Status Reports on Technical Studies for the Storage and Conveyance Refinement Process Alternatives 1A, 1C, 2B, 2D, 2E, 3E

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March 7, 1997

Introduction

Using DWRDSM1, simulations of six of CALFED's Delta alternatives have been completed. This report describes the results of model studies to date.

First described are the alternatives modeled, Delta hydrology used, and a summary of the operating assumptions used. Delta modeling results are then discussed with respect to four parameters: flows and velocities, circulation patterns, salinity, and water levels in the south Delta. Circulation patterns are presented using average flow directions and mass tracking studies. Salinity is discussed using end of month total dissolved solids and the X2 location.

Attached are Appendices A-E which contain the modeling output used for the analysis and discussion in this report. The DWR Delta Modeling Section staff; Bob Suits, Mohammad Rayej and Sanjaya Seneviratne conducted the model studies and prepared this report.

Delta Modeling Background

Delta conditions for six CALFED alternatives were simulated using DWRDSM1, each over a 16-year period. The 16-year period, 1976 - 1991, came from CALFED's baseline study, DWRSIM 472B. These alternatives, labelled to be consistent with CALFED as 1A, 1C, 2B, 2D, 2E, and 3E, were chosen to provide a good range of possible Delta impacts. They are described in detail in CALFED's report, ***Status Reports on Technical Studies for the Storage and Conveyance Refinement Process,*** March 20, 1997. Minor refinements to some of the alternatives described in CALFED's draft report, ***Phase II Alternative Descriptions*** , May 8, 1997 were also included.

CALFED Alternatives' Delta Geometry

Delta alternatives studied in this report ranged from through-Delta conveyance via existing and modified Delta geometry to an isolated facility. Boundaries for modeling these alternatives are Sacramento River at I Street, San Joaquin River at Vernalis, and Carquinez Strait at Martinez.

Alternative 1A

Alternative 1A assumed the existing Delta geometry with no changes to any Delta channels or structures (**Figure 1**). No temporary structures in the south Delta or fish control structure at the head of Old River were installed.

Alternative 1C

Alternative 1C assumed Delta changes consistent with the preferred alternative for the ***Interim South Delta Program Draft Environmental Statement / Environmental Report*** , July 1996 (**Figure 2**). A new forebay intake structure with 30,000 cfs capacity was installed in the northeast section of the forebay. Old River from Victoria Canal to Woodward Canal was dredged up to 5 feet. Permanent flow control structures were installed in Old River, Middle River and Grant Line Canal. A permanent fish control structure was installed at the head of Old River. The Tracy Pumping Plant was connected to Clifton Court Forebay via an intertie.

Alternative 2B

Alternative 2B included the development of North Delta improvements, a 10,000 cfs screened Hood intake, and south Delta improvements (**Figure 3**). It assumed the same changes in the south Delta as described under Alternative 1C. In addition, up to 10,000 cfs of Sacramento River water was diverted from Hood to Snodgrass Slough while McCormack-Williamson Tract was flooded and channels in the Mokelumne River system were enlarged to accommodate the increased cross-Delta flow.

A 10,000 cfs pumping plant at Hood and a 10,000 cfs open channel from Hood to Lambert Road was assumed. Snodgrass Slough was enlarged by a 1000 foot levee setback in the southwest corner of Glanville Tract. The flow down Snodgrass Slough was then allowed to pass through a flooded McCormack-Williamson Tract at levee openings in the northwest,southwest and northeast corners of the island.

The Mokelumne River was widened 500 feet by levee setback in three reaches: from I-5 to New Hope Landing, the North Fork of the Mokelumne River from New Hope Landing to the south end of Tyler Island, and the lower Mokelumne River on the western portion of Bouldin Island.

Alternative 2D

Alternative 2D included development of a 10,000 cfs screened Hood intake, eastern Mokelumne River floodway, east Delta habitat, and south Delta habitat (**Figure 4**). It assumed the same 10,000 cfs pumping plant at Hood, open channel from Hood to Lambert Road, 1000 foot levee setback along Snodgrass Slough, and flooded McCormack-Williamson Tract as in Alternative 2B. This alternative also changed the hydraulics of the south Fork of the Mokelumne River, flooded Bouldin Island, and significantly enlarged the Old River in the south Delta in lieu of flow control structures.

The Mokelumne River was enlarged in three reaches: a 2000 foot levee setback from southeast corner of McCormack-Williamson Tract to Beaver Slough, a 2000 foot levee setback in the South Fork of the Mokelumne River from Sycamore Slough to South Mokelumne River, and a 4,000 foot levee setback on Staten Island for the South Fork of the Mokelumne River. Canal Ranch Tract and Brack Tract were flooded with water exchanged with the South Fork of the Mokelumne River. Bouldin Island was flooded with openings to the Delta channels at the northeast and southwest corners.

Old River was enlarged from Rock Slough to Victoria Canal by a 3,000 foot levee setback. Clifton Court Forebay again included the new 30,000 cfs intake structure in the northeast corner and a CVP intertie.

The permanent fish control structure was installed at the head of Old River.

Alternative 2E.

Alternative 2E included development of Tyler Island Habitat, western Mokelumne River floodway, Dead Horse Island floodway and habitat, east Delta habitat, and south Delta habitat. (**Figure 5**). It assumed a 500 foot levee setback on Georgiana Slough leading to an opening to a flooded Tyler Island. Tyler Island had openings to Georgiana Slough, Snodgrass Slough, and the Mokelumne River on its south end. McCormack-Williamson Tract was flooded with openings to adjacent channels on its northeast corner and along Dead Horse Cut. Dead Horse Island was flooded with openings to adjacent channels along Dead Horse Cut and Snodgrass Slough.

Bouldin Island was flooded with openings to adjacent channels at its north and southwest corners. Canal Ranch Tract and Brack Tract were flooded with openings on the South Fork of the Mokelumne River and Beaver, Hog, and Sycamore sloughs.

In the south Delta, Delta changes were identical to those in Alternative 2D with a 3,000 foot levee setback on Old River from Rock Slough to Victoria Canal, a new north Clifton CourtForebay intake structure, a CVP forebay intertie to the forebay, and a fish control structure at the head of Old River.

Alternative 3E

Alternative 3E included a 15,000 cfs open channel isolated facility and CVP-SWP improvements (**Figure 6**). It assumed a Hood diversion for a 15,000 cfs open channel isolated facility which was placed to the east side of the Delta and joined Clifton Court Forebay just south of Victoria Canal.

A new north Clifton Court Forebay intake structure was also assumed, as was a CVP intertie with the forebay and a fish control structure at the head of Old River.

Delta Boundary Conditions

Delta Hydrology

In order to evaluate different alternatives' impacts on Delta flows and salinity, a 16-year sequence of monthly average Delta inflows and exports was simulated for each alternative. This hydrologic sequence, 1976 - 1991, came from DWRSIM study 472B. This study assumed that the SWRCB 1995 Water Quality Control Plan was followed and that south Delta improvements and a permit allowed for up to 10,300 cfs pumping at Banks Pumping Plant. Study 472B assumed 1995 level of development and an year 2020 level of water demands. Important Delta inflows and exports from 472B over the study period are shown in **Figure 7** and numerical values are presented in **Table A-1** of Appendix A. As shown in Figure 7, the period of 1976 - 1991 includes a wide range of Delta inflows and exports. **Table 1** lists these years and their water year classification according to SWRCB's 40-30-30 Sacramento Valley water year hydrologic classification scheme.

Boundary Tide at Martinez

The 19-year mean tide at the downstream boundary of Martinez in the Carquinez Strait was used for all months for all years (**Figure 8**).

Boundary Salinity at Martinez

Daily average salinity at Martinez was generated by DWR's model, SALDIF (version 4). This model predicts the salinity at Martinez give the Net Delta Outflow index. Monthly average Delta outflows were obtained from DWRSIM study 472B to be consistent with the Delta hydrology. The resulting salinity at the Martinez boundary for the 1976 - 1991 period is shown in **Figure 9** and summarized in **Table A-2** of Appendix A.

Salinity of Delta Inflows

The salinity of Sacramento River and Yolo bypass inflows was held constant at 100 ppm TDS. The salinity of the inflows along the eastern Delta was held constant at 85 ppm TDS. The salinity of the San Joaquin River inflow was obtained from DWRSIM study 472B. Thissalinity varies with the flow. Values are shown in Figure 9 and are summarized in Table A-2 of Appendix A.

Delta Channel Depletions

The monthly net Delta channel depletions were obtained from DWRSIM study 472B. The allocation of diversions and return flows to Delta islands and then to DWRDSM1 model nodes was based upon DWR's DICU model (see DWR's report, ***Estimation of Delta Island Diversions and Return Flows*** , February 1995). The salinity of return flows were assumed to vary by month and by region in the Delta. These regions are shown in Figure A-1 and the salinity is summarized in **Table A-3** of Appendix A.

Operating Assumptions

In order to simulate Delta conditions over the 16-year sequence using monthly average Delta inflows and exports and the 19-year mean tide, some assumptions about how important Delta structures would be operated were also made.

Delta Cross Channel

Alternatives 1A and 1C, consistent with DWRSIM study 472B, assumed that the Delta Cross Channel was operated in accordance to SWRCB's 1995 Water Control Plan. The Delta Cross Channel was open for the periods of: October 1 - 30, November 11 - 30, December 17 - 31, January 21 - 31, and June 5 - September 30. However, if the Sacramento River inflow exceeded 25,000 cfs during these periods, the Delta Cross Channel was closed. The results of applying this strategy to the 16-year period is summarized in **Table A-4** of Appendix A.

Alternatives 2B, 2D, 2E, and 3E assumed that the Delta Cross Channel was closed except during July and August (see Table A-4 of Appendix A).

Clifton Court Forebay

The intake gates to Clifton Court Forebay were operated under one of two possible strategies or priorities (**Figure 10**). Priority 3 provides some protection for minimum water levels in the surrounding Delta channels but may limit how much water can be diverted into the forebay. Most of the alternatives assumed CVP tie-in into the forebay for joint pumping, further making Priority 3 operation difficult. The same operation strategy was used for each year, for each alternative and is shown in **Table 2**.

Suisun Marsh Salinity Control Gates

The Suisun Marsh Salinity Control Gates were operated from October through May in Critical, Dry, and Below Normal Years for each alternative (**Table A-5** of Appendix A).

Flow Control and Fish Control Structures

Alternatives 1C and 2B assumed the operation of permanent flow control structures on Old River, Middle River and Grant Line Canal during the irrigation season. All alternatives except 1A operated the fish control structure at the head of Old River in the fall and spring (**Figure 11**). The head of Old River fish control structure was not operated when San Joaquin River inflow exceeds 8,600 cfs. When the San Joaquin River inflow exceeded 25,000 cfs, the flow control structures were not operated. A summary of flow control and fish control structure operations for each alternative is given in **Table A-6** of Appendix A.

The flow control structures in alternatives 1C and 2B operated to varying strategies. The Grant Line Canal flow control structure was operated to allow downstream flow up until 2 hours before the minimum water level would have been reached. This maintained circulation in the south Delta while improving minimum water levels upstream of the structure. An operation of the other two flow control structures to prevent downstream flow was the first goal. However, when San Joaquin River inflows increased above certain levels, the operation of the structures in Old River and Middle River was modified to allow downstream flow like the Grant Line Canal structure. **Figure 12** shows the modified operation of the flow control structures and **Table 3** summarizes the strategy for going to the modified operation.

Hood Pumping Plant Flow

Alternatives 2B and 2D operated a pumping plant on the Sacramento River at Hood to divert water into Snodgrass Slough. The amount of flow into the diversion channel was assumed to match the total amount of export from Banks Pumping Plant and Tracy Pumping Plant.

Alternative 3E operated a pumping plant on the Sacramento River at Hood to provide for flow in a 15,000 cfs isolated facility connected to Clifton Court Forebay. The amount of flow into the isolated facility matched the total amount of export from Banks Pumping Plant and Tracy Plant, less 1,000 cfs in all months except April, May, and June. The additional 1,000 cfs needed for exports came from diversion into the northern forebay intake gates.

The operating parameters described above are summarized in **Figure 13**.

Delta Modeling Results

DWRDSM1 results were analyzed by four categories: flow and velocity, circulation, salinity, and south Delta water levels. Since Delta conditions for each of the six alternatives were evaluated under identical Delta inflows and exports, the impacts on Delta conditions due to Delta geometries and some closely associated operational changes were examined. At this time, the larger challenge of incorporating changes to Delta inflows and exports which could result from the different alternative configurations was not addressed.

Delta Flows and Velocities

Average Flows

Monthly average flows over the 16-year period at key locations for all six alternatives are reported in **Appendix B**. The locations are QWEST, Three Mile Slough, San Joaquin River at Antioch, Old River near Bacon Island, Middle River at Bacon Island, Sacramento River at Rio Vista, Montezuma Slough near Collinsville, Combined Steam boat and Sutter Slough, Head of Old River and Cross Delta Flow.

Monthly cross Delta flow for the six alternatives, averaged over 16 years, are shown in **Figure 14**. Cross Delta flow is defined as the amount of Sacramento River water that makes it's way to the Mokelumne River system via Delta Cross Channel, Georgiana slough and any diversions where applicable. Because the cross Delta flow for Alternative 1A and 1C was nearly the same, south Delta improvements appeared to have little if any bearing on the cross Delta flow. The cross Delta flow for Alternative 2B was only occasionally slightly higher than Alternative 2D, indicating that improvements in the north fork of the Mokelumne River produced the same effect on the cross Delta flow as did the improvements in the south fork. Cross Delta flow in Alternative 2E was the highest due to the efficient conveyance through flooded Tyler Island. Alternative 3E drew most of the SWP and CVP pumping requirements from the Sacramento River through the isolated facility in Alternative 3E. It therefore had the lowest cross delta flow of the alternatives examined, the major contribution to cross delta flow being through Georgiana slough.

Monthly average flow at Rio Vista is shown in **Figure 15**. Except for Alternative 3E, flow at Rio Vista should be inversely proportional to cross Delta flow, when comparing alternatives. In Alternatives 1A and 1C the relatively lower cross Delta flow resulted in relatively higher flow at Rio Vista since more of Sacramento River flow stayed in the channel. Similarly, Alternative 2E yielded the lowest flow at Rio Vista. Alternative 3E yielded Rio Vista flows similar to Alternatives 2B and 2D despite a very low cross Delta flow relative to these alternatives. The flow taken from the hood diversion in Alternatives 2B and 2E, and the flow sent through the isolated facility in Alternative 3E reduced the Sacramento River flow by about the same amount.

QWEST is a function of cross Delta flow and SWP and CVP pumping rates.

Since the pumping rates were the same for each alternative, changes QWEST should follow changes in cross Delta flow. In a similar trend to cross Delta flow, Alternatives 1A and 1C gave the lowest QWEST values (**see Figure 16**). In summer and early fall when net Delta outflow was low,negative QWEST values (reverse flow) were shown by the model. Low cross Delta flows in Alternative 3E seemed to balance with the low demand towards the pumps (pumping requirements provided by isolated facility) resulting in similar QWEST values as Alternatives 2B and 2D.

Flow at Old River and Middle River near Bacon Island is shown in **Figures 17** and **18**. In October, November, late April and May, Alternatives 1C and 2B caused larger flows towards the SWP and CVP pumps than did Alternative 1A. This was due to the installation of the fish control structure. During the rest of the year, alternatives 1A, 1C, and 2B showed similar flows in Middle River, but in Old River, Alternative 1C and 2B the showed a slightly higher flow. This was mainly due to the enlargement of Old River leading up to the pumps. In the months of December, January and February when there were no south Delta structures operating, the Old River flow for Alternatives 1C and 2B were higher than Alternative 1A. The geometry in the south Delta was the same for both Alternatives 2D and 2E. Therefore, the flow in Old and Middle River was similar for these two alternatives.

Flow Splits

Relationships between cross Delta flow and Sacramento flow for each alternative are shown in **Figures 19A and 19B**. Figure 19A shows the period when the Delta Cross Channel was open for the base condition and Figure 19B shows the period when the Delta Cross Channel was close for the base condition (see Appendix A2 - Alternative 1A). The variables x and y in the linear equations denote the Sacramento flow and cross Delta flow respectively. R is the coefficient of correlation. Except for Alternative 3E, the alternatives's relationship between Sacramento flow and Cross Delta flow naturally showed greater Cross Delta flow in Figure 19B than in Figure 19A. Very strong relationships were obtained in both periods between Sacramento flow and cross Delta flow, except for Alternative 3E for the period when the Delta Cross Channel was open in the base condition (R=0.36).

The base condition had the Delta Cross Channel open in most of June, September and October; however, Alternative 3E assumed that the Cross Channel was closed. Therefore, there was a scatter in the data points. Alternatives 2B, 2D and 2E also had the Delta Cross Channel closed on June, September and October. However for these alternatives a coefficient of correlation greater than 0.88 was observed. This was because Delta Cross Channel flow was only a small contribution on the total cross Delta flow for these alternatives (for clarity, the actual data points were not shown in these figures).

A similar analysis can be made for the relationship between Sacramento Flow and Sutter & Steam Boat Slough. In this relationship, the slope of the lines were larger when the Delta Cross Channel was closed (**see Figures 20A and 20B**) since more water was available in the Sacramento River to pass on to Sutter and Steam boat Slough.

Figure 21 shows the relationship between San Joaquin River flow and the head of Old River flow for periods when the fish control structure was not operated. Delta changes for these alternatives did not have much impact on the flow split relationship.

Figures 22A and 22B show the relationship between Middle River and Old River flows near Bacon Island. Except for Alternative 3E where most of the flow to SWP and CVP pumpswas supplied by the isolated facility, the slope of the lines representing the flow relationships are greater when fish control structure was in operation. There was more water available (Old River + Middle River near Bacon Island) a higher percentage of the flow travel down the middle River. A high coefficient of correlation for all alternatives indicated that a strong flow split relationship existed between Old River and Middle River.

Maximum Velocities

For the purpose of this report, a maximum velocity above 3 ft/s was considered high enough to be of note. A frequency analysis was done to determine what percentage of the maximum tidal velocities modeled in Delta channels exceeded 3 ft/s. Figures 23 - 28 show the velocity profiles for the six alternatives. The values adjacent to the channel reach show the percentage of time daily maximum velocity exceeded 3 ft/s. For example the number 10% seen on Figure 23 indicates that out of 272 maximum velocity values available (17 hydrologies x 16 years), 5%-15% (14 - 42 values) registered a peak velocity over 3 ft/s. For all the alternatives, velocities the central Delta and most of the south Delta never exceeded 3 ft/s.

In Alternative 1A, velocities greater than 3 ft/s were modeled in the main stem of the Sacramento River and San Joaquin River. A higher frequency (60%) was shown near Isleton, while upstream and downstream locations showed significantly lower frequencies. The reason for the higher velocities in the vicinity of Isleton was due to a smaller channel area. Three mile slough had the highest occurrence of velocities above 3 ft/s for the areas shown (**see Figure 23**).

Alternative 1C had a similar distribution as Alternative 1A. Near Victoria Island, there was an increase in the occurrence of higher velocities (**see Figure 24**). This was due to a change in direction of flow towards the SWP and CVP pumps when flow control structures were in operation.

Because the operation of structures in the south Delta for Alternative 2B was the same as Alternative 1C, there were no changes in the frequency plots in the south Delta. However, the velocities in the Sacramento River dropped because of the Hood diversions. This was reflected by a lower frequency of high velocities near Isleton (see Figure 25).

The frequency plot for Alternative 2D is nearly identical to Alternative 2B, except near Victoria island. Due to levee setbacks in Alternative 2D the velocities near Victoria island decreased (see Figure 26).

In Alternative 2E, higher cross Delta flows reduced flow in the Sacramento River. Therefore lower velocities were noted near Ryde (see Figure 27). However an increase in the frequency of velocity over 3 fps was noticed near Isleton.

Alternative 3E yielded a similar frequency distribution as Alternative 2B and 2D. Although there were no levee set backs near Victoria Island, the velocities were low due to lower SWP and CVP diversions from the south Delta (see Figure 28).

Delta Circulation

Flow circulation in Delta channels under CALFED alternatives 1A, 1C, B, 2D, 2E and 3E are shown in Appendix C in figures C-1 through C-48. (C-1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48). Alternative 1A is considered the base in this analysis for comparison with the other alternatives. These figures show the circulation results modeled by DWRDSM1 for four distinct months selected from the 16 water-year study period (1976-1991). The months were selected based on combinations of high and low events of inflows and exports. Combinations and the corresponding months are: high inflow-high export (February 1979), high inflow-low export (April 1981), low inflow-high export (October 1990) and low inflow-low export (July 1991).

Delta Flows

High inflow - high export . Under high inflow-high export conditions, alternative 1C with south Delta improvements of 5 feet dredging along Old River did not have a significant impact on Delta-wide flow circulations when compared to alternative 1A. The greatest impact was in Old River near Palm Tract, where tidal average flow toward the export pumps was increased by 160 cfs (about 10%) over the base conditions (Figure C-5). For alternative 2B, with added improvements of north Delta channels and a Hood diversion (about 9,800 cfs), the impact on flow circulation was more extensive (Figure C-9). This was especially true in the north Delta near the North Fork of the Mokelumne River where average flow toward San Joaquin River was increased by about 8,000 cfs.

A large portion of this increase in flow (about 7,000 cfs) passed down the San Joaquin River toward Jersey Point, resulting in an increased QWEST. The remaining flow increase was drawn toward the export pumps via Old and Middle rivers. The dramatic decline in flow near Rio Vista from 37,000 cfs to about 21,000 cfs was partly due to the Sacramento River flow diversion at Hood. Alternative 2D, with channel enlargements along the south fork of the Mokelumne River and the flooding of few adjacent islands, increased the flow conveyance locally in the South Fork (**Figure C-13**).

Similar to alternative 2B, this alternative greatly improved QWEST and it increased the flow somewhat toward the export pumps. Alternative 2E, which diverted Sacramento River flow into a flooded Tyler Island, resulted in larger increases of flow into San Joaquin River toward Jersey Point and some toward the export pumps via Old River (**Figure C-17**). Alternative 3E with an isolated facility of 15,000 cfs capacity along the eastern edge of the Delta, caused a dramatic effect on the direction of tidal average flow away from the export pumps in Old and Middle rivers (**Figure C-21**).

Medium inflow - low export . Under medium inflow-low export conditions, alternative 1C had only small local impact on flow circulation in south Delta channels (**Figure C-6**). Average tidal flow in lower Old and Middle rivers were slightly increased when compared to the base (alternative 1A). Under this hydrologic condition, flow in downstream San Joaquin River increased because of the Head of Old River fish control structure operation when compared to the base where there was no control structure. This approximately doubled the flow through Turner Cut and almost tripled the flow through Columbia Cut. The combined effect on flow toward the export pumps via Old and Middle rivers was an increase of about 2,300 cfs.Alternative 2B with north Delta improvements and the Hood diversion increased the flow in the north fork of the Mokelumne. Almost all of the Hood diversion flow showed up in the North Fork; 5,000 cfs out of 5,500 cfs total diversion, the remaining portion flowed down the South Fork. A large portion of the increase in the North Fork flow (about 3,500 cfs) entered the San Joaquin River junction toward Jersey Point and the remaining 1,500 cfs was drawn toward the export pumps via Old River. Alternative 2D, with South Fork Mokelumne improvements and few adjacent island flooding, had similar impacts on flow circulations (**Figure C-14**).

Alternative 2E, assumed similar North Delta islands flooding as in alternative 2D, with an additional Tyler Island inundation. When compared to alternative 2D, it had a similar impact on flows in the south Delta region but showed more impact on westward flow with less flow past Rio Vista and more flow toward Jersey Point. With alternative 3E providing the bulk of export flow through the Isolated Facility, the South Delta region flow pattern significantly changed. In the main channels leading to export pumps, the flow reversed the direction away from the pumps (**Figure C-22**). In the west

Delta, the flow past Rio Vista decreased, but the flow in the San Joaquin River toward Jersey Point increased because there was less export demand on the San Joaquin River via lower Old and Middle rivers.

Low inflow - high export . Under low inflow-high export conditions, a reverse flow of about 1,370 cfs was modeled in the San Joaquin River at Antioch under the base Delta configuration (Alternative 1A). In fact, the reverse average tidal flow conditions persisted all the way to Stockton and further upstream to Mossdale and to the Head of Old River (**Figure C-3**). With high SWP and CVP combined pumping (relative to inflows) of about 8,900 cfs, the flow pattern in major channels; lower Old and Middle rivers, Columbia and Turner cuts were all directed toward the pumps. Almost all of the Vernalis flow (about 1,300 cfs) was drawn towards the pumps via the Head of Old River. Alternative 1C, with Old River enlargements and SWP and CVP improvements as well as flow and fish control structures in place, had a positive impact on flow circulation in South Delta. Flow in lower Old and Middle rivers towards the pumps increased because of Old River channel dredging. The fish control structure at the Head of Old River blocked the San Joaquin River flow from entering the Old River toward export pumps; although some of that water subsequently found its way towards the pumps via Turner Cut.

The flow control structures in Middle River and Old River (near Tracy) also helped water circulation upstream of the structures and helped flush the Grant Line canal in the absence of San Joaquin River flow source (**Figure C-7**). Alternative 2B, with South Fork Mokelumne channel enlargements and a Hood diversion, had almost the same magnitude of impact on South Delta water circulation as did Alternative 1C. But in the west Delta, it had a more dramatic impact by eliminating the reverse flow completely in San Joaquin River at Antioch, resulting in average seaward flow (**Figure C-11**). Alternative 2D with South Fork of the Mokelumne enlargements and adjacent islands flooding also caused more flow into San Joaquin River towards Jersey Point, eliminating reverse flow at Antioch. Also, the 3,000 ft levee setback feature along Old River caused more flow from San Joaquin River via lower Old River toward the export pumps (**Figure C-15**). Similar to alternative 2D, the alternative 2E with Tyler Island flooding showed similar results but with less flow circulation impacts on west Delta reverse flow (**Figure C-19**). Alternative 3E, providing the entire export flow via the Isolated Facility reduced the flow in Old and Middle rivers toward export pumps drastically. With the isolated facility providing the bulk of export flow requirements, the demand on San Joaquin River flow toward pumps via lower Old and Middle rivers diminished giving the San Joaquin River an opportunityto continue flowing towards Jersey Point and past Antioch, eliminating the (alternative 1A) reverse flows in the lower San Joaquin River (**Figure C-23**).

Low inflow - low export . Under the low inflow (about 10,000 cfs) and low export (about 2,200 cfs) hydrologic condition, alternative 1C with South Delta flow control structures and 5 ft dredging along Old River had only local impact on flow circulation. This was mainly along Old and Middle rivers as flows increased towards pumps (**Figure C-8)**. Alternative 2B, like alternative 1C, had similar impact on flow circulation in the south Delta, but it had more impact on Antioch flow. This was because increased flow in the North Fork of the Mokelumne due to channel enlargements, increased the San Joaquin River flow past Jersey Point and Antioch (**Figure C-12**). Alternative 2D with South Fork Mokelumne enlargements had slightly more impact, compared to Alternative 2B, on Antioch flow. Shifting channel enlargements from the North to the South Fork delivered more flow toward the San Joaquin River via Bouldin Island. Some of the improved flow moved toward the pumps from the Old and Middle rivers and the rest continued toward Jersey Points and Antioch (**Figure C-16**). Alternative 2E, with island flooding as in alternative 2D and diverting Sacramento River into a flooded Tyler Island, increased San Joaquin flow even more compared to Alternative 2D. Most of the increase in flow went toward Jersey Point and Antioch and none toward the pumps when compared to Alternative 2D (**Figure C-20**). Compared to the base condition, this alternative reduced Rio Vista flow (from 3,200 to 1,200 cfs), increased Antioch flow drastically (from 900 to 2500 cfs), and slightly changed flow towards the export pumps. Alternative 3E, with an east Delta isolated facility, provided almost 1,200 cfs of the export requirement of 2,200 cfs (the remaining 1,000 cfs export provided by South Delta). This reduced Rio Vista flow by 600 cfs, increased Antioch flow nearly the same amount, and reduced the Old and Middle rivers flow towards the export pumps by almost the same amount of export flow delivered by isolated facility (**Figure C-24**).

Mass Tracking by Regions

Mass was injected in 11 regions as shown in **Figure C-50** of **Appendix C** and tracked for 60 days under CALFED alternatives 1A, 1C, 2B, 2D, 2E and 3E using DWRDSM1. Within each region, mass was injected simultaneously at a few sites to track the percent of combined mass remaining in the region with time. This process gives an indication of the residence time of fish egg or larvae as affected by these alternatives. These mass tracking results for the different CALFED alternatives under different hydrologic conditions can be found in Appendix C. For the purpose of this discussion, three injection regions and two hydrologic conditions were selected. These were regions 3, 9, and 11 with the hydrologic conditions of low inflow with low export (July of water year 1991) and low inflow with high export (October of water year 1990).

Mass injected in region 3 of the existing Delta configuration (alternative 1A) rapidly disappeared in about 10 days under the low inflow-low export (July 1991) conditions as shown in **Figure 29**. All other alternatives reached the same level of mass in region 3 except alternative 2D where mass disappeared in about five days. This was probably because of flow circulation changes in South Fork of the Mokelumne River causing the injected mass of that region to disappear more rapidly. Under low inflow-high export (October of water year 1990) conditions, there was a drastic change in mass behavior with alternatives 2E and 3E. With other alternatives, mass disappeared five days after injection, while alternatives 2E and 3E kept the mass in the region for a longer time. With alternative 3E, there was still about 30 percent mass left in theregion 30 days after the injection (**Figure 30**). This was probably because alternative 3E diverting most of export flow directly from the Delta at Hood, there by diminishing flow circulation in region 3.

For all alternatives, mass injected in region 9 stayed longer in that region when compared with region 3 injection under low inflow-low export conditions (**Figure 31**). Under this condition, alternatives 2D and 3E did not have significant impact on region 9 mass compared to the base (alternative 1A). Alternative 2B with North Fork Mokelumne enlargements, had greater movement of mass out of region 9. Under low inflow-high export (October of water year 1990) conditions, these alternatives showed much greater impacts (**Figure 32**). Alternative 3E significantly increased the residence time of the mass injected in this region. Sixty days after injection, there was still 18 percent mass left in this region under Alternative 3E. Other alternatives, shortened the residence time with only about 10 percent of the mass remaining in the region after 30 days and almost all the mass gone after 60 days.

Under the low inflow-low export condition, mass injected in region 11 quickly disappeared (about five days after injection) with alternatives 2D, 2E, and 3E. This was similar to alternative 1A (**Figure 33**). With alternatives 1C and 2B, mass stayed until 20 days after injection. For the condition of higher export of October of water year 1990, residence time for all alternatives drastically increased over the base condition (**Figure 34**). After 30 days, 30 percent to 50 percent of the mass remained, and by day 60 about 10 percent to 15 percent mass was still in the region.

Mass Tracking by Discrete Injection Points

Mass was also introduced at discrete locations in the Delta to determine its fate under different CALFED alternatives. Mass was injected at Vernalis, Terminous, Freeport, Rio Vista, Jersey Point, San Andreas Landing, Prisoners Point, and Benicia (**see Figure C-49**). The results for all injection sites are in the **Appendix C**. For the purpose of this discussion three injection sites were examined: Vernalis, Prisoners Point, and Freeport.

Figure 35 shows the mass fate 30 days after injection at Freeport along Sacramento River under low inflow-low export (July 1991) hydrologic conditions for the different CALFED alternatives. Alternative 2E had the greatest impact of keeping the mass within the Delta channels and open water areas when compared to alternative 1A; about 84 percent compared to 59 percent in alternative 1A. This was probably due to flooding of about five islands in the north Delta and added opportunity of keeping the mass in those islands. Alternative 3E with isolated diversion to the export pumps had the greatest percent mass lost to export pumps. About 24 percent mass was lost to the export from the isolated facility feature in alternative 3E compared to 4 percent in the base condition. This alternative had the least amount of mass remaining in the Delta (about 49%) because of large portion of flow and mass diverted to the pumps at the downstream of injection site. Alternatives 2B and 2D both had more impact on mass past Chipps Island compared to other alternatives. This was probably because of North and South Fork of Mokelumne River enlargements which enhanced flow circulation toward San Joaquin River. Low July export amounts helped more flow toward Chipps than toward the pumps sending more mass toward the ocean. Under low inflow-high export (October of water year 1990) hydrologic condition, more mass stayed in the Delta (about 68 percent) with alternatives 2B and 2D (**Figure 36**). Alternative 3E still had the greatest percent mass (about 63 percent) routed toward exportpumps compared to other alternatives. It seems that under this high export condition, all alternatives sent less mass toward Chipps Island when compared to alternative 1A.

When mass was injected at Prisoners Point along the San Joaquin River in the central Delta, under low inflow-high export (July 1991) conditions, alternative 3E caused more mass to stay in the Delta (about 72 percent) compared to the other alternatives and to the alternative 1A (44 percent) (**Figure 37**). Alternative 2B with North Fork Mokelumne enlargements caused more mass to move toward the export pumps. None of the alternatives significantly changed the routing of mass toward Chipps Island. Under low inflow-high export condition (October of water year 1990), Alternative 3E kept 91 percent of mass injected within the Delta, compared to 3% under alternative 1A (**Figure 38**). Except for Alternative 3E, all of the alternatives lost about 90% of mass to the export pump. This shows that alternatives impact on mass fate, is highly dependent on where mass is injected.

When mass was injected in Vernalis, alternatives 1C and 2B kept the mass in the Delta better than did other alternatives under low inflow-low export (July 1991) conditions (**Figure 39**). Under this condition, the majority of the mass (about 60 percent to 70 percent) was lost to the islands through irrigation pumps with all alternatives. None of the alternatives had a major impact on changing the percent of the mass that ended up in the islands. Almost all of the alternatives helped reduce mass loss to the export pumps when compared to alternative 1A. Under high export (October water year 1990) condition, the majority of mass (80%) was lost to the export pumps with all alternatives except alternative 3E which kept 78% of mass within the Delta (**Figure 40**).

Delta Salinity

End of Month Salinity

End of the month total dissolved solids (salinity) in mg/l simulated by the DWRDSM1 under different CALFED alternatives at key locations in Delta are shown Figures 41-48. **Figure 41** shows salinity at the end of each month averaged over the 16 water-year study period (1976-1991) at Jersey Point. Alternative 1C with South Delta improvements did not impact the salinity at Jersey Point very much when compared with alternative 1A. Other alternatives 2B, 2D, 2E, and 3E had reduced salinity particularly during the first and the last quarter of the water year when water was less abundant, because these alternatives improved the cross-Delta flow into San Joaquin river system toward Jersey Point. During the middle part of the year when more water was available in the Delta, the alternatives made little difference on salinity at Jersey Point. The same alternatives (2B, 2D, 2E, and 3E) which improved Jersey Point salinity, worsened Emmaton salinity as shown in **Figure 42**. This was expected because there was less fresh Sacramento River water availabe at Emmaton because of diversion to Jersey Point via cross Delta flow under these alternatives. During wet seasons all alternatives made little difference on Emmaton salinity when compared to alternative 1A.

Salinity at Rock Slough was improved with alternatives 2B, 2D, and 2E during the first and last quarter when water was less abundant (**Figure 43**). Salinity improvements with alternatives 1C and 3E were not as great when compared with alternative 1A salinity during the same period. Alternative 3E worsened the salinity during the middle period of the water yearwhen there was more water available. This was probably because of large diversion of fresh Sacramento flow to Isolated Facility in alternative 3E during the wet season.

Salinity at Clifton Court forebay was greatly improved during less abundant water season under all alternatives except alternative 1C (**Figure 44**). During the middle portion of the year (March, April, May and June), all alternatives, except 3E, had adverse impact on the Forebay salinity. This implies that alternative 3E with isolated facility consistently improved the Forebay water quality year around. This was because alternative 3E delivers the fresh Sacramento water directly to the Forebay bypassing the Delta.

Antioch salinity showed a similar trend as in Jersey Point (**Figure 45**). All alternatives, except 1C, improved Antioch salinity during the first and last quarter of the water year when less water was available. This was probably due to the higher QWEST resulted under these alternatives. During the wet season the alternatives had little impact on water quality compared to alternative 1a.

Impacts on Collinsville salinity followed the same trend as in Emmaton (**Figure 46**), but to a lesser degree. Alternatives 2B and 3E increased the salinity at Collinsville slightly more than the other alternatives when compared to alternative 1A salinity. During the wet season, the impact was similar with each alternative when comparing to alternative 1A.

Salinity at Old River near Middle River and Old River near Tracy was not impacted by the alternatives (**Figures** **47** and **48**) except for October, November, April and May when alternatives 2D, 2E, and 3E showed more impacts. It seemed that alternatives 2D, 2E, and 3E had adverse impact on salinity of Old River near Middle River and near Tracy during October. In November, salinity improved at Old River near Middle River but worsened near Tracy under the same alternatives.

End of the month salinity for24 locations are shown in **Appendix D**.

X2 Location

Tidal day averaged location of 2,000 ppm salinity (an indicator of x2) for all alternatives is shown in **Figure 49**. Generally, alternatives changed the position of 2,000 ppm only slightly. Besides alternative 1C which did not impact x2, the other alternatives 2B, 2D, 2E, and 3E had slightly more impact on x2 in landward direction during the first and the last quarter of the water year. During the wet season, however, x2 moved slightly in seaward direction. Although the Delta outflow, a major factor in determining the position of x2, was constant during the study (same hydrology used for each alternative), various local effects of different alternatives may have caused the slight change in x2 location. Maximum, minimum and average locations where 2,000 ppm salinity occured for each alternative are reported in Tables **E 73 - E78**.

South Delta Water Levels

Water levels in key locations in the south Delta during the irrigation season (April - September) are tabulated in **Appendix E**. Changes in water levels because of the different alternatives are discussed below.

Figure 50, 51, and 52 show the water levels for all six alternatives both upstream and downstream of the Middle River, Old River and Grant Line Canal flow control structures sites. Flow control structures were used only in alternatives 1C and 2B. Improved minimum water levels immediately upstream of the flow control structure sites in alternatives 1C and 2B were caused by these structures. Other Delta changes in Alternatives 2D, 2E, and 3E could be attributed to the improved water levels for these alternatives.

Except for some months in 1983, the Middle River flow control structure operated from April through September (see Appendix A6). As shown in

Figure 50, water levels upstream of the structure in alternatives 1C and 2B was more than 18 inches higher than downstream of the structure. Water levels for alternatives 2B, 2D, 2E, and 3E downstream of the sites were higher than alternatives 1A and 1C. This shows that even without flow control structures, water levels would rise in alternatives 2B, 2D, 2E, and 3E.

The flow control structure in the Old River was operated at the same time as the Middle River structure. Improvements in water levels between 12 inches - 20 inches were observed in alternatives 1C and 2B because the flow control structure (**see Figure 51**). Alternatives 2D and 2E increased the water levels by more than 6 inches over alternative 1A.

The Grant Line Canal flow control structure was operating from June through September. A substantial increase in water levels were shown in alternatives 1C and 2B (**see Figure 52**). An increase in water levels were observed for alternatives 2D, 2E and 3E even without the flow control structure. In the latter part of April, and May, when the fish control structure is in operation, all alternatives had similar water levels. In the first part of April when only Old and Middle River flow control structures are in operation, alternatives 1C, 2B, 2D, 2E, and 3E showed similar increases in water level over alternative 1A.

Water levels in the Old River at Middle River were similar to upstream of Grant Line Canal flow control structure. Between June and September, when the Grant Line Canal structure is in operation, water levels in alternative 1C and 2B are substantially higher than alternative 1A (**see Figure 53**). During this time alternatives 2B, 2D, 2E, and 3E had increases in water level over alternative 1A. The water levels in alternatives 1C, 2B, 2D, 2E, and 3E were lower than Alternative 1A in the latter part of April and May because fish control structure was in operation. However at Tracy, the other alternatives caused a higher water level than alternative 1A because of the Old River flow control structure.

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Last modified: September 30, 2002 .

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