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

25th Annual Progress Report
October 2004

Chapter 5:
Calculating Net Delta Outflow Using CALSIM II and DSM2

Author: Jamie Anderson

5 Calculating Net Delta Outflow Using CALSIM II and DSM2

5.1 Introduction

This chapter describes methods for computing Net Delta Outflow (NDO) using inputs or simulation results from CALSIM II and DSM2. CALSIM II is an application of the California Department of Water Resources' (DWR) and U. S. Bureau of Reclamation's (USBR) water resources operations model CALSIM of the State Water Project and Central Valley Project. In other words, CALSIM II is the specific version of the CALSIM model. DSM2 is DWR's one-dimensional unsteady flow and water quality model of the Sacramento-San Joaquin Delta.

The Sacramento-San Joaquin Delta is 738,000 acres with freshwater inflows from the Sacramento, San Joaquin, Mokelumne, Cosumnes, and Calaveras Rivers and tidal brackish water inflows from San Francisco Bay (DWR, 1995) (Figure 5.1). Net Delta Outflow is an indication of how much net flow leaves the Delta, typically considered as the net flow at Martinez or Chipps Island. NDO is difficult to measure directly at either Martinez or Chipps Island, so NDO is often estimated by either summing flows in several channels that represent total outflows, or by computing the mass balance between inflows, exports, and consumptive use in the Delta. This chapter documents how NDO is represented in CALSIM II, and how NDO can be computed from DSM2 inputs and simulation results.

5.2 NDO Computations in CALSIM II

NDO is computed in CALSIM II by computing a flow balance between channel flows, precipitation, exports and Delta Consumptive Use (DCU). The values for the flow balance are provided by CALSIM output at selected channel arcs (CALSIM flow paths).   In CALSIM nomenclature, each channel arc is identified by a letter and a number. The following naming convention is used for the CALSIM channel arcs:

- C###: Channel flow, e.g. C169 represents Sacramento River inflow to the Delta
- D###: Delivery (export) or consumptive use, e.g. D419 represents SWP exports
- I###: Inflow/Precipitation, e.g. I404 represents one of four Delta precipitation arcs

The Delta portion of the CALSIM II grid is shown in Figure 5.2. Descriptions of the CALSIM II arcs that are used in the NDO computations are presented in Table 5.1.

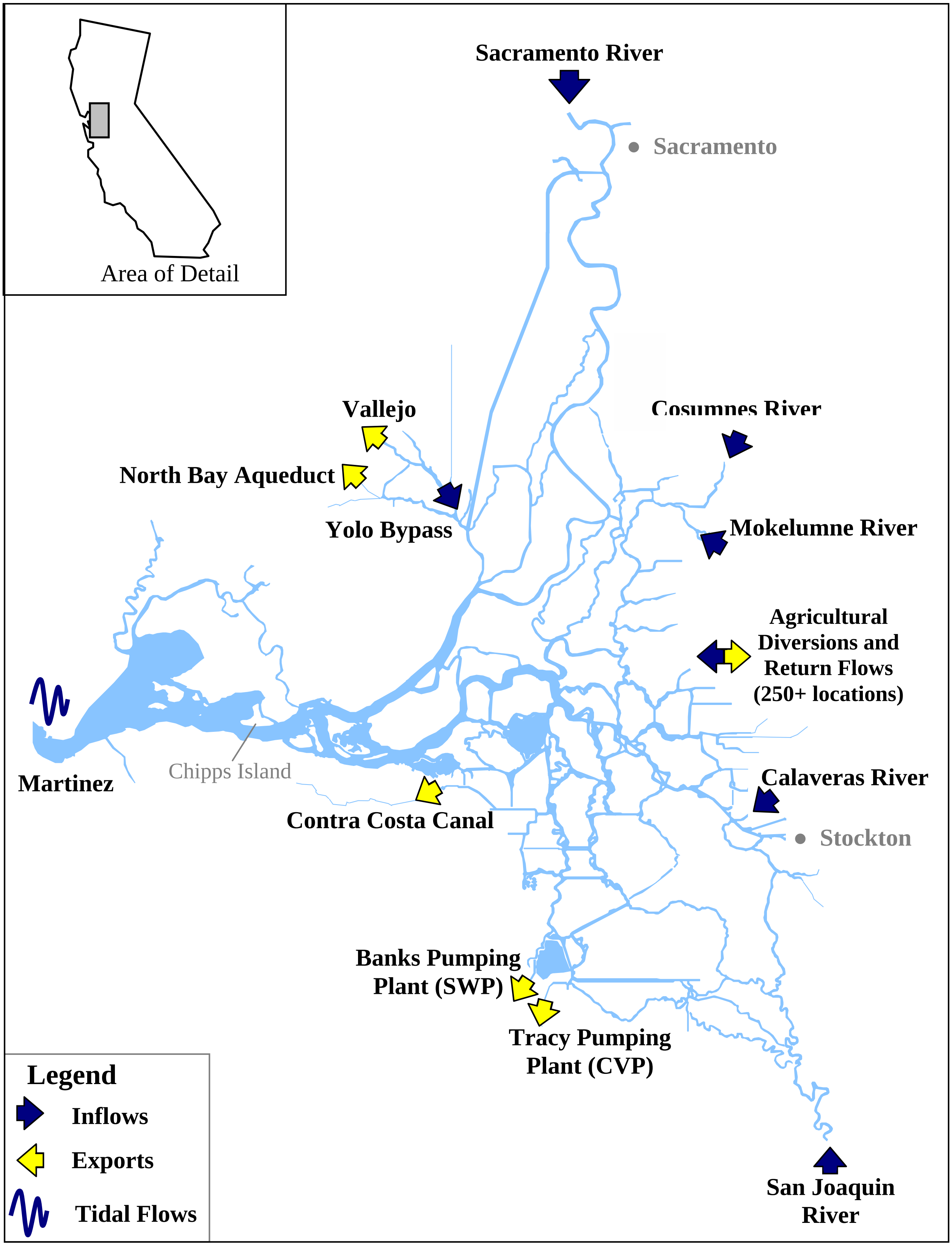

Figure 5.1: Sacramento-San Joaquin Delta.

There are two main methods for computing NDO based on CALSIMII output. The first method sums the various Delta outflow requirements using the following equation:

$$NDO_{CALSIM} = C407 + D407 \qquad \text{[Eqn. 5-1]}$$

where,
D407 = Delta outflow requirements under D1641, and
C407 = Additional delta outflow due to other constraints such as import/export ratios.

Alternatively, NDO can be computed by using the individual CALSIM II arcs to compute a flow balance (see Table 5.1 for definition of each CALSIM II arc):

$$NDO_{CALSIM} = \underbrace{C157 + C169 + C504 + C508 + C639}_{\text{River Inflows}} + \underbrace{I406}_{\text{Marsh Creek}} + \underbrace{I404 + I410 + I412 + I413}_{\text{Delta Precipitation}}$$

$$-\underbrace{D403A - D403B - D408 - D418 - D419}_{\text{Exports}} - \underbrace{D404 - D410 - D412 - D413}_{\text{Delta Consumptive Use}} \qquad \text{[Eqn. 5-2]}$$

Table 5.1: CALSIM II Values Used to Compute NDO.

CALSIM II Arc	Sign in NDO computation	Description
Sum of Delta Outflows		
C407	+	Additional delta outflow due to other constraints such as import/export ratios
D407	+	Delta outflow requirements under D1641
Inflows minus Exports		
C157	+	Yolo Bypass inflow to the Delta
C169	+	Sacramento River inflow to the Delta
C504	+	Mokelumne and Cosumnes rivers combined inflow to the Delta
C508	+	Calaveras River inflow to the Delta
C639	+	San Joaquin River inflow to the Delta
I 406	+	Marsh Creek inflow to the Delta
I404, I410 I412, I413	+	Delta Precipitation
D403A	-	Vallejo
D403B	-	North Bay Aqueduct
D408	-	Contra Costa Exports
D418	-	CVP Exports
D419	-	SWP Exports
D404, D410 D412, D413	-	Delta Consumptive Use

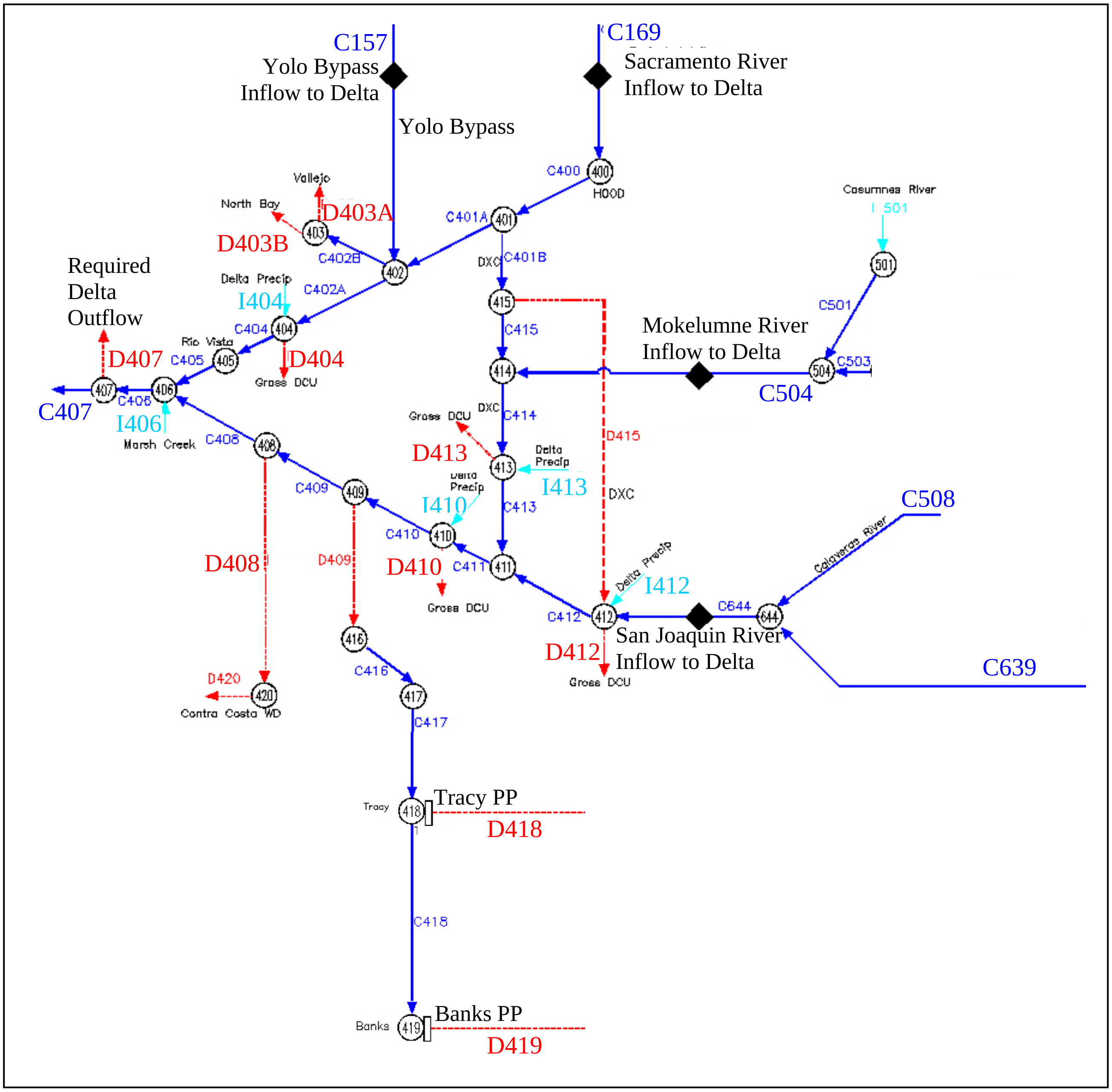

Figure 5.2: Delta Portion of the CALSIM II Grid.

5.3 NDO Computations Using DSM2

This section presents methods for computing NDO using either DSM2 boundary input values or simulation results from DSM2.

5.3.1 NDO Computations Using DSM2 Inputs

NDO can be computed as a mass balance of the boundary inflows and exports specified as inputs for a DSM2 simulation. The mass balance NDO is computed by summing inflows and subtracting total exports and total Delta Island Consumptive Use (DICU):

$$NDO_{DSM2} = \sum Inflows_{DSM2} - \sum Exports_{DSM2} - DICU_{DSM2} \qquad \text{[Eqn. 5-3]}$$

Equation 5-3 can be rewritten referring to the DSM2 node numbers associated with each inflow and export (see Table 5.2 for definitions of each node number):

$$NDO_{DSM2} = \underbrace{Q_{Node330} + Q_{Node17} + Q_{Node257} + Q_{Node21} + Q_{Node316}}_{DSM2\ Inflows}$$

$$\underbrace{-Q_{Node72} - Q_{Node118} - Q_{Node206} - Q_{Node273} - Q_{Node320}}_{DSM2\ Exports} - DICU_{DSM2} \qquad \text{[Eqn. 5-4]}$$

Note that total DICU includes consumptive use for Byron Bethany Irrigation District (BBID).

Table 5.2: DSM2 Input Values Used to Compute NDO.

DSM2 Node	DSM2 Name	Sign in NDO computation	Description
Inflows			
17	sjr	+	San Joaquin River inflow to the Delta
21	cal	+	Calaveras River inflow to the Delta
257	eastside	+	Mokelumne and Cosumnes combined inflow to the Delta
316	yolo	+	Yolo Bypass inflow to the Delta
330	sac	+	Sacramento River inflow to the Delta
Exports			
72	swp,clfct	-	SWP Exports
118	cvp	-	CVP Exports
206	ccc	-	Contra Costa Exports
273	nba	-	North Bay Aqueduct
320	vallejo	-	Vallejo

5.3.2 NDO Computations Using DSM2 Outputs

NDO can be estimated three different ways by computing tidally averaged simulated flows from DSM2 at selected locations that represent all outflow sources from the Delta (Figure 5.3):

- Martinez (DSM2 channel 441) (Figure 5.4)
- Chipps Island and Montezuma Slough (DSM2 channels 437, 442, and 511) (Figure 5.5)
- (Rio Vista, 3-Mile Slough, Jersey Point, and Dutch Slough (DSM2 channels 430, 309, 83, and 274) (Figure 5.6)

NDO-Martinez

NDO can be estimated from the tidally averaged flow at Martinez by tidally averaging DSM2 simulated flow results at channel 441 (Figure 5.4):

$$NDO_{DSM\,2} = \underbrace{Q_{Channel\,441}}_{Martinez} \qquad \text{[Eqn. 5-5]}$$

NDO-Chipps Island

NDO can be estimated by summing tidally averaged flows at three channels near Chipps Island: South of Chipps Island (channel 437), North of Chipps Island (channel 442) and Montezuma Slough (channel 511) (Figure 5.5):

$$NDO_{DSM\,2} = \underbrace{Q_{Channel\,437}}_{Chipps\,Is\,South} + \underbrace{Q_{Channel\,442}}_{Chipps\,Is\,North} + \underbrace{Q_{Channel\,511}}_{Montezuma\,Sl} \qquad \text{[Eqn. 5-6]}$$

NDO-Rio Vista/Jersey Point

NDO can be estimated by summing tidally averaged flows at four channels that flow into the Delta: the Sacramento River at Rio Vista (channel 430), 3-Mile Slough (channel 309), San Joaquin River at Jersey Point (channel 83), and Dutch Slough (channel 274) (Figure 5.6):

$$NDO_{DSM\,2} = \underbrace{Q_{Channel\,430}}_{Sac\,R@\,Rio\,Vista} + \underbrace{Q_{Channel\,309}}_{3\text{–}Mile\,Slough} + \underbrace{Q_{Channel\,83}}_{SJR@\,Jersey\,Po\mathrm{int}} + \underbrace{Q_{Channel\,274}}_{Dutch\,Slough} \qquad \text{[Eqn. 5-7]}$$

The USGS maintains UVM (Ultrasonic Velocity Meter) flow monitoring sites at these four locations (IEP, 2004). Thus NDO computed using Eqn. 5-7 for a DSM2 historical simulation can be compared to field measurements.

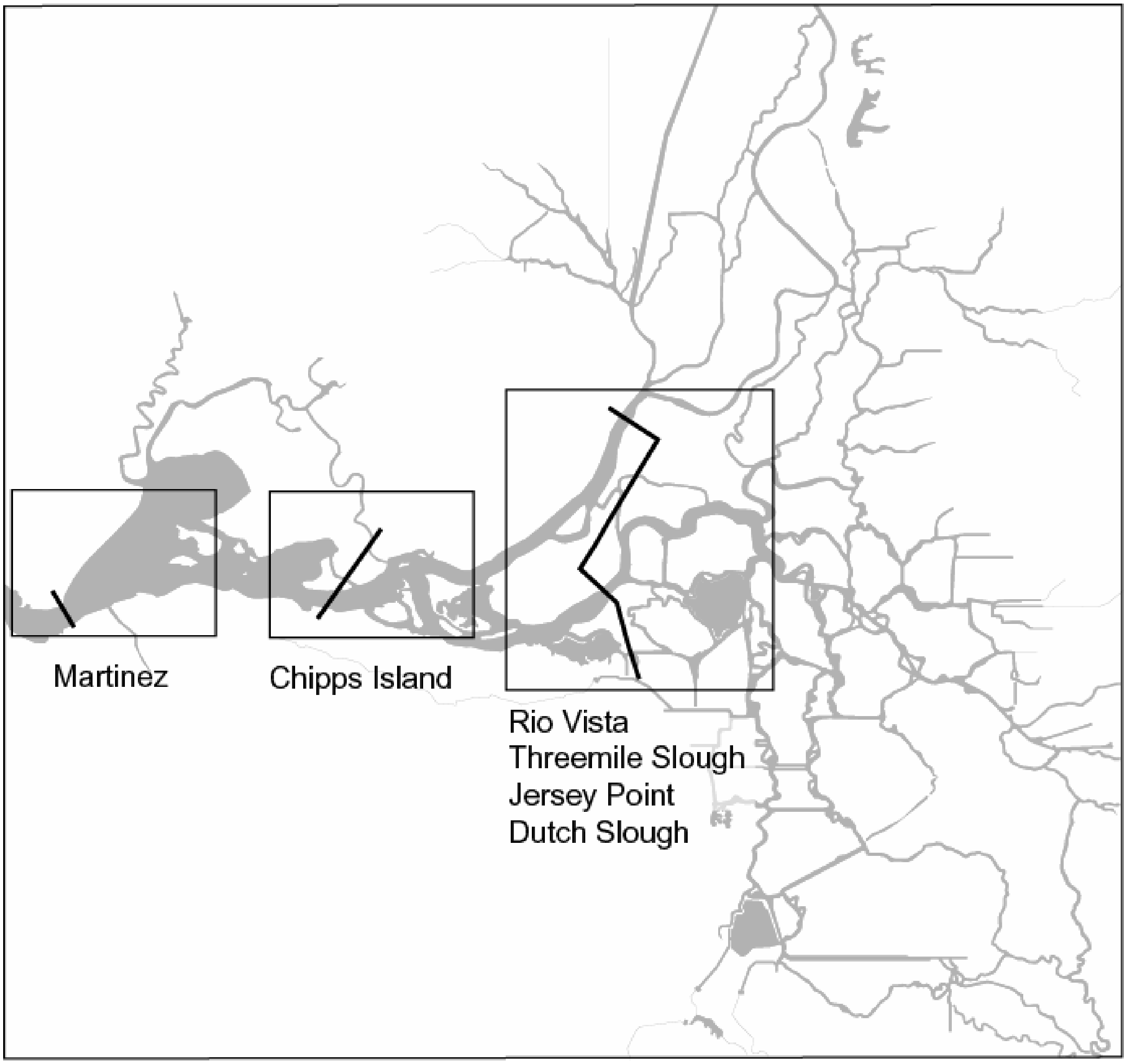

Figure 5.3: DSM2 Net Delta Outflow Estimation Locations.

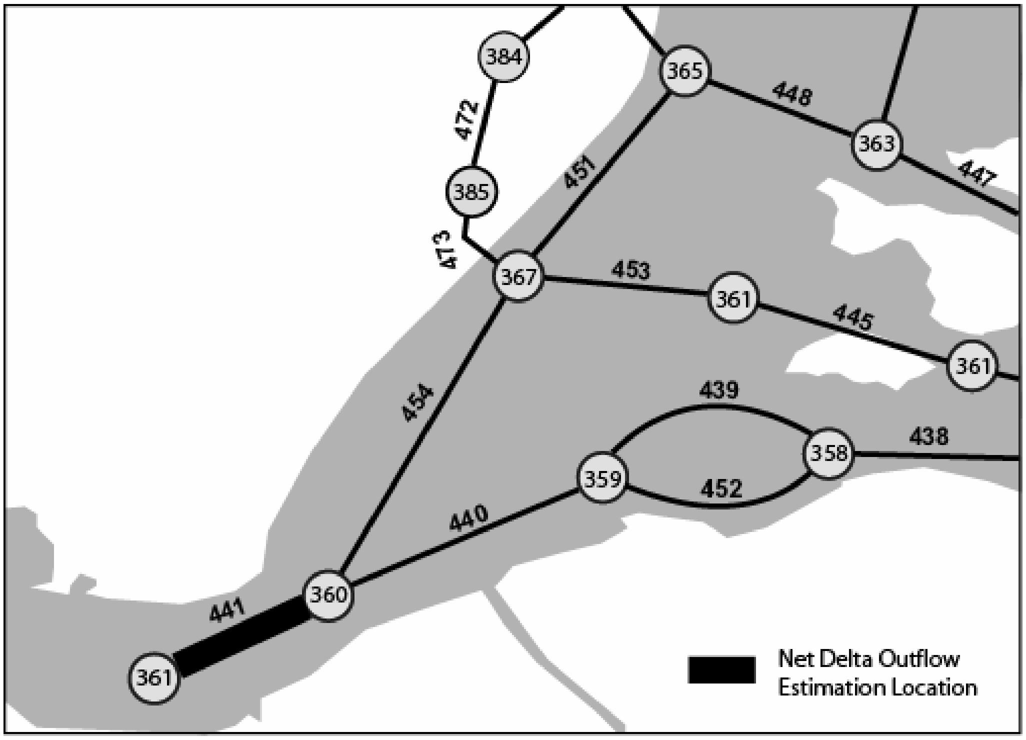

Figure 5.4: Martinez NDO Estimation Location on the DSM2 Grid.

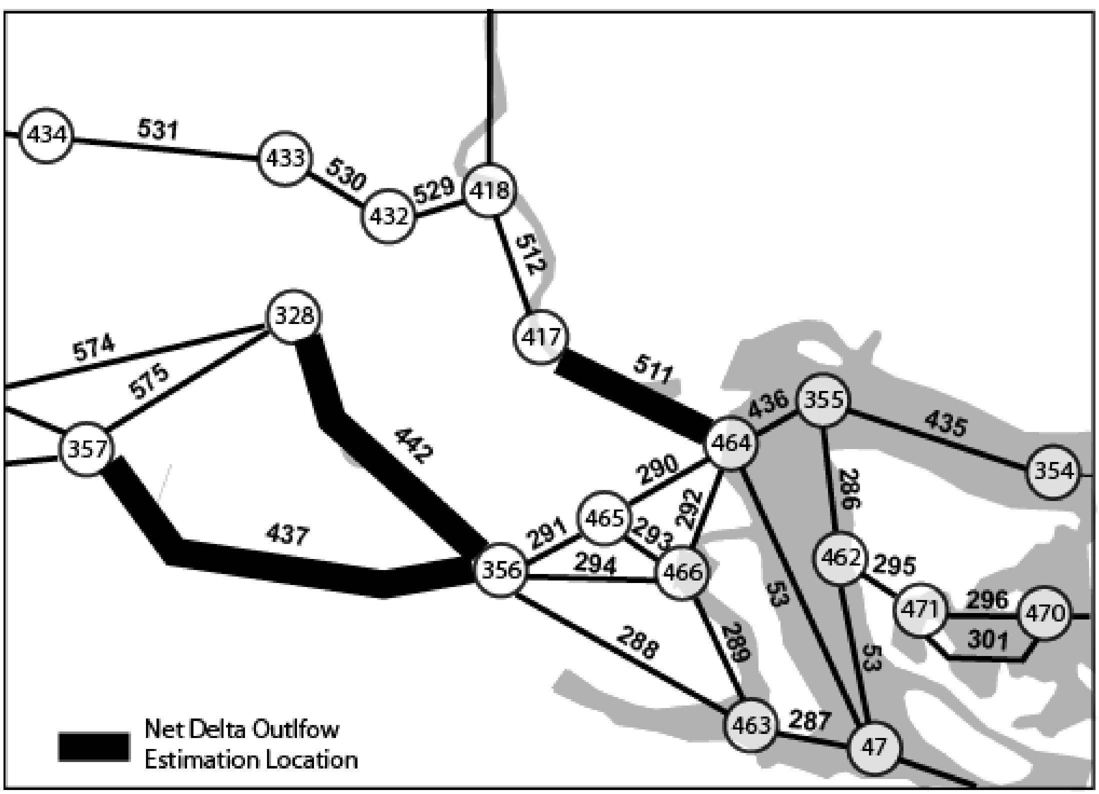

Figure 5.5: Chipps Island NDO Estimation Locations on the DSM2 Grid.

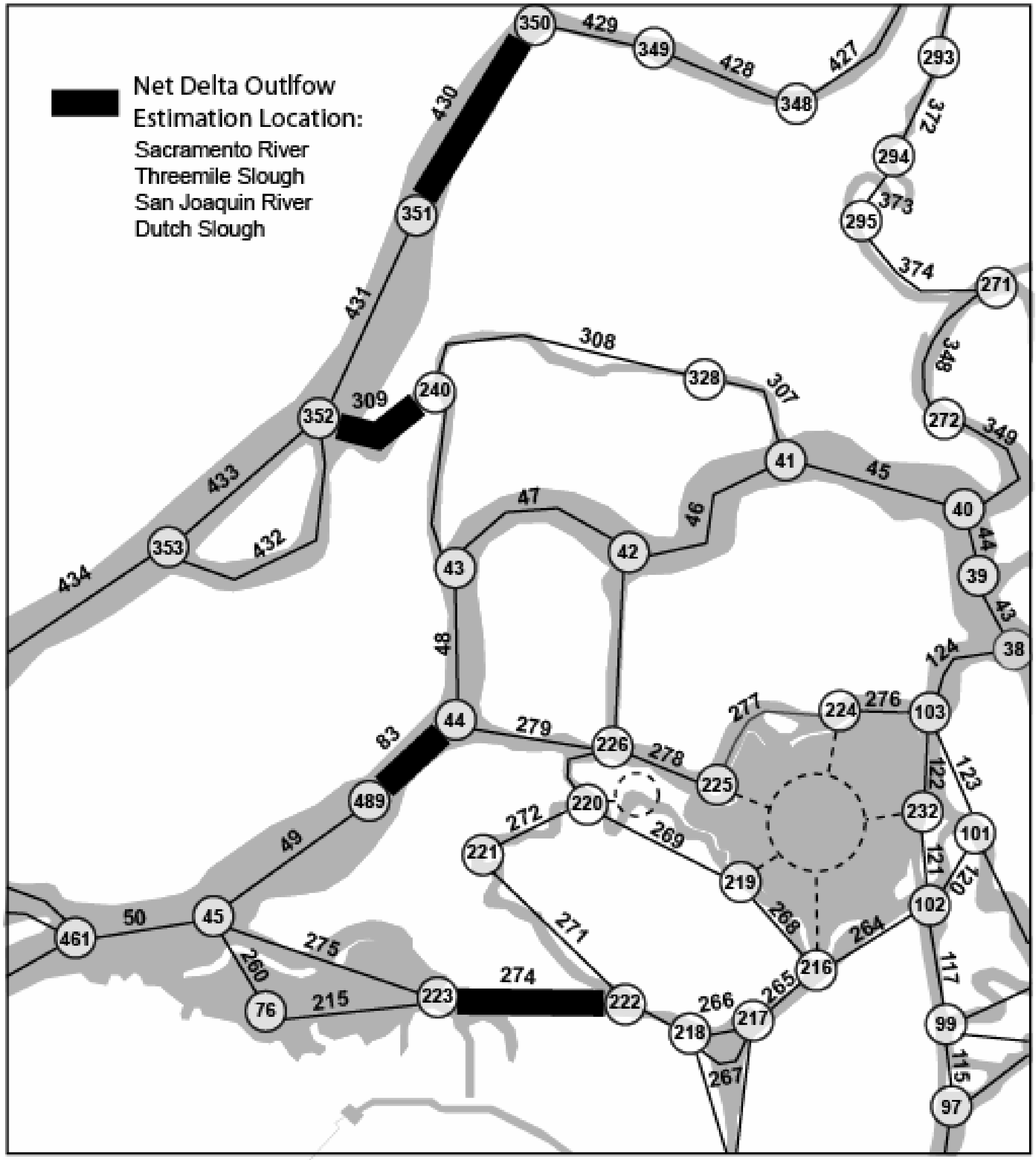

Figure 5.6: Rio Vista / Jersey Point NDO Estimation Locations on the DSM2 Grid.

5.3.3 Differences in NDO Computations Using DSM2 Inputs or Outputs

Steady state DSM2 simulations have confirmed that NDO computed from Equations 5-4 through 5-7 will produce identical results (see Chapter 6; Anderson, 2004). These steady state results confirm that:

- ❑ DSM2 conserves mass (also see Nader, 1993)
- ❑ Parameters used in Equations 5-4 through 5-7 represent all Delta outflows for NDO computations

Although NDO computed from Equations 5-4 through 5-7 will produce identical results for steady state DSM2 simulations, these equations will not produce identical results for DSM2 simulations that include the spring-neap tidal cycle. Typically spring-neap tidal cycles are represented in DSM2 historical simulations that use historical tidal data at Martinez and in DSM2 planning simulations that use an Adjusted Astronomical Tide boundary condition at Martinez. Sample monthly NDO computations using the four DSM2 input and output NDO equations (Eqn. 5-4 through Eqn. 5-7) are shown in Figure 5.7 for the South Delta Improvement Project's 2020 Integrated scenario which utilized an Adjusted Astronomical Tide. Figure 5.8 illustrates differences between the NDO computations using DSM2 outputs (Eqns. 5-5 through 5-7) and NDO computed from DSM2 inputs (Eqn. 5-4) which ranged from ± 2,500 cfs for Oct 75-Oct 81 2020 Integrated scenario data. One factor that contributes to the differences in NDO estimates based on DSM2 outputs compared to DSM2 inputs is that the mass balance computation based on DSM2 inputs (Eqn. 5-4) does not account for complex tidal dynamics.

Differences in NDO computations using DSM2 inputs and outputs for simulations that include spring-neap tidal cycles and dynamic inflow boundary conditions are due to several complex dynamics of unsteady flows in tidal systems including:

- ❑ Filling and draining of the Delta during spring-neap cycles,
- ❑ Travel time of transient Delta flows,
- ❑ Ability of the data processing technique used to compute NDO parameters to reflect tidal dynamics (monthly average, 24.75 hour running average, Godin filter, etc.) (see Chapter 6; Anderson, 2004), and
- ❑ Seasonal pattern of stage at Martinez, typically lower in winter and spring and higher in summer and fall (see Chapter 6; Anderson, 2004).

Note that similar discrepancies between NDO estimates have also been noted in DAYFLOW (IEP, 2004). DAYFLOW estimates NDO based on a mass balance of inflows and exports (analogous to Eqn. 5-3 and Eqn. 5-4). This mass balance is referred to as the Net Delta Outflow Index (NDOI). DAYFLOW documentation indicates that differences in NDOI values compared with NDO estimates based on USGS field data at Rio Vista, 3-Mile Slough, Jersey Point and Dutch Slough (analogous to Eqn. 5-7) are due to filling and draining of the Delta.

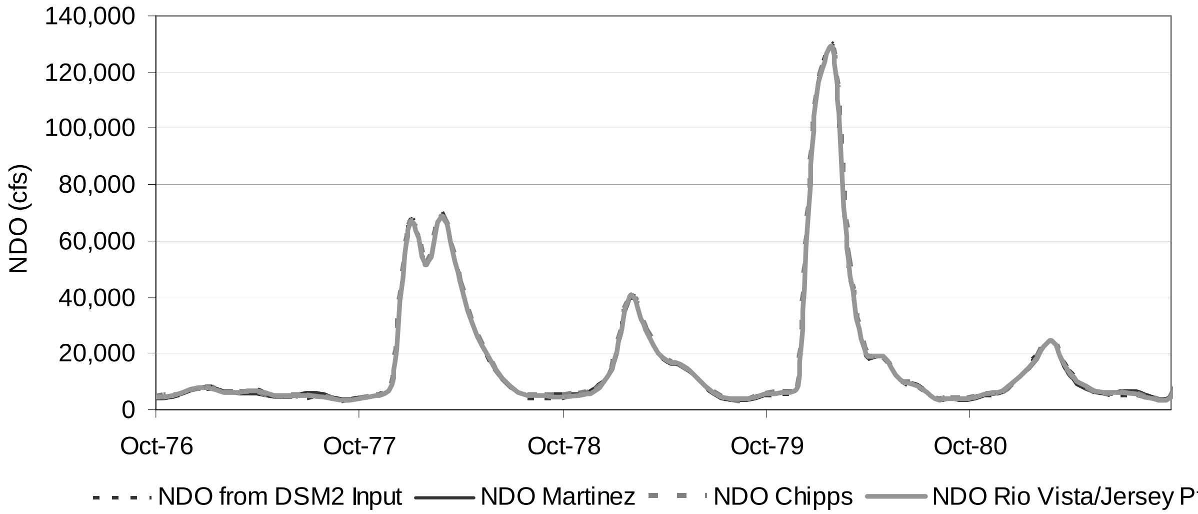

Figure 5.7: Monthly Averaged NDO Computed from DSM2 Inputs and Outputs for the SDIP 2020 Integrated Scenario.

Note: The four time series are similar, thus making the separate lines hard to distinguish.

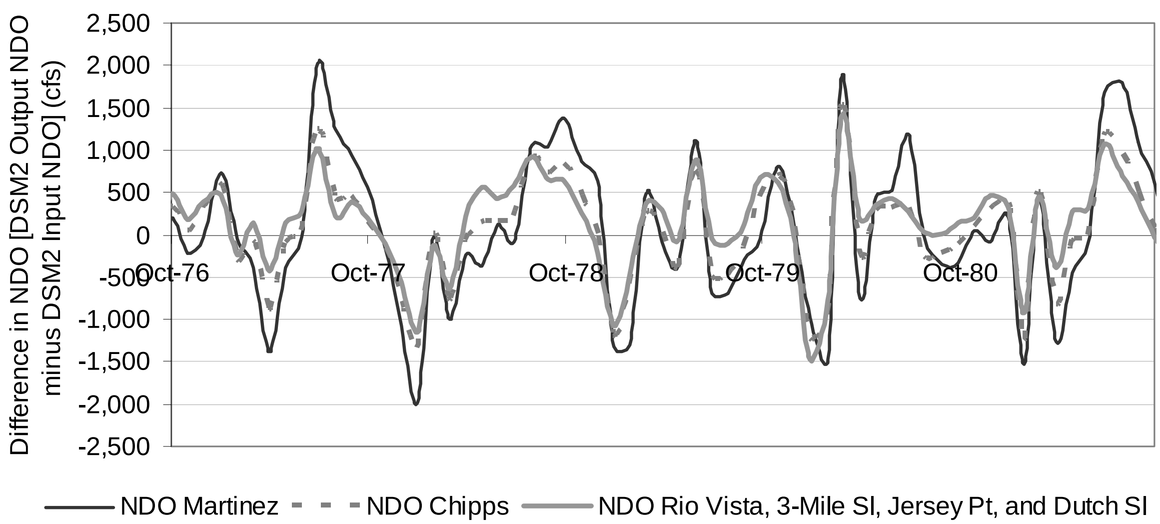

Figure 5.8: Difference in Monthly Averaged NDO (DSM2 Output NDO minus DSM2 Input NDO) for the SDIP 2020 Integrated Scenario.

5.4 Comparison of CALSIM II and DSM2 NDO Computations

For Quality Assurance/Quality Control (QAQC) purposes, it can be verified that the NDO in a DSM2 planning study matches the NDO from the CALSIM II simulation upon which the DSM2 study is based. This section compares NDO computed by CALSIM II (Eqns. 5-1 or 5-2) to NDO estimated from DSM2 inputs for planning studies (Eqns. 5-3 or 5-4). Parameters used in the NDO computations are discussed first, followed by a comparison of NDO computations for the two models.

5.4.1 CALSIM II Output Used Directly in DSM2 Planning Studies

For typical DSM2 planning studies, the channel inflows to the Delta (C157 Yolo Bypass, C169 Sacramento River, C504 Mokelumne and Cosumnes Rivers, C508 Calaveras River, and C639 San Joaquin River) and Delta exports (D403A Vallejo, D403B North Bay Aqueduct, D408 Contra Costa Exports, D418 CVP, and D419 SWP) used in the CALSIM II NDO calculations (Eqn. 5-2) are directly input into DSM2.

For some DSM2 planning studies, the monthly Sacramento River and San Joaquin River flows are smoothed to daily values to minimize numerical instabilities between months with large flow transitions. Monthly CALSIM II values for the San Joaquin River, CVP and SWP may also be converted to daily values to represent flows during the Vernalis Adaptive Management Plan (VAMP) period from April 15-May 15.

5.4.2 NDO Components not Included in Both CALSIM II and DSM2

In CALSIM II, inflow from Marsh Creek is included in the NDO computations (Eqn. 5-2), however this flow is typically not included in DSM2 planning studies. For the 2020 Integrated Scenario, the maximum flow in Marsh Creek was approximately 375 cfs.

5.4.3 DICU in CALSIM II and DSM2

Total Delta Island Consumptive Use (DICU) in CALSIM II is computed by summing the Delta Consumptive Use arcs and subtracting the precipitation inflow arcs as follows:

$$DICU_{CALSIM} = \underbrace{D404 + D410 + DI412 + DI413}_{\text{Delta Consumptive Use}} - \underbrace{I404 - I410 - I412 - I413}_{\text{Delta Precipitation}} \qquad \text{[Eqn. 5-8]}$$

For consistency between CALSIM II and DSM2 planning studies, the total DICU in DSM2 is modeled as being mathematically equivalent to the DICU in CALSIM II:

$$DICU_{DSM2} = DICU_{CALSIM} \qquad \text{[Eqn. 5-9]}$$

The distribution of DICU values used in DSM2 planning studies are determined by running DWR's DICU and Adjusted Delta Island Consumptive Use (ADICU) models using CALSIM II DICU as input (Mahadevan, 1995). Based on water year type, monthly average historical precipitation, monthly average historical pan evaporation and fixed values of land use for each DICU subarea, and a single Delta-wide irrigation efficiency value, the DICU model computes the historical irrigation diversions, seepage, and drainage (return flows) at each of the 257 DSM2 DICU locations (Figure 5.9). DWR's ADICU model then disaggregates the total Delta Consumptive Use from CALSIM II to these 257 locations by adjusting the historical patterns. Total DICU in DSM2 is computed by adding the irrigation diversions and seepage and subtracting the drainage (Eqn. 5-10). The total DICU computed from the irrigation diversions, seepage, and drainage computed from the DICU model will be mathematically equivalent to the DICU computed from CALSIM (Eqn. 5-9).

$$\mathrm{DICU}_{\mathrm{DSM2}} = \sum^{DSM2\,DICU\,Nodes} Irrigation\,Diversions + Seepage - Drainage \qquad \text{[Eqn. 5-10]}$$

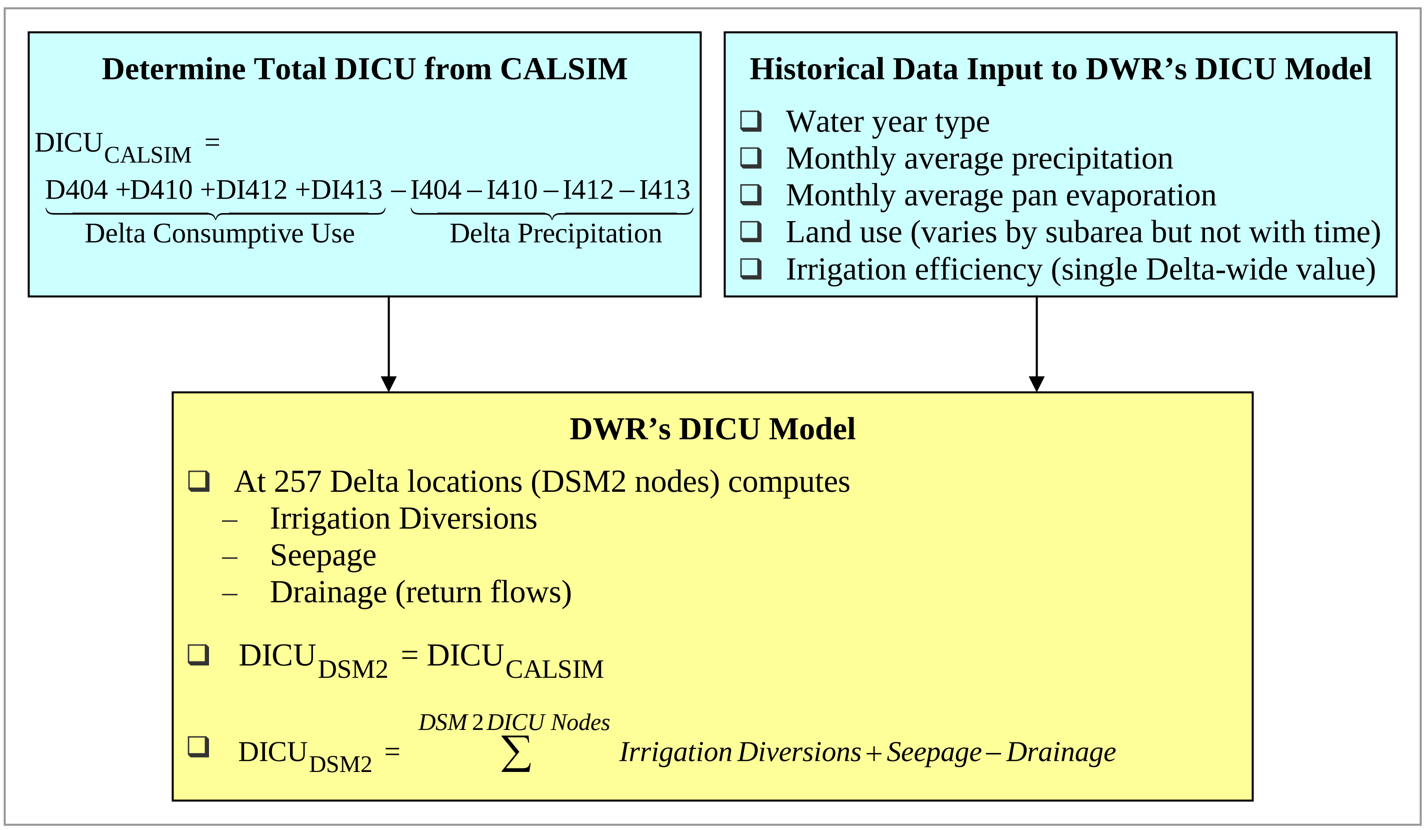

Figure 5.9: Computation of DICU for DSM2 based on CALSIM Results.

5.4.4 Comparing CALSIM II and DSM2 NDO

To verify that the NDO in a DSM2 planning study matches the NDO from the CALSIM II simulation upon which the DSM2 study is based (a typical QAQC procedure), the NDO from the DSM2 study can be compared to the NDO from the CALSIM II study with appropriate adjustments for parameters that are included in one model but not the other. The following equations compare DSM2 NDO to CALSIM II NDO with an adjustment to reflect Marsh Creek inflows that are considered in CALSIM II but not in DSM2:

$$NDO_{DSM\,2} = NDO_{CALSIM} - \underbrace{I406_{CALSIM}}_{Marsh\,Creek} \qquad \text{[Eqn. 5-11]}$$

Substituting Eqn. 5-3 into Eqn. 5-11 results in the following equation:

$$NDO_{CALSIM} = \sum Inflows_{DSM\,2} - \sum Exports_{DSM\,2} - DICU_{DSM\,2} + \underbrace{I406_{CALSIM}}_{Marsh\,Creek} \qquad \text{[Eqn. 5-12]}$$

Substituting Eqn. 5-4 into Eqn. 5-12 results in the following equation:

$$NDO_{CALSIM} = \underbrace{Q_{Node\,330} + Q_{Node\,17} + Q_{Node\,257} + Q_{Node\,21} + Q_{Node\,316}}_{DSM\,2\ Inflows} \qquad \text{[Eqn. 5-13]}$$

$$-\underbrace{Q_{Node\,72} - Q_{Node\,118} - Q_{Node\,206} - Q_{Node\,273} - Q_{Node\,320}}_{DSM\,2\ Exports} - DICU_{DSM\,2} + \underbrace{I406_{CALSIM}}_{Marsh\,Creek}$$

The comparison of CALSIM II and DSM2 NDO using Equation 5-13 will be equivalent if the CALSIM II outputs are used directly in DSM2. However monthly CALSIM II data are often modified in DSM2 to smooth flow transitions from month to month (typically Sacramento and San Joaquin River flows) or to represent flow and export adjustments during the VAMP period from April 15-May 15 (typically San Joaquin River flows, and CVP and SWP exports).

Depending on the technique used to modify the CALSIM II input from monthly to daily values, the CALSIM II and DSM2 NDO values may not be exactly the same. For example, a tension spline is often used in planning studies to smooth monthly Sacramento and San Joaquin River flows to daily values. The tension spline is conservative over the entire smoothing period (typically the 16-year planning study period), however the average values for any given month may not be identical to the monthly values from CALSIM II. Thus, monthly DSM2 NDO computations using the average of the daily smoothed values may not be identical to the CALSIM II NDO when comparing individual months, but the total NDO for the simulation period will be identical. For the 2020 Integrated Scenario which smoothed monthly flows to a daily time step for the Sacramento River, the maximum difference in monthly NDO was approximately 135 cfs.

The techniques typically used to create daily time series to represent VAMP for San Joaquin River flows and CVP and SWP exports preserves the monthly average values at those locations. Thus monthly NDO computations using flow and export values that had been adjusted to represent the VAMP period would still be identical for CALSIM II and DSM2 if no other variables were modified.

5.5 Summary

Net Delta Outflow is an estimate of the net flow leaving the Delta. NDO values can be estimated from CALSIM II and DSM2 data using a variety of techniques summarized below:

- ❑ Mass balance of system inflows and outflows
  - CALSIM II Output: NDO = Inflows + Precipitation – Exports – Consumptive Use (Eqn. 5-2)
  - DSM2 Output: NDO = Inflows – Exports – DICU (Eqn. 5-3)

- ❑ Summation of flows that represent all Delta outflow sources
  - CALSIM II Output: NDO = D1641 Delta Outflow + Other Outflow Requirements (Eqn. 5-1)
  - DSM2 Output: NDO = Average Martinez Flow (Eqn. 5-4)
  - DSM2 Output: NDO = Average Flow Chipps Island + Montezuma Slough (Eqn. 5-5)
  - DSM2 Output or USGS UVM station data:
NDO = Average Flow Rio Vista + 3-Mile Slough + Jersey Point + Dutch Slough (Eqn. 5-6)

NDO computations using the above relationships may not result in identical NDO values due to a variety of reasons:

- ❑ CALSIM II and DSM2 do not necessarily use identical representations for all Delta inflows and withdrawals
  - Inclusion of Marsh Creek inflow in CALSIM but not in DSM2
[max 375 cfs for 2020 Integrated wy1975-1991]
  - Smoothing of monthly CALSIM II flows for the Sacramento and San Joaquin River to daily values in DSM2 [average difference over 15-years of zero cfs, however monthly differences were up to 135 cfs for 2020 Integrated wy1975-1991]

- ❑ Complex dynamics of unsteady flows in tidal systems
  - Filling and draining of the Delta during spring-neap cycles
  - Travel time of transient Delta flows
  - Ability of data processing technique used to compute NDO parameters to reflect tidal dynamics (monthly average, 24.75 hour running average, Godin filter, etc)
  - Seasonal pattern of stage at Martinez (typically lower in winter and spring and higher in summer and fall)

5.6 References

Anderson, J. (2004). "Chapter 6: Net Delta Outflow Computations for DSM2 Steady State Simulations." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 25th Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources, Bay-Delta Office. Sacramento, CA.

Department of Water Resources. (1995). *Sacramento-San Joaquin Delta Atlas.* California Department of Water Resources. Sacramento, CA.

Mahadevan, N. (1995). *Estimation of Delta Island Diversions and Return Flows.* California Department of Water Resources, Division of Planning and Local Assistance. Sacramento, CA.

Nader, P. (1993). "Chapter 6: New Model Development: Four-Point and BLTM." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 14th Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources, Division of Planning. Sacramento, CA.

Interagency Ecological Program. (2004). Interagency Ecological Program's Dayflow website: http://iep.water.ca.gov/dayflow/ndoVsNdoi/index.html, accessed on 5-5-04.