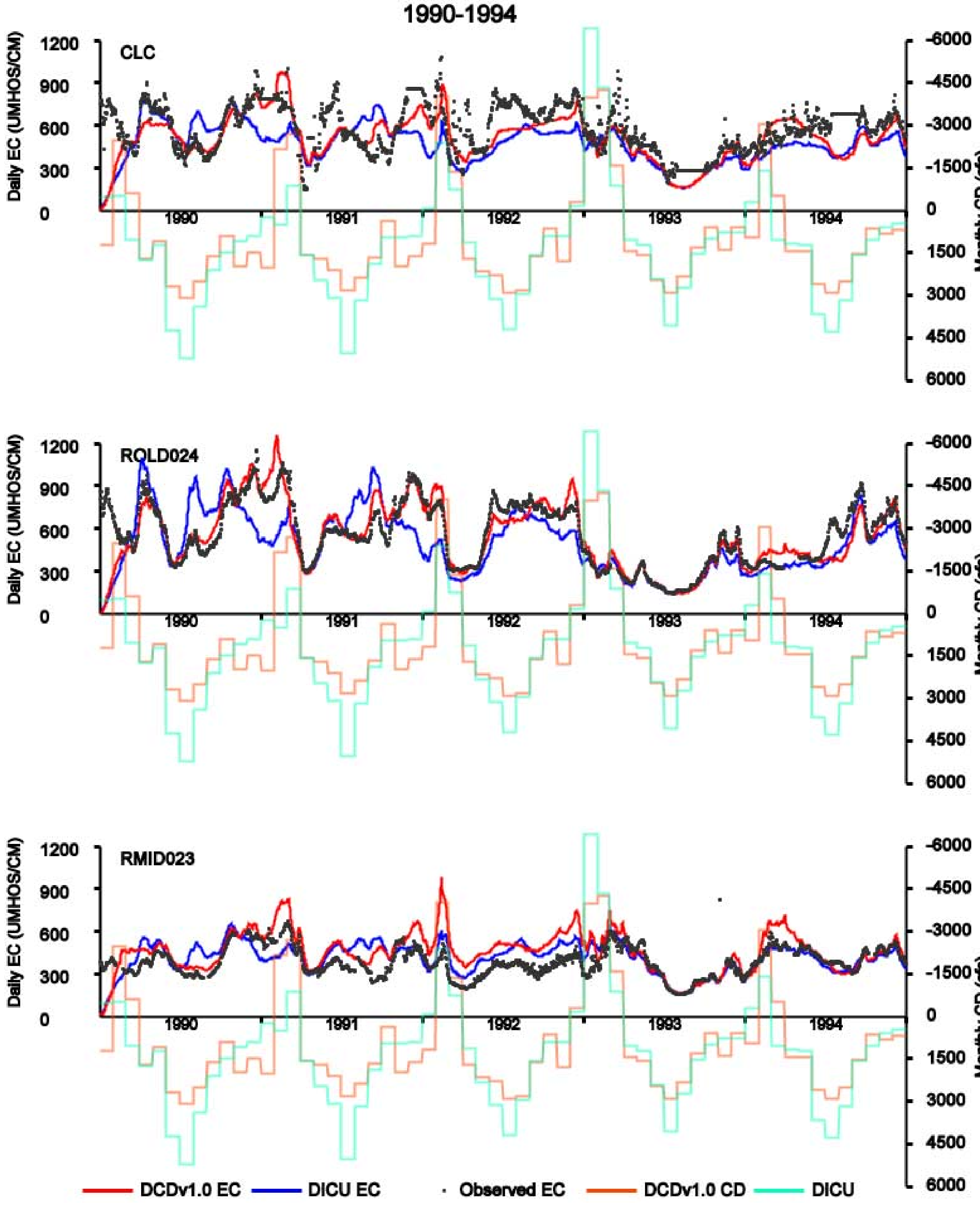


Figure 2-15 **Comparison of DSM2-Simulated EC and Observed EC in the South Delta under DCD v1.0 and DICU, 1995–1999**

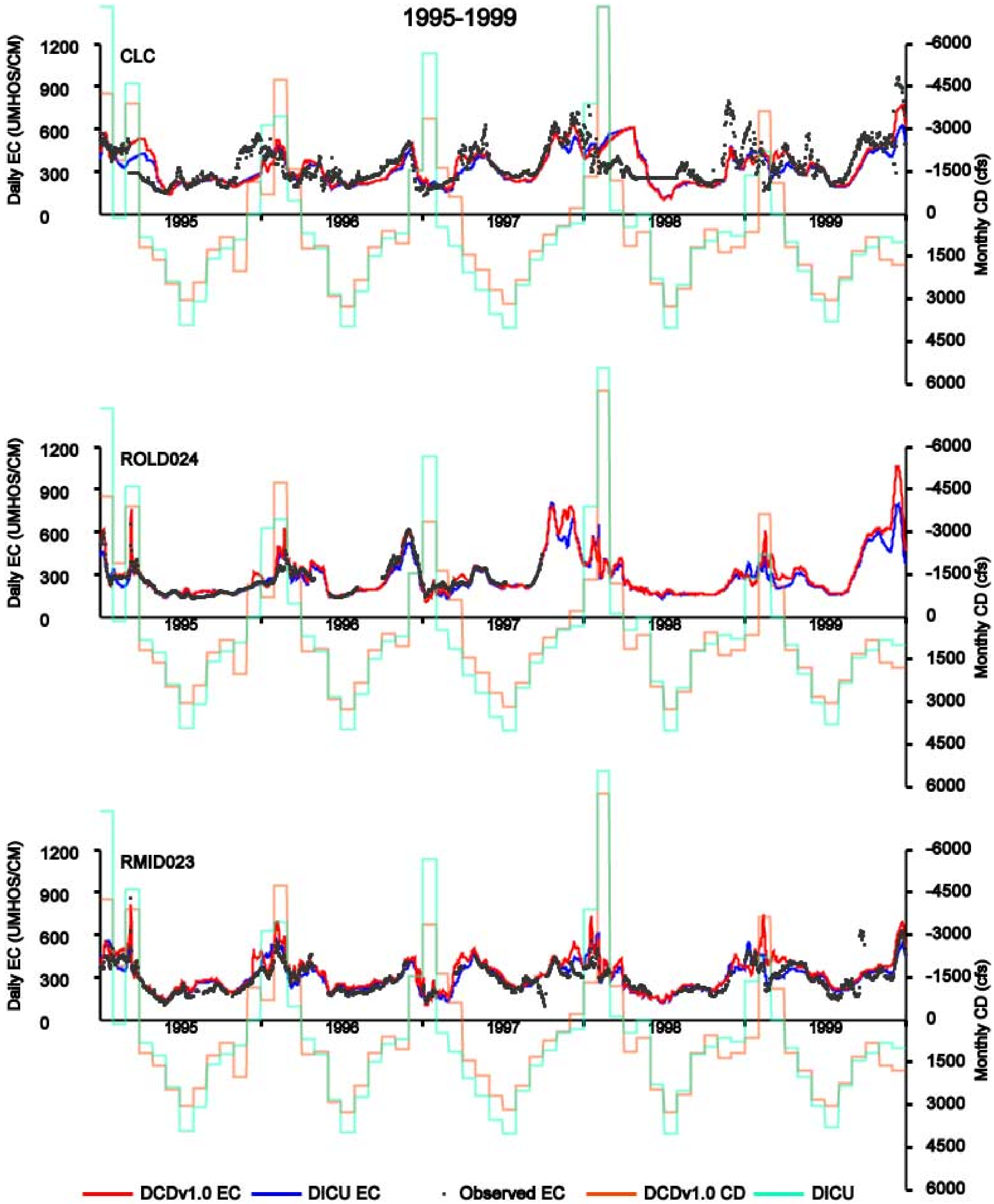


Figure 2-16 Comparison of DSM2-Simulated EC and Observed EC in the South Delta under DCD v1.0 and DICU, 2000–2004

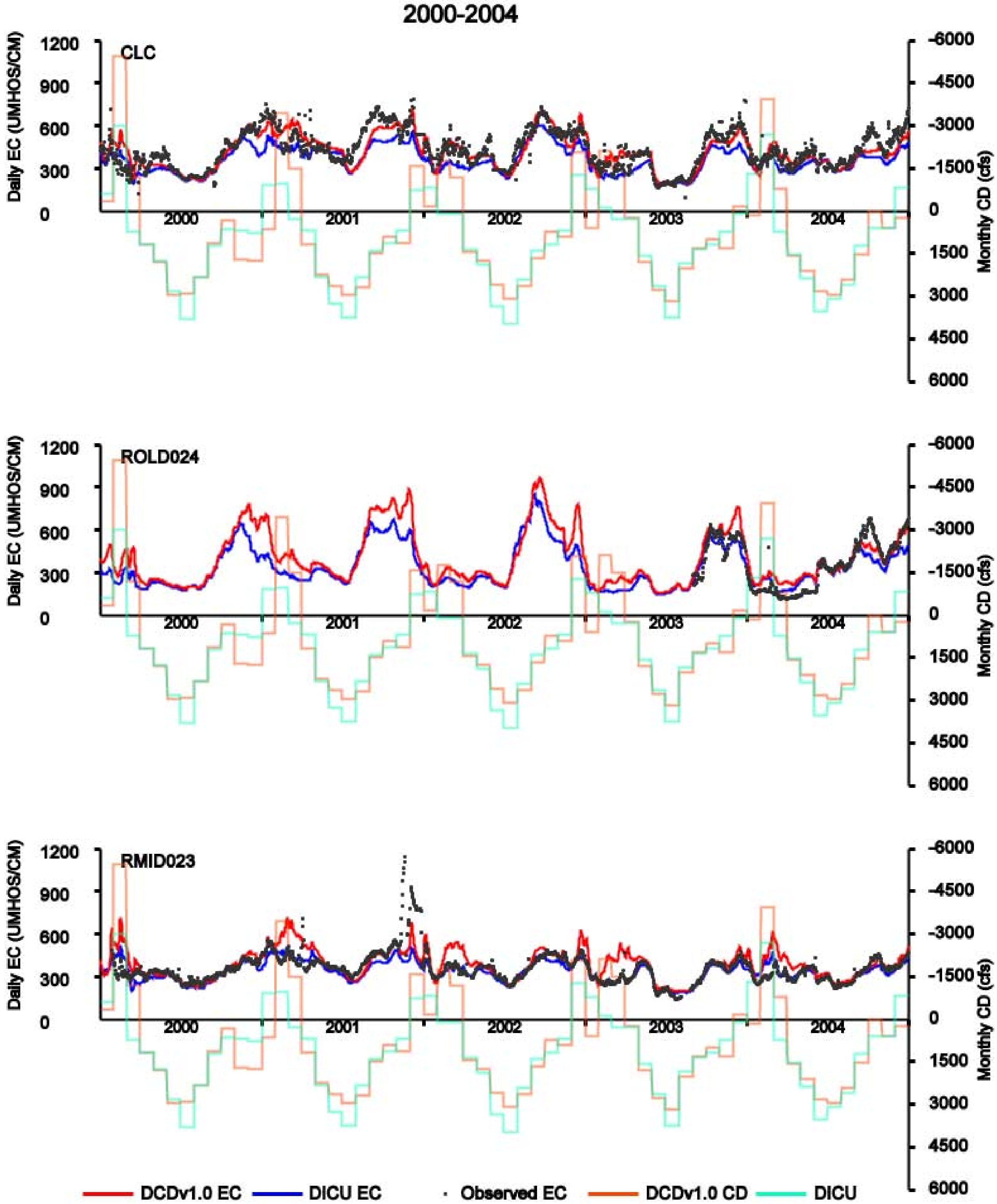
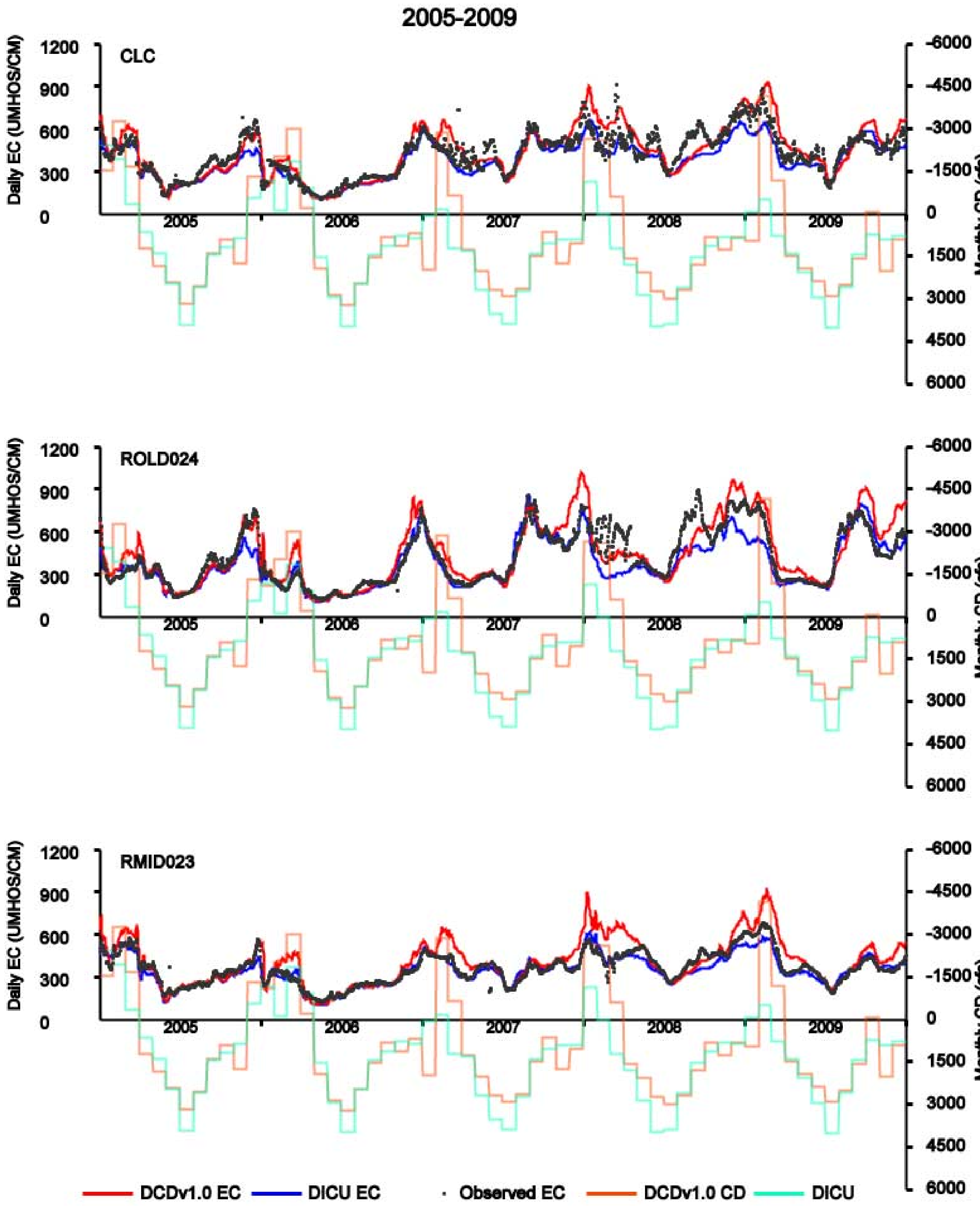


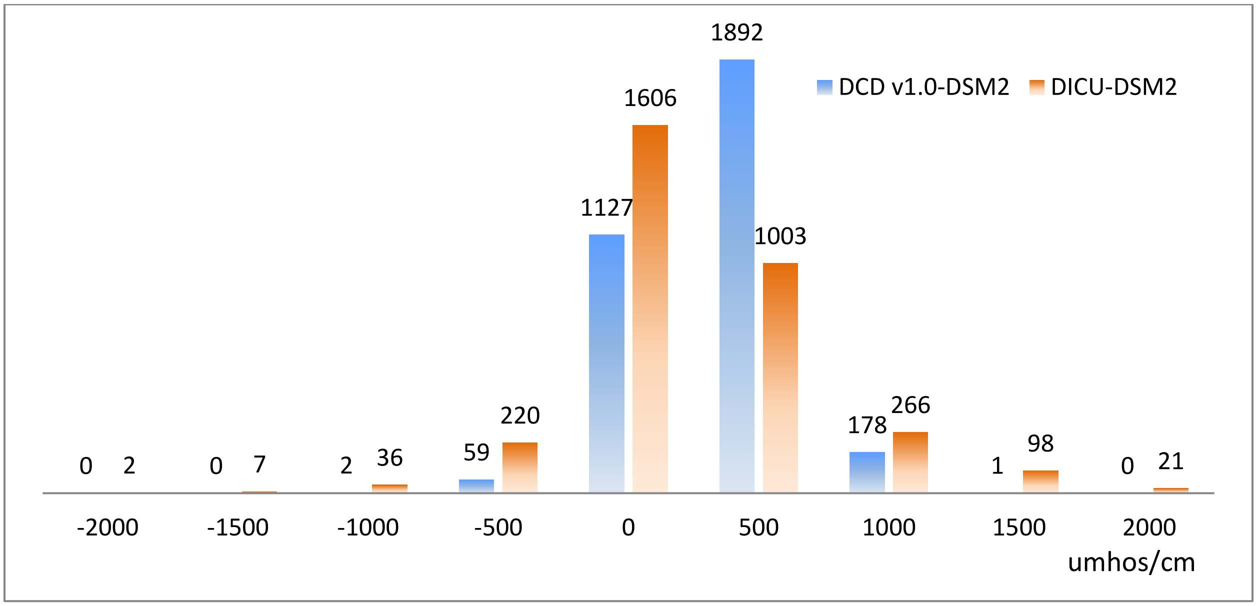
Figure 2-17 Comparison of DSM2-Simulated EC and Observed EC in the South Delta under DCD v1.0 and DICU, 2005–2009



Figures 2-18 through 2-20 compare the distribution of errors in daily EC for DCD v1.0-DSM2 and DICU-DSM2 at three sites (RSAN018, ROLD024, and CLC). The EC errors are the differences between the simulated and observed daily EC. Under high NDOs and inflows, Delta EC is not sensitive to DCD and can be simulated mostly well. As a result, only the daily data for the dry or critical dry years, 1990, 1991, 1992, 1994, 2001, 2002, 2007, 2008, and 2009, are included in these three figures. At RSAN018, the range of the daily EC errors by DETAW-DSM2 is -500~1,000 umhos/cm, much smaller than -2,000~2,000 umhos/cm by DICU-DSM2. The same trend is seen for ROLD024 and CLC. The excessive underestimation and overestimation of the EC over the entire Delta under DICU-DSM2 has been removed mostly, and the simulated EC by DCD v1.0-DSM2 is much closer to the observed EC.

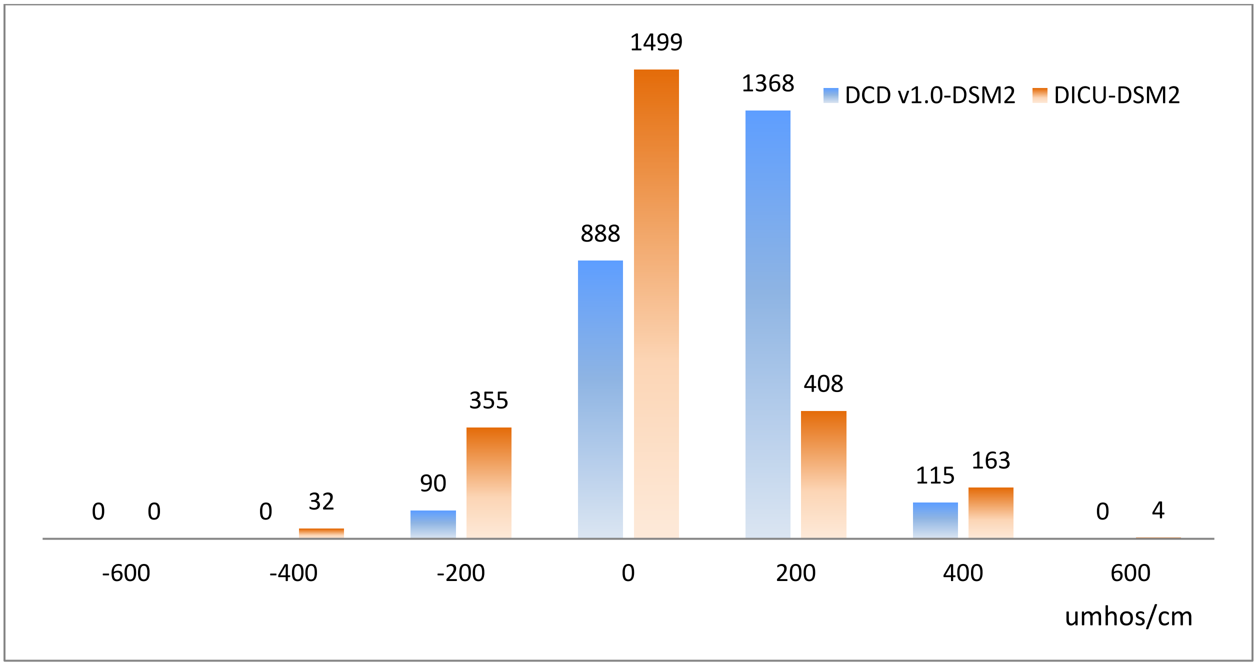
But, simulated EC at CLC does not improve as much as other sites. CLC is far from the confluence area and is affected by local diversions, State and federal exports, and Sacramento River and San Joaquin River inflows. It is anticipated that simulated EC at CLC can be improved by more specific dispersion coefficient calibration of the entire Delta. In Figure 2-18, EC errors at approximately 500 umhos/cm occur for 1,892 days, much more than the 1,127 days at approximately 0 umhos/cm. Other sites have similar results which show that the estimated EC under DCD v1.0-DSM2 is generally higher than the observed EC under the preliminary and partial recalibration.

Figure 2-18 Frequencies of Daily EC Errors at RSAN018 for the Dry Years in 1990–2009



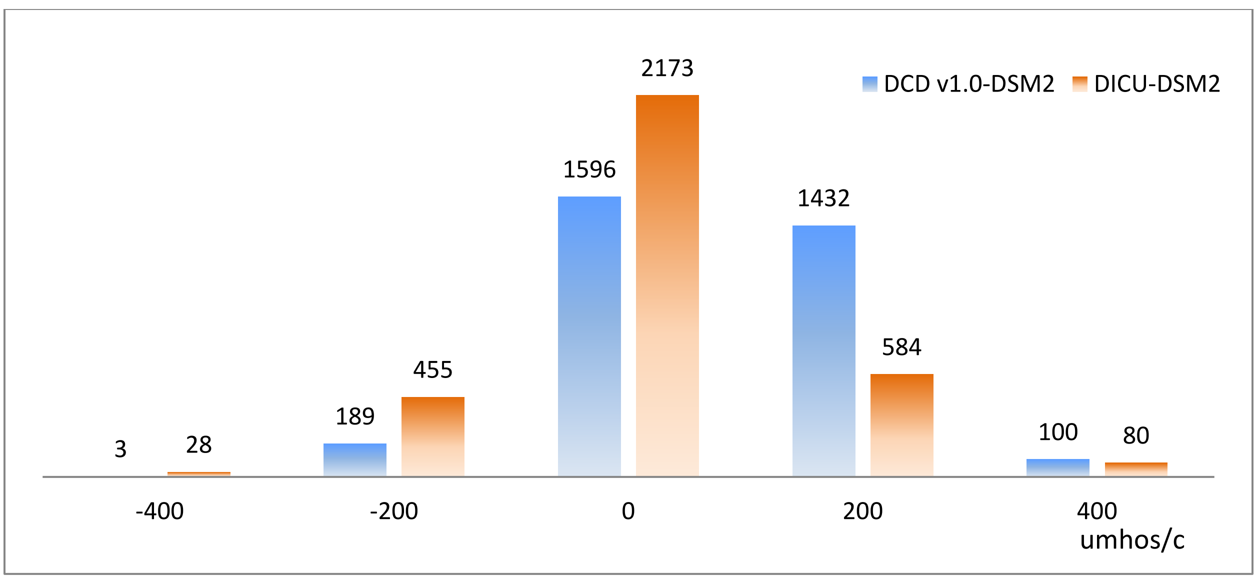
Note: RSAN018 = Delta at Jersey Point

Figure 2-19 Frequencies of Daily EC Errors at ROLD024 for the Dry Years in 1990–2009



Note: ROLD024 = Old River at Bacon Island

Figure 2-20 Frequencies of Daily EC Errors at CLC for the Dry Years in 1990–2009



Note: CLC = Clifton Court Forebay

Table 2-5 presents average, maximum overestimation and maximum underestimation errors in daily EC errors at three locations and shows that DCD v1.0 improves EC estimation compared to DICU. Introducing the subsurface flow and groundwater flow into the channel depletion model is essential to improving Delta surface water models. A simulation of historical conditions with SCHISM using DCD v1.0 channel depletions improved. Incorporating the channel depletions calculated by DCD v1.0 should improve the performance of other Delta surface water models.

Table 2-5 Characteristics of Errors for the Dry and Critical Dry Years from 1990 to 2009 (in umhos/centimeter)

	RSAN018		ROLD024		Clifton Court	
	DCD v1.0	DICU	DCD v1.0	DICU	DCD v1.0	DICU
Average	63	42	16	-56	-16	-82
Maximum Overestimation	1020	1957	391	410	292	392
Maximum Underestimation	-1282	-2199	-321	-571	-407	-545

Note: DETAW = Delta Evapotranspiration of Applied Water, DICU = Delta Island Consumptive Use, ROLD024 = Old River at Bacon Island, RSAN018 = Delta at Jersey Point

2.4 Validation (1975–1989, 2011–2015)

The integrated DCD v1.0-DSM2 model has been validated by simulating two time periods, 1976–1989 and 2011–2015. The DCD v1.0 parameters and preliminary calibrated DSM2 dispersion coefficients were set according to the calibration results. Because modeled EC at CLC, ROLD024, and RMID023 are below the observed EC from 1975 to 1989, only the simulated and observed EC comparison at Antioch, Jersey Point, and Emmaton (Figures 2-21 through 2-23) have been presented here. For the period of 2011–2015, EC was compared at all six sites in Figures 2-24 and 2-25.

In all these figures, the excessive overestimation and underestimation in the dry or critical dry years 1976, 1985–1989, and 2013–2015 have been reduced substantially as well. The fact that both serious overestimation and underestimation errors are much improved with DCD v1.0 in the validation periods is strong evidence that the simple calculations to adjust channel depletions in DCD v1.0 are meaningful. The effect of Delta subsurface water and groundwater to the surface water have been quantified in a reasonable range for the years 1975–2015.

Figure 2-21 **Comparison of DSM2-Simulated EC and Observed EC in the Sacramento-San Joaquin Rivers Confluence Area under DCD v1.0 and DICU, 1975–1979**

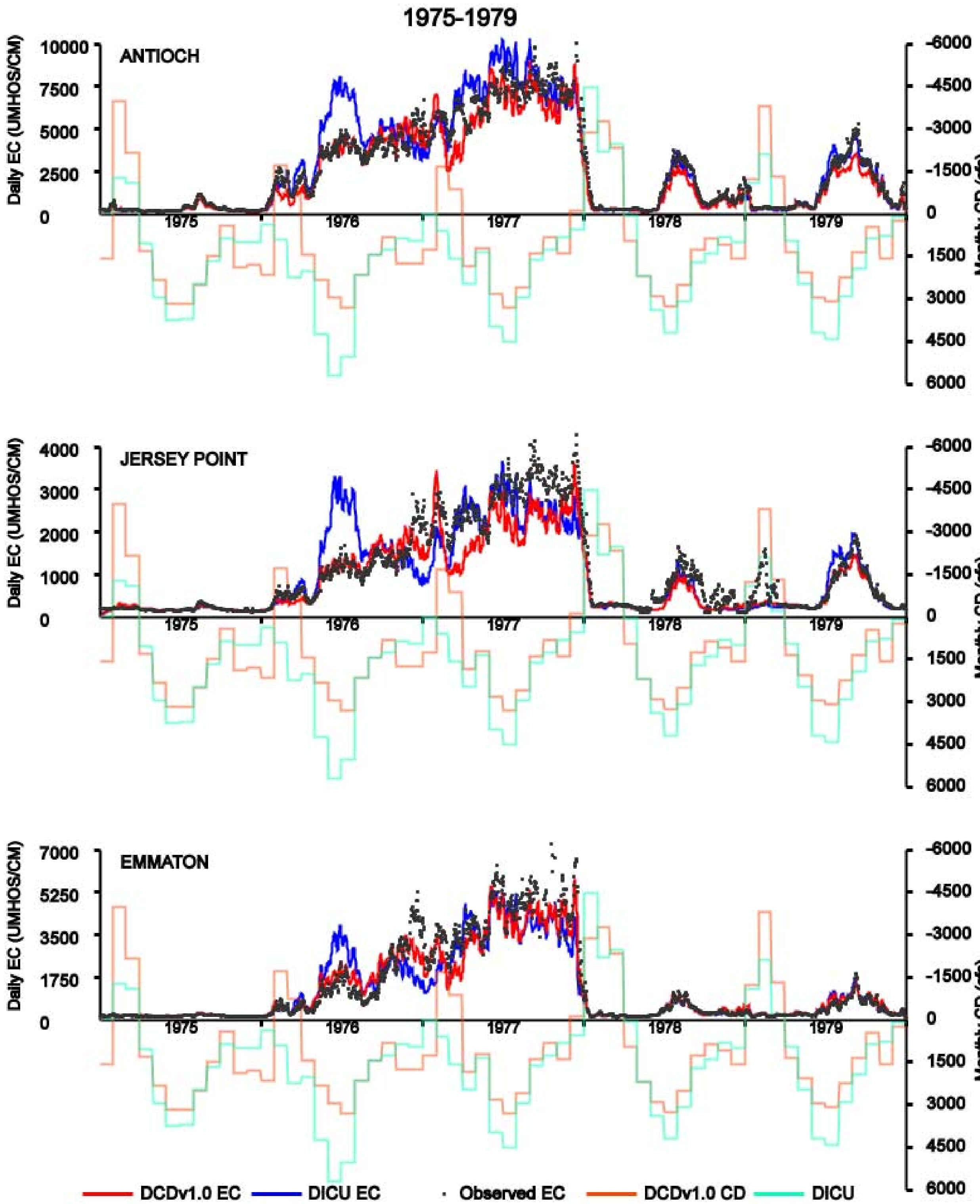


Figure 2-22 **Comparison of DSM2-Simulated EC and Observed EC in the Sacramento-San Joaquin Rivers Confluence Area under DCD v1.0 and DICU, 1980–1984**

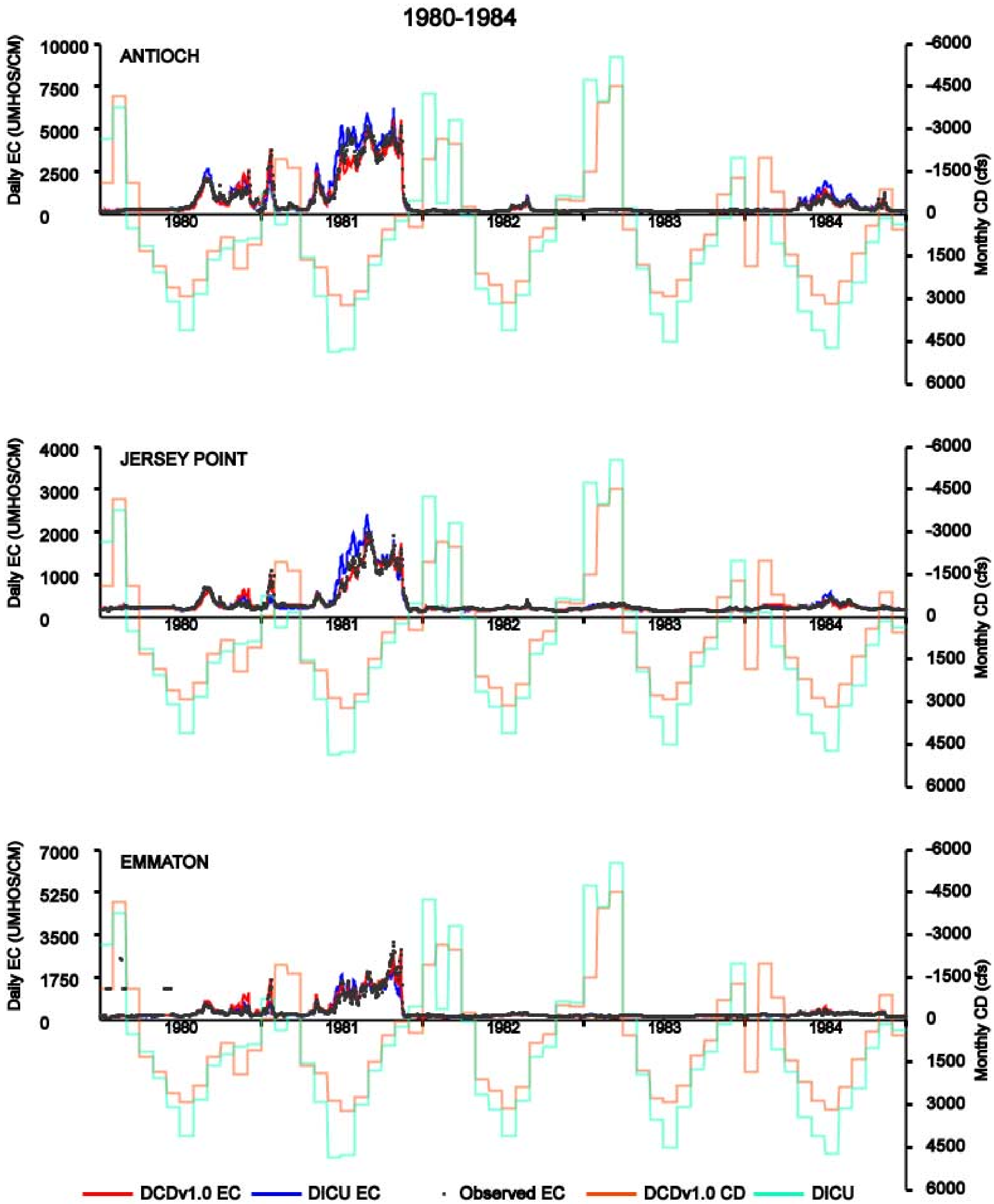


Figure 2-23 **Comparison of DSM2-Simulated EC and Observed EC in the Sacramento-San Joaquin Rivers Confluence Area under DCD v1.0 and DICU, 1985–1989**

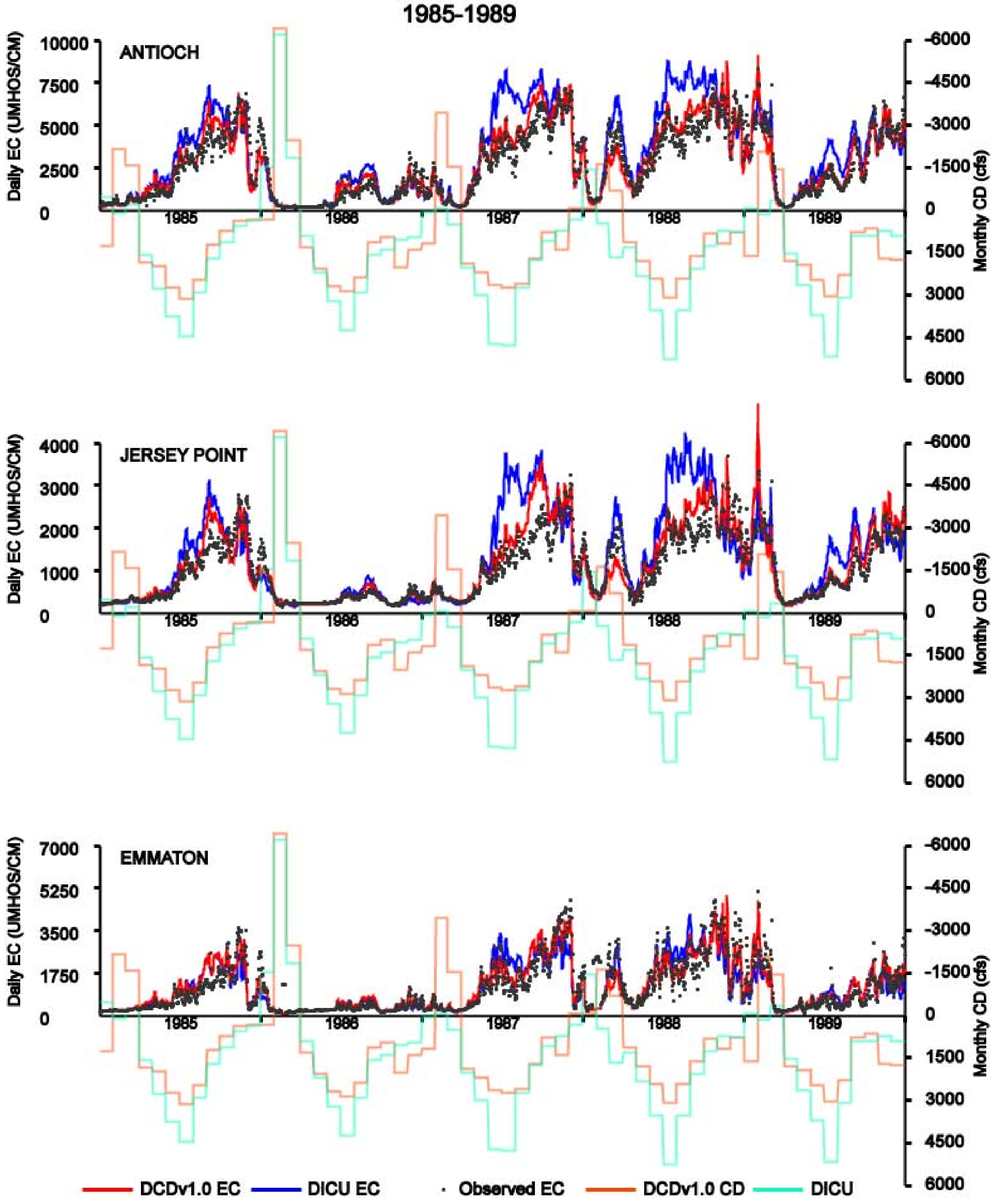


Figure 2-24 Comparison of DSM2-Simulated EC and Observed EC in the Sacramento-San Joaquin Rivers Confluence Area under DCD v1.0 and DICU, 2011–2015

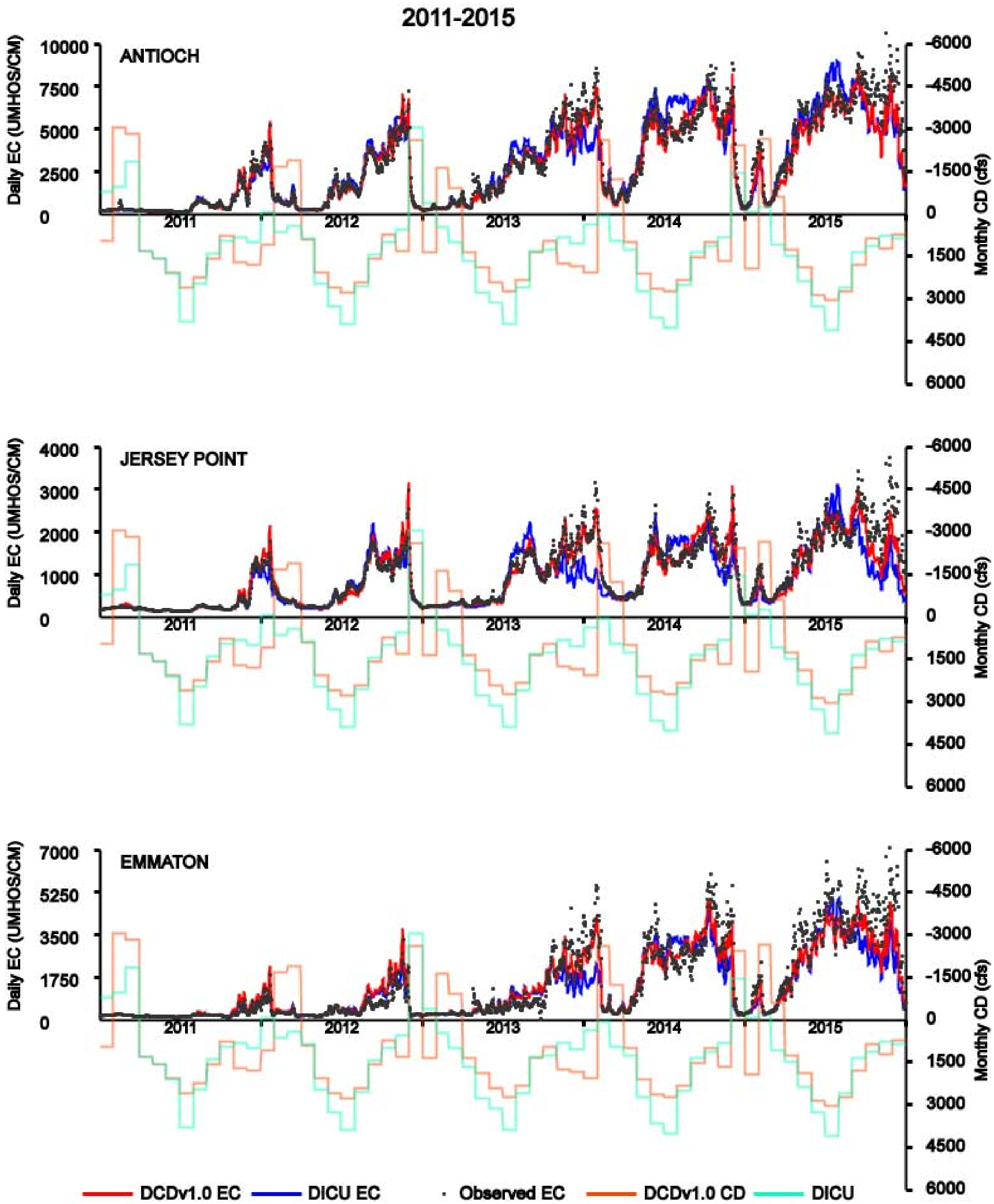
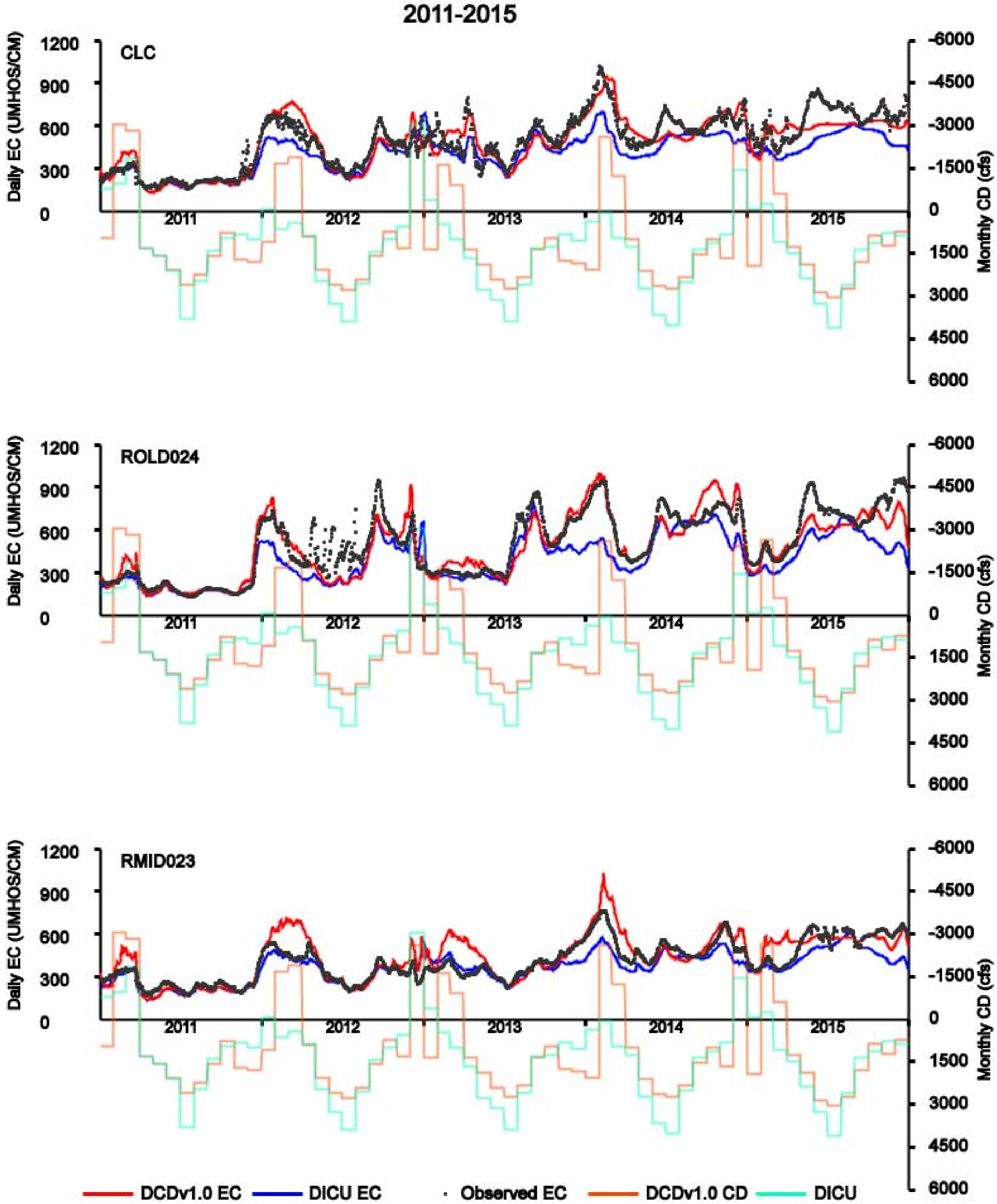
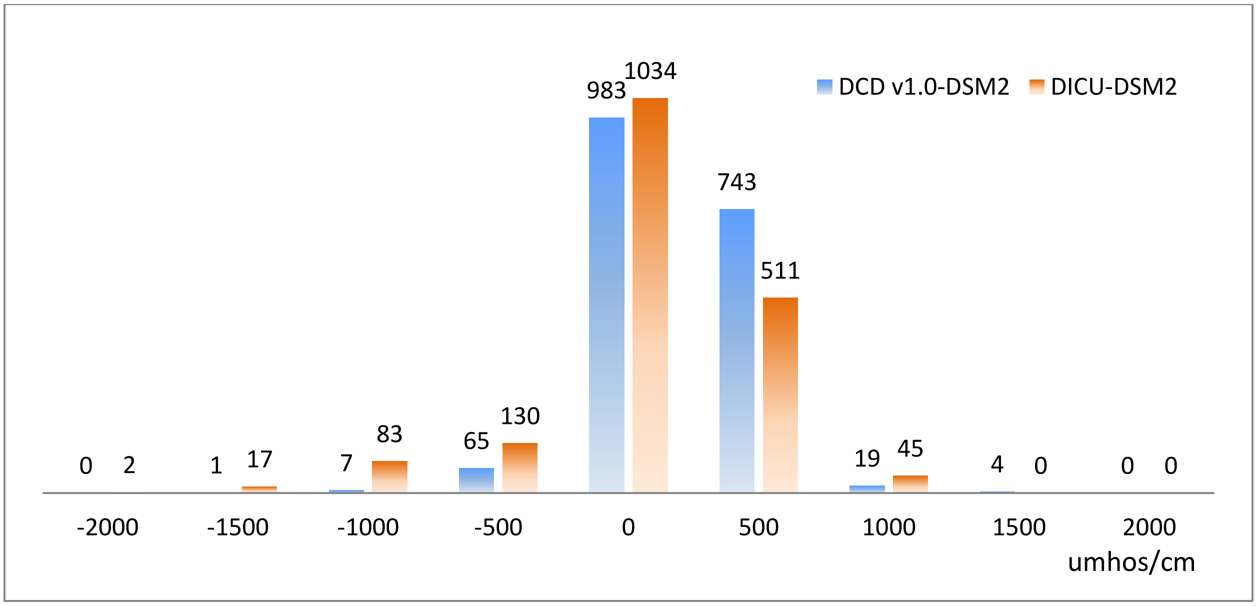


Figure 2-25 Comparison of DSM2-Simulated EC and Observed EC in the South Delta under DCD v1.0 and DICU, 2011–2015



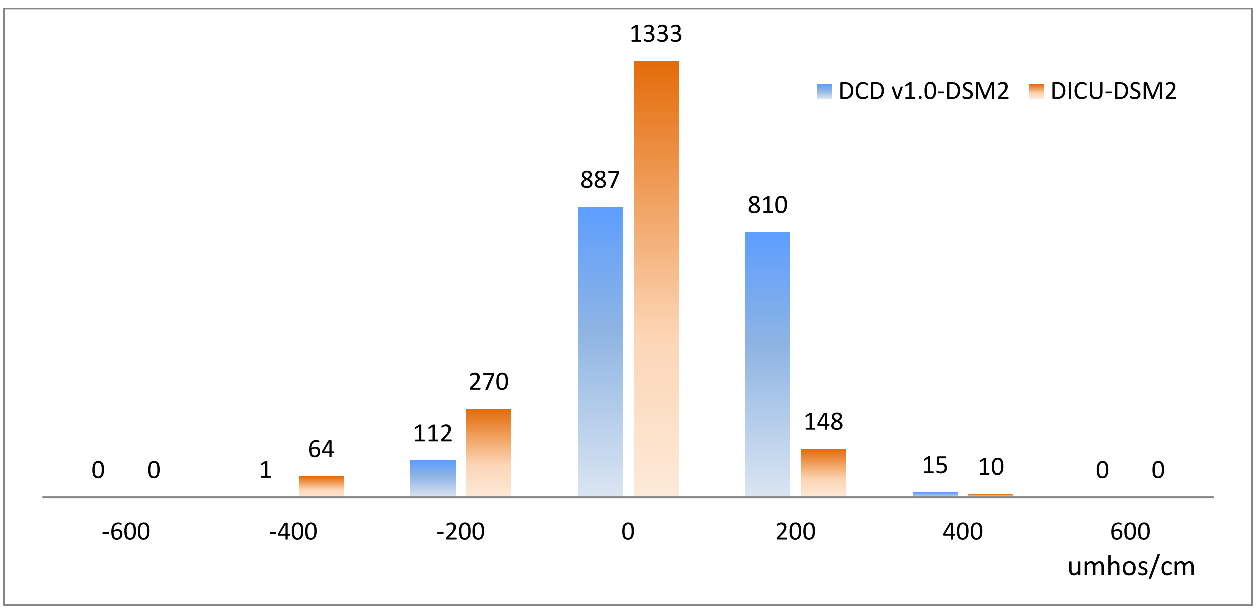
Figures 2-26 through 2-28 show the distributions of the daily EC errors at RSAN018, ROLD024 and CLC from 2011 to 2015. Similar to the data in the dry years from 1990 to 2009, the ranges of the daily EC errors for these three sites by DCD v1.0-DSM2 have been compressed. Table 2-6 lists the averages, maximum over estimation, and maximum underestimation of the daily EC errors from 2011 to 2015. All the average and maximum errors by DCD v1.0-DSM2 have been reduced greatly, except the maximums overestimations at RSAN018 and Clifton Court. More specific calibration might remove the exceptions.

Figure 2-26 Distribution of Daily Electrical Conductivity Errors at RSAN018, 2011–2015



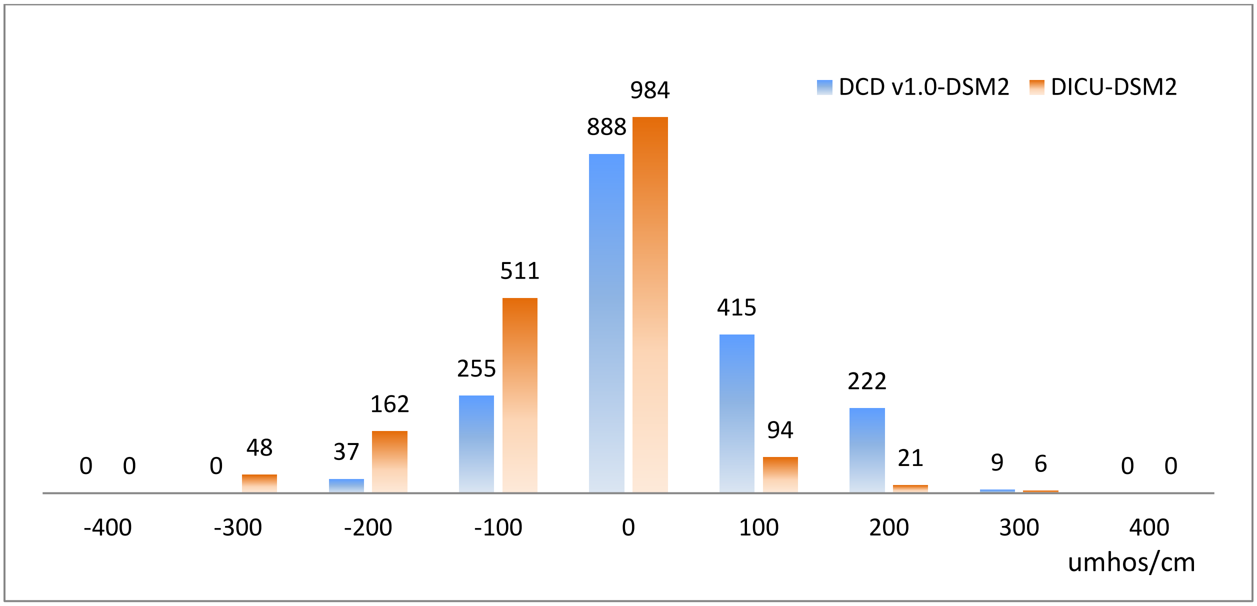
Note: RSAN018 = Delta at Jersey Point

Figure 2-27 The Distribution of Daily Electrical Conductivity Errors at ROLD024, 2011–2015



Note: ROLD024 = Old River at Bacon Island

Figure 2-28 The Distribution of Daily Electrical Conductivity Errors at CLC, 2011–2015



Note: CLC = Clifton Court Forebay

Table 2-6 Statistical Summary of Daily Electrical Conductivity Errors, 2011–2015 (in umhos/centimeter)

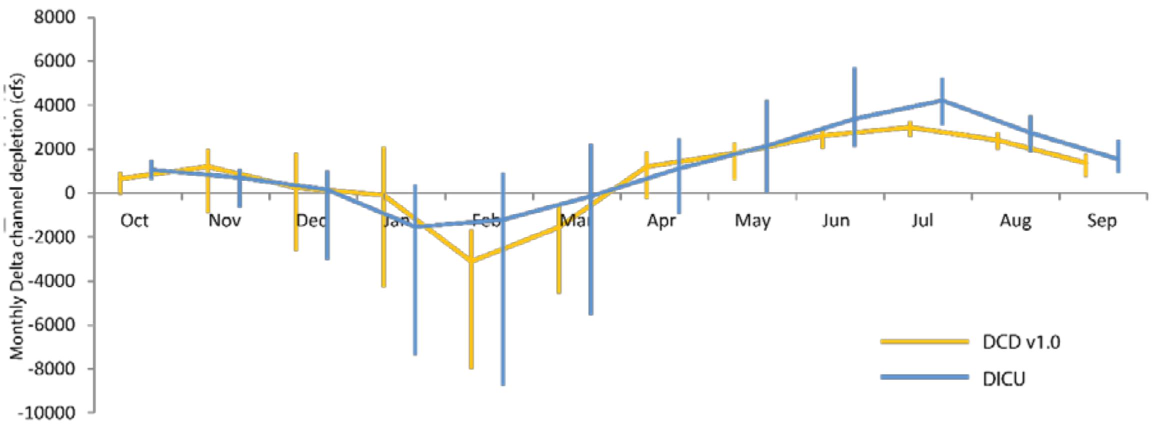
	RSAN018		ROLD024		Clifton Court	
	DCD v1.0	**DICU**	**DCD v1.0**	**DICU**	**DCD v1.0**	**DICU**
Average	-37	-120	-25	-110	-15	-91
Maximum Overestimation	1329	867	244	324	239	232
Maximum Underestimation	-1722	-2062	-472	-526	-288	-361

Note: DETAW = Delta Evapotranspiration of Applied Water, DICU = Delta Island Consumptive Use, ROLD024 = Old River at Bacon Island, RSAN018 = Delta at Jersey Point

These analyses support the concept that Delta subsurface water and groundwater act as a reservoir transferring water with the surface water. The impact of the subsurface water and groundwater to the surface water have been quantified by referring to the relationship between salinity intrusion and net Delta outflow/Delta channel depletion. Table 2-7 and Figure 2-29 show the averages, maximums, and minimums of the monthly Delta channel depletion from 1975 to 2015 for DCD v1.0 and DICU. The 40-year averages of the monthly Delta channel depletion by DCD v1.0 is lower in May–September and higher in November–January than those by DICU. This pattern of when DCD v1.0 has higher or lower channel depletions compared to DICU agrees with the findings in the Twitchell Island study which reported on the difference between consumptive use and channel depletions based on a water balance (Figure 2-1). DCD v1.0 calculates approximately 1,200 cfs lower Delta channel depletion in July than does DICU, and approximately 1,500 cfs higher Delta channel depletion in January (red numbers in Table 2-7). Referring to the previous daily EC plots, the differences in summer Delta channel depletions can be approximately 1,000 cfs, which could reduce the errors in simulated EC around the confluence area by as much as 1,000 uhmos/cm, or more. In general, the differences in Delta channel depletion as estimated by DCD v1.0 compared to DICU significantly reduces DSM2-simulated EC errors.

Currently, based on the definitions and assumptions in DCD v1.0, the crop ET, subsurface water, and groundwater are the main reason to explain the Delta channel depletion difference of DCD v1.0 and DICU in summers. Rainfall, deep percolation, and leach assumed in DCD v1.0 determine the difference in Delta channel depletion between the two models in winters and early springs. As stated above, the difference in the amount of leaching, as calculated by DICU and DCD v1.0, cannot by itself explain the difference of the net channel depletions in winters. More investigation of Delta in winters and springs is needed.

Figure 2-29 DCD v1.0 and DICU Minimum, Maximum, and Average Monthly Delta Channel Depletion, 1975–2015



Note: cfs = cubic feet per second, DCD = Delta Channel Depletion Model, DICU = Delta Island Consumptive Use

Table 2-7 DCD v1.0 and DICU Minimum, Maximum, and Average Monthly Delta Channel Depletion, 1975–2015 (in acre-feet)

	DCD v1.0			DICU		
Month	**Maximum**	**Minimum**	**Average**	**Maximum**	**Minimum**	**Average**
October	997	-68	684	1,506	609	1,062
November	2,042	-864	1,242	1,101	-662	707
December	1,857	-2601	284	1,033	-3028	162
January	2,137	-4,253	-52	380	-7,362	-1,530
February	-1,631	-7,966	-3,069	933	-8,757	-1,217
March	-533	-4,529	-1,508	2,235	-5,521	-144
April	1,910	-237	1,242	2,476	-929	1,122
May	2,317	639	1,838	4,238	36	2,142
June	2,974	2,051	2,649	5,723	2,098	3,386
July	3,319	2,612	3,020	5,262	3,083	4,215
August	2,802	2,026	2,446	3,528	1,851	2,740
September	1,814	764	1,411	2424	902	1,545

Note: DCD = Delta Channel Depletion Model, DICU = Delta Island Consumptive Use

2.5 Conclusion and Outlook

In order to estimate reasonable Delta net channel depletions, DETAW v2.0 was modified to create DCD v1.0 through changing several fundamental assumptions and enclosing the effect of the subsurface water and groundwater to the surface water. The integrated DCD v1.0 and DSM2 model has been preliminarily calibrated and validated based on subsurface water and groundwater effects on Delta channel depletion and EC over 40 years of observed data at six sites in the Delta. The promising EC results at the Sacramento-San Joaquin rivers confluence area and the analysis of Delta channel depletion and EC support the concept of the subsurface water and groundwater being connected to the Delta surface water environment. This linkage is of crucial importance in accurately modeling Delta salinity intrusion in dry or critical dry years.

Although DCD v1.0-DSM2 model results are encouraging, several issues need to be addressed. First, the way diversions, drainages, and seepage are assigned to each DSM2 node in the central and south Delta needs refinement. Similarly, accurately locating drainage channels, pumps, and siphons on Delta islands, and knowing farming practices, are required to refine the distribution of flows to DSM2 nodes. The new assumptions in DCD v1.0 and the calibration of the integrated model are based on the relationship between net Delta outflow/Delta channel depletion and Delta salinity intrusion. Only the total Delta channel depletion in DCD v1.0 has been calibrated. It doesn't necessarily follow that the diversion, drainage, and seepage at any DSM2 node are sufficiently accurate to adequately model localized mixing and movement of channel waters, an important issue in the central and south Delta. Some recent seepage and drainage data in Delta lowlands have been collected by communicating and collaborating with other agencies and stakeholders. This information will be implemented in the next version of DCD v1.0. Some additional adjustments might also be made to assumptions concerning variations among Delta channels with regards to seepage, drainage, and leaching, but no significant changes to calculated Delta channel depletion presented in this memo are expected.

Second, other parameters in DCD v1.0 also need more investigation. For example, the subsurface water rate is currently assumed constant in the model. Significant subsidence was first reported in the 1930s and has continued since. Subsurface water rates should vary over time and space to reflect the spatial and temporal development of subsidence.

Third, a rigorous DSM2 calibration is required if DCD v1.0 is adopted for input. For this memo, a preliminary calibration focusing on the river confluence area was done to demonstrate how modifying Delta channel depletion and, as a result, Delta outflow makes a subsequent calibration of DSM2-QUAL far better than can be attained through calibration without modifying Delta channel depletion. A thorough calibration which includes EC modeling in the central, south Delta, and north Delta should yield a significantly better performing water quality model.

2.6 References

Brown, RL. 2004. *Screening Agricultural Diversions in the Sacramento-San Joaquin Delta.* State Water Resources Control Board. Viewed online at: http://www.swrcb.ca.gov/waterrights/water_issues/programs/bay_delta/wq_control_plans/2006wqcp/exhibits/append2/cdwa/cdwa-03.pdf

California Department of Water Resources 1962: "*Salinity incursion and water resources, Appendix to Bulletin No. 76, Delta water facilities*."

California Department of Water Resources 1978: "*Bulletin 168, Sacramento valley water use survey 1977*."

California Department of Water Resources 1995: "*Estimation of Delta Island Diversion and Return Flows*."

California Department of Water Resources 2006. *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.* "Chapter 9: DSM2 Simulation of Historical Delta Conditions over the 1975-1990 Period," by Myint T, and Nader-Tehrani P. Sacramento(CA): California Department of Water Resources. Bay-Delta Office.

California Department of Water Resources and U.S. Bureau of Reclamation 2016. *Final Environmental Impact Report/Environmental Impact Statement for the Bay Delta Conservation Plan/California WaterFix – Volume I. Final EIR/EIS for the BDCP/California WaterFix*. "Chapter 7 Groundwater." Viewed online at: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/exhibit102/docs/vol1/Final_EIR-EIS_Chapter_7_-_Groundwater.pdf

California Department of Water Resources 2015. *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 36th Annual Progress Report to the State Water Resources Control Board.* "Chapter 3: Estimating the Impact of Groundwater on Delta Channel Depletions," by Liang L, and Suits B. Sacramento (CA): California Department of Water Resources. Bay Delta Office.

California Department of Water Resources 2017. *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 38th Annual Progress Report to the State Water Resources Control Board*. "Chapter 3: Implementing DETAW in Modeling Hydrodynamics and Water Quality in the Sacramento-San Joaquin Delta," by Liang L, and Suits B. Sacramento (CA): California Department of Water Resources. Bay Delta Office.

Ingebritsen SE, Ikehara ME, Galloway DL, Jones DR 2000. *Delta Subsidence in California; The sinking heart of the State*. U.S. Geological Survey. Fact Sheet 005-00.

Kabakov S, et al. 1956a. *Investigation of the Sacramento-San Joaquin Delta, Report No. 1, ground water geology*. Water Project Authority of the State of California.

Kabakov S, et al. 1956b. *Investigation of the Sacramento-San Joaquin Delta, Report No. 2, water supply and water utilization on Medford island.* Water Project Authority of the State of California.

Kabakov S, et al. 1956c. "*Investigation of the Sacramento-San Joaquin Delta, Report No. 4, quantity and quality of waters applied to and drained from the Delta lowlands.* Department of Water Resources.

Kabakov S, et al. 1959, "*Investigation of the Sacramento-San Joaquin Delta, Report No. 3, water supply and water utilization on McDonald Island*." California Department of Water Resources.

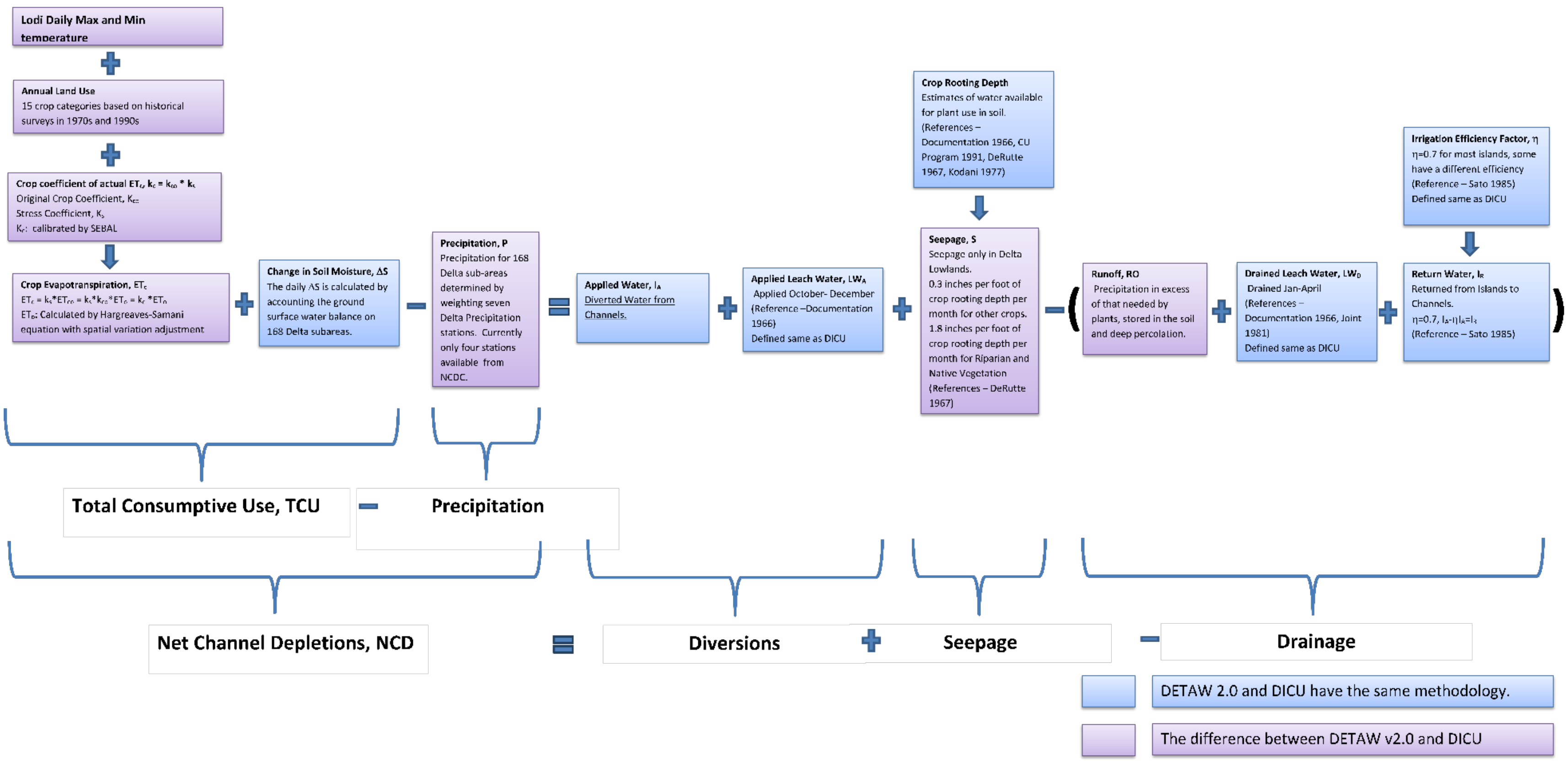
Marvin Jung and Associates, Inc. 2000, *Revision of Representative Delta Island Return Flow Quality for DSM2 and DICU Model Runs*. Prepared for: CALFED Ad-Hoc Workshop to simulate historical water quality conditions in the Delta. Consultant's report to the California Department of Water Resources Municipal Water Quality Investigations Program, MWQI-CR#3.

Owen LW and Nance DH 1962. "*Hydrology of the Sacramento-San Joaquin Delta*." American Society of Civil Engineers Hydraulics Division Conference.

Snyder RL, et al. 2006. *Final Report, Delta Evapotranspiration of Applied Water (DETAW) Version 1.0.* California Department of Water Resources, and University of California, Davis, Department of Air, Land and Water Resources.

Appendix 1

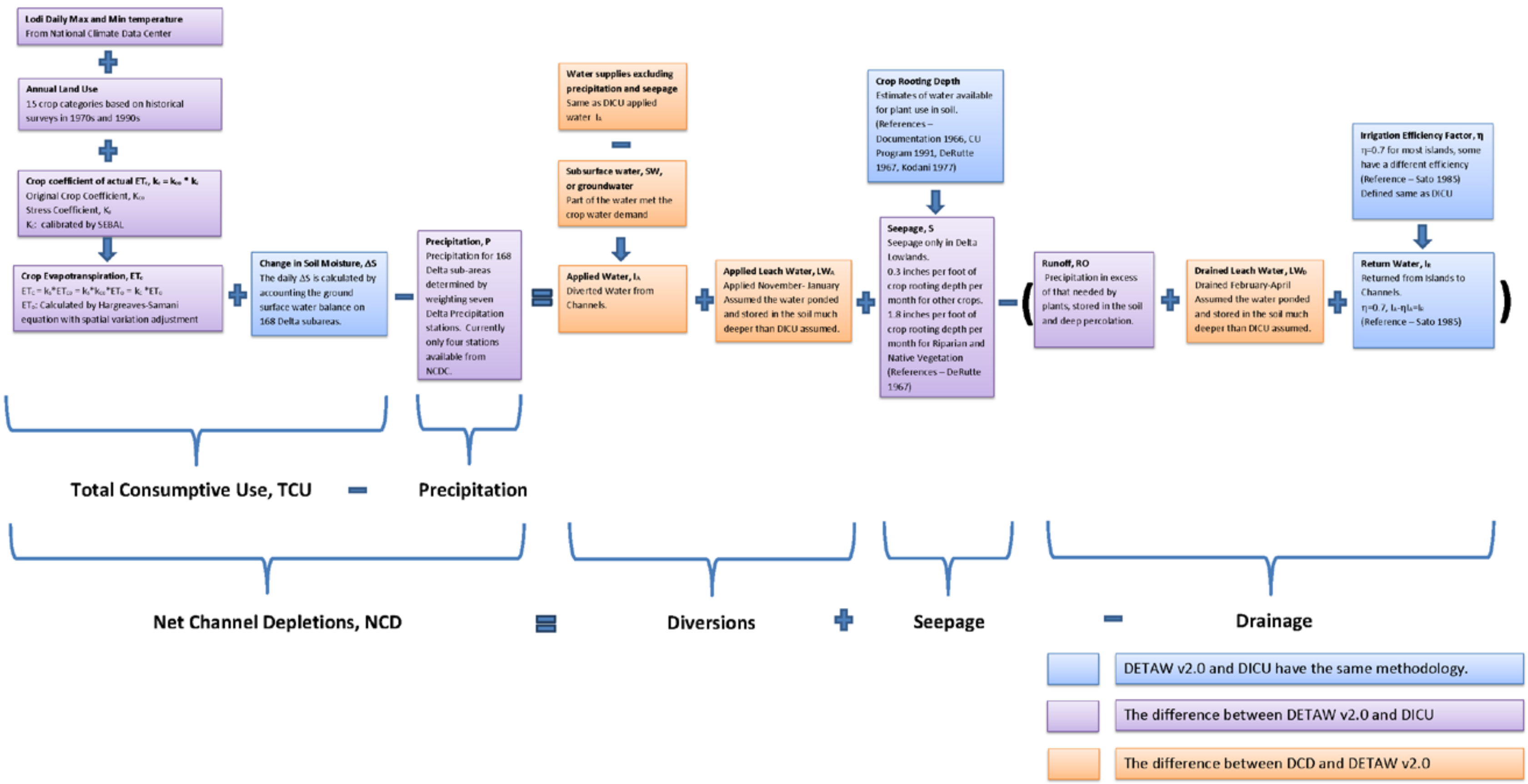
Figure A1-1 DETAW v2.0 Daily Net Channel Depletions



Note: DETAW = Delta Evapotranspiration of Applied Water, DICU = Delta Island Consumptive Use

Appendix 2

Figure A2-1 DCD v1.0 Daily Net Channel Depletions



Note: DCD = Delta Channel Depletion Model, DETAW = Delta Evapotranspiration of Applied Water, DICU = Delta Island Consumptive Use