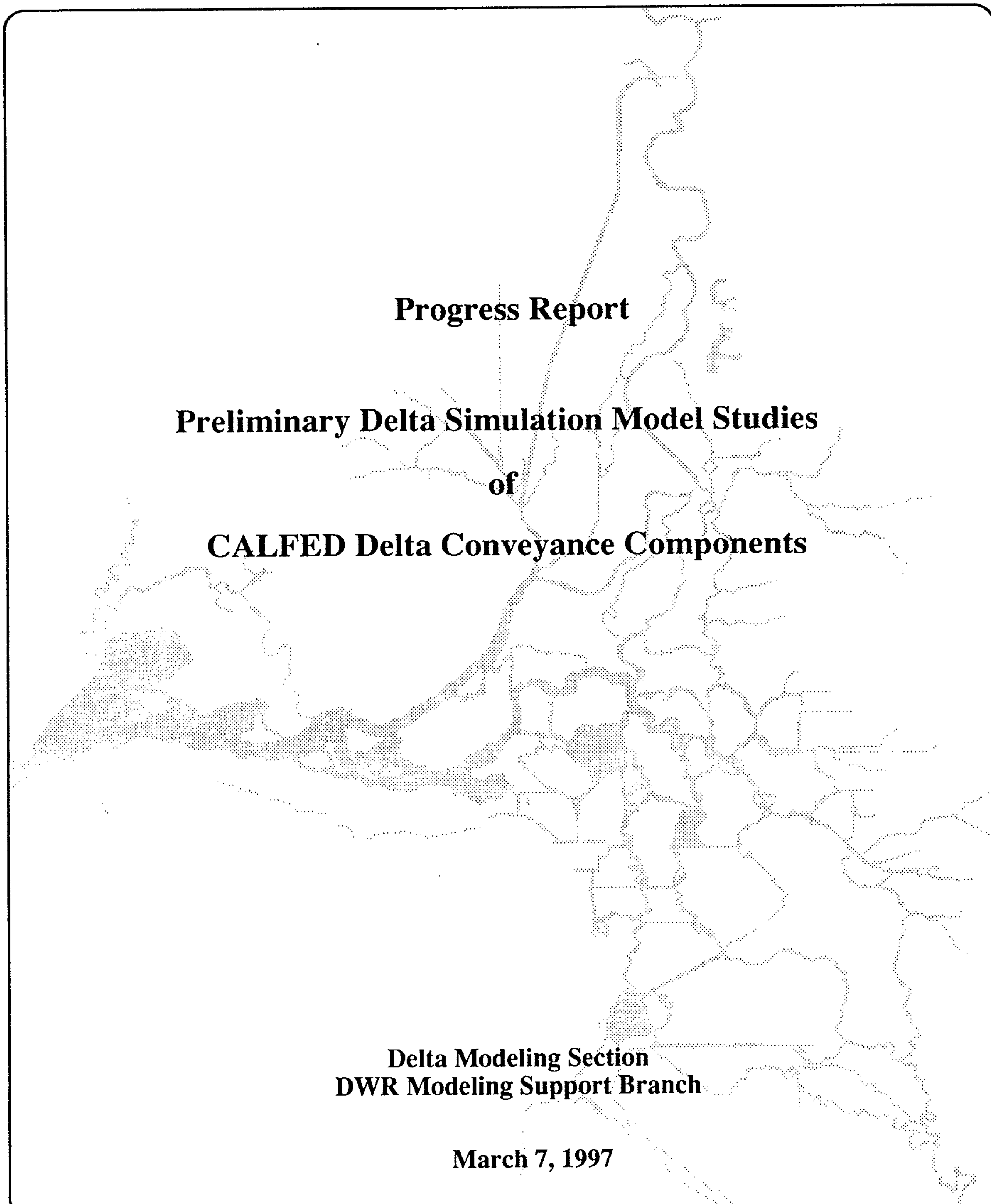

Progress Report

Preliminary Delta Simulation Model Studies of CALFED Delta Conveyance Components

Delta Modeling Section
DWR Modeling Support Branch

March 7, 1997

Introduction

DWR Modeling Support Branch has been actively engaged in computer modeling activities to support CALFED. As part of this work, Delta modeling with DWRDSM1 has been initiated to address various issues associated with analysis of Delta impacts using computer simulations. The purpose of this report is to present and describe results to date related to this process.

Chapter 1 analyzes the modeling results for five Delta alternatives over an April through May period. Figures and discussion of averaged hydrodynamic and mass tracking results over different intervals of time are presented. Chapter 2 compares results from two strategies for Delta modeling. One method averages the results of modeling daily Delta inflows and exports and historic boundary tide from a May hydrology. The second method models a single 25-hour period using average Delta inflows and exports from the same May hydrology with the 19-year mean tide. Chapter 3 evaluates the hydraulics of the "Chain of Lakes" alternative under maximum CVP and SWP pumping.

Chapter 1
Analysis of Five Delta Alternatives

Five Delta alternatives were simulated by DWRDSM1 over an April and May period. These alternatives were chosen to provide a good range of possible Delta impacts and include key components of various CALFED alternative components as described in a preliminary report, ***CALFED Bay-Delta Program Draft Delta Conveyance and Storage Components***, January 30, 1997. The results which follow are meant to provide preliminary trends and modeling output formats for review rather than be a definitive, in-depth analysis. Revisions to descriptions of alternative components to more closely match CALFED's refinements, salinity modeling, and further modeling of different hydrology conditions are planned for future analysis.

Delta Alternatives

Delta alternatives included in this report are labelled as: Existing Delta Geometry, Interim South Delta Program Geometry (ISDP), North Delta Program Geometry (NDP), North Delta Program with Hood Diversion Geometry (NDPH), and CUWA Alternative C Geometry (CUWA-C).

Existing Delta Geometry

Delta conditions under the existing configuration was modeled. Boundaries for this alternative, as well as for all other alternatives, consisted of Sacramento River at I Street, San Joaquin River at Vernalis, and Carquinez Strait at Martinez. Temporary flow and fish control structures in the south Delta were assumed to be installed from mid April through May (Figure 1). This period was chosen to provide results in April for two conditions - for with and without installation of the structures. The flow control structures consisted of a weir and culverts. The culverts allowed landward flow on the flood tide, but closed on the ebb tide preventing seaward flow. Seaward flow over the weir was possible for sufficiently high water levels. The fish control structure at the head of Old River was assumed to be a complete closure, sending all San Joaquin River flow down past the bifurcation with Old River. Table 1 describes these structures and the times of installation.

Clifton Court Forebay intake gates were assumed to take flow into the forebay any time water levels allowed. This was assumed for all alternatives. Maximum allowable flow into the forebay was set at 15,000 cfs.

The Delta Cross Channel was assumed open during the April through May period.

Figure 1

Existing Delta Geometry

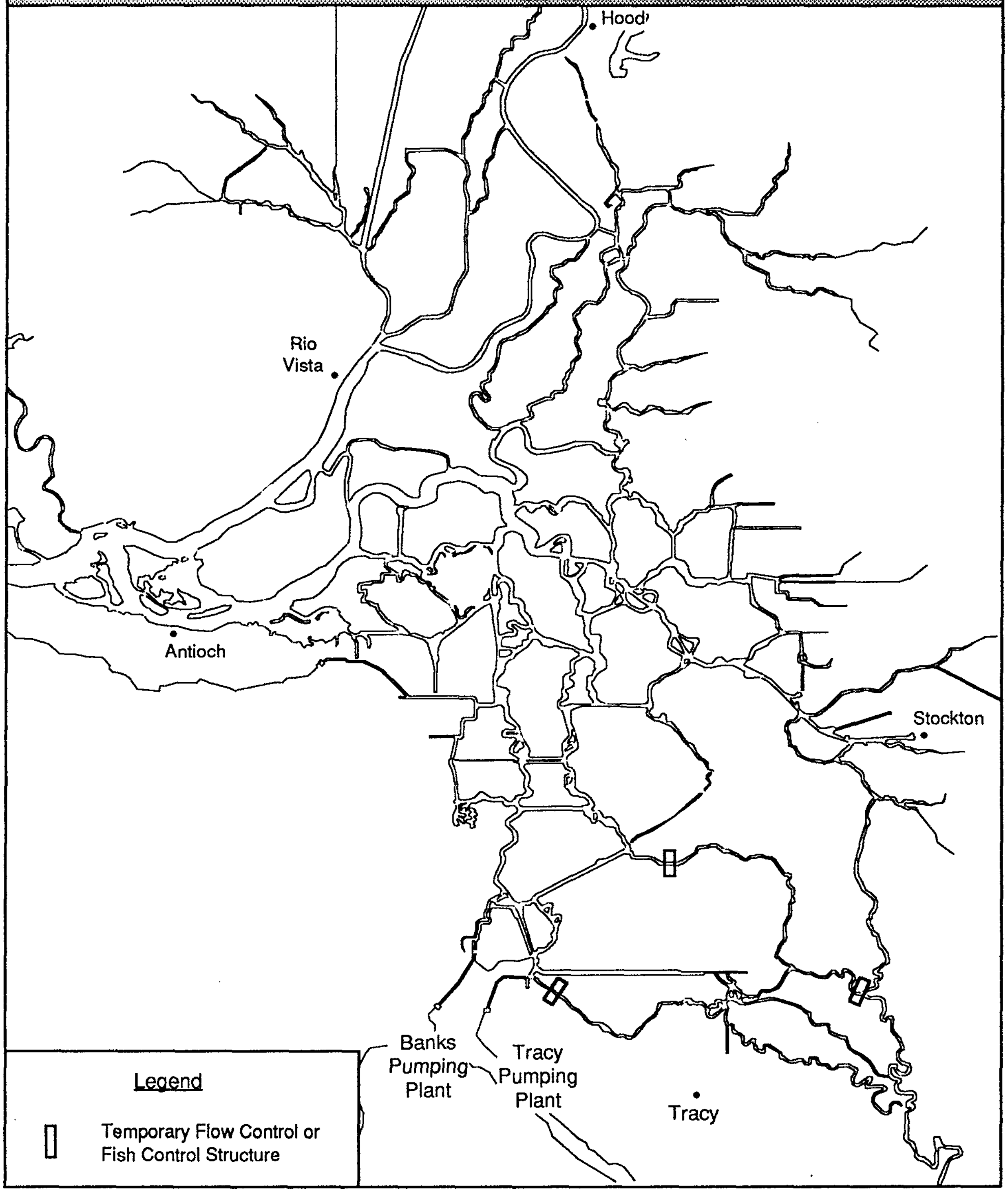

Table 1
Flow Control and Fish Control Structures
Existing Delta Geometry

Fish Control Structure	
Location:	Head of Old River
Components:	Complete Closure
Timing:	April 16 - May 31
Flow Control Structures	
Location:	Old River near Tracy
Components:	75' weir at +2 msl nine 4' diameter culverts
Timing:	April 16 - May 31
Location:	Middle River near Victoria Canal
Components:	140' weir at +1 msl six 4' diameter culverts
Timing:	April 16 - May 31

Interim South Delta Program Geometry

Delta conditions for the Interim South Delta Program Geometry were simulated (Figure 2). This alternative replaced the temporary flow and fish control structures with permanent structures holding radial gates, placed additional forebay intake gates on the north of the forebay and enlarged a portion of Old River.

The flow control structures on Middle and Old rivers were operated to allow landward flow on the flood tide, then closed to prevent any seaward flow on the ebb tide. Interim South Delta Program's proposed flow control structure on Grant Line Canal was not operated in the April through May period since current planning assumes that the fish control structure and the flow control structure on Grant Line Canal would not be operated simultaneously. The fish control structure was operated to create a complete closure at the head of Old River. Table 2 further describes these structures and their operation schedule.

The intake to Clifton Court Forebay was moved to the northern end of the forebay. Intake gates with a total flow opening of 2500 sq feet and a capacity of 25,000 cfs were assumed. Old River from Victoria Canal to Woodward Canal was dredged 5 feet. The Delta Cross Channel was open.

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Figure 2

Interim South Delta Program Geometry

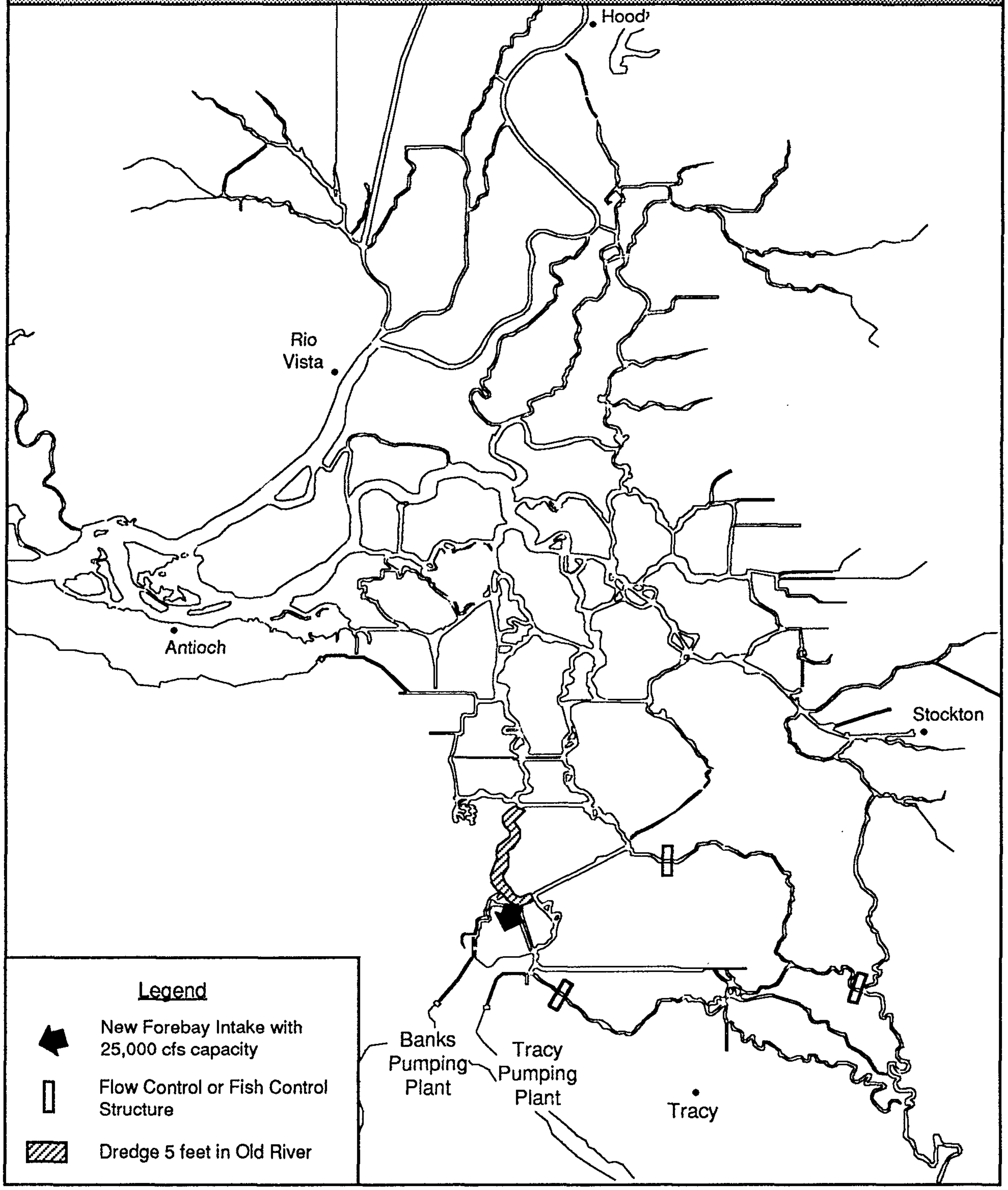

Table 2
Flow Control and Fish Control Structures
Interim South Delta Program Geometry

Fish Control Structure	
Location:	Head of Old River
Components:	Complete Closure
Timing:	April 16 - May 31
Flow Control Structures	
Location:	Old River near Tracy
Components:	three 20' wide radial gates
Timing:	April 1 - May 31
Location:	Middle River near
Victoria Canal	
Components:	two 25' wide radial gates
Timing:	April 1 - May 31

North Delta Program Geometry

This alternative increased through-Delta conveyance while minimizing changes to the Delta configuration (Figure 3). This alternative widened and added additional gates to the Delta Cross Channel and enlarged portions of Snodgrass Slough, Dead Horse Cut, and the North and South forks of the Mokelumne River. Table 3 describes these changes.

The description and operation of the flow control and fish control structures, Clifton Court Forebay modifications, and Old River enlargement were consistent with the ISDP Preferred Alternative. The Delta Cross Channel was open.

Figure 3

North Delta Program Geometry

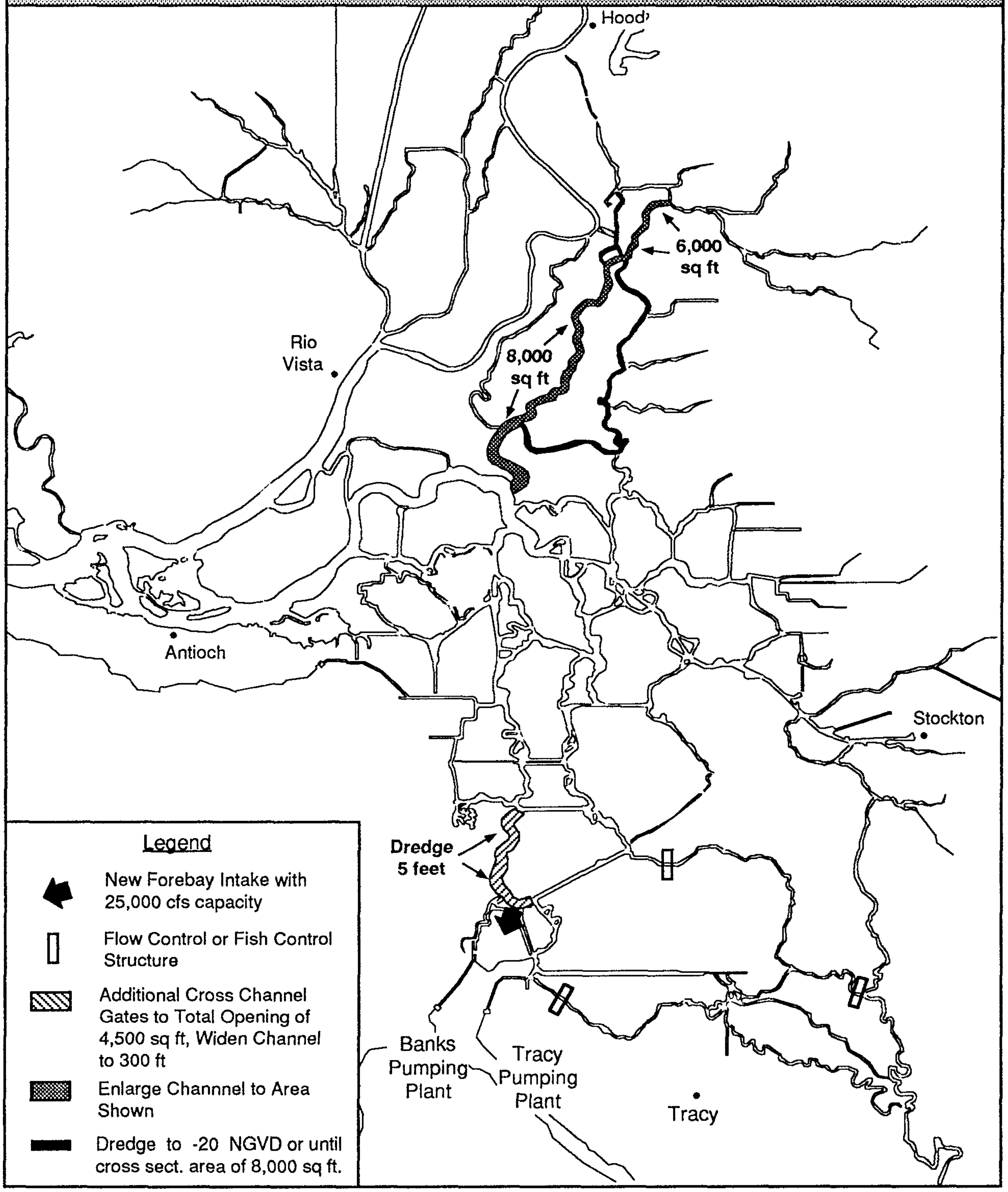

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Table 3
Delta Configuration Changes
North Delta Program Geometry

Delta Cross Channel
New Width: 300 feet Total Gates: Operational opening of 4,500 sq ft
Channel Enlargement
Snodgrass Slough, Dead Horse Cut, South Fork Mokelumne:
Dredge to -20 feet NGVD or until cross sectional area of 8,000 sq feet reached.
Mokelumne River upstream of New Hope Landing:
Levee setback and dredge to 6,000 sq ft
North Fork Mokelumne and Mokelumne from split to San Joaquin River:
Levee setback and dredge to 8,000 sq ft

North Delta Program with Hood Diversion Geometry

The North Delta Program Geometry alternative was modified to include a 5,000 cfs diversion from the Sacramento River at Hood to Snodgrass Slough (Figure 4). The Snodgrass Slough enlargement was extended upstream to its junction with the diversion canal. Delta Cross Channel enlargements were no longer assumed and channel width and gate descriptions reverted back to existing conditions. All other Delta configurations were the same as for the North Delta Program Geometry.

CUWA Alternative C Geometry

This proposed alternative provided through-Delta conveyance with creation of extensive habitat and areas of low velocities. This alternative's description was received from Metropolitan Water District and, at the time of this analysis, labelled CUWA Alternative C (see Figure 5). This alternative used Tyler Island for conveyance of Sacramento River water into the interior Delta in lieu of the Delta Cross Channel. Open water areas were created in the interior and east Delta through the flooding of islands and tracts. Clifton Court Forebay was modified by adding intake gates at Italian Slough. Sections of Old River and Italian Slough were enlarged. Alternative components are listed in Table 4. The flow control and fish control structures from the Interim South Delta Program Geometry were also assumed installed and operating according to the same schedule as before.

Figure 4

North Delta Program with Hood Diversion Geometry

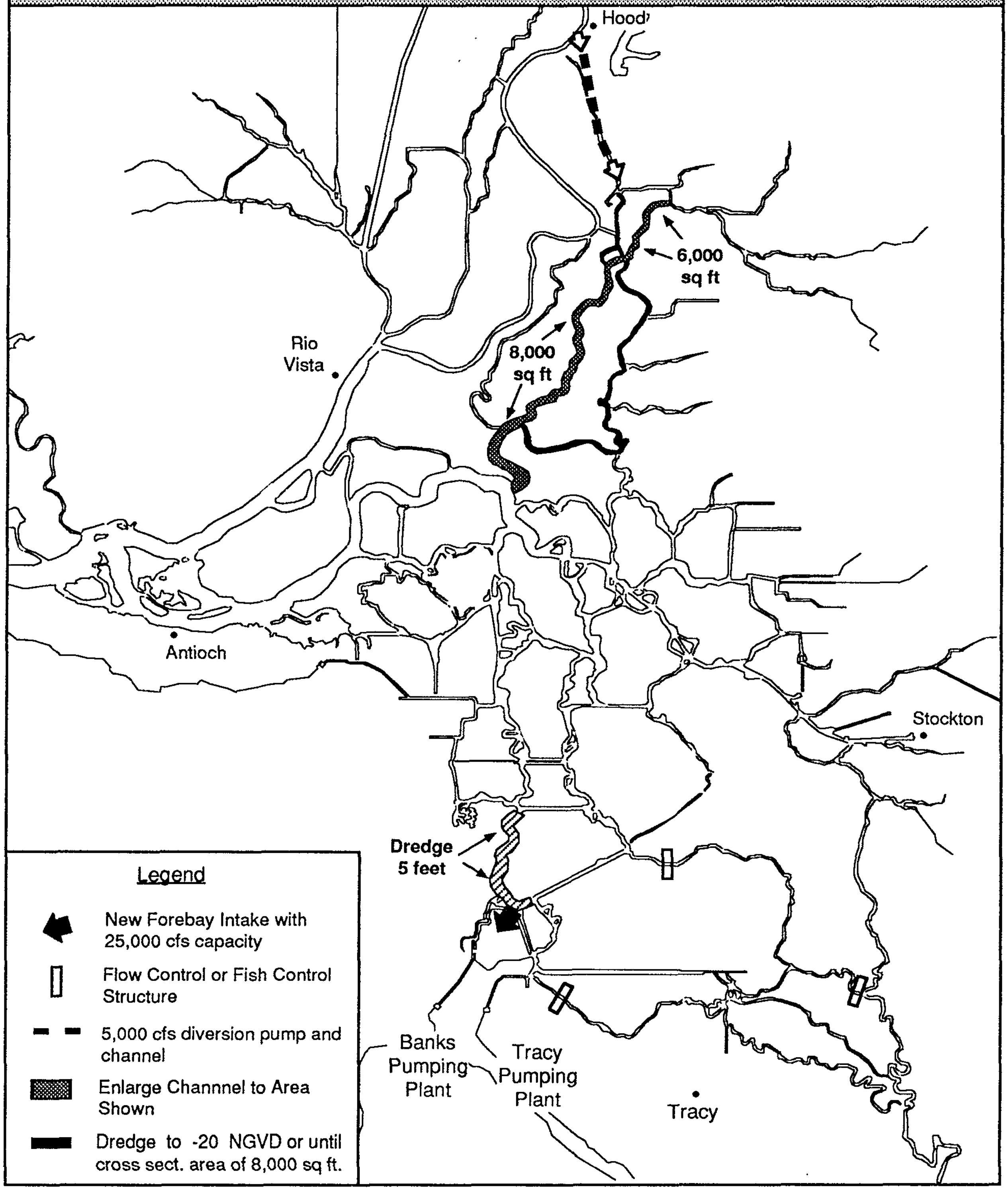


Figure 5

CUWA Alternative C Geometry

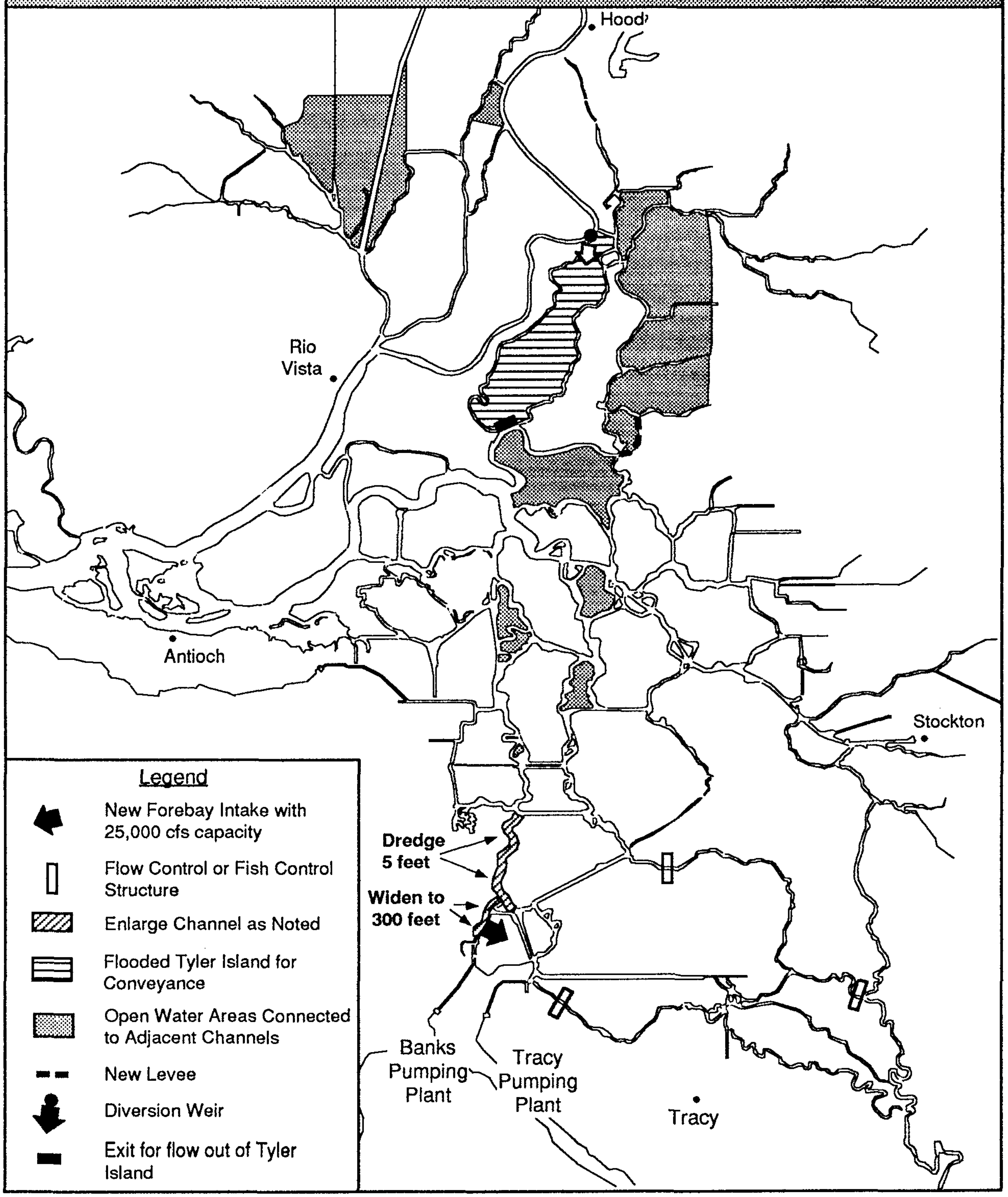


Table 4
Delta Configuration Changes
CUWA Alternative C Geometry

Tyler Island Conveyance

Intake Weir on Sacramento River: 300' wide at -8 msl
Outlet at southern end
Flow kept separate from surrounding channels except at outlet

Open Water Areas

15 open water areas created which allow mixing with adjacent channels: Prospect Island, Lower Yolo Bypass, Cache Slough, northern Sutter Island, McCormack-Williamson Tract, New Hope Tract, Canal Ranch Tract, Brack Tract, northern Terminous Tract, Bouldin Island, Medford Island, Mildred Island, and Quimby Island (3 areas).

New levee on Terminous Tract

Enlarge Channels in south Delta

Dredge Old River from Woodward Canal to Italian Slough 5'
Widen Italian Slough from Old River to forebay intake to 300'

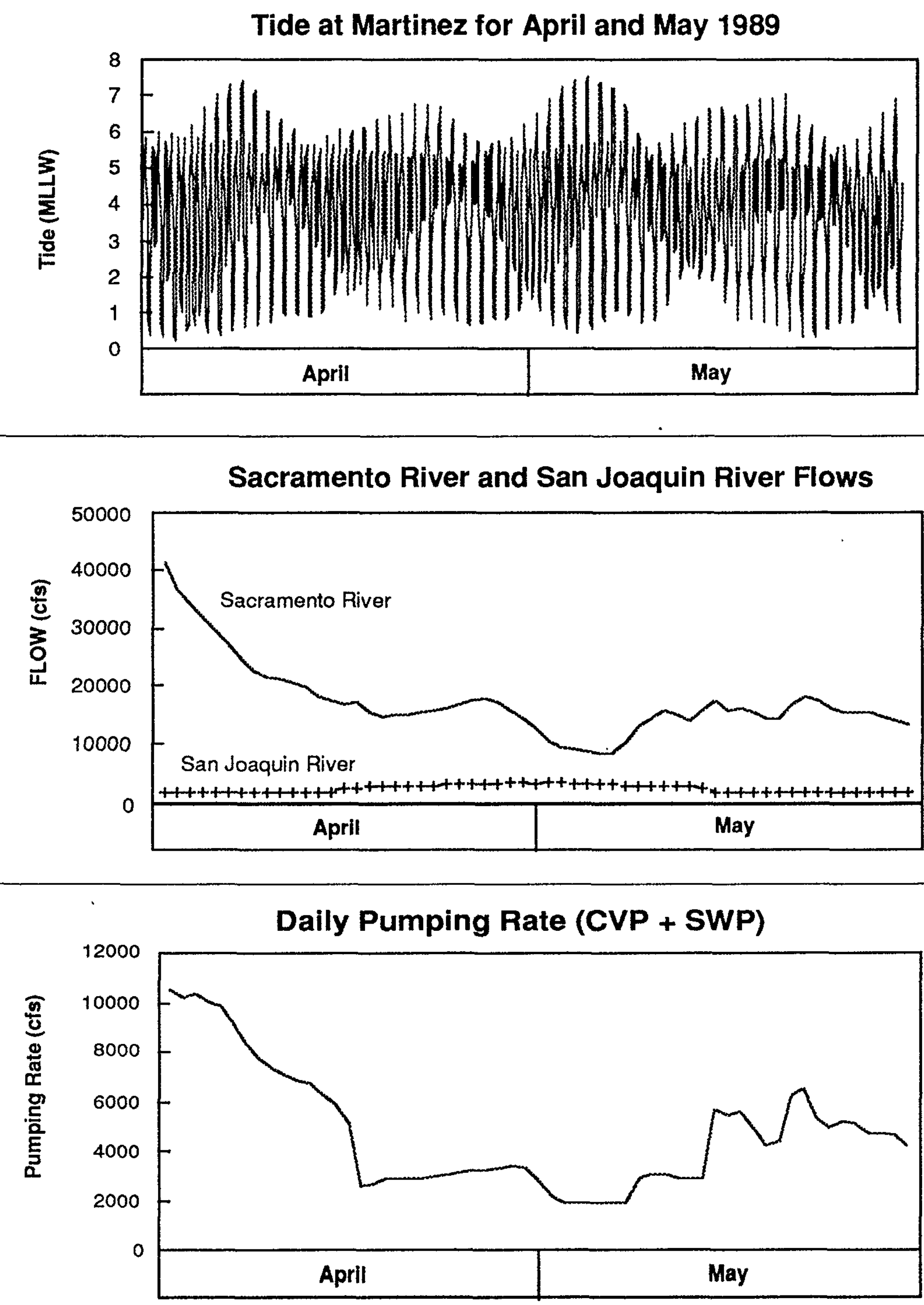
Clifton Court Forebay

New intake gates on Italian Slough with openings of 2500 sq ft and total capacity of 25,000 cfs.

Delta Boundary Conditions

The period of April through May was simulated. The Delta inflows and exports were derived from the historic period of April and May of 1989. These flows were adjusted to reflect how SWP and CVP might have been operated over this period to meet State Water Resources Control Board's 1995 Water Quality Control Plan. As shown in Figure 6, the Sacramento River inflow varied from over 40,000 cfs at the start of April to near 10,000 cfs in May. Combined CVP and SWP pumping ranged from over 10,000 cfs to 2,000 cfs. The boundary tide at Martinez was the historically observed tide during April and May of 1989. DWRDSM1 daily results of maximum, minimum, and average flows, velocities, and stages were averaged over the periods of April 1 - 15, April 16 - 30, and May 1 - 31. April was broken up into two periods because of the operation or installation of a fish control structure on April 16th for each alternative, substantially changing flow patterns in the south Delta.

Figure 6
Boundry Tide at Martinez
Sacramento River Flow, San Joaquin River Flow, Combined CVP & SWP Exports
April and May of 1989 Reoperated for SWRCB WQCP



Delta Modeling Results

DWDSM1 results for the five alternatives are presented in Figures 7 through 42. Figures 7 through 21 show average flows and velocities throughout the Delta for the periods of April 1 - 15, April 16 - 30, and May 1 - 31, 1989. Figures 22 through 36 show maximum seaward, maximum landward, and tidally average flows in the central and south Delta along channels off of the San Joaquin River. Minimum water levels in the south Delta are also shown. Figures 37 through 42 show mass tracking results after 15 and 30 days resulting from injection at San Joaquin River at Vernalis, Sacramento River at Freeport, and Columbia Cut.

For the purpose of analysis, modeling results for the Existing Delta Geometry and the Interim South Delta Program Geometry are compared to each other. Then all other analysis is based on comparisons to the Interim South Delta Program Geometry alternative since they all include the same permanent flow control and fish control structures and structure operation schedule.

A summary of these results is provide in Table 5.

Delta Hydrodynamics

<u>Existing Delta Geometry and Interim South Delta Program Geometry (ISDP).</u> Figures 7 - 12 show that the ISDP alternative had very little impact on flows and velocities in the Sacramento River and the north Delta. In the south Delta, however, the ISDP alternative could change flows and levels. In the first half of April, the Existing Delta Geometry alternative assumed that no flow control structures were installed while the ISDP alternative operated structures in Middle and Old rivers. The operation of the Middle River and the Old River flow control structures in the ISDP alternative caused more San Joaquin River water to flow downstream of the head of Old River. Minimum water levels were raised and changes in the flow circulation in the south Delta also resulted (Figures 22 - 27). The periods of the second half of April and May operated similar structures for these two alternatives. The permanent flow control structures in the ISDP alternative boosted minimum water levels more and induced greater circulation than did the temporary structures in the Existing Delta Geometry alternative. Also, the ISDP alternative tended to draw more flow up Old River towards the pumps and less up Middle River (Figures 7 - 12). As shown in Figures 22 - 27, The ISDP alternative tended to increase the range of maximum downstream and upstream flow in lower Old River, lower Middle River, Columbia Cut, and Turner Cut.

<u>North Delta Program Geometry (NDP).</u> The NDP alternative substantially increased flow in the Delta Cross Channel. This increased the flow down the Mokelumne River into the San Joaquin River and the flow down Little Potato Slough which eventually found its way to the San Joaquin River (Figures 13 - 15). Average flow down the lower San Joaquin River substantially increased while average flow down the Sacramento River decreased. Average velocities increased and decreased in patterns similar to those of flows. Average velocities in the central and southern Delta were relatively unaffected. The increases in flow into the interior Delta via the Delta Cross Channel substantially increased flow up lower Old River and out into the San Joaquin River via False River and Dutch Slough. Upstream flow in lower Middle River, Columbia Cut, and Turner Cut also increased, though not as dramatically as for lower Old River. Figures 28 - 30 show that these increases in upstream flow in these channels were reflected in

Figure 7
Flows and Velocities
Averaged over April 1 - 15, 1989 (Reoperated)
Existing Delta Geometry

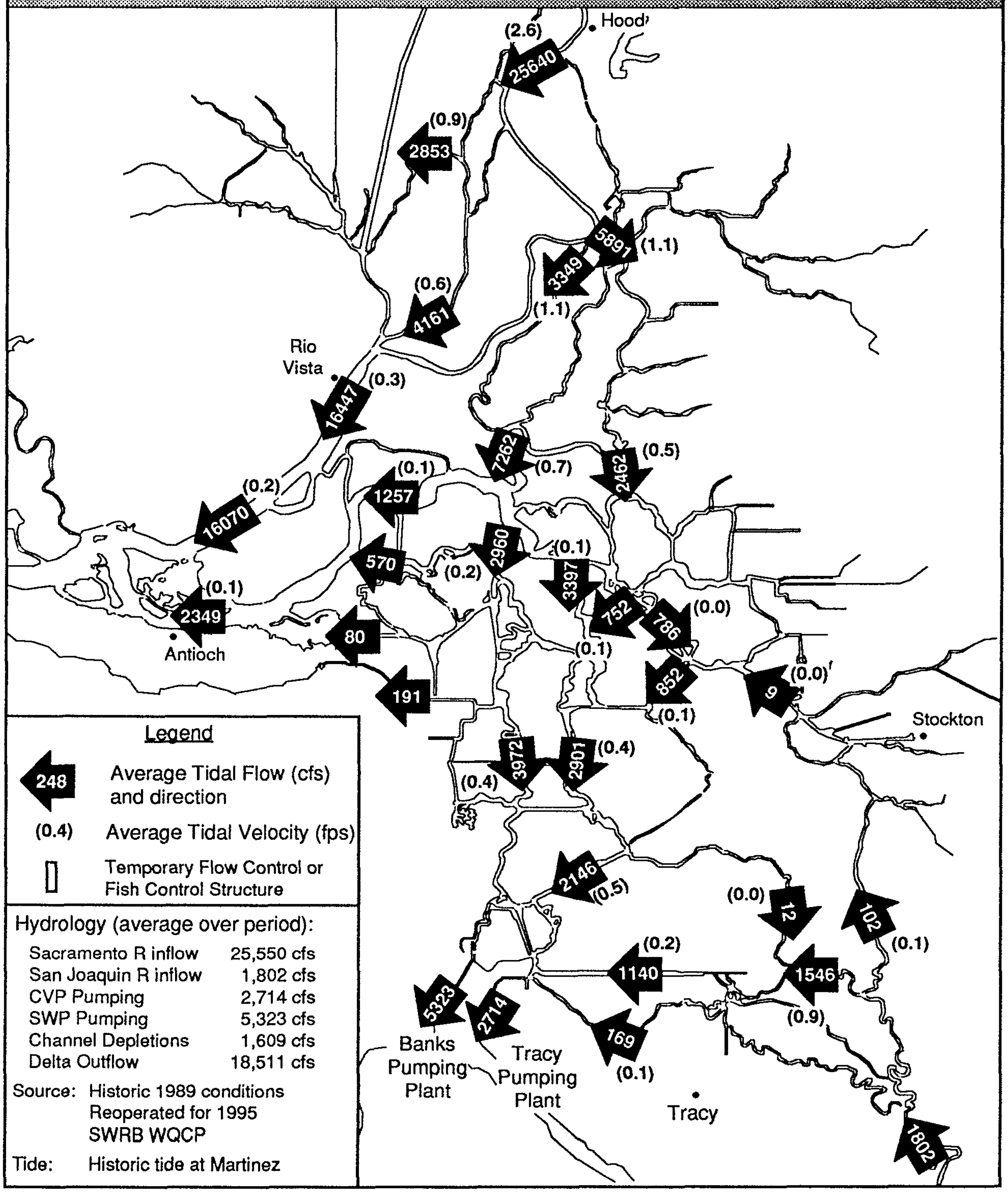


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Figure 8
Flows and Velocities
Averaged over April 16 - 30, 1989 (Reoperated)
Existing Delta Geometry

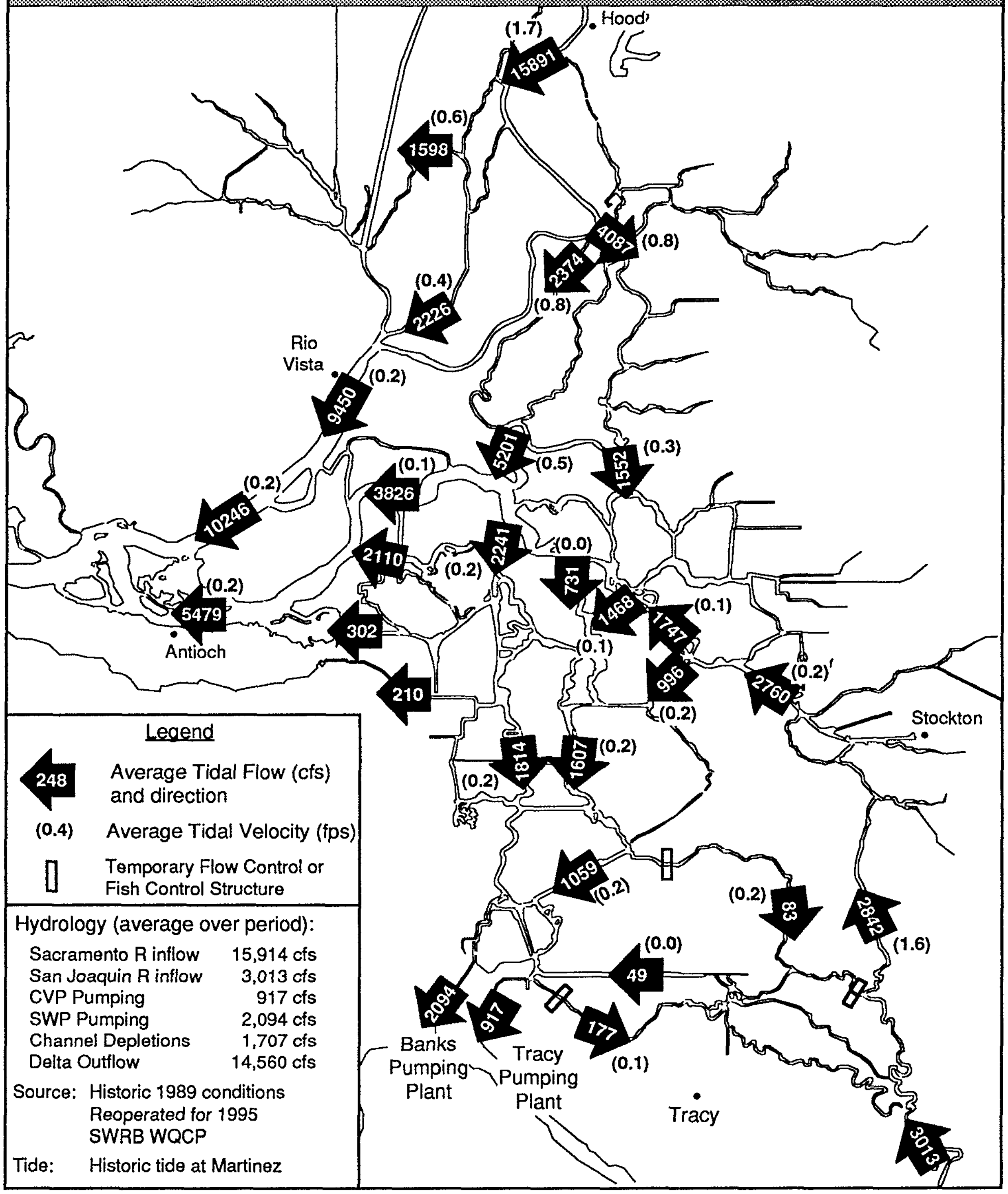

Figure 9
Flows and Velocities
Averaged over May 1 - 31, 1989 (Reoperated)
Existing Delta Geometry

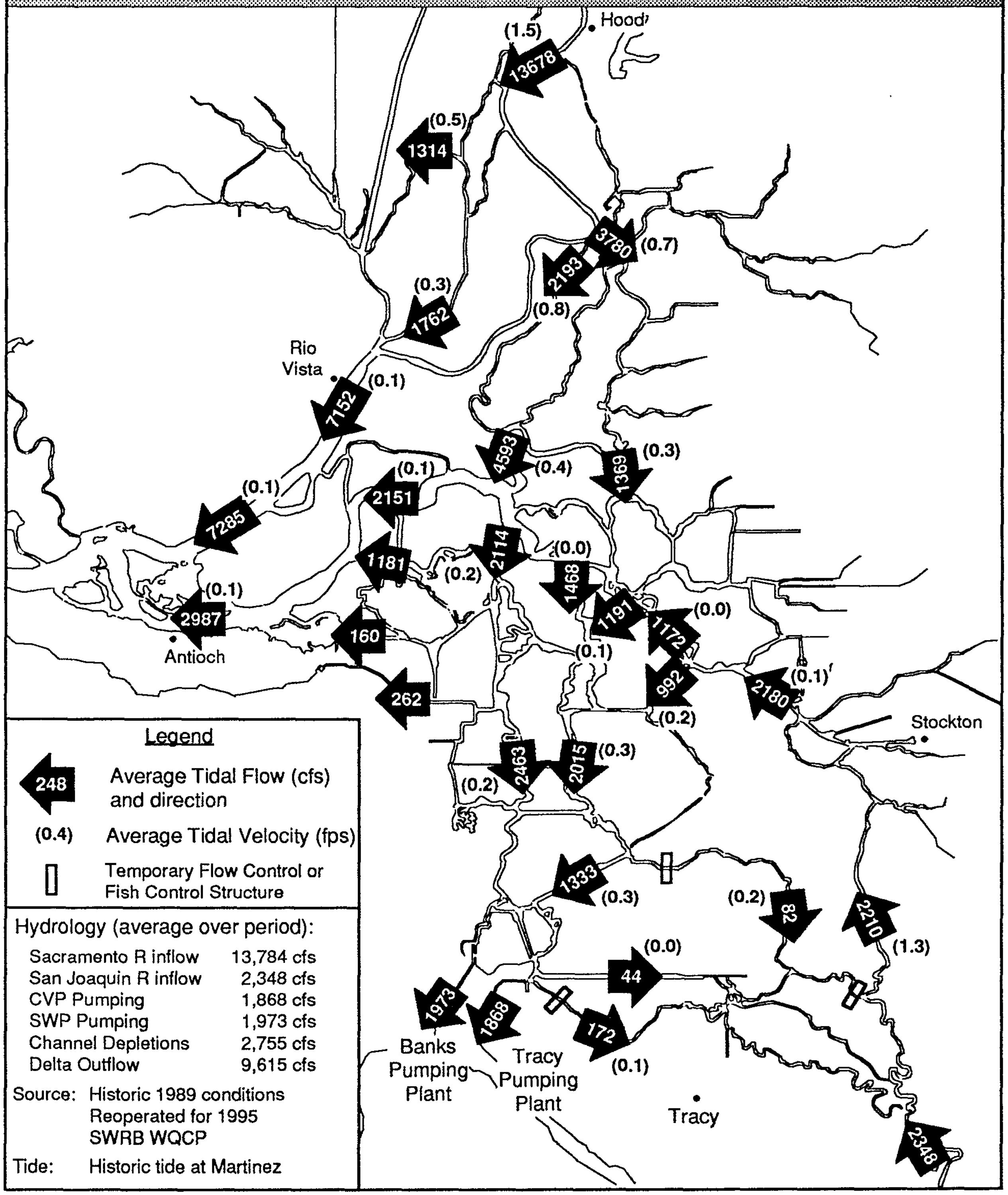

Figure 10
Flows and Velocities
Averaged over April 1 - 15, 1989 (Reoperated)
Interim South Delta Program Geometry

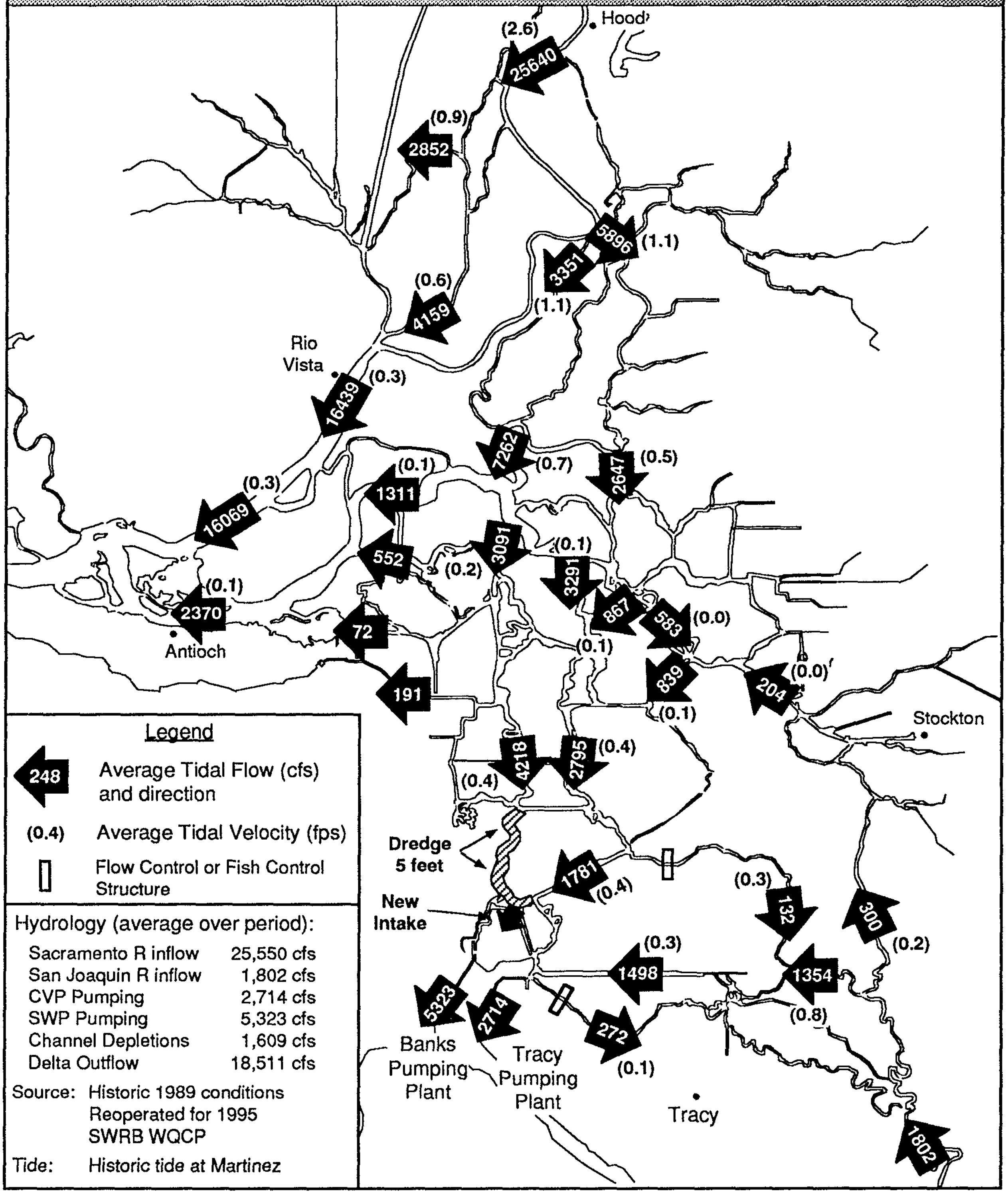

Figure 11
Flows and Velocities
Averaged over April 16 - 30, 1989 (Reoperated)
Interim South Delta Program Geometry

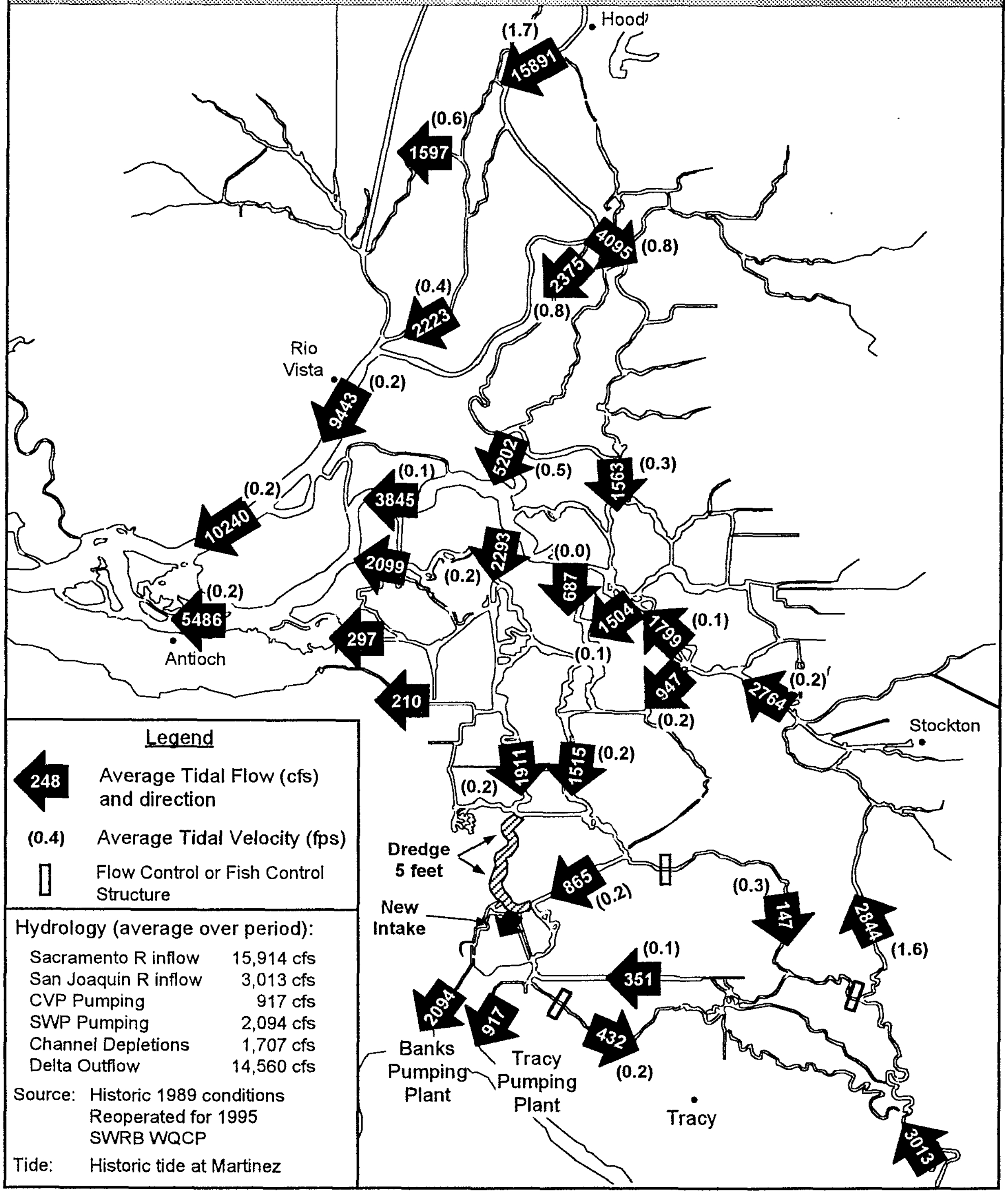

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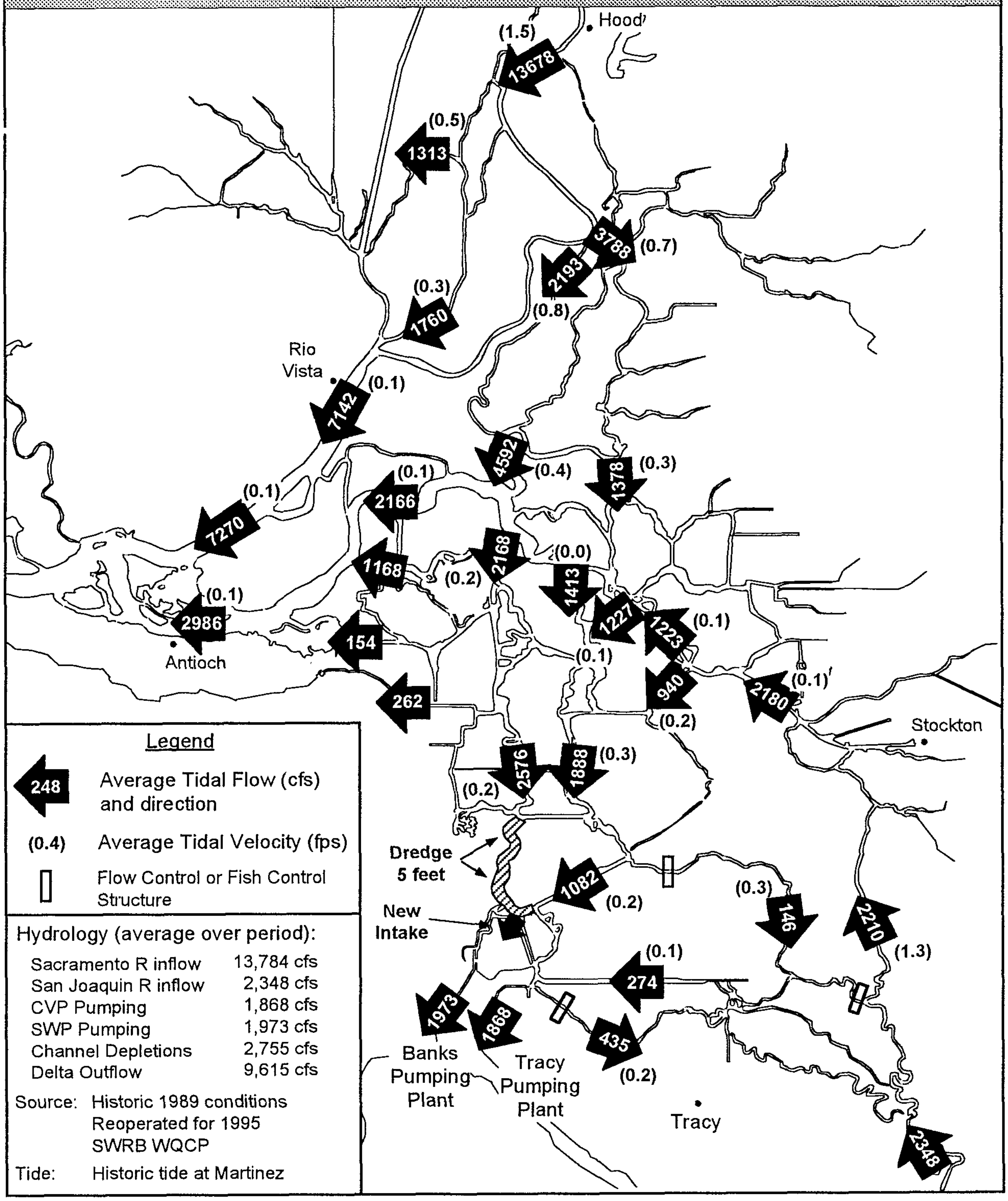
Figure 12
Flows and Velocities
Averaged over May 1 - 31, 1989 (Reoperated)
Interim South Delta Program Geometry



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D-005673

Figure 13
Flows and Velocities
Averaged over April 1 - 15, 1989 (Reoperated)
North Delta Program Geometry

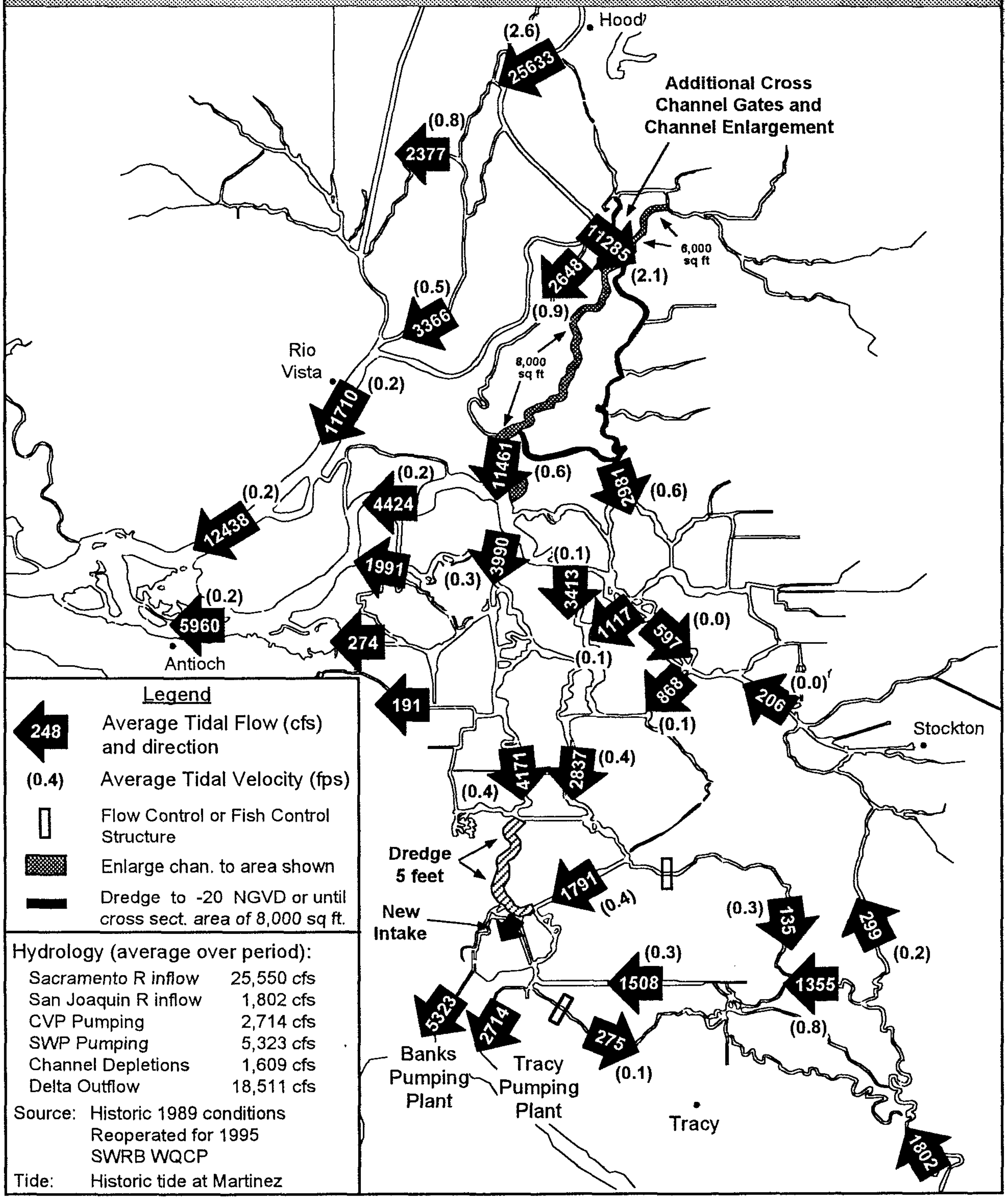

Figure 14
Flows and Velocities
Averaged over April 16 - 30, 1989 (Reoperated)
North Delta Program Geometry

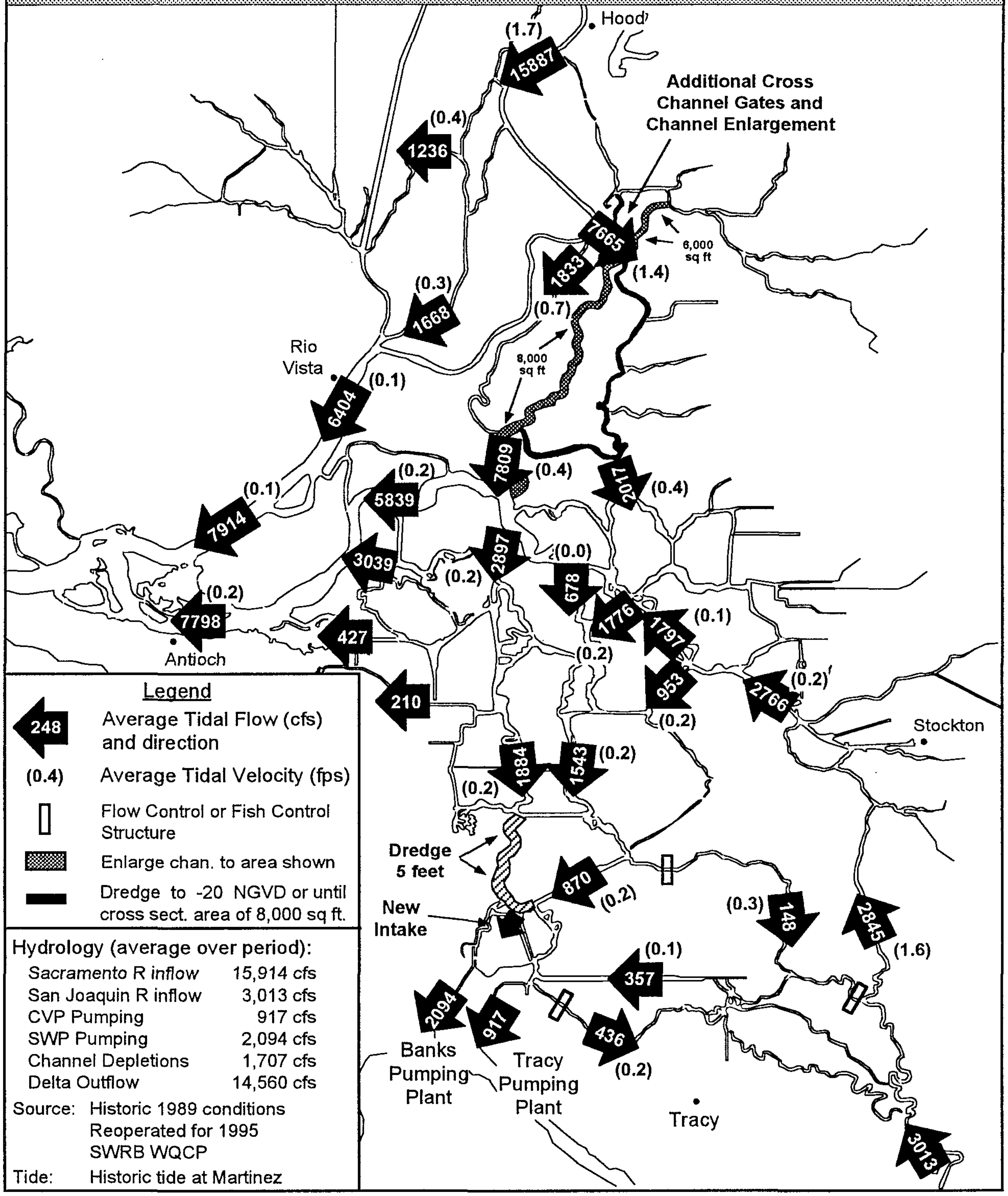

Figure 15
Flows and Velocities
Averaged over May 1 - 31, 1989 (Reoperated)
North Delta Program Geometry

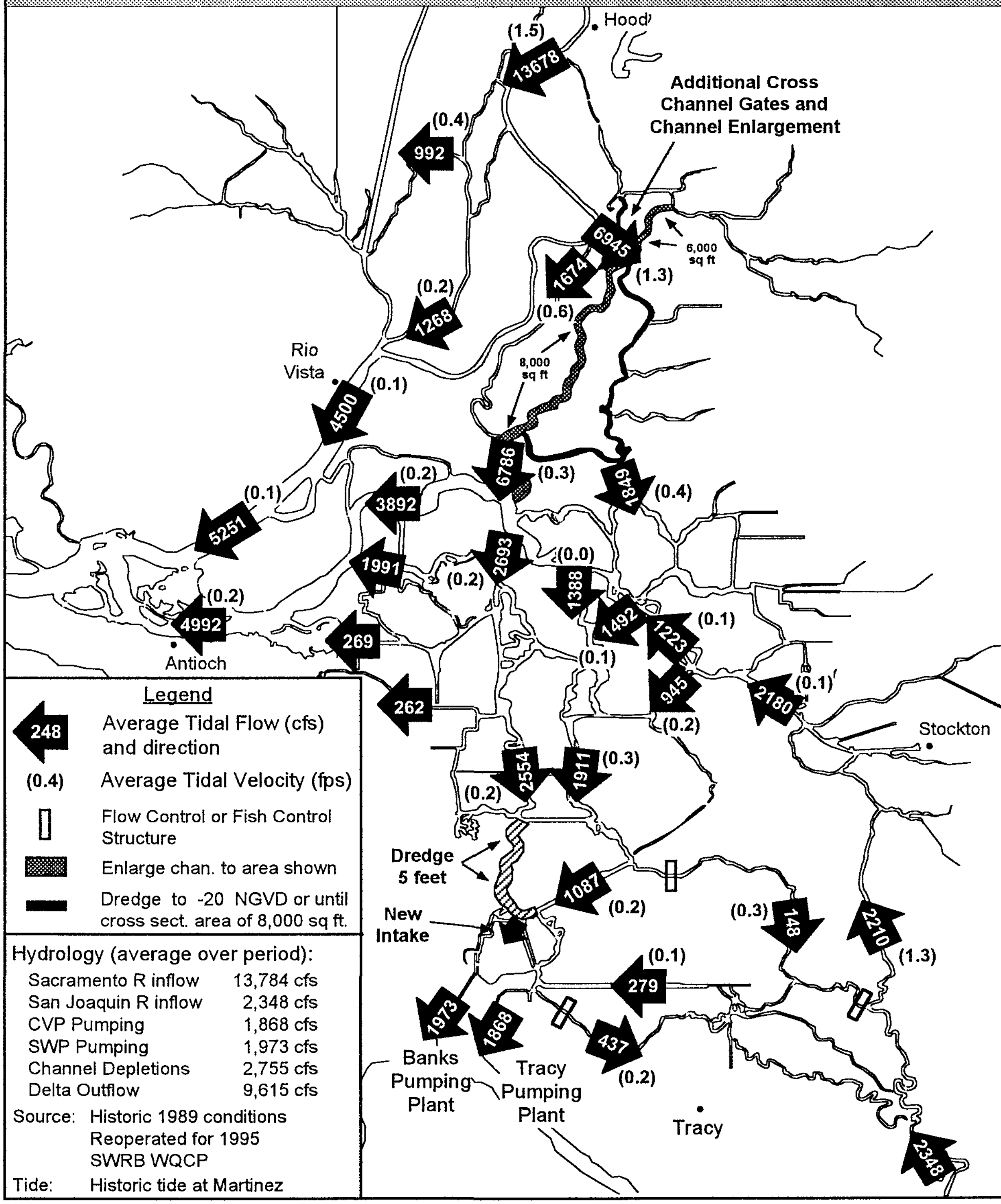

Figure 16

Flows and Velocities
Averaged over April 1 - 15, 1989 (Reoperated)
North Delta Program with Hood Diversion Geometry

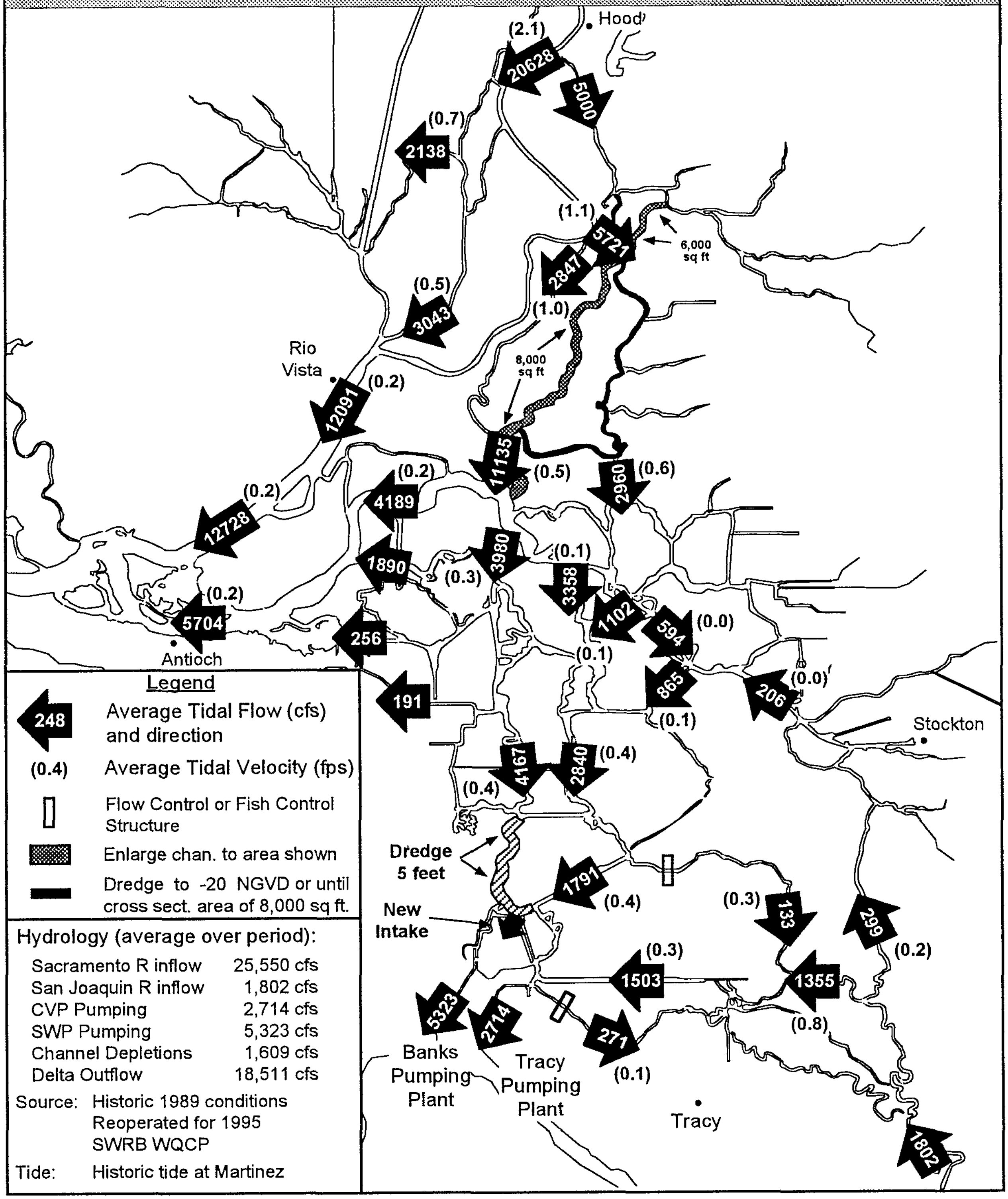

Figure 17
Flows and Velocities
Averaged over April 16 - 30, 1989 (Reoperated)
North Delta Program with Hood Diversion Geometry

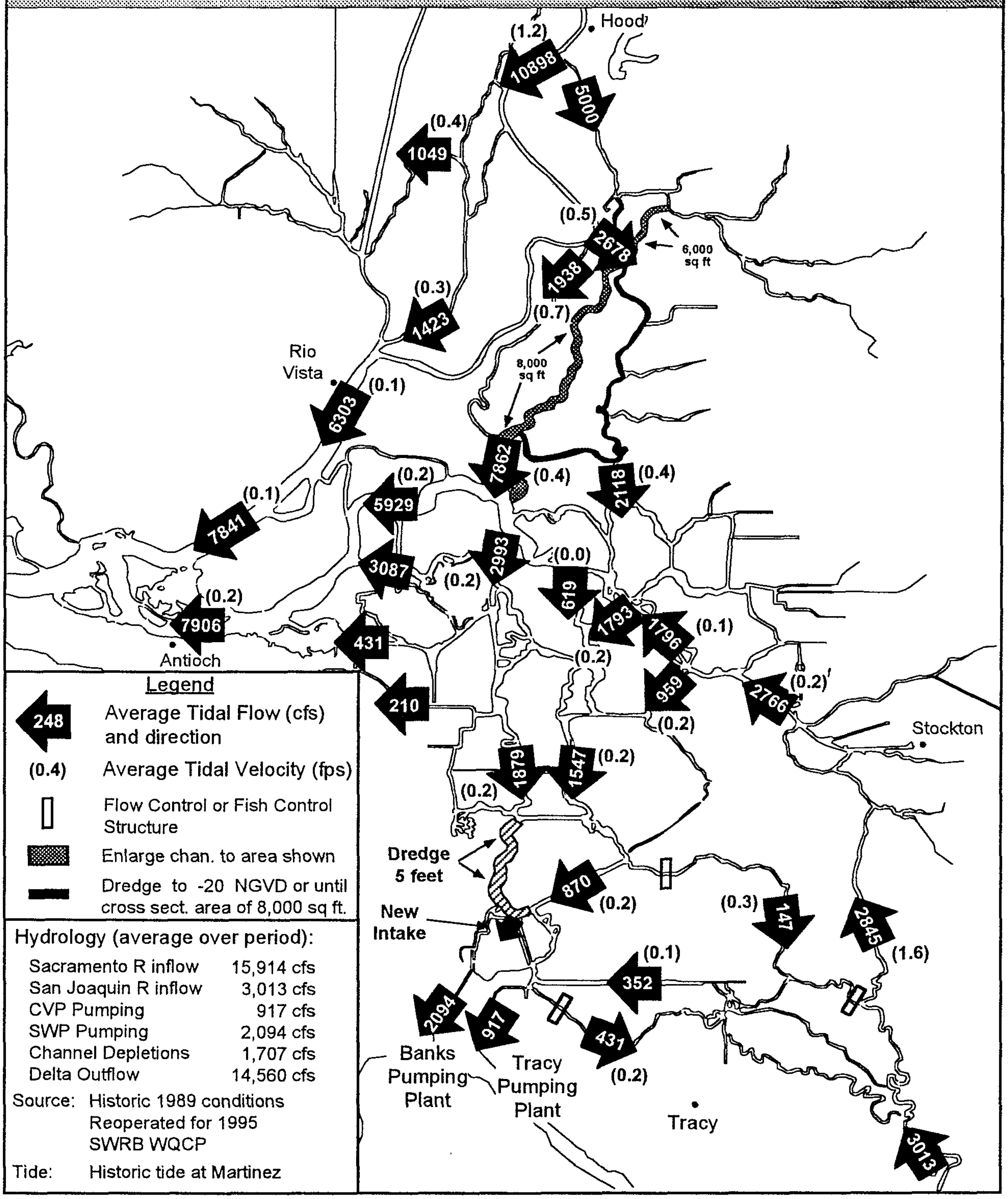

Figure 18

Flows and Velocities
Averaged over May 1 - 31, 1989 (Reoperated)
North Delta Program with Hood Diversion Geometry

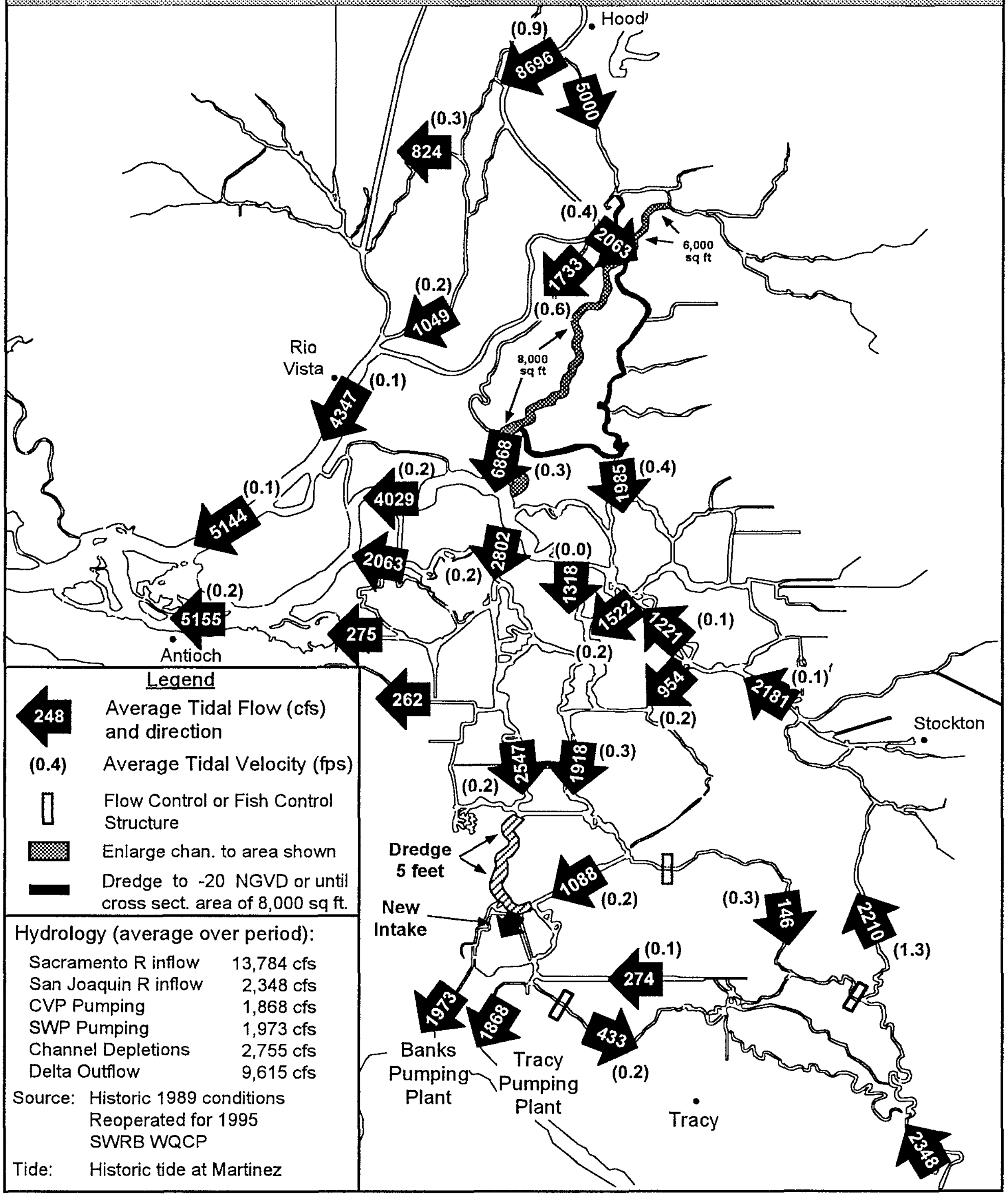

Figure 19
Flows and Velocities
Averaged over April 1 - 15, 1989 (Reoperated)
CUWA Alternative C Geometry

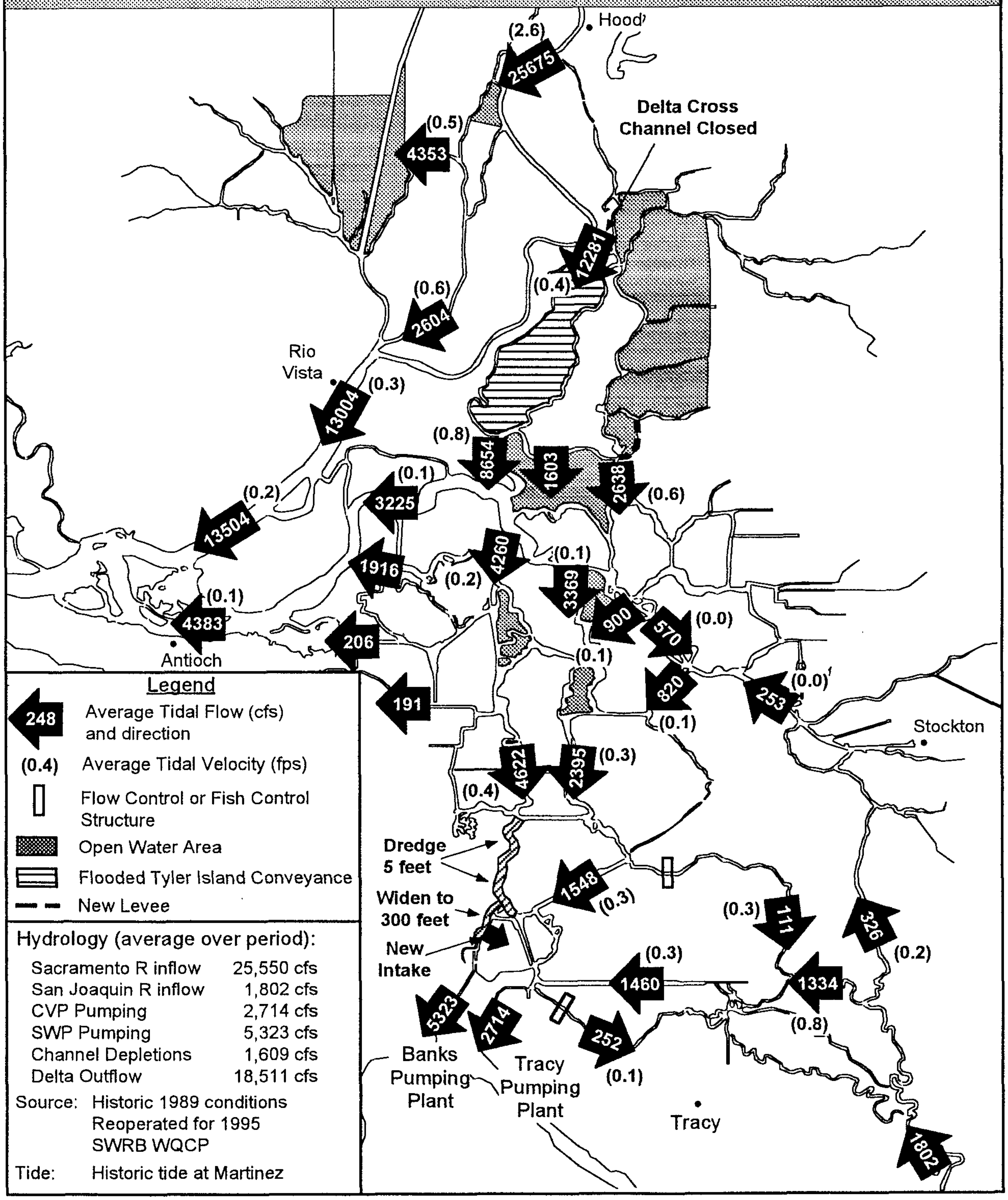

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Figure 20

Flows and Velocities
Averaged over April 16 - 30, 1989 (Reoperated)
CUWA Alternative C Geometry

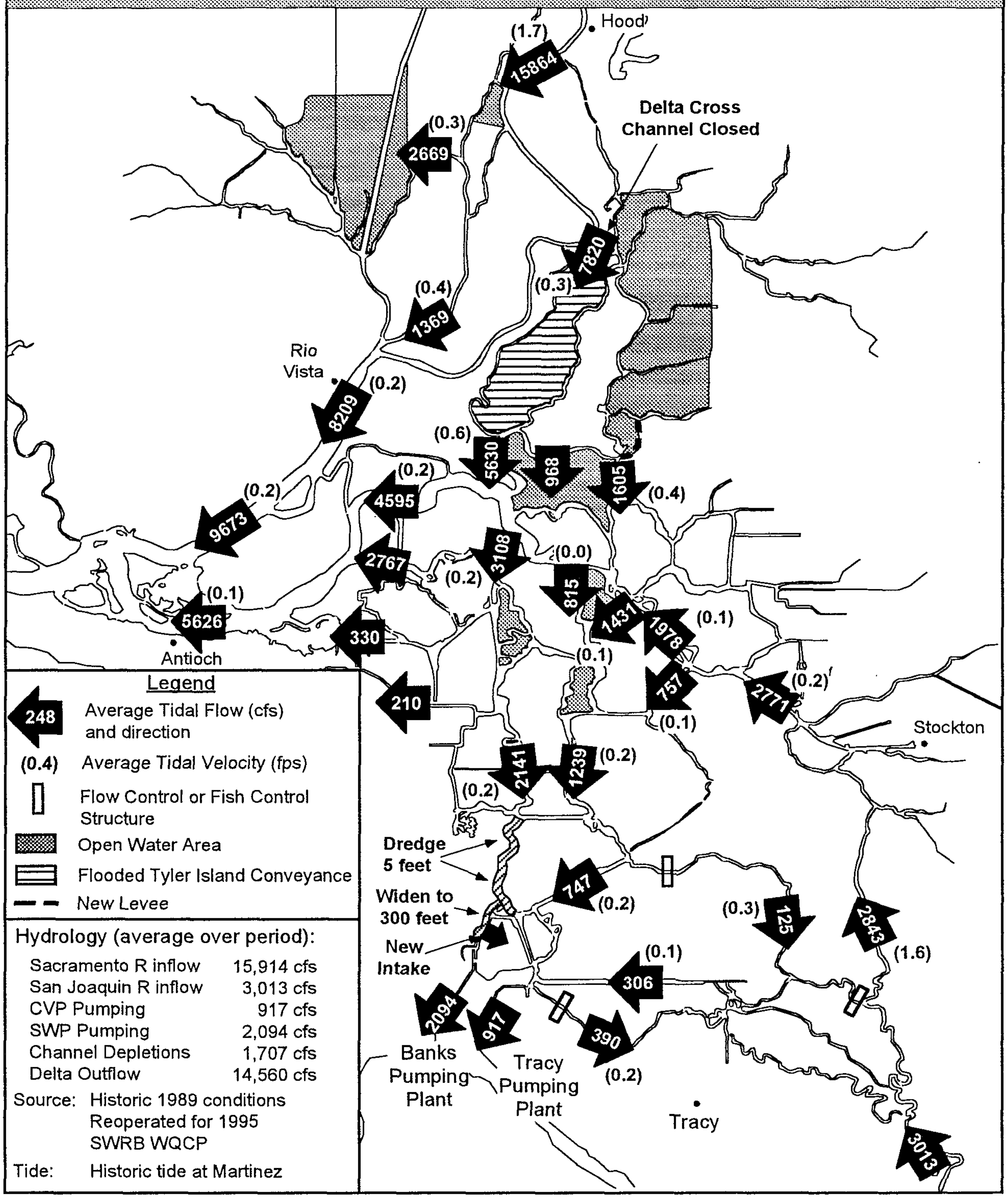

Figure 21

Flows and Velocities
Averaged over May 1 - 31, 1989 (Reoperated)
CUWA Alternative C Geometry

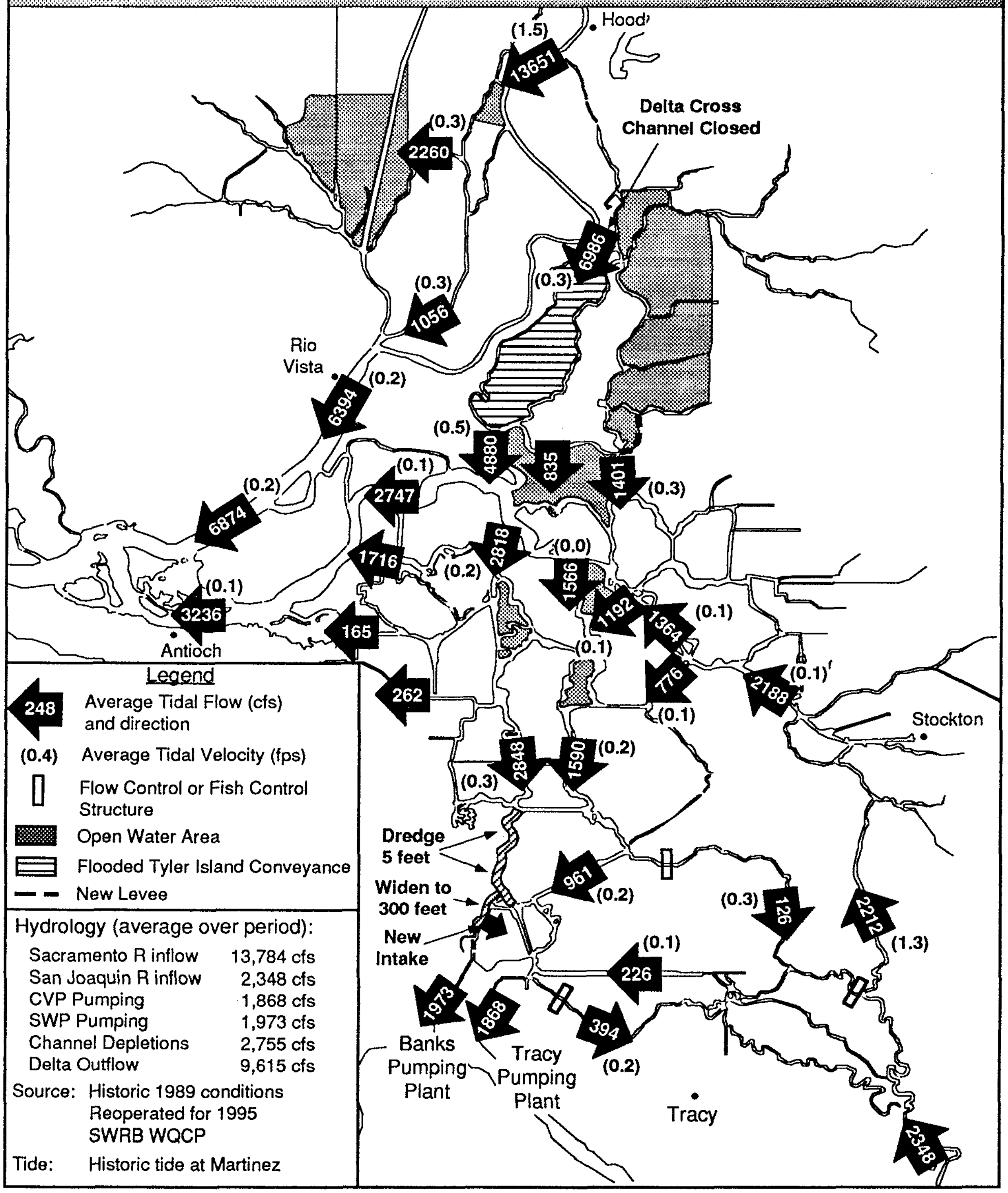

Figure 22
Flows and Water Levels
Averaged over April 1 - April 15, 1989 (Reoperated)
Existing Delta Geometry

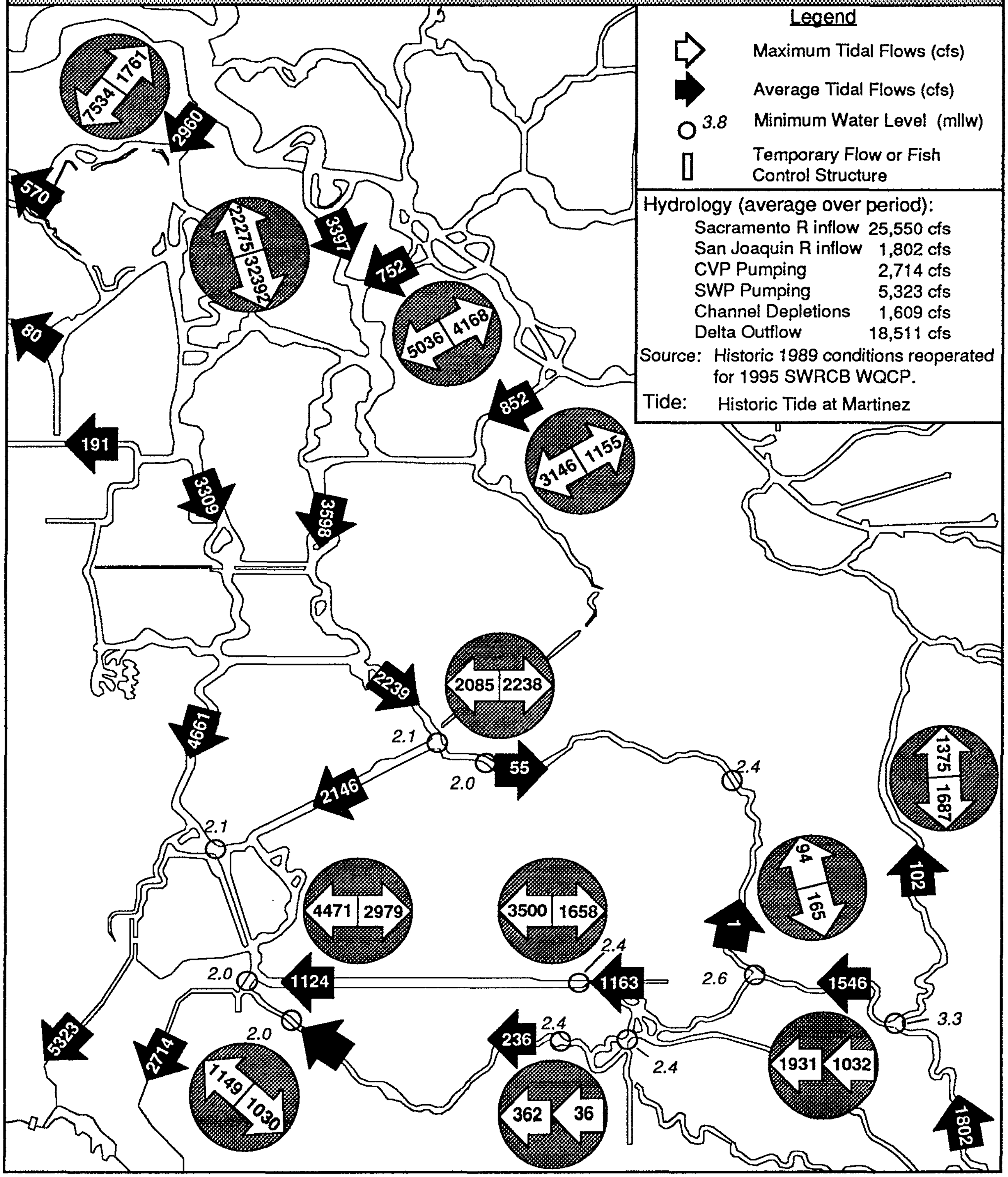

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Figure 23
Flows and Water Levels
Averaged over April 16 - April 30, 1989 (Reoperated)
Existing Delta Geometry

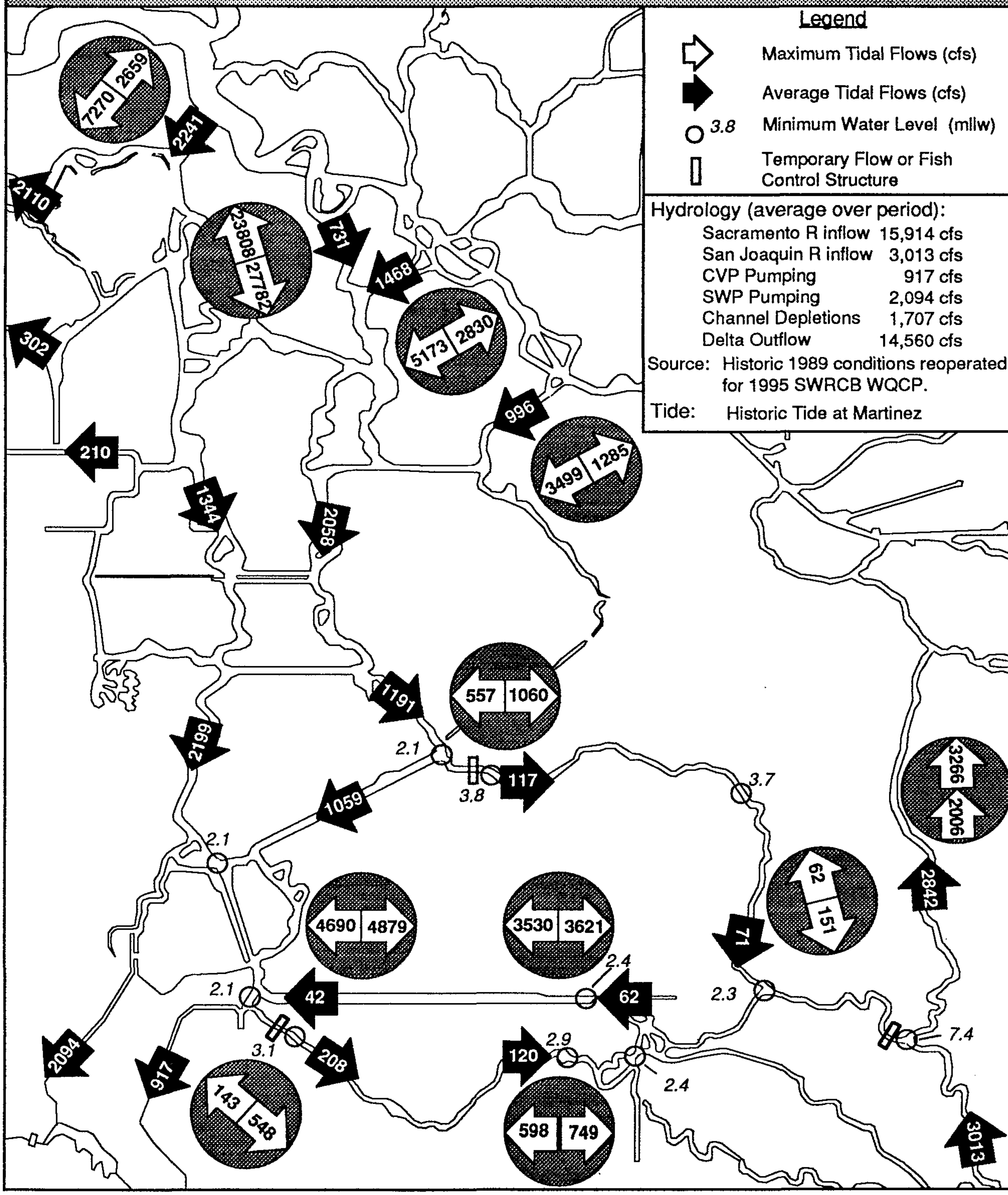

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Figure 24
Flows and Water Levels
Averaged over May 1 - May 31, 1989 (Reoperated)
Existing Delta Geometry

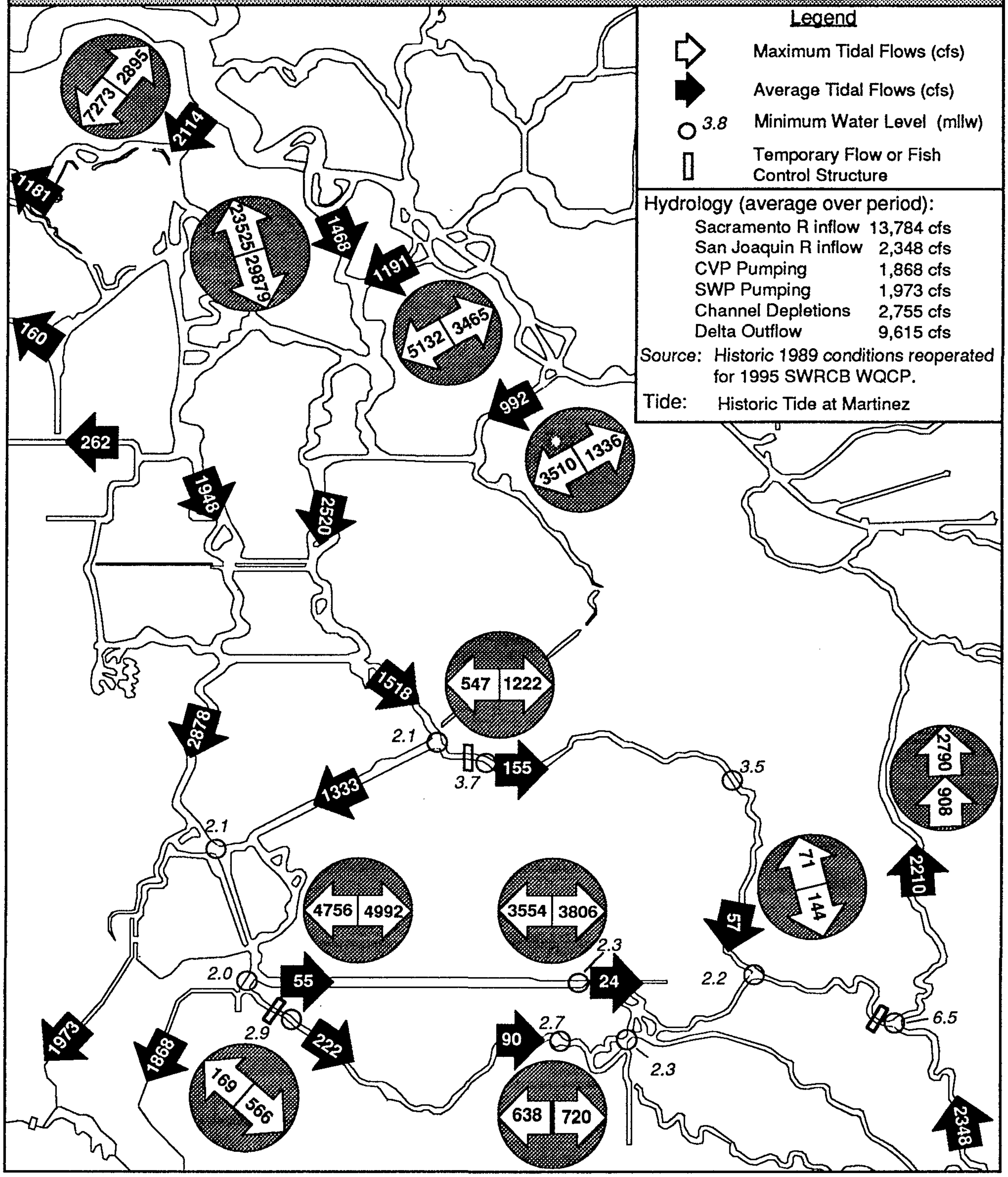

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Figure 25
Flows and Water Levels
Averaged over April 1 - April 15, 1989 (Reoperated)
Interim South Delta Program Geometry

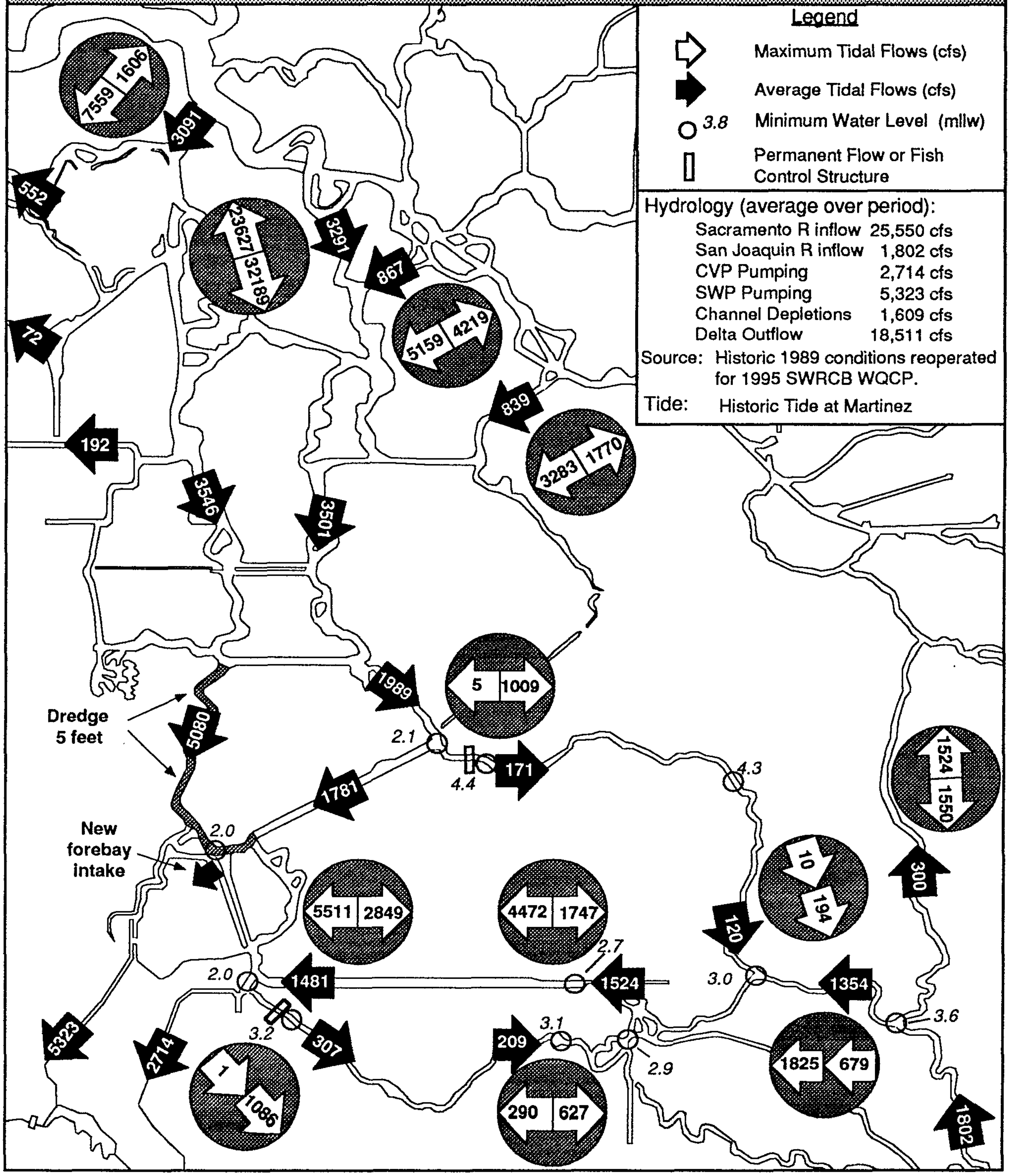

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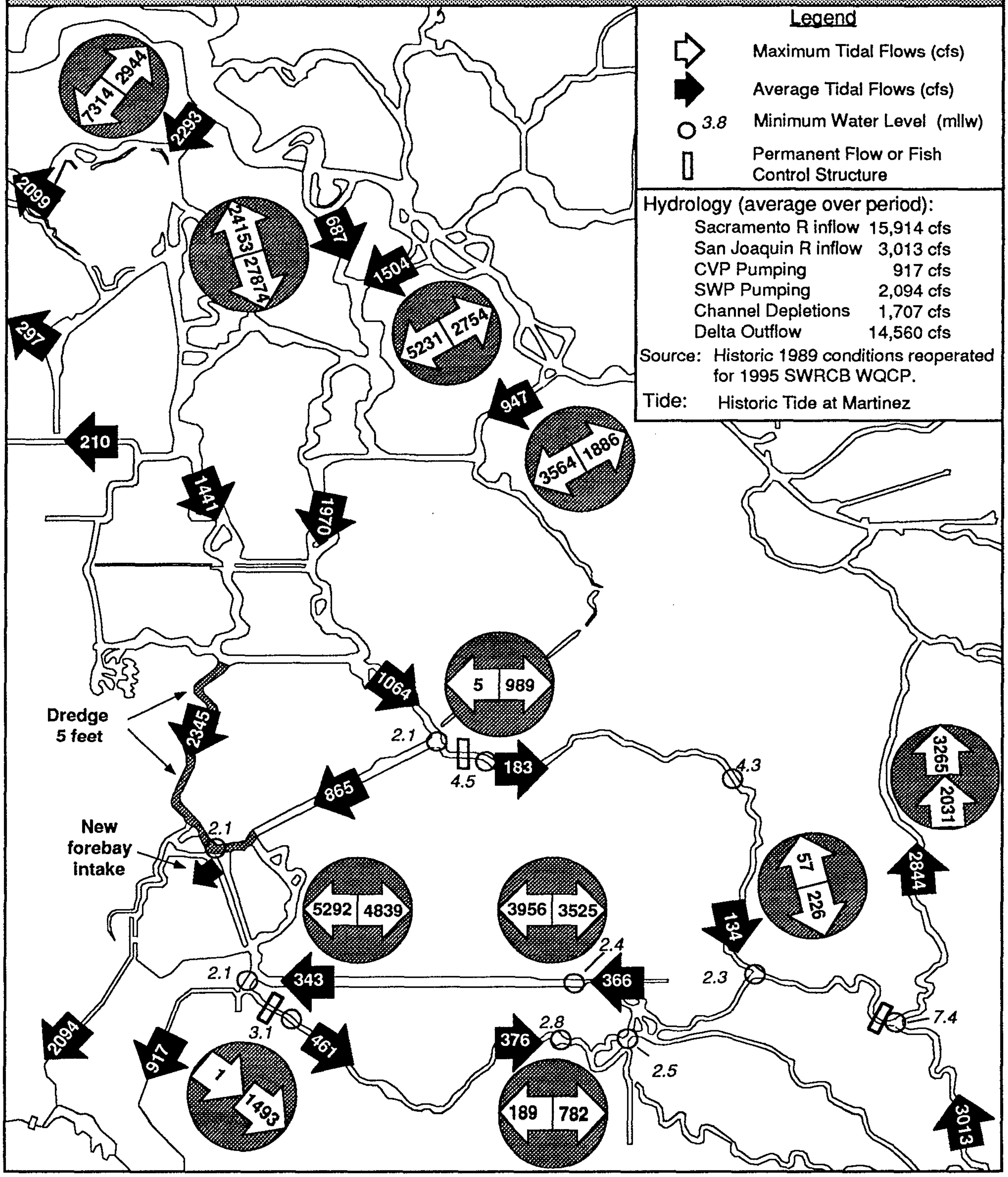
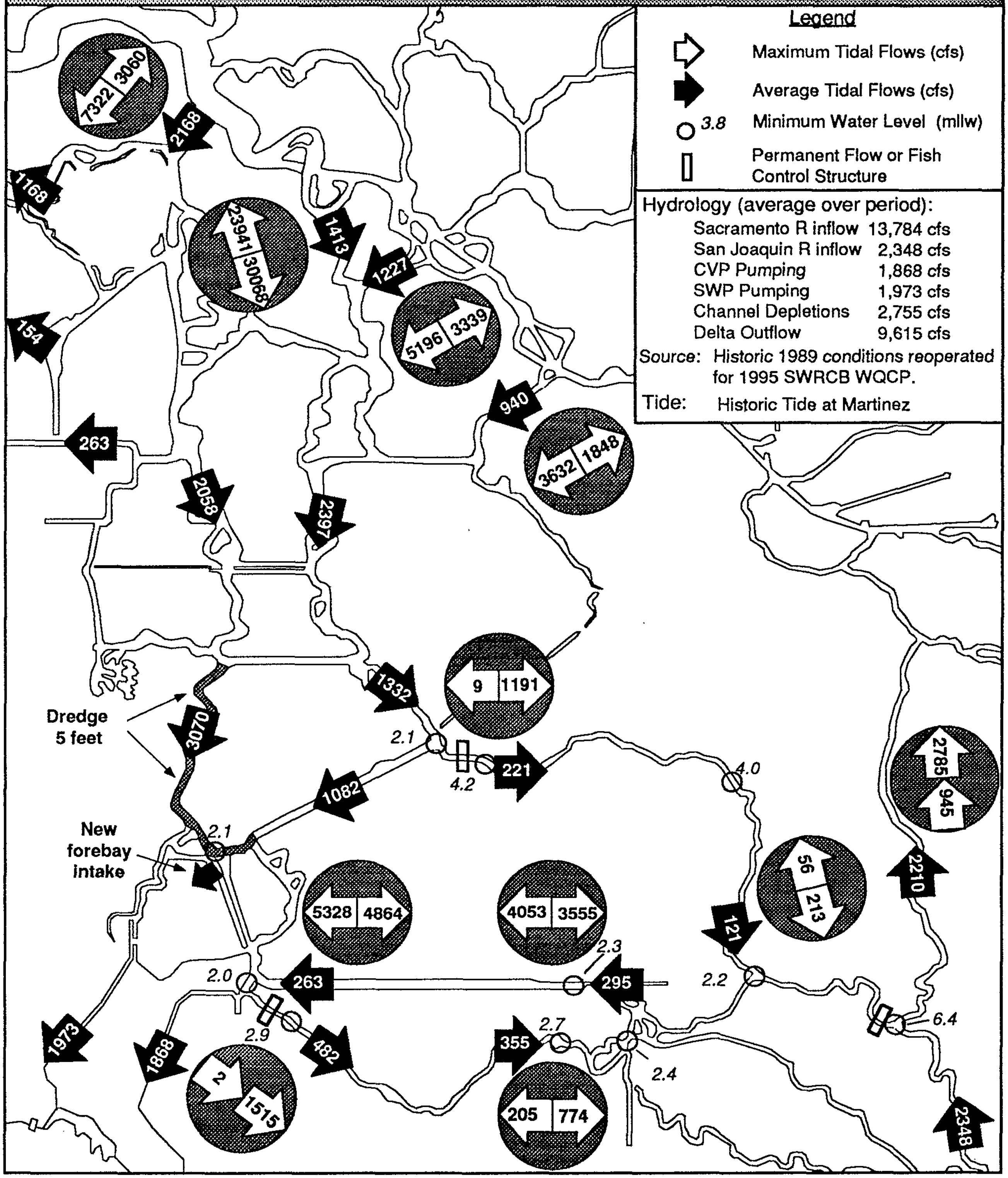
Figure 26
Flows and Water Levels
Averaged over April 16 - April 30, 1989 (Reoperated)
Interim South Delta Program Geometry



D-005687

Figure 27
Flows and Water Levels
Averaged over May 1 - May 31, 1989 (Reoperated)
Interim South Delta Program Geometry



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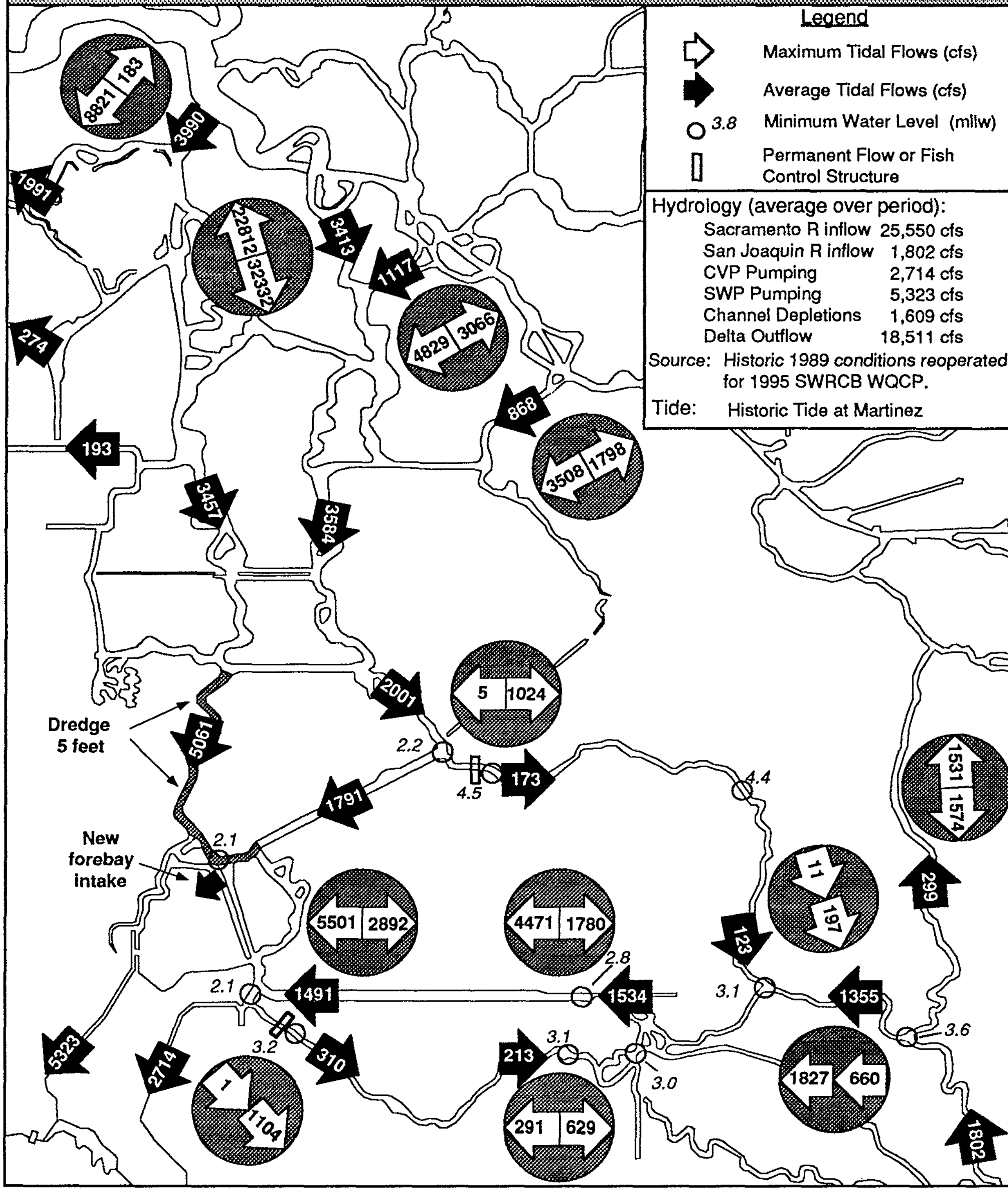
D-005688

Figure 28
Flows and Water Levels
Averaged over April 1 - April 15, 1989 (Reoperated)
North Delta Program Geometry



D-005689

Figure 29
Flows and Water Levels
Averaged over April 16 - April 30, 1989 (Reoperated)
North Delta Program Geometry

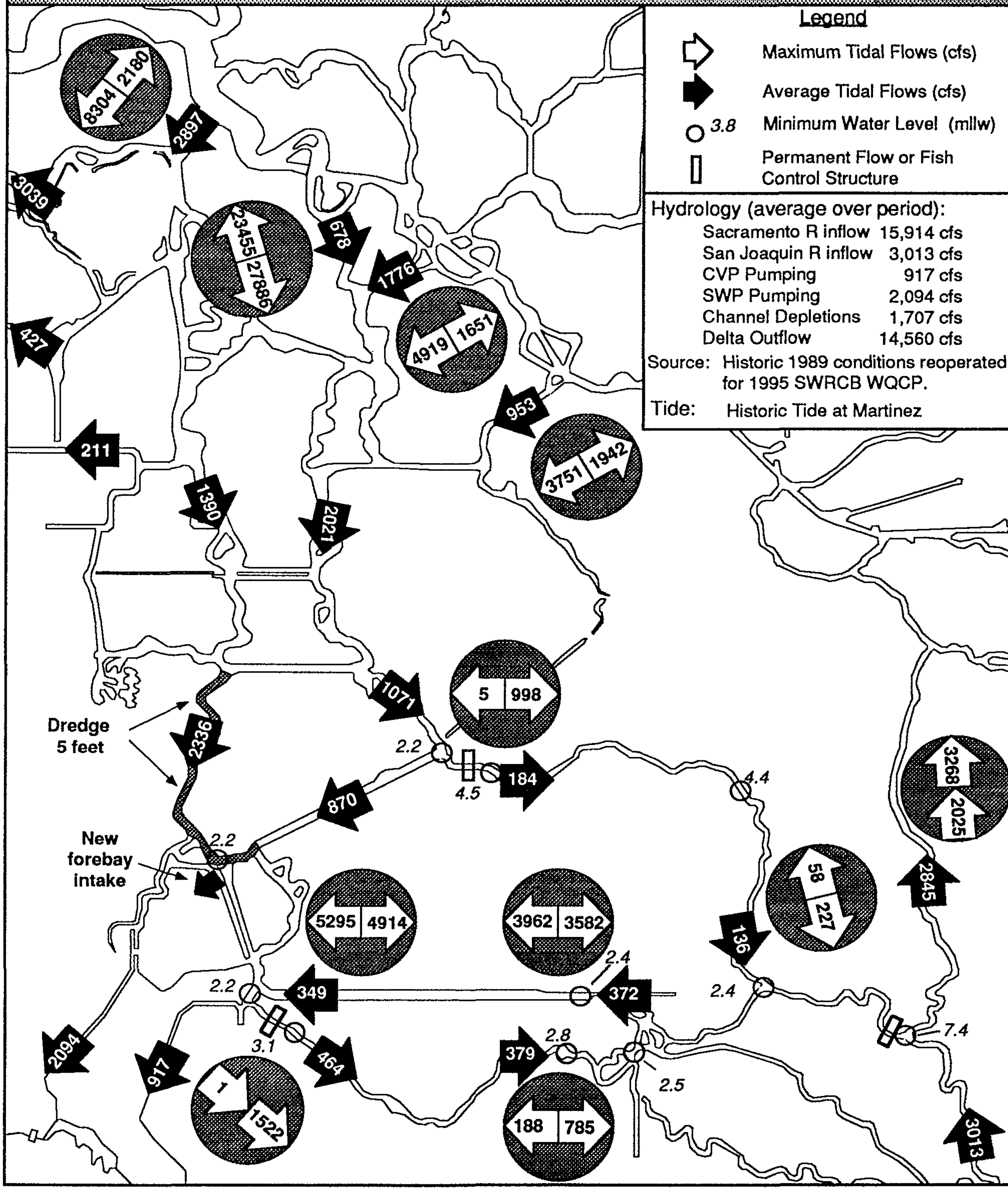
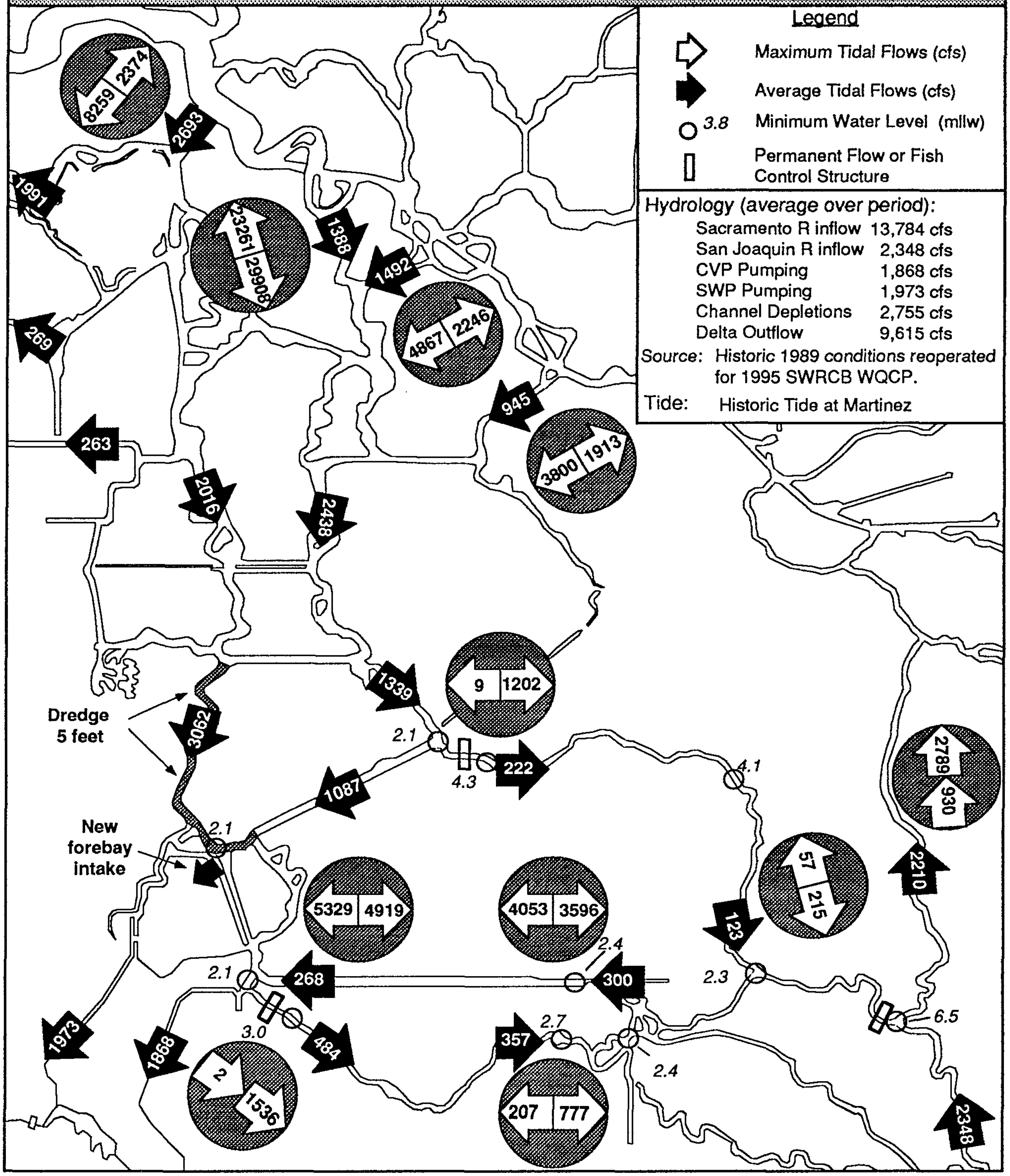
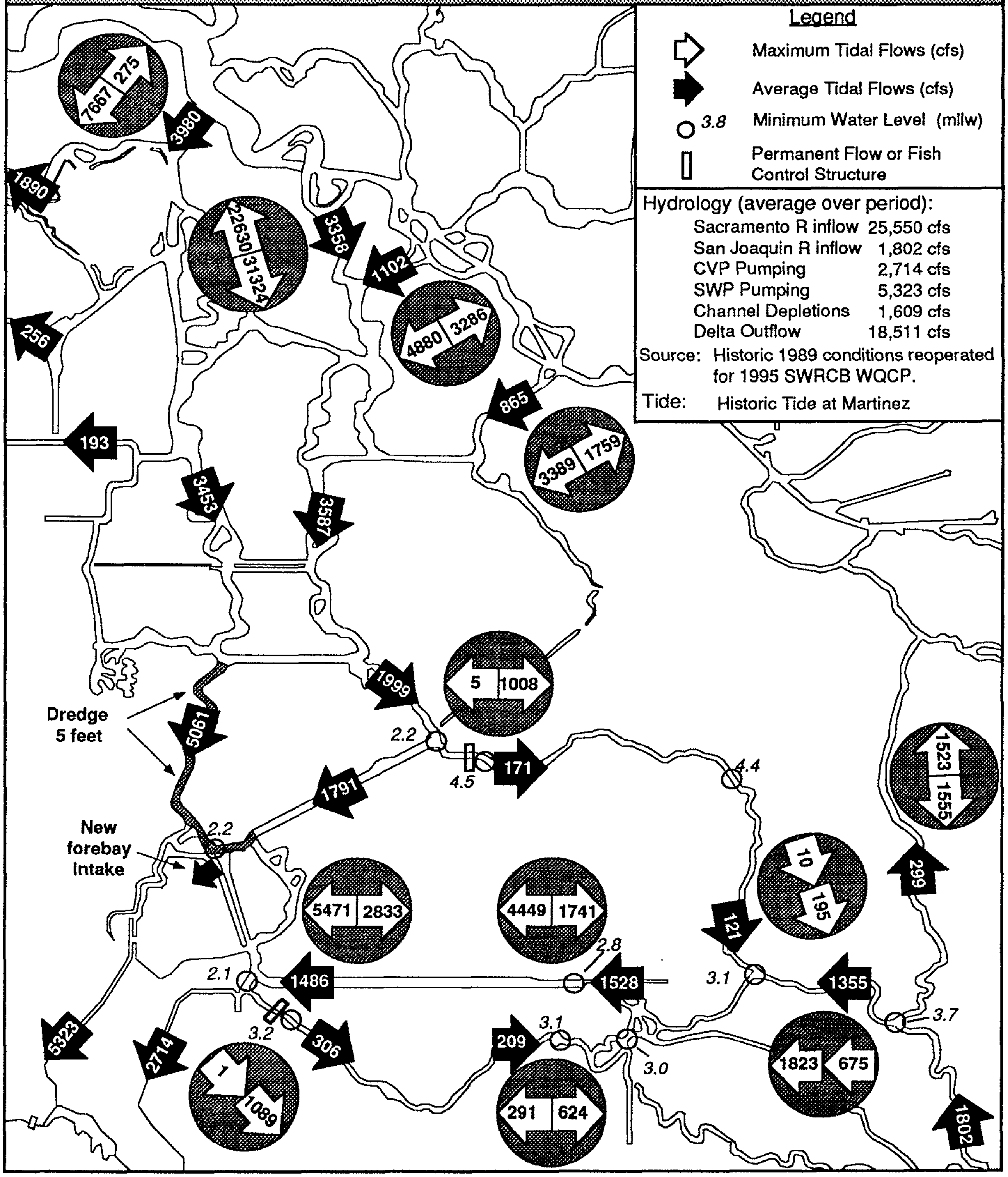


Figure 30
Flows and Water Levels
Averaged over May 1 - May 31, 1989 (Reoperated)
North Delta Program Geometry



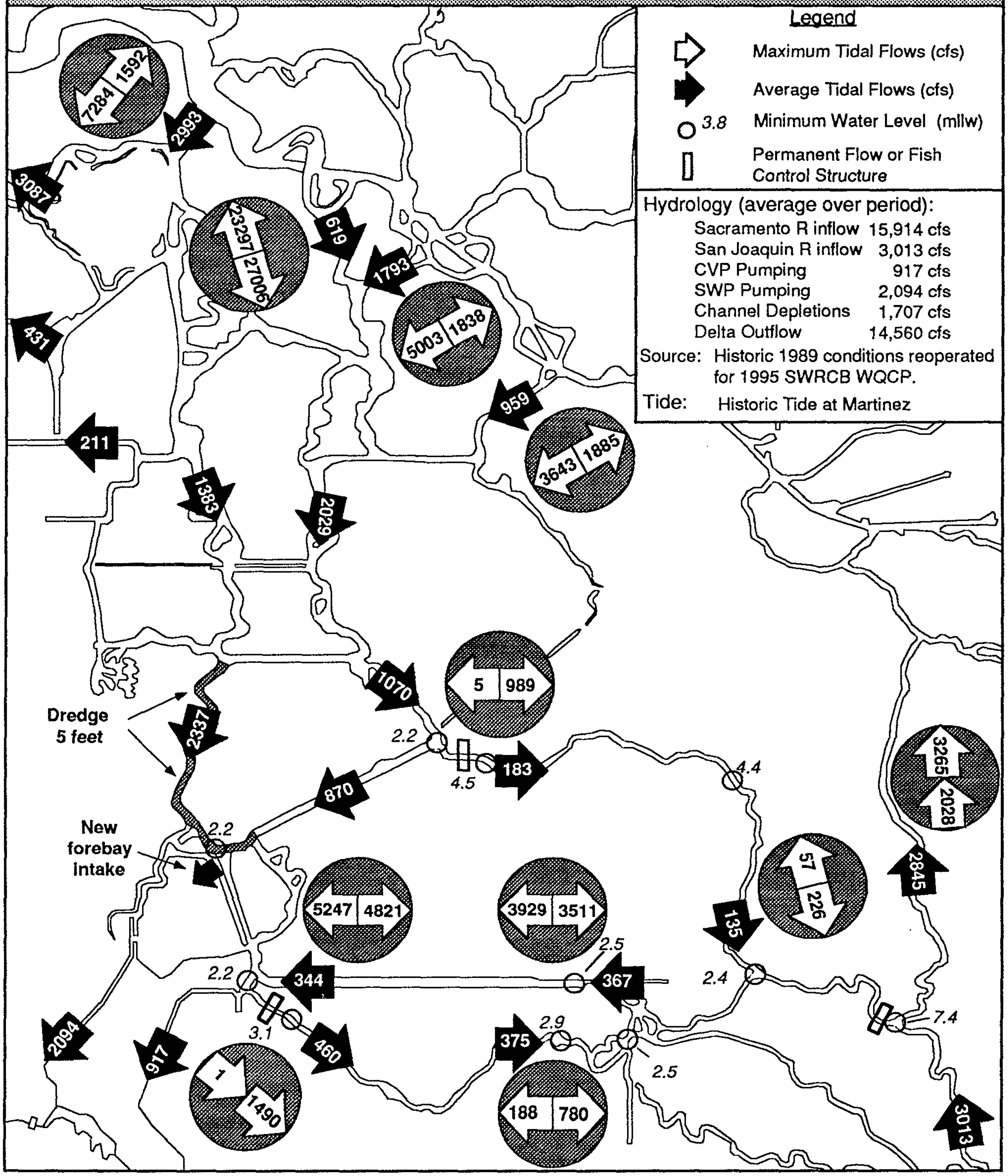
D-005691

Figure 31
Flows and Water Levels
Averaged over April 1 - April 15, 1989 (Reoperated)
North Delta Program with Hood Diversion Geometry



D-005692

Figure 32
Flows and Water Levels
Averaged over April 16- April 30, 1989 (Reoperated)
North Delta Program with Hood Diversion Geometry



D-005693

Figure 33
Flows and Water Levels
Averaged over May 1 - May 31, 1989 (Reoperated)
North Delta Program with Hood Diversion Geometry

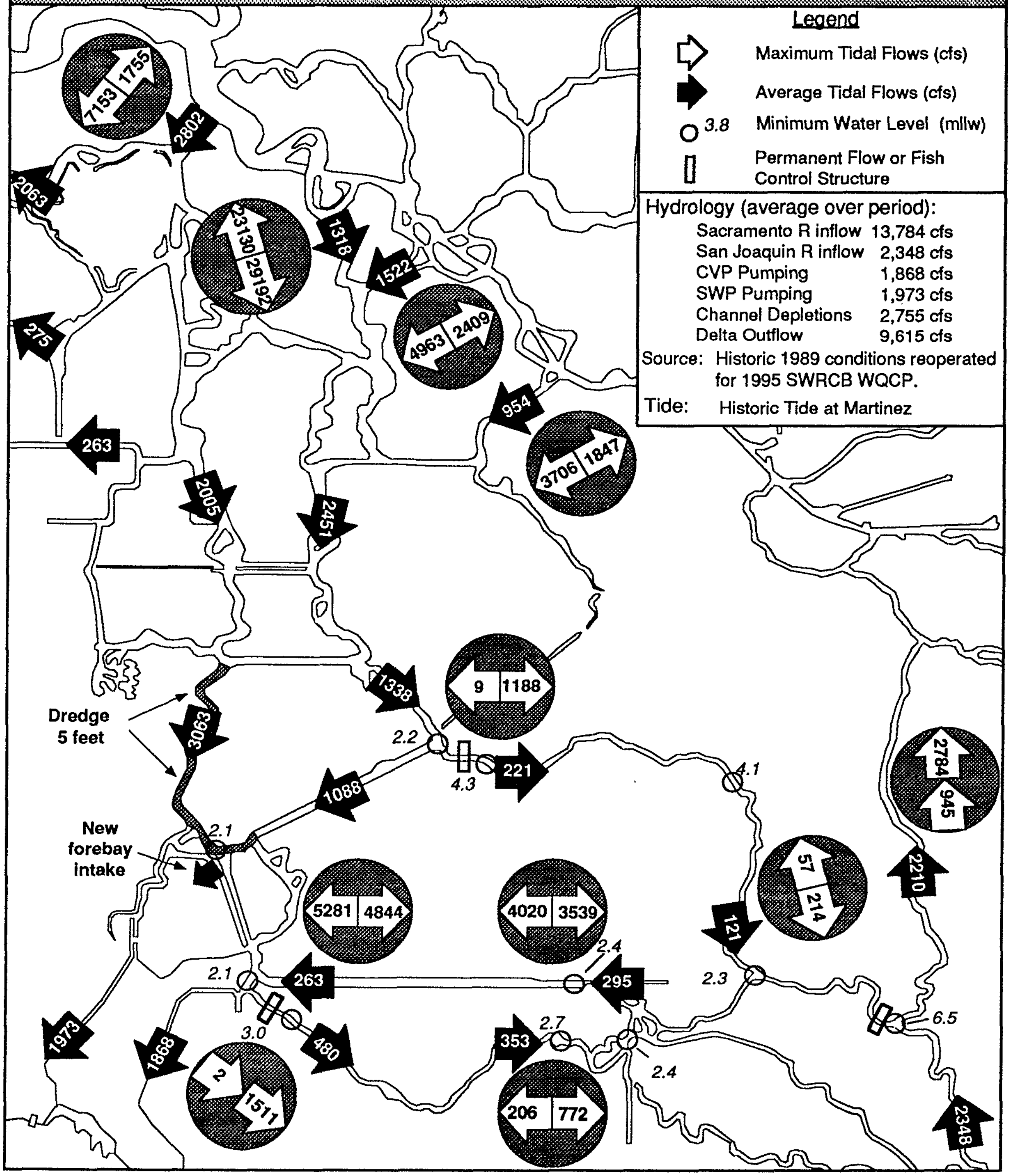


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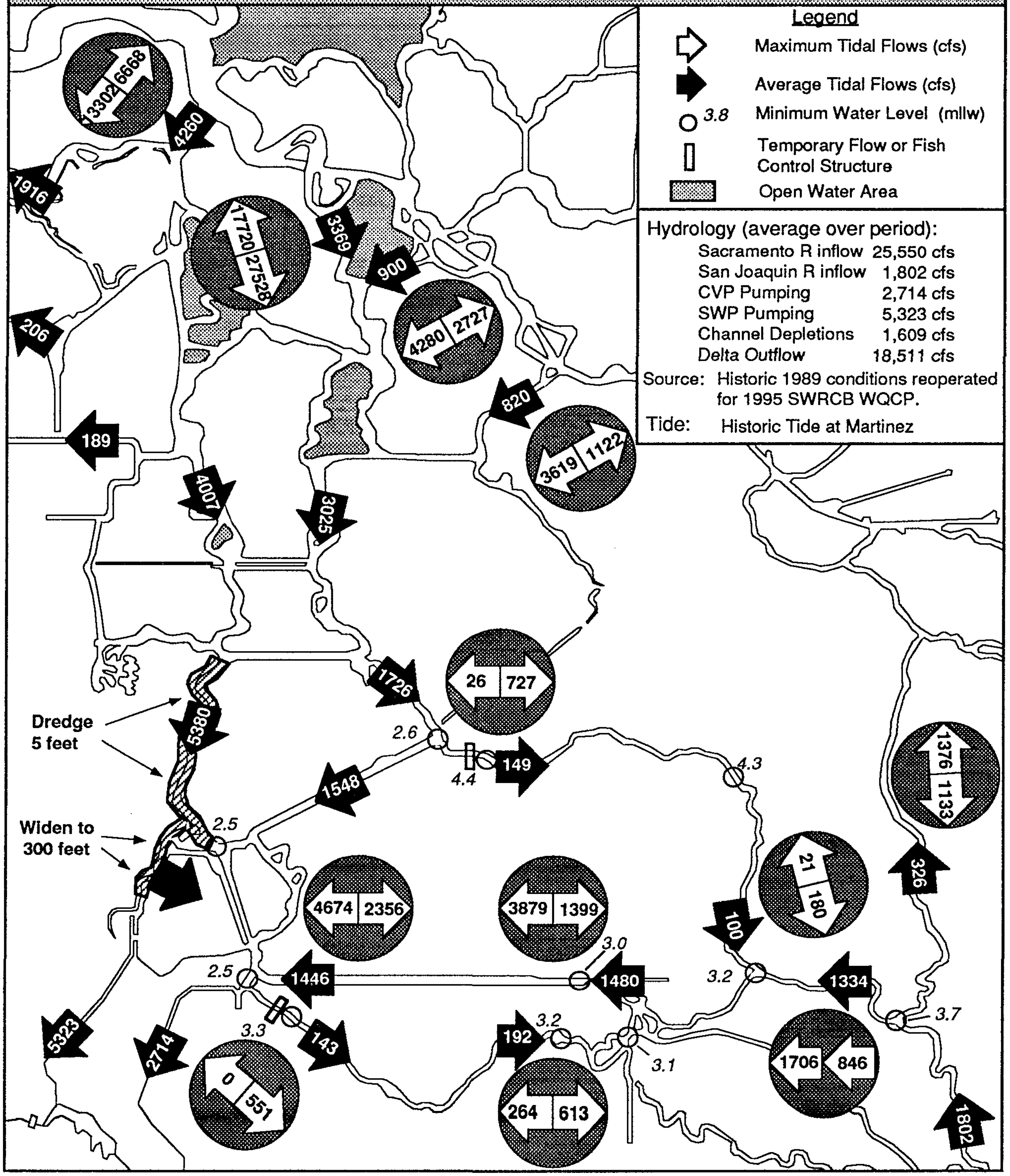
Figure 34
Flows and Water Levels
Averaged over April 1 - April 15, 1989 (Reoperated)
CUWA Alternative C Geometry



D-005695

Figure 35
Flows and Water Levels
Averaged over April 16 - April 30, 1989 (Reoperated)
CUWA Alternative C Geometry

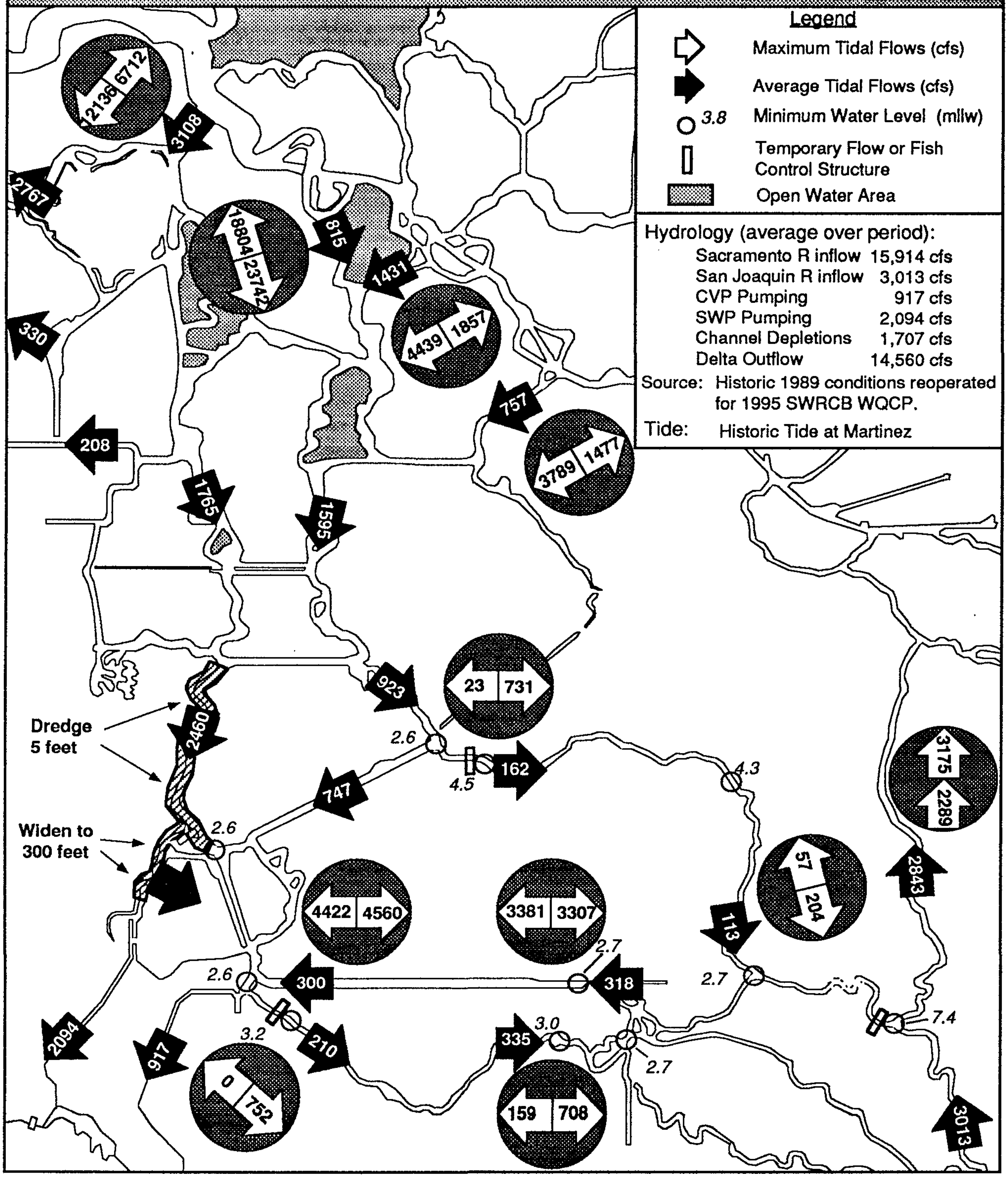


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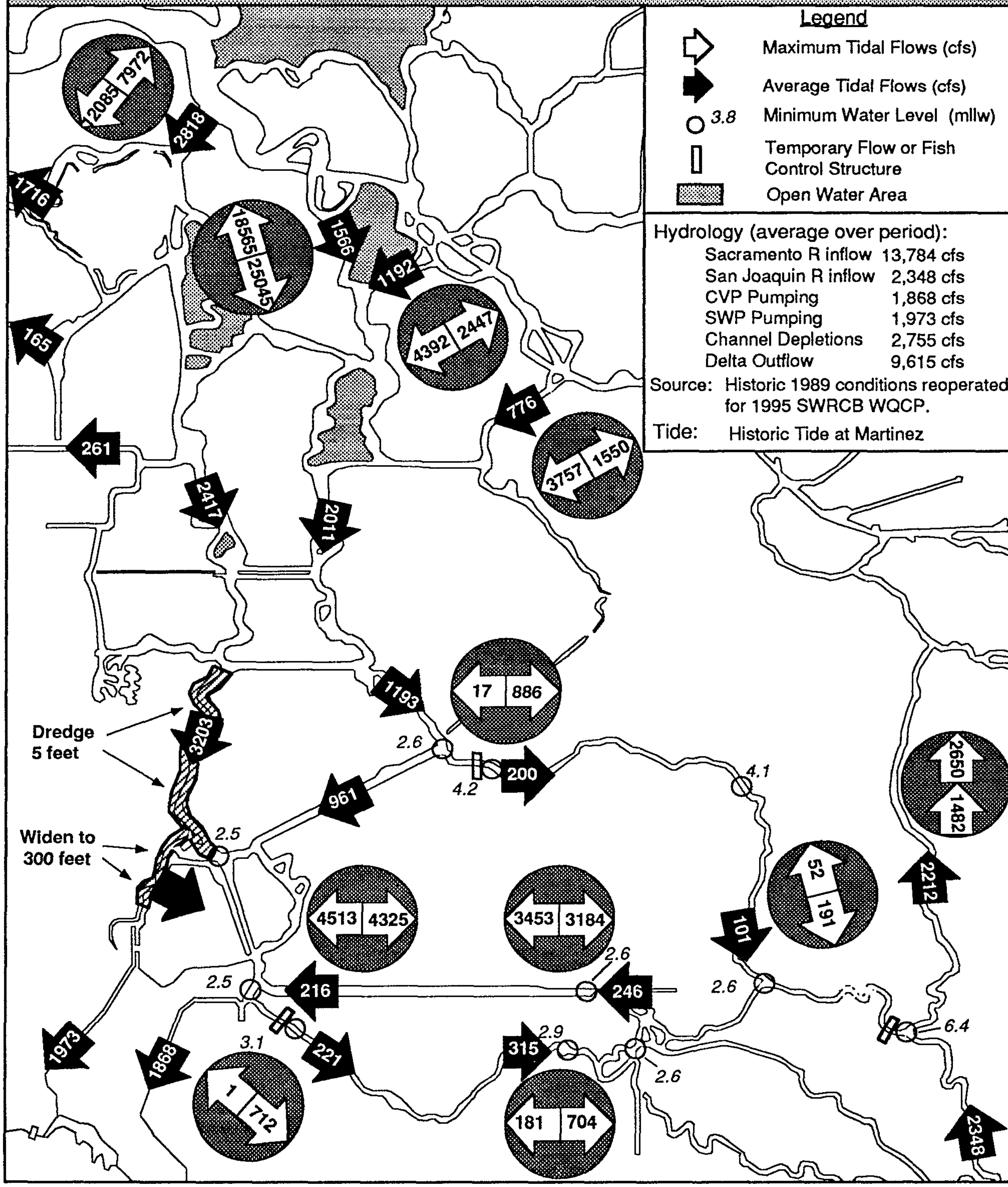
Figure 36
Flows and Water Levels
Averaged over May 1 - May 31, 1989 (Reoperated)
CUWA Alternative C Geometry



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changes in the maximum tidal flows. In lower Old River, increases in maximum upstream flow and decreases in maximum downstream flow were substantial. However, the range between maximum downstream and upstream flow remained about the same. Similar trends were seen at lower Middle River, Columbia Cut and Turner Cut, although the magnitude of changes were not nearly as large. Flows, velocities, and minimum water levels in the south Delta didn't significantly change between the NDP alternative and the ISDP alternative.

North Delta Alternative with Hood Diversion Geometry (NDPH). Except for the flow and velocities in the Delta Cross Channel, Georgiana Slough, and the Mokelumne River system, the NDPH alternative changed Delta flows, velocities, and water levels much the same as did the NDP alternative. Total cross-Delta flow was similar to the NDP alternative despite the 5,000 diversion because flow in Georgiana Slough and the Delta Cross Channel decreased (Figures 16 - 18). Maximum downstream and upstream flows in lower Old River, lower Middle River, Columbia Cut, and Turner Cut were about the same as for the NDP alternative (Figures 31 - 33).

CUWA - Alternative C Geometry (CUWA-C). The CUWA-C alternative increased cross-Delta flow over the ISDP alternative but to a less extent than did the NDP alternative. However, average conveyance velocities through Tyler Island were much lower than velocities in Georgiana Slough and the North and South forks of the Mokelumne River for the NDP alternative (Figures 19 - 21). Average velocities in the central Delta channels were not changed much from the ISDP alternative; however, low velocities in the many open water areas of the CUWA-C alternative which surely exist are not shown. As in the NDP alternative, increasing the cross-Delta flow increased upstream flow in lower Old River and lower Middle River. The increases in upstream flow were actually substantially more than what occurred in the North Delta alternative. Most dramatic were the large changes in the ranges in maximum upstream and downstream flows in lower Old River and lower Middle River under the CUWA-C alternative (Figures 34 - 36). Under the CUWA-C alternative, there was significantly more movement of tidal flow back and forth in the channels of lower Old River and lower Middle River, with a larger net upstream flow which then passes out into the San Joaquin River via False Tract and Dutch Slough.

Unlike the other alternatives studied, the CUWA-C alternative seemed to change flows, velocities and minimum water levels in the south Delta. Figures 34 - 36 show that average flow from the San Joaquin River upstream towards the CVP and SWP pumps tended to increase in Old River and decrease in Middle River. Minimum water levels in the south Delta downstream of the flow control structures were significantly raised. The minimum water levels in the south Delta were generally raised, causing less head differential across the flow control structures and thus less flow and circulation upstream of the structures.

Mass Tracking

Mass tracking studies were done under the May hydrology for each of the alternatives. In this simulation, a high concentration of a conservative, buoyant mass was injected at one location at a time in the Delta for three separate locations: San Joaquin River at Vernalis, Columbia Cut, and Sacramento River at Freeport. Through advection and dispersion, mass moves in the Delta and is tracked with time as it may end up at state or federal pumps, on Delta islands, flow past Chipps Island, or remain in the Delta channels and open water areas. Results are presented in terms of percent of total mass injected. Mass tracking results are commonly presented after 15 and 30 days of simulation past the day of injection. These modeling results are an indicator of how flow patterns caused by the alternatives might move neutrally buoyant, conservative particles through the Delta.

Existing Delta Geometry and ISDP. Mass tracking results were very similar for the Existing Delta Geometry alternative and the ISDP alternative for each injection point after 15 and 30 days. Both alternatives assumed a complete closure of the head of Old River and the dredging in Old River for the ISDP alternative didn't result in significant changes to mass tracking results.

North Delta Program Geometry. The NDP alternative showed little difference from the ISDP alternative after 15 or 30 days when mass was injected at Vernalis. When mass was injected at Columbia Cut, more mass moved past Chipps Island and less remained in the Delta after 30 days than for the ISDP alternative. However, when mass was injected in Freeport, less mass tended to pass past Chipps and more remained in the Delta than for the ISDP alternative. This was presumably because of the substantial increase in cross-Delta flow.

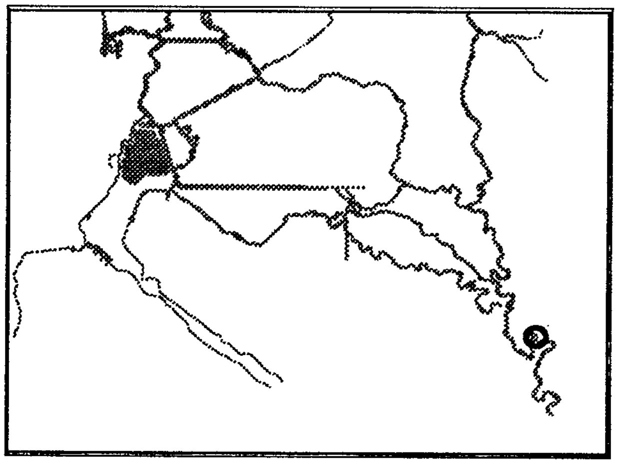
North Delta Program with Hood Diversion Geometry. The NDPH alternative behaved very similar to the NDP alternative for mass tracking studies.

CUWA Alternative C Geometry. The CUWA-C alternative caused more mass to remain in the Delta for each injection site. The increase in mass remaining in the Delta was substantial when mass was injected at Freeport. Substantially less mass passed past Chipps Island when injected at Freeport, but more passed past Chipps Island when injected in Columbia Cut. When mass was injected in Columbia Cut, the CUWA-C alternative caused less mass to end up at the SWP and CVP pumps.

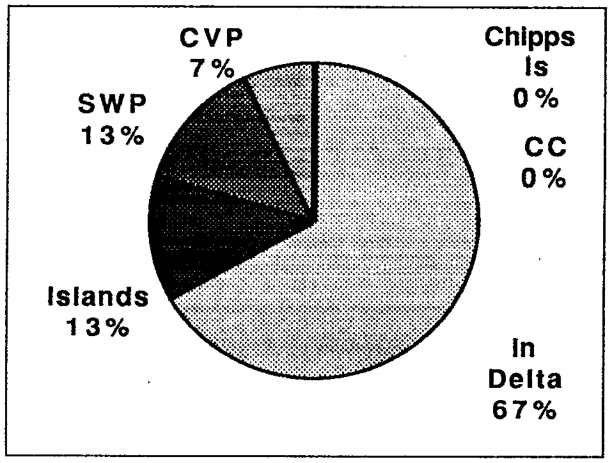
Figure 37

Mass Tracking Study For May 1989 (Reoperated)

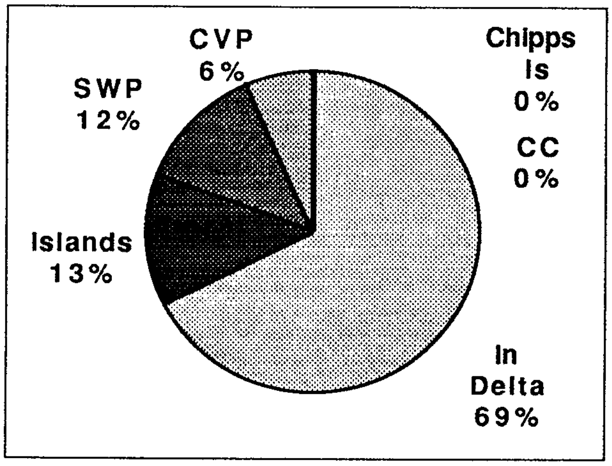
Mass Fate After 15 Days



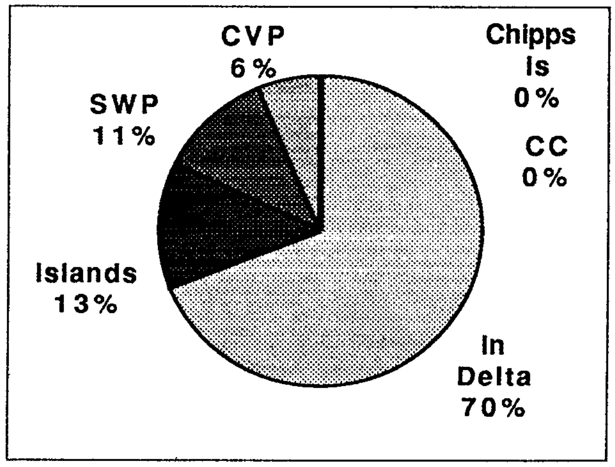
Inject at SJR near Vernalis



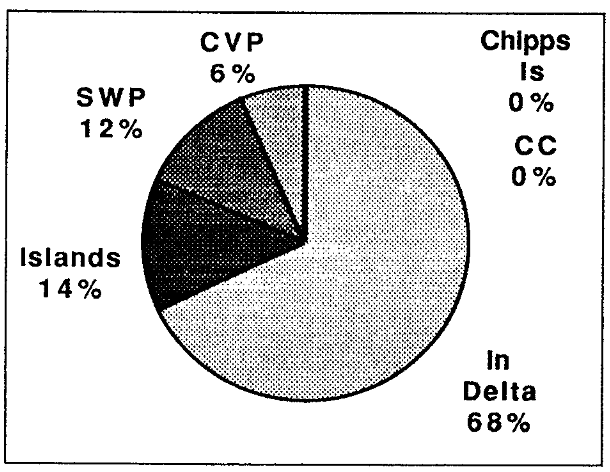
Existing Delta Geometry



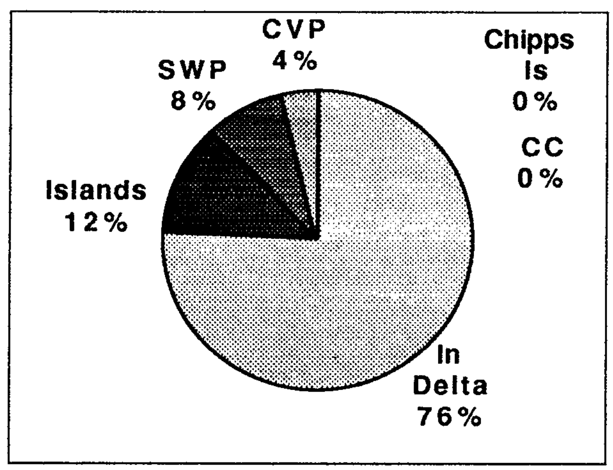
North Delta Program Geometry



Interim South Delta Program Geometry

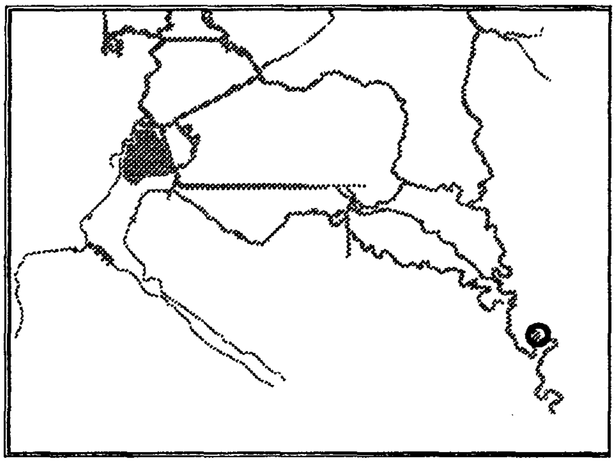


North Delta Program with Diversion Geometry

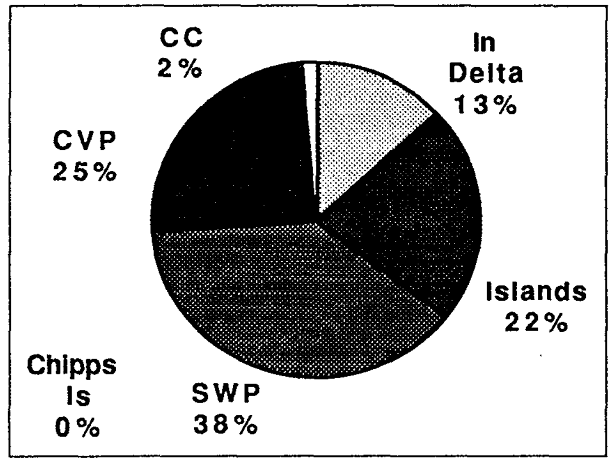


CUWA Alternative C Geometry

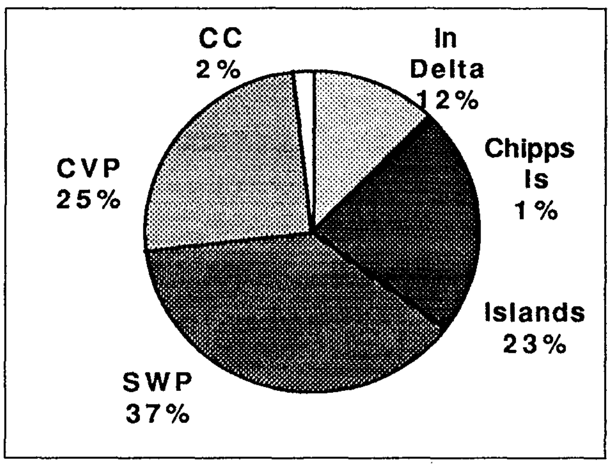
Figure 38
Mass Tracking Study For May 1989 (Reoperated)
Mass Fate After 30 Days



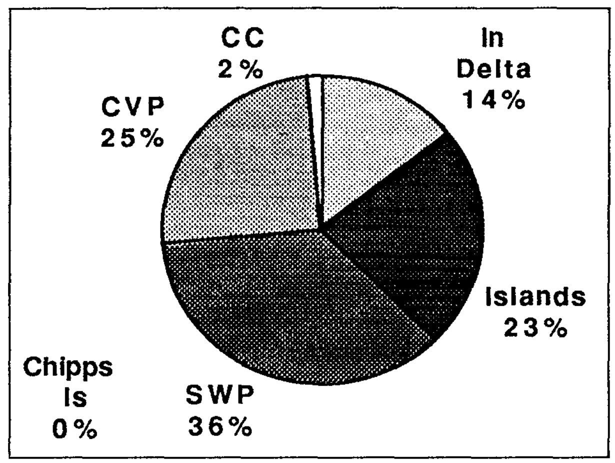
Inject at SJR near Vernalis



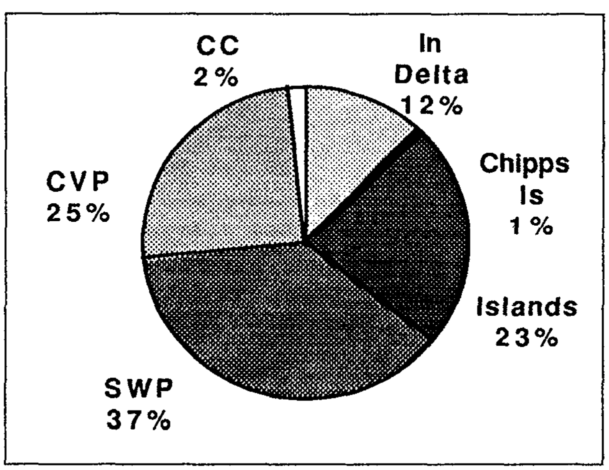
Existing Delta Geometry



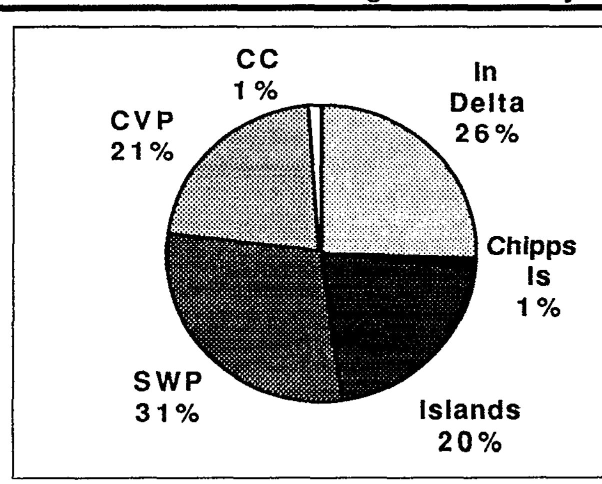
North Delta Program Geometry



Interim South Delta Program Geometry



North Delta Program with Diversion Geometry



CUWA Alternative C Geometry

Figure 39
Mass Tracking Study For May 1989 (Reoperated)
Mass Fate After 15 Days

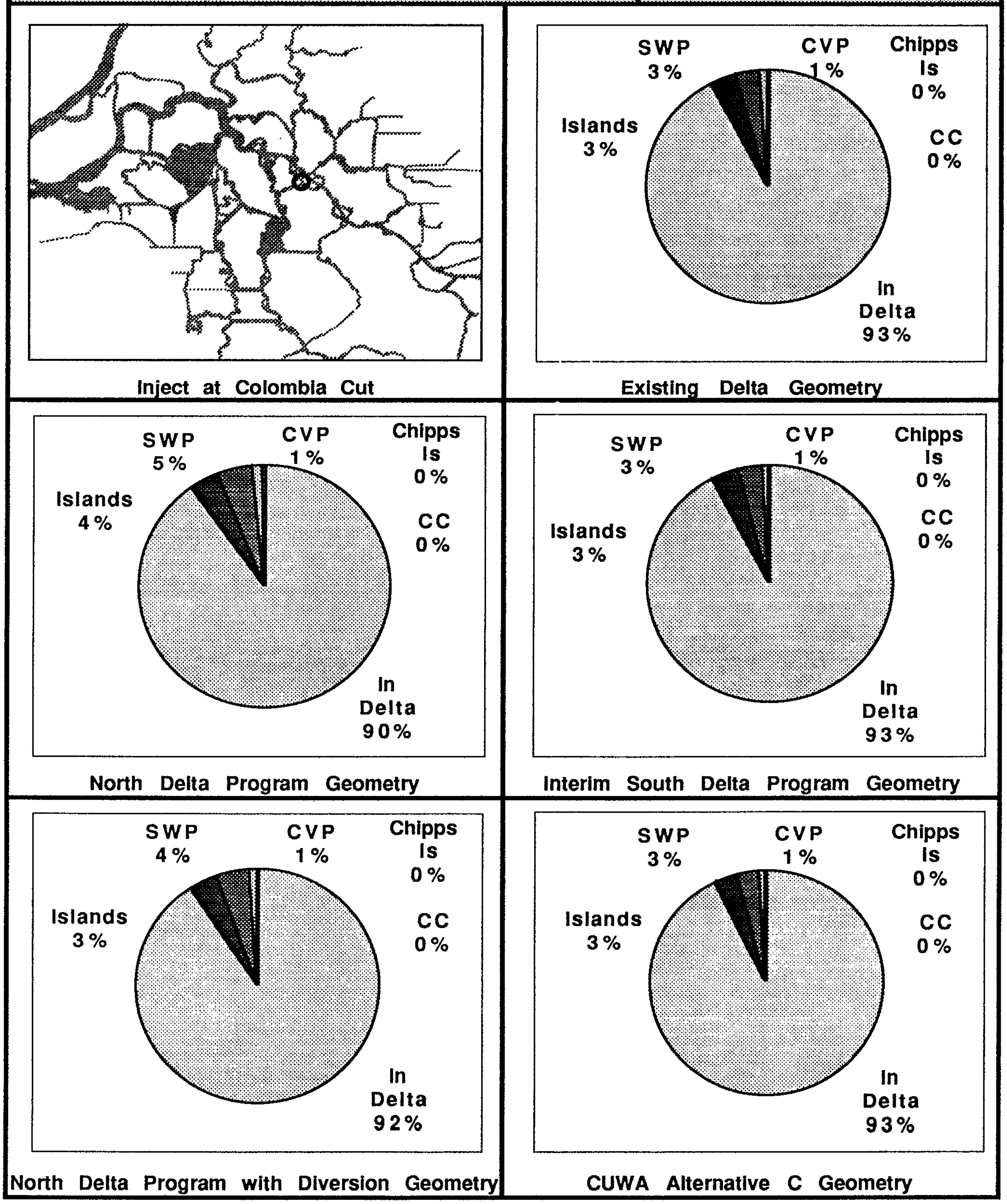


Figure 40
Mass Tracking Study For May 1989 (Reoperated)
Mass Fate After 30 Days

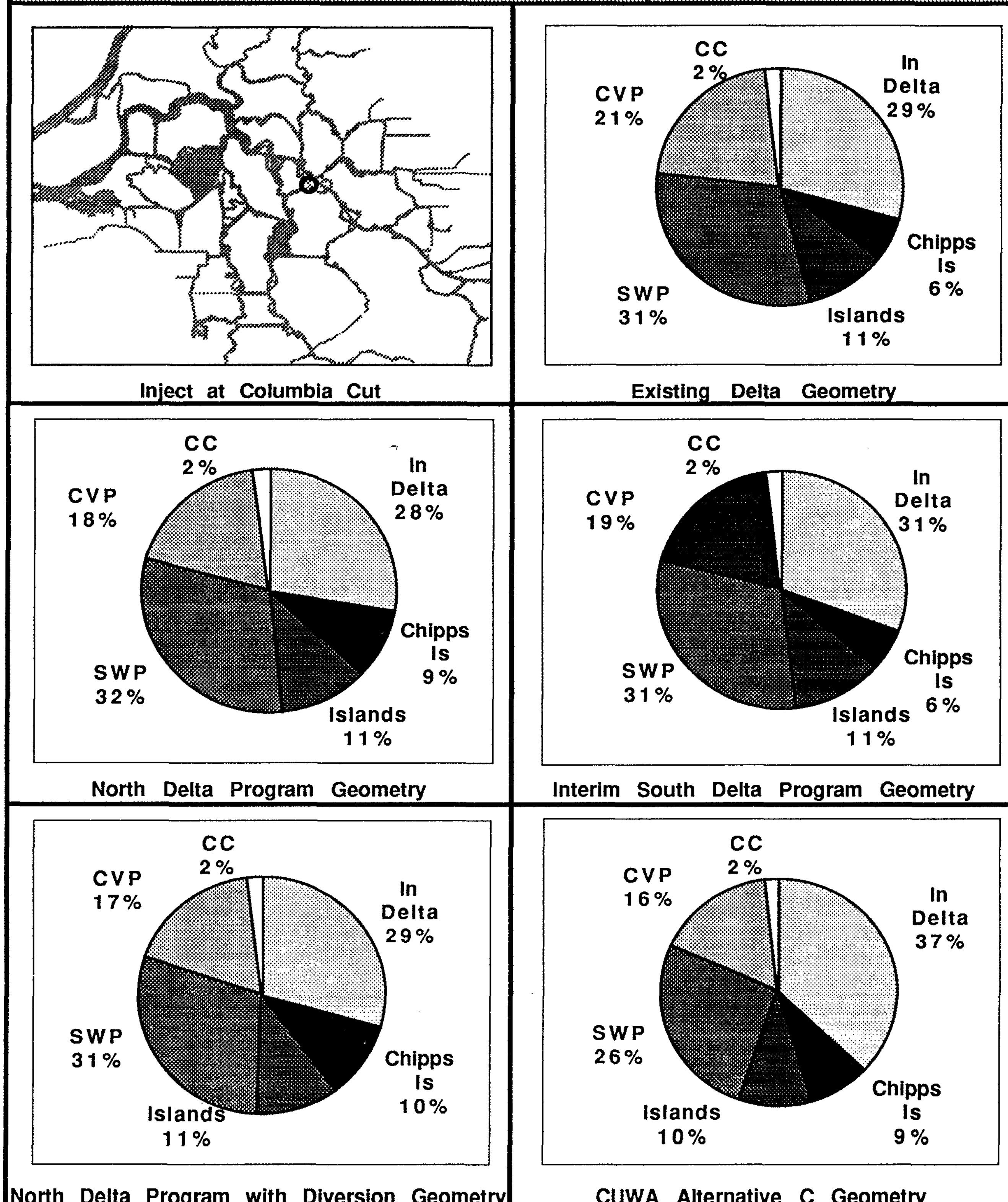


Figure 41
Mass Tracking Study For May 1989 (Reoperated)
Mass Fate After 15 Days

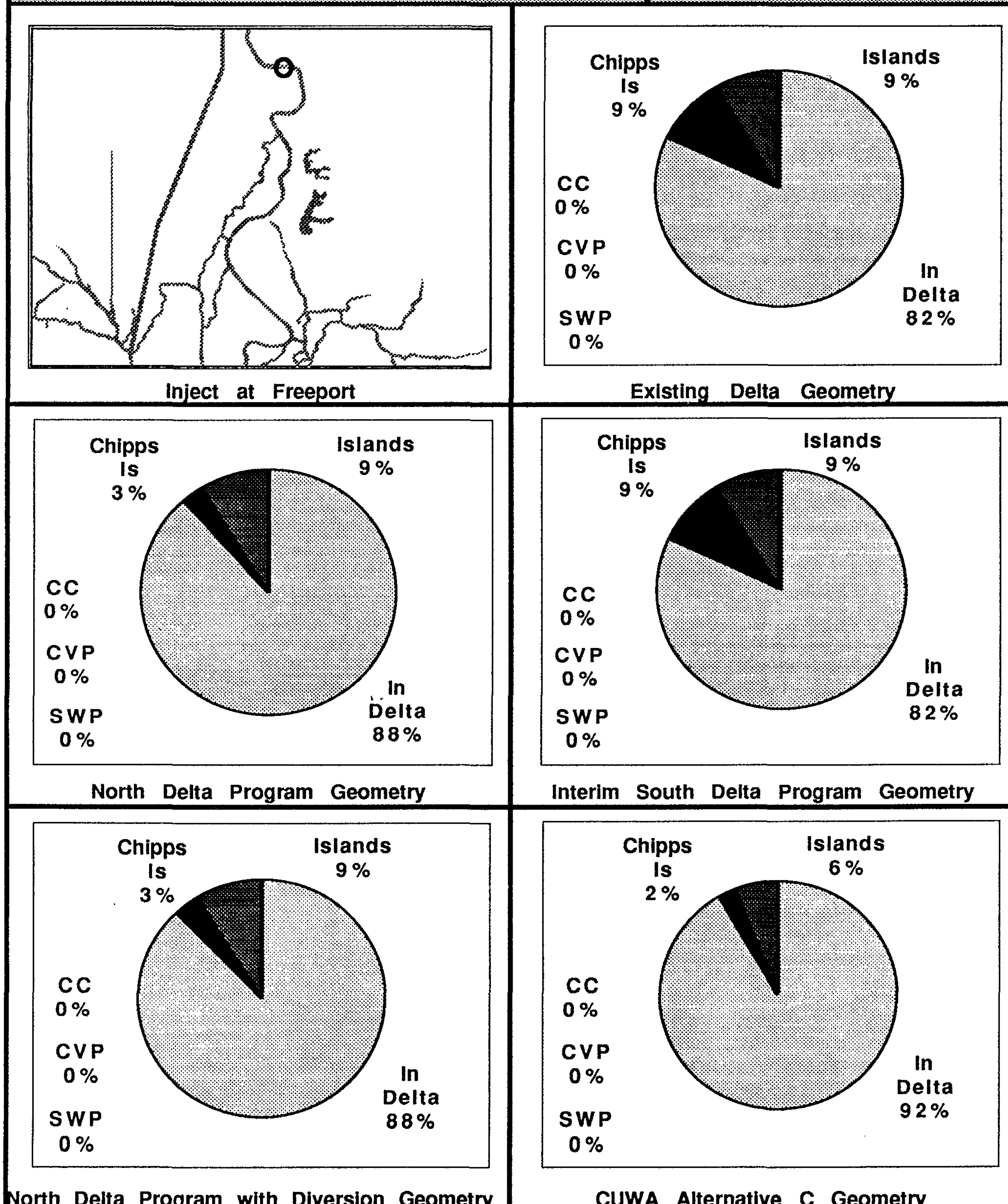


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Figure 42
Mass Tracking Study For May 1989 (Reoperated)
Mass Fate After 30 Days

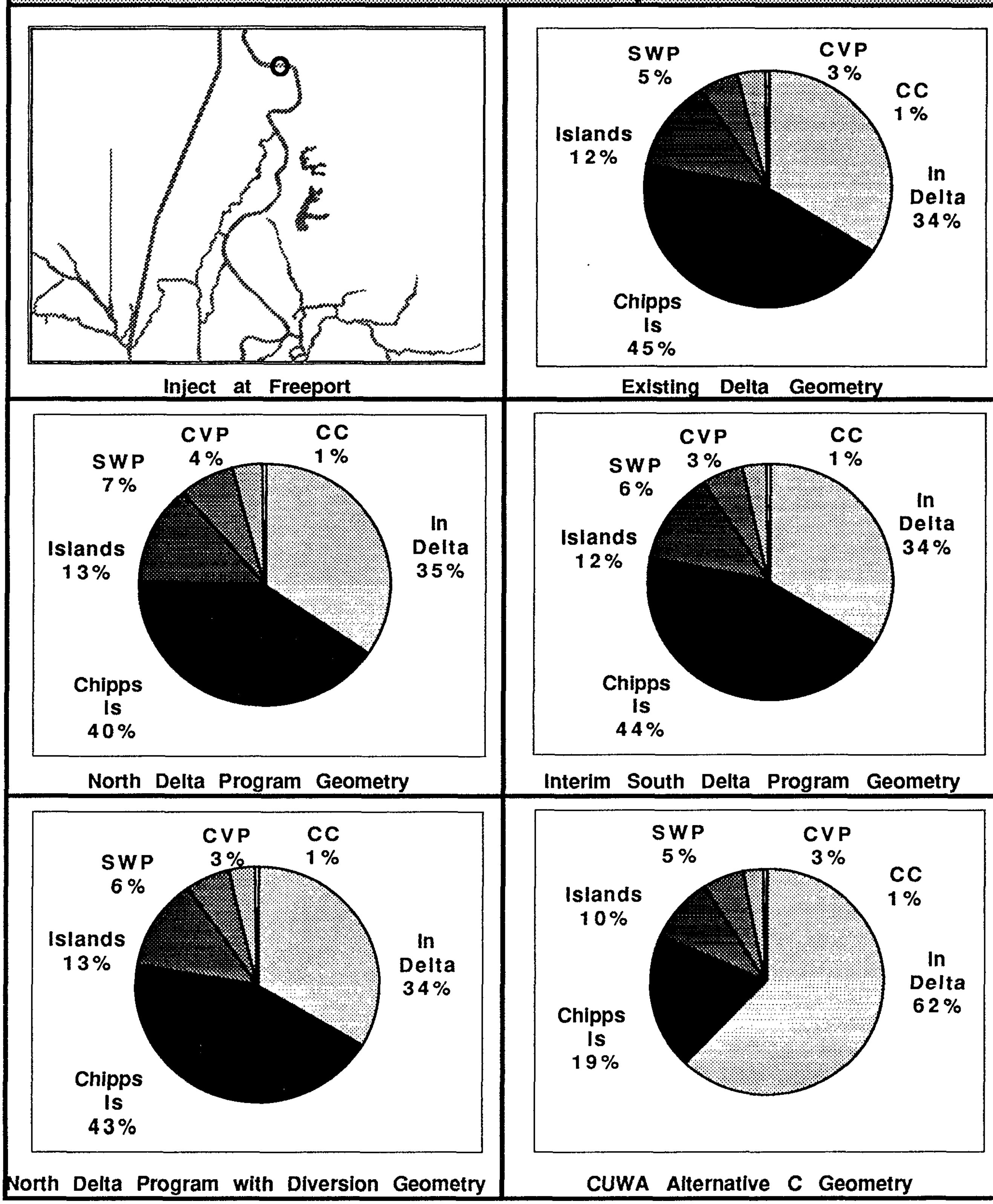


Table 5
Summary of Delta Impacts by Alternative

Interim South Delta Program Geometry (with respect to Existing Delta Geometry)

1. Permanent flow control structures raised minimum water levels higher and induce stronger circulation patterns than the temporary structures.
2. SWP and CVP pumps moved more water up Old River and less water up Middle River.
3. Increased the range in maximum upstream and downstream flow in lower Old River, lower Middle River, Columbia Cut, and Turner Cut.
4. No change in fate of injected mass.

North Delta Program Geometry (with respect to ISDP)

1. Large increase in cross-Delta flow through Delta Cross Channel.
2. Large increase in average tidal flow up lower Old River and back into San Joaquin River via False River and Dutch Slough.
3. Large increase in average flow down San Joaquin River and corresponding decrease in Sacramento River flow past Rio Vista.
4. Some increase in upstream flow in lower Middle River, Columbia Cut, and Turner Cut.
5. More of the mass injected in Columbia Cut moved past Chipps Island while less remained in the Delta.
6. Less of the mass injected at Freeport moved past Chipps Island while less remained in the Delta.

North Delta Program with Hood Diversion Geometry (with respect to ISDP)

1. Similar changes as for the North Delta Program Geometry.

CUWA Alternative C Geometry (with respect to ISDP)

1. Large increase in cross-Delta flow through Tyler Island.
2. Much lower conveyance velocities through the North Delta.
3. Large increases in average tidal flow up lower Old River and back into the San Joaquin River via False River and Dutch Slough.
4. Large increases in the range of maximum upstream and downstream flows in lower Old and Middle rivers.
5. Shift in upstream flows towards the SWP and CVP pumps from Middle River to Old River.
6. Increase in minimum water levels in the south Delta.
7. More of injected mass remained in the Delta after 30 days regardless of the point of injection.
8. Substantial increase in mass injected at Freeport remaining in the Delta after 30 days.
9. Less of the mass injected in Columbia Cut ended up at the SWP and CVP pumps.

Chapter 2
Comparison of Two Modes of DWRDSM1 Applications

Modeling of Delta impacts caused by changes in the configuration of the Delta is in part related to the Delta inflows, exports, and boundary tides. In Chapter 1, an April through May period was simulated with daily inflows and exports and a historic hourly tide at Martinez. Delta simulations for alternative screening or impact analysis under a wide range of Delta hydrologies are often desirable. However, resource limitations usually prevent detailed computer modeling with daily changing Delta inflows and exports and hourly boundary tides for more than a few years. Even when such a detailed computer modeling is done, modeling results are usually reduced by some method to perhaps monthly statistics to enable comprehension of Delta-wide patterns and trends between Delta configurations.

One common mode of application of DWRDSM1 is to use DWR's statewide model, DWRSIM, to provide Delta inflows and exports on a monthly average basis over an extended range of hydrologies. Current DWRSIM capabilities are to simulate 73 different water year sequences, labelled "1922" through "1994." A single 25-hour Delta hydrodynamics pattern is generated for each month using the monthly average hydrology from DWRSIM and a 19-year mean tide for the boundary. This tide is repeated every day during the month with boundary salinity changing hourly over the month. The maximum, minimum, and average flows, water levels, and velocities over the 25-hour period would then be reported as the maximum, minimum, and average conditions over the month since the boundary tide and Delta hydrology remain the same during the month. The concern about this method is its potential failure to include spring and neap tides and the inability to catch monthly extremes in Delta hydraulics caused by extremes in the boundary tide.

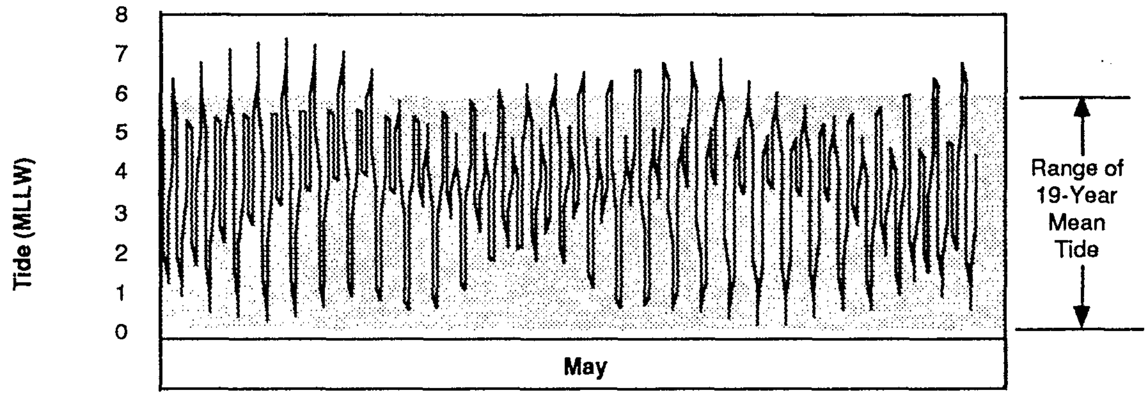
This chapter compares modeling results for May of 1989 from Chapter 1 which used daily changing hydrology and historic hourly tides at Martinez to results using the 19-year mean tide and averaged Delta hydrology over the same period. The later method is similar to the application of using DWRDSM1 with DWRSIM results as input. Figure 43 shows how the range in the 19-year mean boundary tide compares to the trace of the actual tide from May of 1989 and how the averaged Delta inflows and exports compare to daily values. The following analysis focuses on how modeling an average hydrology and 19-year mean tide compares to modeling a daily changing hydrology and hourly changing boundary tide for a month and then averaging those results. For mass tracking, both methods report the mass fate at the end of May.

Delta Modeling Results

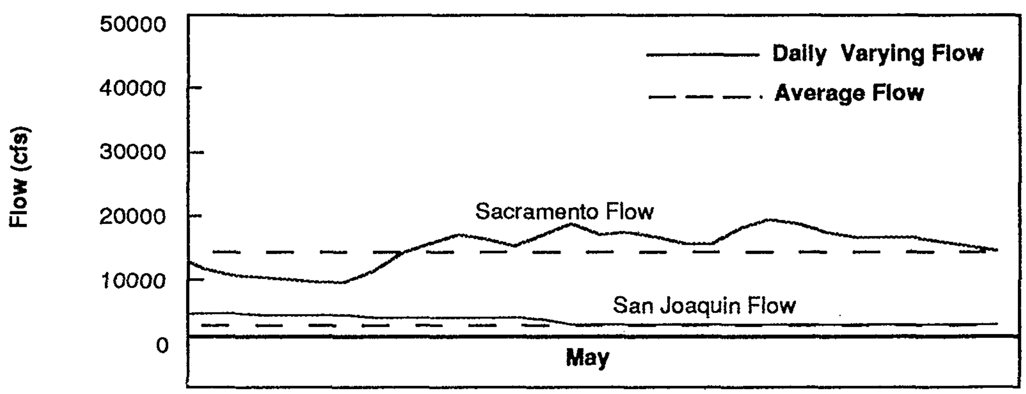
The hydrodynamic results at several locations in the Delta are shown in Figures 44, 45, 46, 47 and 48. The model showed that maximum upstream and downstream and average velocity and flow for all alternatives were almost identical under historic as well as 19-year mean tide conditions. This implies that running the model under average tide and hydrology conditions will suffice for studies of flow circulation patterns under different alternatives if monthly averages are to be computed from results of the model applied in a daily mode. Maximum and minimum and average water levels, however, were different under these tidal conditions. The historic tide and hydrology resulted in higher water levels throughout the Delta. The historic tide at the

Figure 43
Comparison of Historic and 19 - Year Boundry Tide at Martinez
Daily Varying and Monthly Average Hydrology
for May of 1989

Historical Tide and the Range of 19 Year Mean Tide



Daily Varying and Average Sacramento and San Joaquin Flows



Daily Varying and Average Pumping (CVP + SWP)

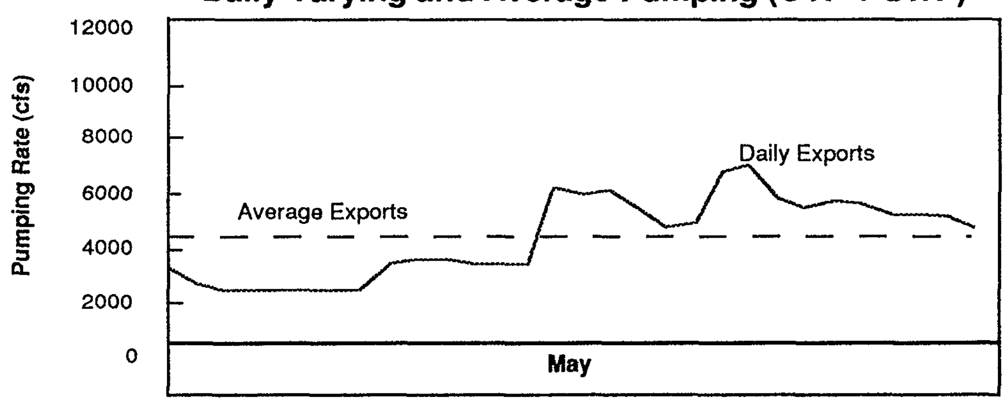
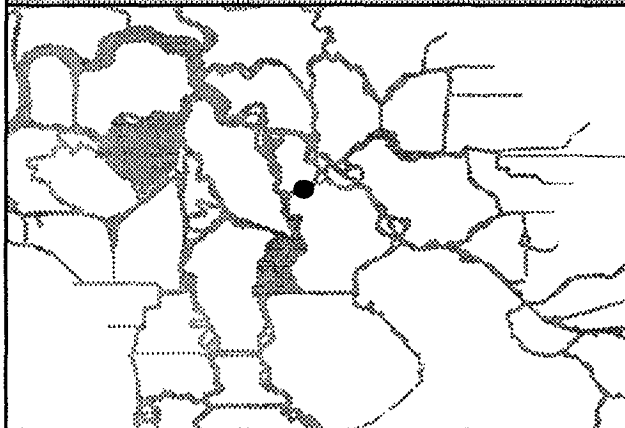
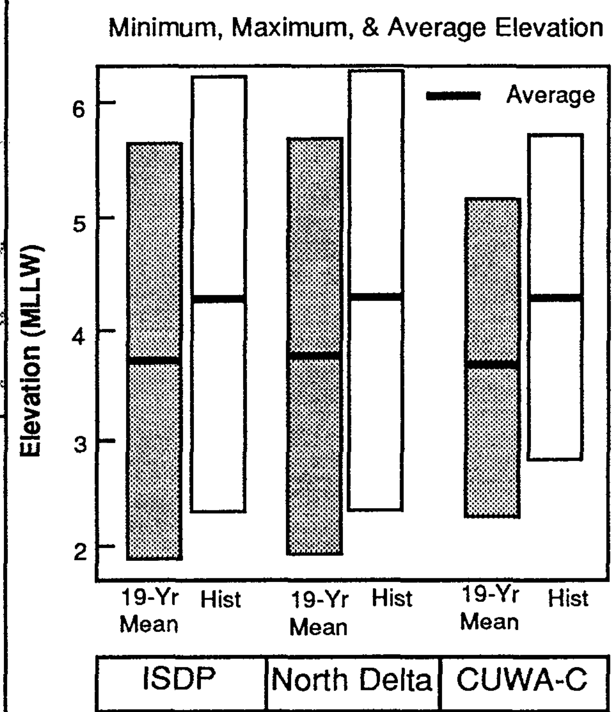


Figure 44
Comparison of Hydraulics
Daily Hydrology and Historic Tide vs Avg Hydrology and 19 - Yr Mean Tide
Columbia Cut

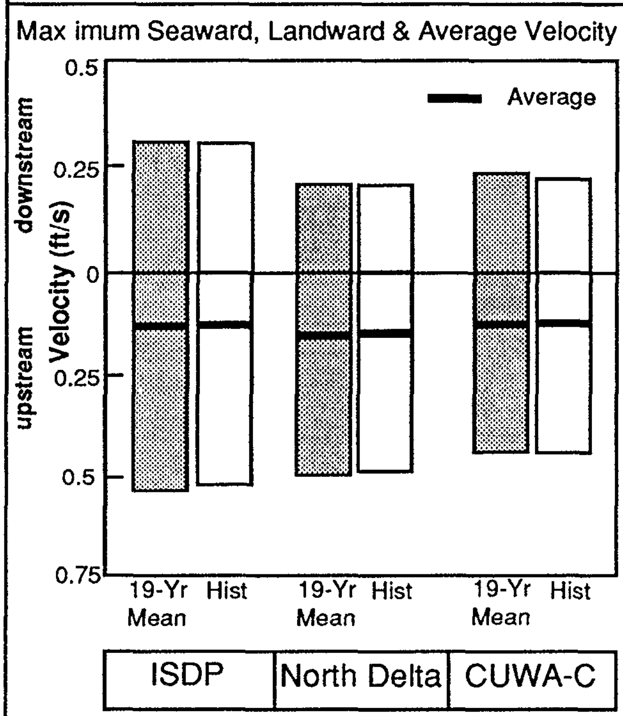




Hydrology (average over period):

Sacramento R inflow	13,784 cfs
San Joaquin R inflow	2,348 cfs
CVP Pumping	1,868 cfs
SWP Pumping	1,973 cfs
Channel Depletions	2,755 cfs
Delta Outflow	9,615 cfs

Source: *Historic 1989 conditions reoperated for 1995 SWRCB WQCP.*



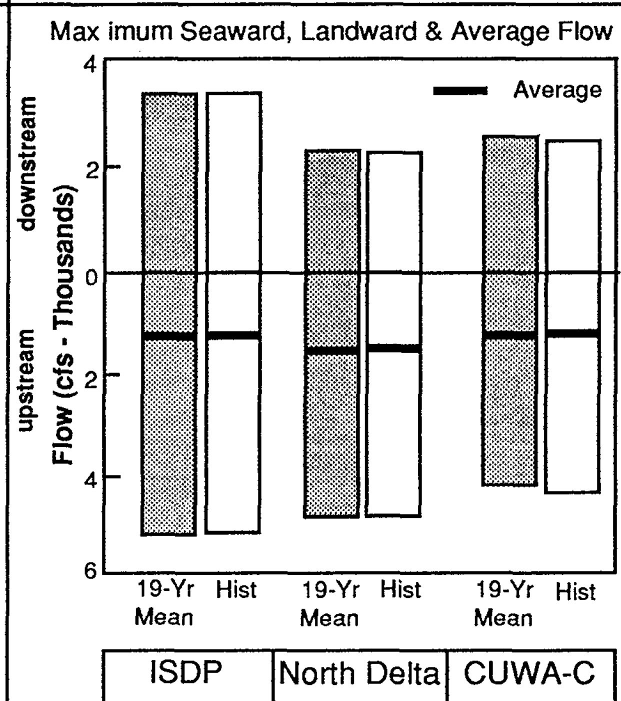
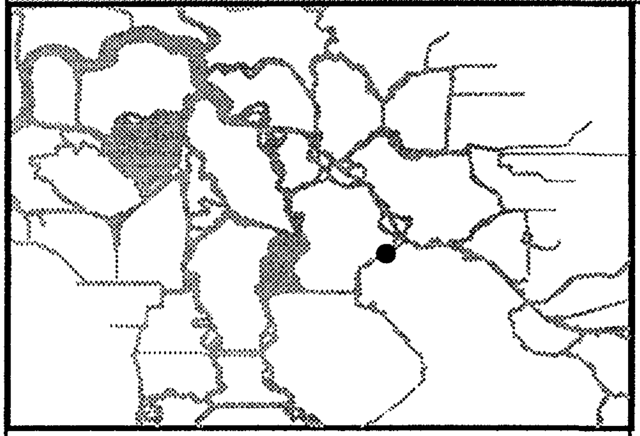
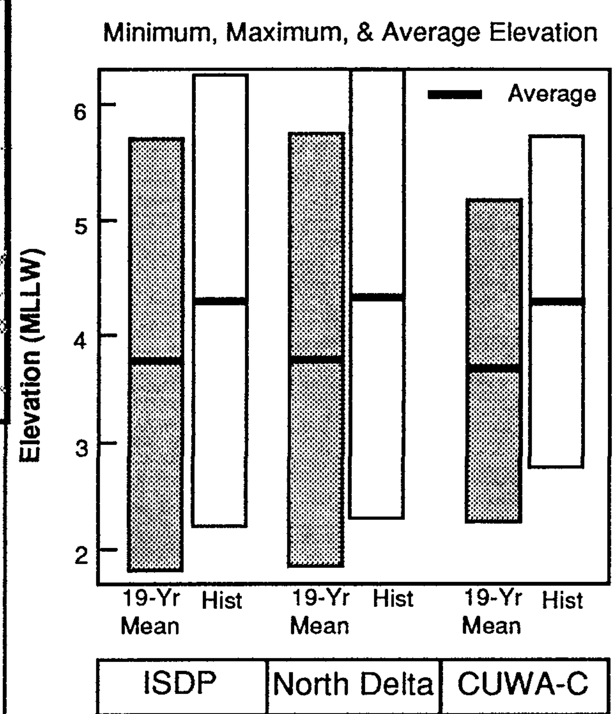


Figure 46
Comparison of Hydraulics
Daily Hydrology and Historic Tide vs Avg Hydrology and 19 - Yr Mean Tide
Turner Cut

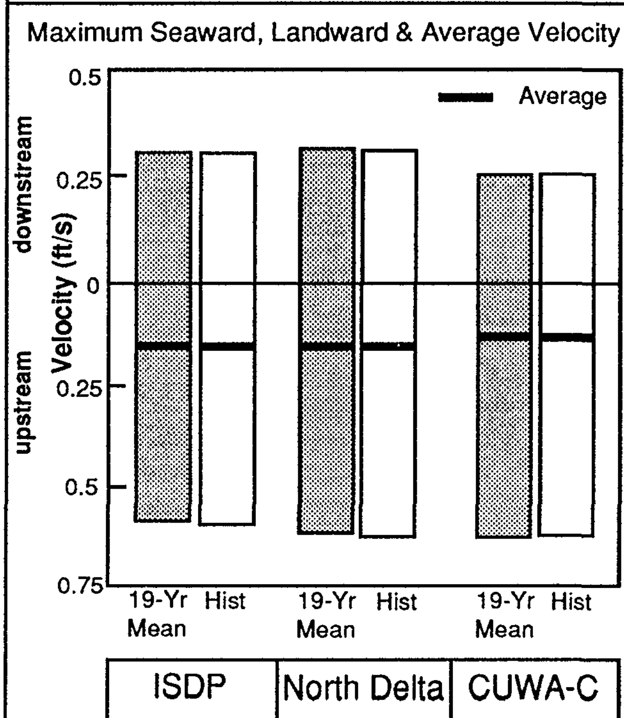




Hydrology (average over period):

Sacramento R inflow	13,784 cfs
San Joaquin R inflow	2,348 cfs
CVP Pumping	1,868 cfs
SWP Pumping	1,973 cfs
Channel Depletions	2,755 cfs
Delta Outflow	9,615 cfs

Source: Historic 1989 conditions reoperated for 1995 SWRCB WQCP.



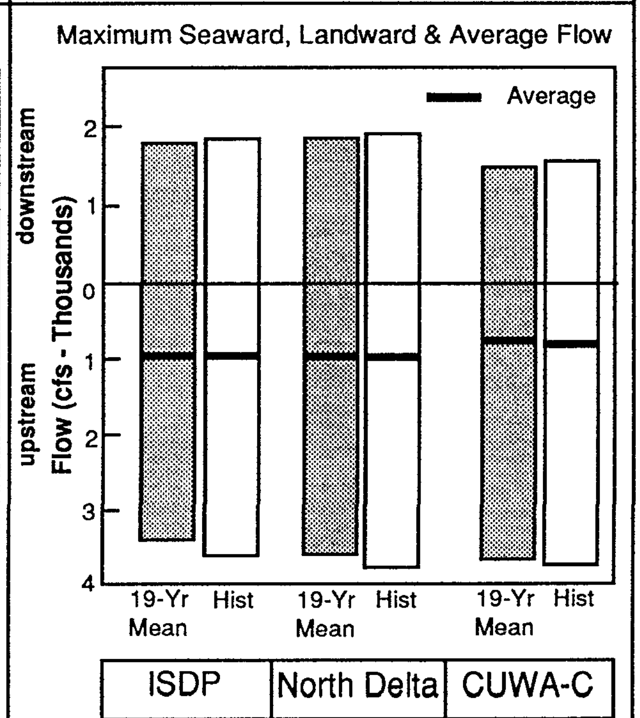
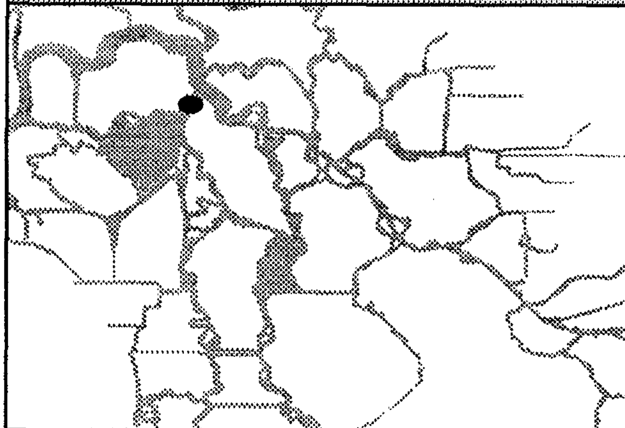


Figure 47

Comparison of Hydraulics

Daily Hydrology and Historic Tide vs Avg Hydrology and 19 - Yr Mean Tide

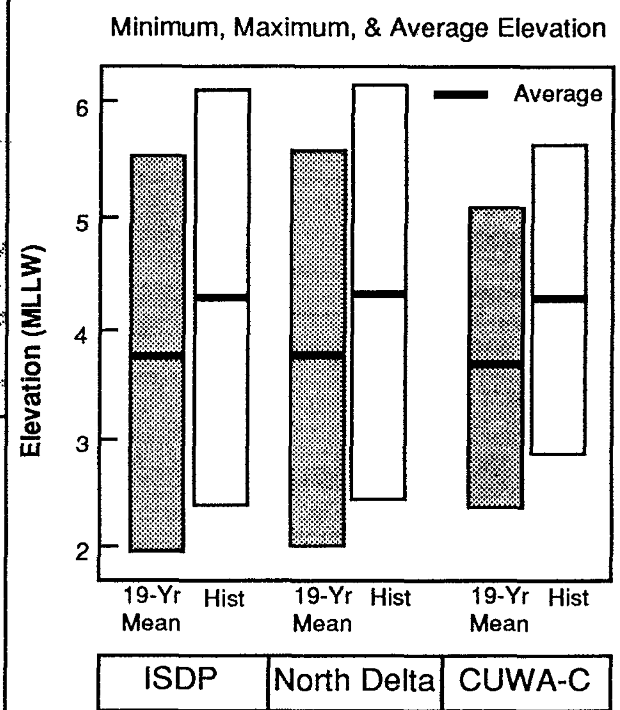
Lower Old River at SJR

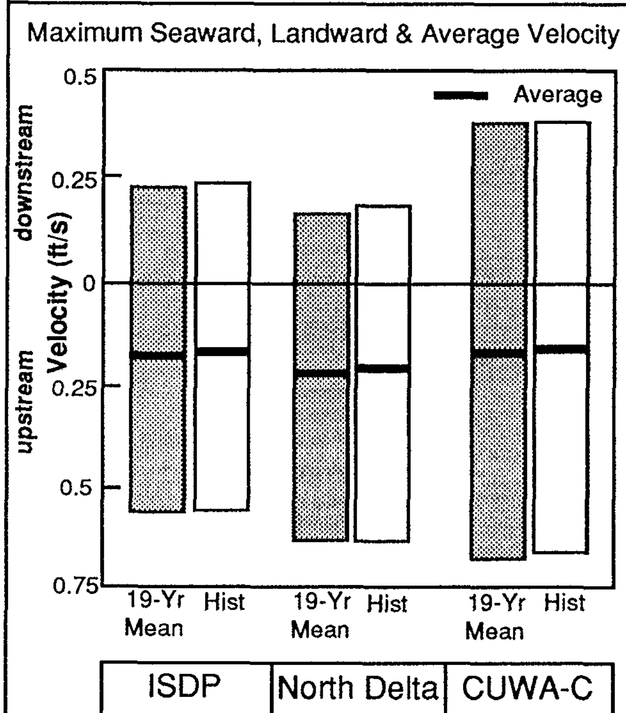


Hydrology (*average over period*):

Sacramento R inflow	13,303 cfs
San Joaquin R inflow	2,147 cfs
CVP Pumping	4,245 cfs
SWP Pumping	4,472 cfs
Channel Depletions	1,171 cfs
Delta Outflow	5,725 cfs

Source: Historic 1989 conditions reoperated for 1995 SWRCB WQCP.





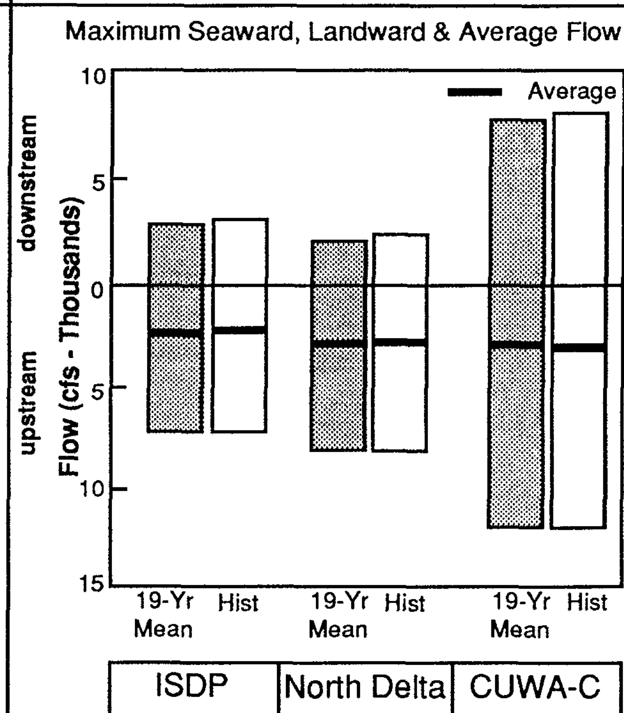
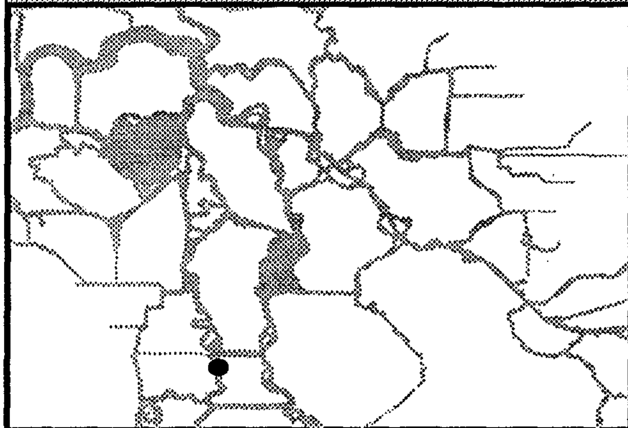
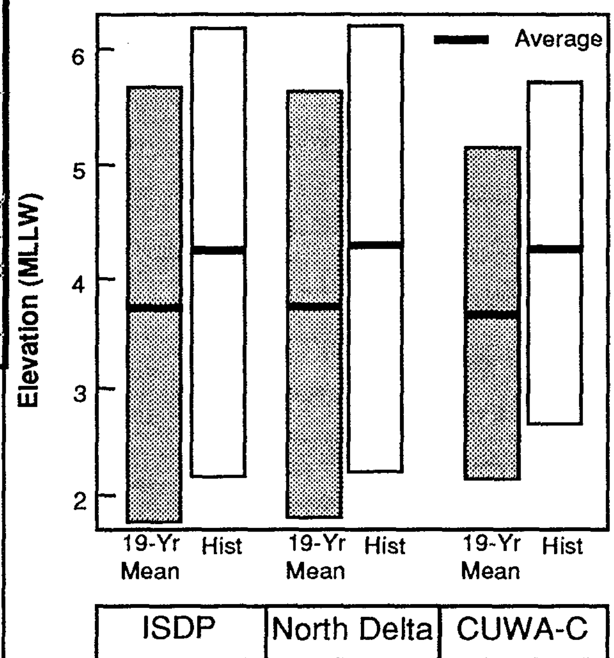


Figure 48

Comparison of Hydraulics
Daily Hydrology and Historic Tide vs Avg Hydrology and 19 - Yr Mean Tide
Old River near SFRR



Minimum, Maximum, & Average Elevation

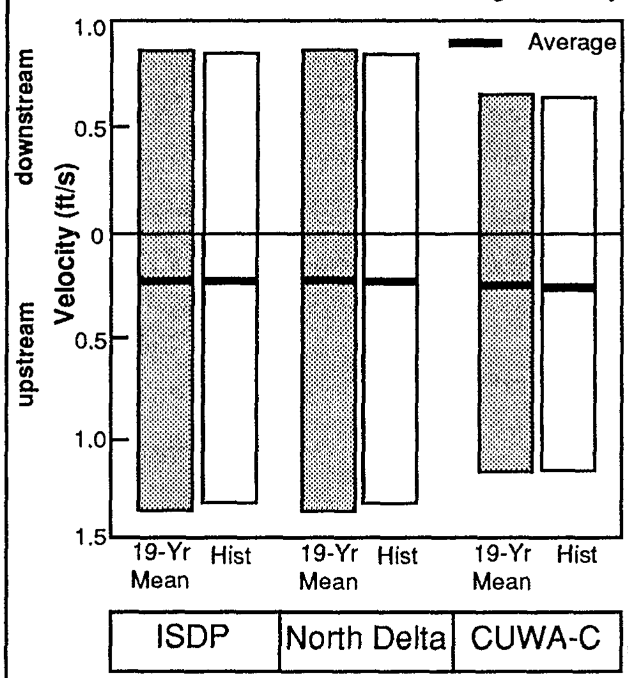


Hydrology (average over period):

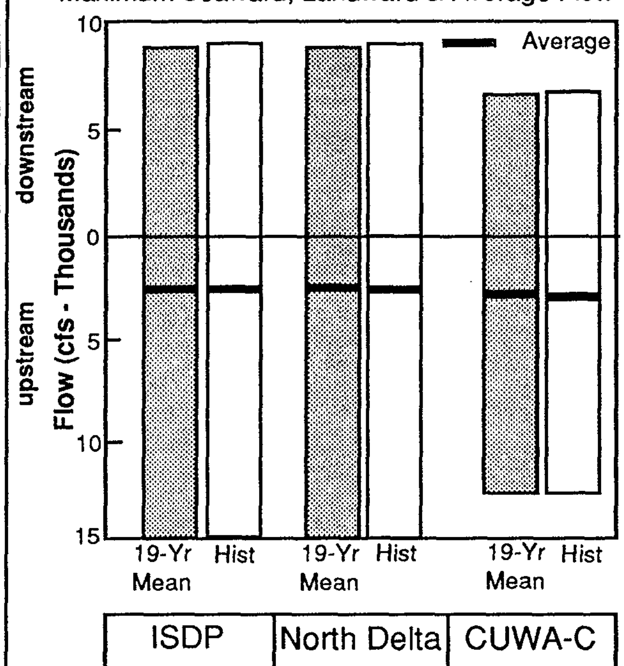
Sacramento R inflow	13,784 cfs
San Joaquin R inflow	2,348 cfs
CVP Pumping	1,868 cfs
SWP Pumping	1,973 cfs
Channel Depletions	2,755 cfs
Delta Outflow	9,615 cfs

Source: Historic 1989 conditions reoperated for 1995 SWRCB WQCP.

Maximum Seaward, Landward & Average Velocity



Maximum Seaward, Landward & Average Flow

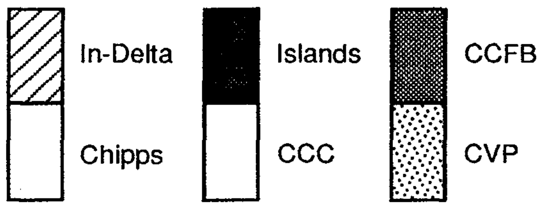


boundary (Martinez), which drives the model, had larger energy (higher high and low tides) as it went through spring-neap variations over the month, compared to the 19-year mean tide as shown in Figure 43. This higher energy embedded in the boundary propagated into interior Delta, giving higher water levels.

The mass tracking results with historic and 19-year mean tide show results consistent with hydrodynamics. The distribution of the mass over the Delta under these two tide conditions are similar as shown in Figure 49. This is because the mass is moved within the Delta channels via advection (mean channel velocity) and dispersion. Since, average velocities were almost identical under these two tidal conditions and both used equal dispersion coefficients, both resulted in a similar distribution of mass. The incremental differences observed by these two modes of appication are strikingly close.

Figure 49
Comparison of Mass Tracking After 30 Days
Daily Hydrology and Historic Tide vs Avg Hydrology and 19-Yr Mean Tide
May of 1989 (Reoperated)

Fate of Mass



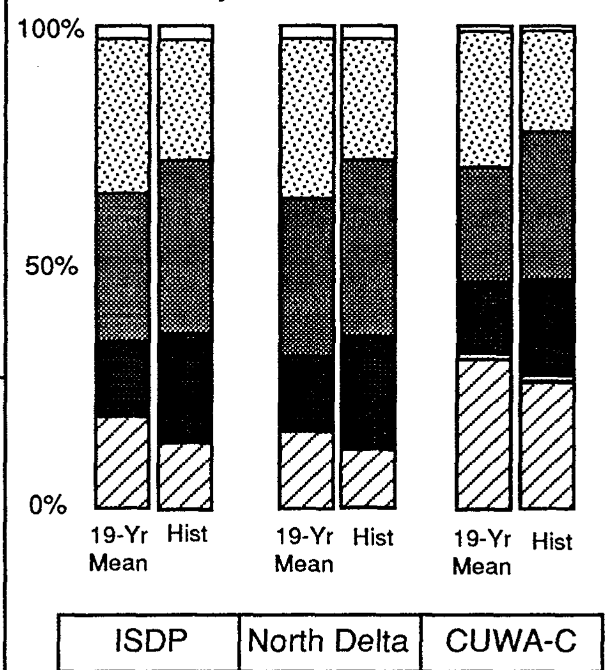
Terminology: "19-Yr Mean" refers to 19-year mean tide, average hydrology. "Hist" refers to daily changing hydrology and historic tide at Martinez.

Hydrology (average over period):

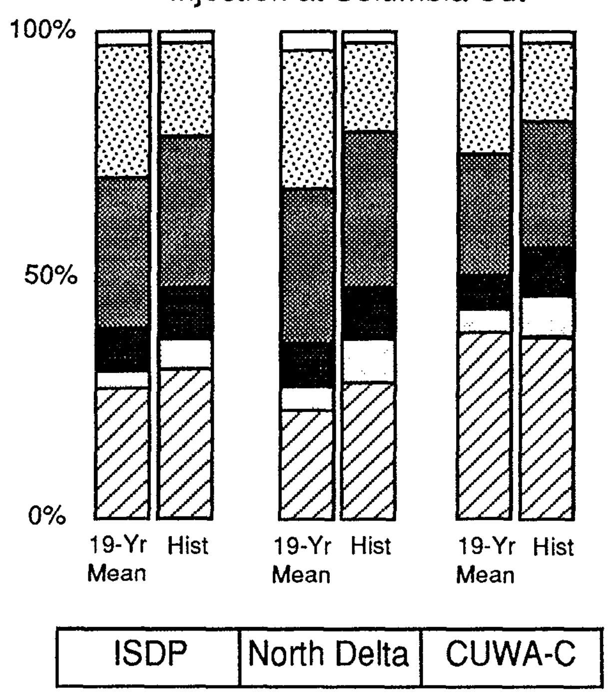
Sacramento R inflow	13,784 cfs
San Joaquin R inflow	2,348 cfs
CVP Pumping	1,868 cfs
SWP Pumping	1,973 cfs
Channel Depletions	2,755 cfs
Delta Outflow	9,615 cfs

Source: Historic 1989 conditions reoperated for 1995 SWRCB WQCP.

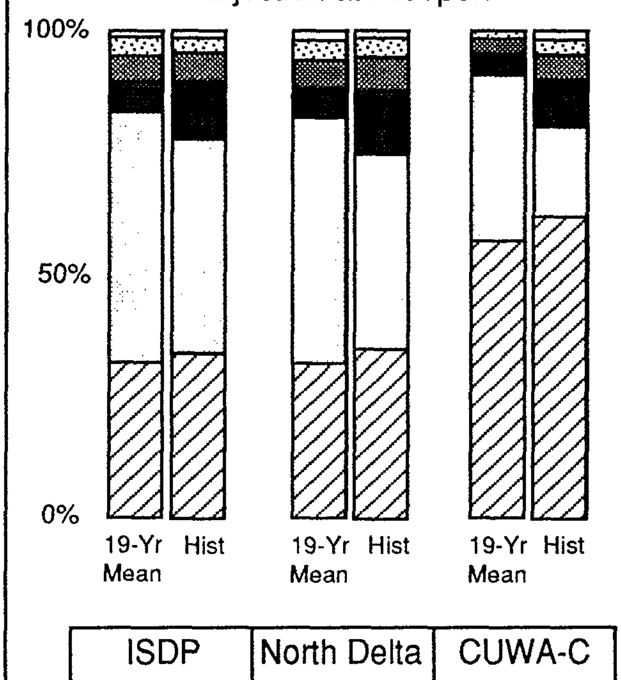
Injection at Vernalis



Injection at Columbia Cut



Injection at Freeport



Chapter 3
Hydraulic Analysis of the Chain of Lakes Alternative

As one of CALFED's Delta Conveyance and Storage Components, the Chain of Lakes alternative would function as a combined isolated storage and conveyance facility to transfer Sacramento flow across the Delta to Clifton Court forebay (CCFB) for export. A chain of up to 8 lakes, created by flooding Delta islands, would be connected via siphons and pumps beneath Delta channels. These islands-turned-lakes include; Tyler Island at the head end of the chain followed by Bouldin Island, Venice Island, Mandeville Island, Bacon Island, Woodward Island and finally Victoria Island connected to CCFB at the downstream end of the chain (Fig. 50). The Chain-of-Lakes component in effect moves the Delta export location from the current CCFB site to the lower Sacramento river near the Delta Cross Channel.

Hydraulic Analysis

As shown in Figure 50, the water from Sacramento River would be diverted through the enlarged Delta Cross Channel (DXC) gates. To enlarge the DXC gates to a new 300 ft opening, two new radial gates would be constructed to accommodate the 15,000 cfs design conveyance capacity of the chain of lakes system. Once Sacramento River water enters the Delta Cross Channel it flows through a fish screen constructed downstream of the radial gates. A low lift pump would be located downstream of the fish screen to control the hydraulic performance of the fish screens and to lift the water into a new 500 feet wide open channel leading to Tyler Island. The downstream end of the Delta Cross Channel would be closed off from the existing connection to Snodgrass Slough.

When water arrives at the end of Tyler Island, it would be siphoned under Mokelumne River into Bouldin Island. Islands in the Chain-of-Lakes system are hydraulically inter-connected via either 18 feet diameter siphons or low lift pumps. In islands connected via siphons, the gravity flow under the available head gradient between adjacent islands would deliver the design flow of 15,000 cfs. In islands with pump interconnection, a low lift pump with 15,000 cfs capacity would provide the required flow. Distributed pump stations around each island are also considered to supplement flow and facilitate filling islands from adjacent channels or draining flow from storage. With the combinations of siphons and pumps the design flow would run from one island to the next downstream until reaching the CCFB.

One of the key design parameters is the minimum number of siphons required to carry the design flow with the constraint of maximum head gradient available between the most upstream end of the Chain-of-Lakes system (Tyler Island) and the most downstream end (CCFB). The maximum upstream lake level in Tyler island should not exceed +6 mean sea level (MSL) for safety considerations related to possible levee failure. The minimum water level at the most downstream end of the Chain at CCFB should not fall below -2 MSL due to potential export pump cavitation problems. This would give a maximum total allowable head gradient of 8 feet from Tyler island at the upstream end and CCFB at the downstream end.

If the number of siphons is under-estimated, the reduced total flow area will result in large energy (head) loss exceeding the maximum head available, causing back-water in each island

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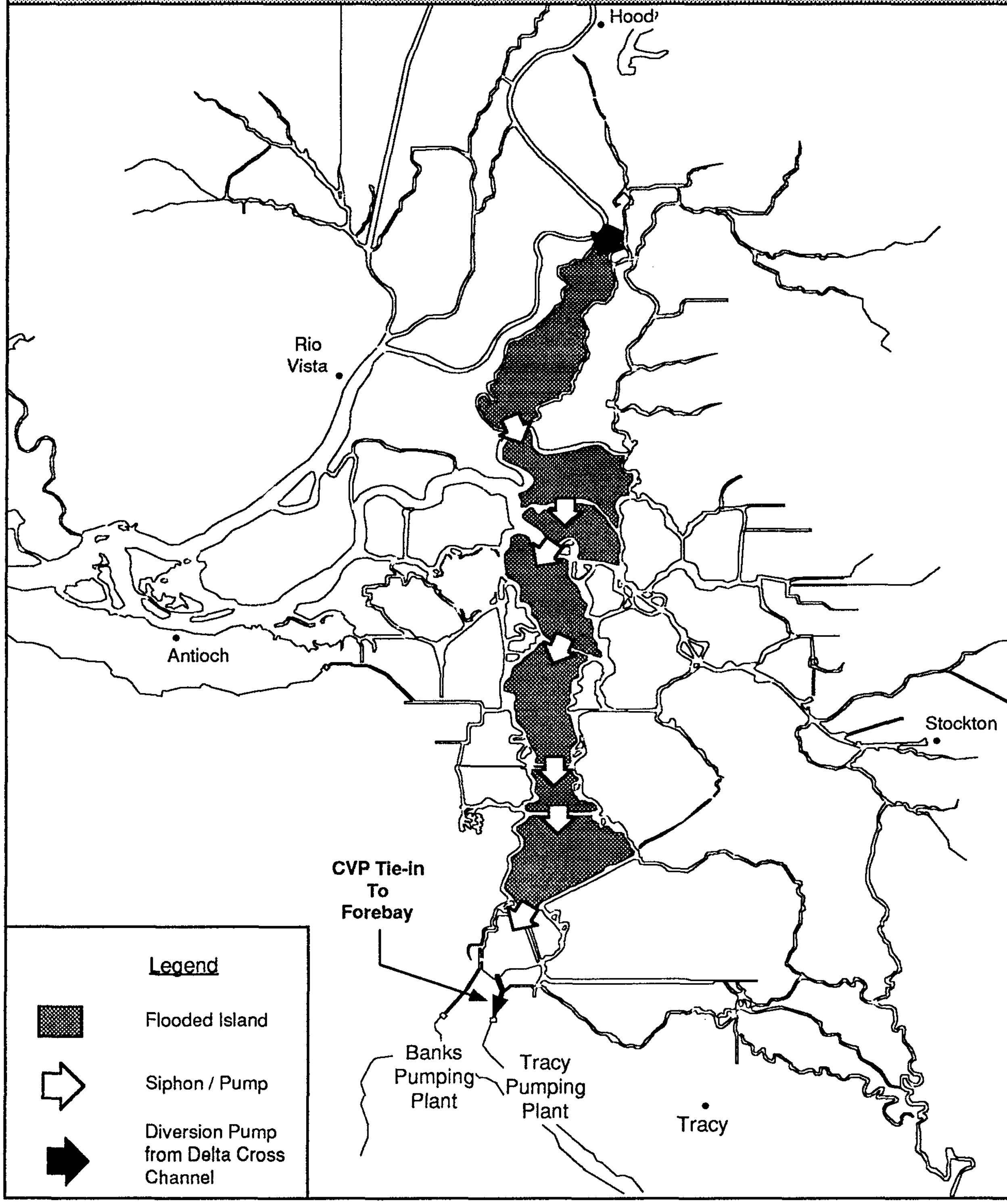
Figure 50

Chain of Lakes Alternative



and possibly over-topping the levees. On the other hand if the number of siphons is over-estimated, the resulting large flow area may give head loss less than the available head; costing unnecessary siphons which could have been otherwise saved by correct estimation.

To arrive at the correct and optimum number of siphons satisfying the allowable head gradient constraint, the hydraulics of the Chain-of-Lakes facility was incorporated into the DWR Delta Simulations Model (DWRDSM). The model was run under two scenarios. The optimum number of siphons was first sought when only siphons were used at each island connection. Then, siphons were used at all connections except at 3 sites where instead 15,000 cfs capacity low lift pumps would be used to inject flow into the same size siphons (18 ft diameter pipes). The island inter-connections with pumps were; Bouldin-Venice Island, Mandeville-Bacon Island and Bacon-Woodward Island. The objective of the second scenario was to find the number of siphons which could replaced at the cost of installing the three pump stations.

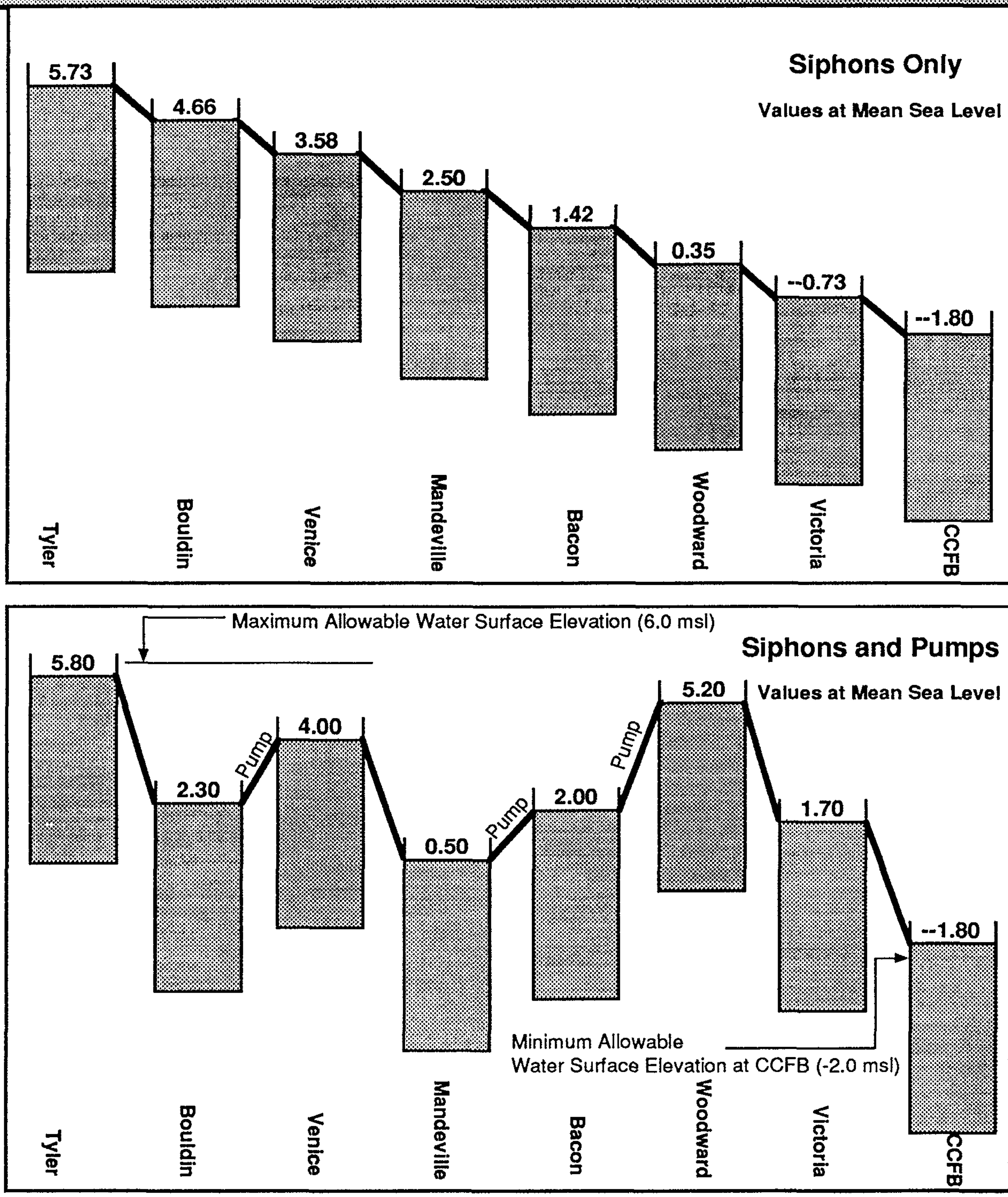
In the first scenario, which used only siphons, the model was run several times with different numbers of siphons until a solution with a minimum number of 9 siphons per island connection, each 18 ft in diameter, delivering 15,000 cfs design flow was achieved. The water levels at each lake, including the Tyler island (+5.73 MSL), was maintained below the prescribed +6 MSL and at CCFB it was -1.80 MSL which is above the cavitation level of -2 MSL. The total number of siphons then required for the entire system having 7 island connections would be 63; (9X7 connections). Any number of siphons per island connection less than 9 would require a rise in water level of Tyler island above the allowable +6 MSL due to larger energy (head) loss caused by reduced flow area. The hydraulic gradient between each lake was about 1.07 ft and velocity through each siphon was about 7.5 fps; less than the allowable maximum 15 fps. The water levels in each lake are shown in Figure 51.

In the second scenario, where pumps were installed at 3 island connections to replace siphons, DWRDSM showed that with the 3 pumps installed at the 3 sites mentioned above, the minimum number of siphons per connection required for siphon flow could be reduced from 9 to 5; still delivering 15,000 cfs gravity flow but requiring steeper hydraulic head gradient of 3.5 ft between lakes. The siphon velocity was 13.5 fps which is still below the allowable 15 fps velocity. Since there are 4 siphon sites, each with 5 siphons required, there would be a total of 20 siphons required for siphon flow. Setting the pipe velocity to the maximum allowable 15 fps at the pump sites resulted in 4 siphons; each a 18 ft diameter pipe/site, to deliver 15,000 cfs of pump flow. With 3 pump station sites, the total number of siphons required for pump flow would be 12 siphons. Then the combined number of siphons for siphon flow and pump flow for the entire system of Chain-of-Lakes would be 32. This is about one half of the number required in first scenario where only siphon gravity flow (no pumps) were assumed throughout the system. The water levels in each lake under the second scenario is also shown in Figure 51.

As shown in Figure 51, the water levels for the first scenario, where only gravity flow through the siphons (no pumps) delivered the design flow throughout the system, the water level continuously declined from Tyler Island to CCFB but remained within the allowable limits of +6 MSL, and -2 MSL at CCFB. With pumps included, however, the water surface profile along the system was falling and rising (Figure 51). The DWRDSM model showed that the water level would fall after leaving the siphons and would rise after leaving the pumps. This can be explained by head loss through the siphons causing the water level to drop in the next downstream island. The head loss, however, is compensated for by the downstream pump

Figure 51

Lake Water Levels
Chain of Lakes Alternative



causing the water level to rise in the next island. The water level fell in Bouldin Island to +2.30 MSL, after leaving Tyler Island through siphons. But it is raised to +4.00 MSL in Venice Island after it is pumped from Bouldin Island. The water level dips again in Mandeville Island to +0.50 MSL after leaving the siphons but rises to +2.00 MSL in Bacon and then to +5.20 MSL in Woodward as it is pumped through these two islands. The water level rises in Woodward to +5.20 MSL which is still below the allowable +6.0 MSL but it is large enough to deliver 15,000 cfs gravity flow through siphons to the next downstream Victoria Island and finally to CCFB at -1.80 MSL; above the required -2.0 MSL. Any number of siphons less than 5 at each siphon site would require raising water levels above the allowable level of +6 MSL in any flooded islands.

Finally, the analysis presented herein considers only the hydraulic factors in determining the optimum number of siphons. To arrive at a more realistic number of siphons, an economic analysis and optimization should be performed which most likely will change the results obtained by the hydraulic analysis. As in second scenario where siphons and pumps are used, less number of siphons per site could be used allowing water level to dip further in the island due to additional head loss. But additional horsepower, in turn, would be needed by the pump to lift the lower water level in the island to the next island downstream. The savings from one less siphon (marginal cost) should be weighed against the additional cost of pumping. The trade-off between marginal costs of a siphon and of the pumping would then be a key element in the determining the optimum number of siphons required for the Chain-of-Lake system with the pump option.