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Simulation of Environmental Water Account Actions to Reduce Entrainment Losses from South Delta Exports During CALFED Stage 1

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This is a short description of the challenges to finding a way to provide both improved fish protection and increased water supply reliability using the existing Delta facilities during CALFED Stage 1. The water supply target of 5 to 6 MAF requires that the Delta export pumping plants be operated for the majority of the time. However, efforts to further reduce fish entrainment effects would restrict the number of days with high export pumping.

Entrainment losses occur when a vulnerable life stage of a fish species of interest is directly entrained at the pumping facilities or indirectly drawn towards the vicinity of the pumping facilities. The daily entrainment loss is assumed proportional to the density of fish in the south Delta water and the volume of water diverted. The existing fish salvage facilities were designed to effectively screen some of the larger fish life stages (i.e chinook and striped bass). These fish screening facilities may not be as effective for smaller fish (i.e. Delta smelt). The density of fish in the south Delta is governed by natural spawning and migration events, but may also be influenced by the hydrodynamic transport and mixing conditions that are controlled by the Delta inflow and south Delta pumping patterns. Changes in Delta inflow or south Delta pumping patterns may change the distribution of vulnerable fish within the Delta channels. Many of the existing Delta operations objectives (i.e. WQCP objectives such as the export/inflow ratio and X2 requirements) attempt to govern basic Delta hydrodynamic conditions that are thought to influence entrainment losses. The distribution and abundance of each fish population is influenced by the hydrodynamic conditions within the Delta, but is also a function of habitat conditions important to the various life stages of each fish. Therefore, in addition to operating the existing fish salvage facilities and complying with current Delta flow and salinity objectives, the entrainment of fish in the Delta may be reduced with the following basic entrainment management "tools":

- Sacramento River inflow can be increased to control conditions along the migratory pathway for fish entering the Delta from the Sacramento River corridor, and to regulate Delta outflow and other hydrodynamic conditions.
- The Delta Cross Channel (DCC) gates can be closed to reduce the diversion of fish

into the central Delta. The DCC directly influences hydrodynamic conditions in the central Delta (i.e. QWEST).

- San Joaquin River inflow can be increased to control conditions along the migratory pathway for fish entering the Delta from the San Joaquin River corridor, and to regulate central Delta hydrodynamic conditions.

- The temporary Head of Old River (HOR) barrier can be closed to reduce the diversion of fish into the south Delta channels. The HOR barrier directly influences hydrodynamic conditions in the south Delta (i.e. reverse net flow from the central Delta).

- Delta export pumping can be reduced to protect vulnerable life stages of fish species of interest during periods when high densities of these fish are observed in the south Delta or in central Delta habitat.

The entrainment management "tools" could be implemented in combination to increase Delta outflow or change other hydrodynamic conditions within the Delta and represent the only actions currently available for managing (i.e. reducing) entrainment at the beginning of CALFED stage 1.

Additional Tools for Reducing Entrainment

Additional entrainment management "tools" may be implemented but will require the construction of new facilities or habitat restoration activities, and would not be available immediately. The additional tools include:

- The temporary rock barrier at the head of Old River should be replaced with an operable tidal gate, similar to the Suisun Marsh salinity control structure in Montezuma Slough. This would give hydraulic control of the fraction of San Joaquin River water that is diverted into Old River. Opening the gate on flood tide could allow fish that may be migrating or trapped in south Delta channels to escape into the San Joaquin River.

- The fish screening facilities can be replaced with new facilities which will be more effective at diverting water without diverting vulnerable life stages of fish, allowing more of the fish to remain in south Delta channels or to be more successfully "salvaged" and moved to another Delta location that is more isolated from the pumping effects. Improved fish screening facilities are assumed by ERPP, and would be constructed during Stage 1.

- New screens can be installed on large agricultural diversions within the Delta or improved screens can be installed on the cooling water intakes for the Delta power plants.

- A new screened diversion channel at Hood (or screen facilities at DCC and Georgiana Slough) would allow diversion of the water from the Sacramento River into the central Delta without also diverting vulnerable fish life stages (i.e. juvenile chinook). The screened facilities would allow greater hydrodynamic control than is presently available with DCC closure. The DCC gates should be automated to allow more flexible tidal operations for fish protection, water quality control, and recreation (boat passage) uses.

- New and restored habitat throughout the Delta may increase fish populations and shift the distributions of vulnerable life stages. This will reduce the net effect of entrainment losses on fish populations. The habitat restoration effort is expected to follow the targets and priorities described by ERPP but will require longer than the seven years of CALFED Stage 1.

Water Supply Targets and Delta Export Constraints

The water supply targets (i.e. 1995 level of demands used by DWRSIM) require at least 6 million acre feet (MAF) of Delta exports. The demand follows a seasonal pattern with the majority of water needed in the summer months for agricultural purposes. The San Luis Reservoir capacity of 2 MAF, with an assumed carryover storage of 500 TAF, allows some (i.e. 1,500 TAF) of the water supply to be pumped in the winter period and stored until needed in the summer. Demands for the October-March period total about 1.8 MAF, so the exports during these months cannot be more than about 3.3 MAF (with existing storage and demand patterns). The remaining exports (2.7 MAF) must occur during the April-September period of high demands.

The currently permitted maximum combined CVP and SWP pumping rate is about 10,000 cfs, which allows a maximum of about 20 TAF of exports per day. The 6 MAF water supply target would require about 300 days of maximum permitted pumping. If full pumping capacity at SWP is allowed (i.e. about 15,000 cfs combined capacity), then a maximum of about 30 TAF can be exported per day, and about 200 days of maximum capacity pumping could supply the 6 MAF water supply target.

To maintain water supply reliability, pumping restrictions to reduce fish entrainment losses must be limited to less than 65 days at the permitted capacity (i.e. about 1.3 MAF of unused permitted capacity). The number of days with pumping restrictions to reduce entrainment could be increased if the permitted capacity was raised to equal the existing physical capacity. To fill San Luis reservoir by the end of March from an initial volume of 500 TAF and to meet the 1.8 MAF of demands would require 165 days of maximum permitted pumping, leaving less than 20 days of suspended pumping during this period. To meet the demands in the second half or the year would require 135 days of maximum pumping, leaving a maximum of about 45 days of suspended pumping for fish protection.

Maximum pumping is only allowed when Delta inflows are relatively high (i.e. to satisfy Delta outflow and E/I ratios). For example, during the winter and spring when the E/I ratio is 0.35, the inflow necessary to allow exports of 10,000 cfs would be about 28,500 cfs. During the summer and fall, with an E/I ratio of 0.65, a required outflow of 5,000 cfs, and a channel depletion of 4,000 cfs, the necessary inflow to allow 10,000 cfs of pumping would be about 19,500 cfs. Because these necessary inflows for full pumping are not available during all years, some fish protection is already obtained because of the water supply limitations on pumping. However, the water supply limits reduce the ability to further restrict pumping for fish protection. In dry years there are very limited opportunities to further restrict pumping without causing a water supply reduction.

The basic challenge for entrainment reduction during CALFED Stage 1 is to adaptively manage the south Delta pumping to provide the greatest possible pumping in periods with low risk of entrainment and reduce pumping only when entrainment risk is higher. The DNCT team has developed several different scenarios for accomplishing this task. One necessary component will be fish distribution monitoring (i.e. real-time monitoring) that will alert the operators to the presence of high fish densities. The second component is an Environmental Water Account (EWA) that is proposed to provide an environmental water supply and allow direct control over pumping restrictions to reduce entrainment. The goal of the EWA is to provide a water supply bank to increase export pumping flexibility.

Potential Methods to Control Delta Export Pumping

Five potential controls or limits on south Delta export pumping include:

- The physical size of the pumps (i.e. 15,000 cfs) , the Corps of Engineers permitted capacity (i.e. 11,280 + 1/3 SJR flow), or the estimated interim hydraulic Clifton Court tidal gate capacity (i.e. about 8,500 cfs).

- Requirements for Delta outflow, including the fixed monthly outflow objectives, X2 requirements in February-June, and salinity control for agricultural and M&I diversions (i.e. 250 mg/l chloride). A minimum outflow of about 4,000 cfs is required to maintain export salinity at 250 mg/l chloride. A minimum outflow of 5,000 cfs will reduce the export chloride to about 150 mg/l, providing a substantial water quality benefit.

- The export/inflow ratio or the allowable export/SJR inflow ratio that is specified during the SJR pulse flow period in the delta smelt biological opinion or the VAMP agreement.

- QWEST flow targets and DCC closure for fish protection. A screened Hood diversion would allow increased exports if QWEST targets were specified.

- Fish salvage density triggers, or real time monitoring at Mossdale and Franks Tract that might provide early warning of high fish density. A combination of all available information about fish population size and distributions within the Delta would be used to govern the need for additional pumping restrictions.

The relative magnitude of the these export limits changes with fluctuations in Delta inflows and with observed fish distribution and density patterns. The effect of imposing new export restrictions or allowing relaxations in existing export limits can be visualized by plotting each of the applicable export pumping limits on a single plot and estimating the changes in pumping that would occur if new restrictions were imposed or if one of the existing restrictions was relaxed. This is the basis of the daily simulation or "gaming" of potential EWA changes in Delta exports and upstream reservoir releases that has been used to evaluate the potential benefits of an EWA.

Environmental Water Account

The EWA would be a combination of real water, available storage and/or conveyance capacity, and necessary funding and agreements to allow increased pumping during periods of low fish entrainment risk and reduced pumping during periods of high fish entrainment risk. The EWA is assumed to be a method for providing additional fish protection by allowing exports to be shifted to periods that have lower environmental effects, without reducing net water supply exports. The EWA might be used to actually increase water supply slightly, if some of the relatively fixed Delta export restrictions were found to be overly protective and could be relaxed during some periods.

The EWA would provide an accounting method to allow the shifting of exports from one period to another, without causing any net reduction in water supply. The EWA would put definitive boundaries on the amount of water that can be used for entrainment reduction, and would provide assurances for the payback of any shortages that these reductions may cause. The EWA has the following advantages compared with the no action alternative (i.e. no further entrainment reduction measures) or compared with the likely alternative of imposing additional export restrictions using prescriptive (i.e. fixed) standards:

- EWA will provide the ability to increase and decrease exports consistent with fish protection goals (i.e., flexibility) and without the constraints of fixed monthly rules.

- The EWA will allow more efficient use of water for environmental protection because only the water necessary for protection will be used, and the EWA manager will look for periods of increased exports to replenish the EWA. The existing monthly Delta objectives (i.e., WQCP) provide a good starting point for EWA adjustments to increase protection.

- The EWA requires accounting of water supply benefits achieved by relaxing the existing fixed standards (i.e. AFRP minimum flows, E/I ratio, or X2 requirements) and the water supply impacts caused by increased reservoir releases or reduced exports for fisheries protection. The value of California water is properly considered because the water supply effects must be balanced with replacement water or purchased water transfers.

Perhaps the most important remaining task for creating and operating a successful EWA will be development of the biological decision-making framework for EWA actions and performance measures for evaluating EWA fish protection actions.

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Daily EWA Simulation Model Features

A combination of DWRSIM monthly planning model results and a daily simulation model of the Delta flows and exports was used for the EWA gaming simulations. The DWRSIM results were used to approximate the baselin conditions that might include different facilities or operating contraints. The daily model was then used to show the daily patterns of Delta flows and the effects of various Delta objectives on required Delta outflow and allowable export pumping. The daily model included the historic CVP and SWP salvage density data, which were used to guide the EWA adjustments in a month-by-month gaming exercise. The major features of the daily simulation model are briefly described below.

An existing spreadsheet model (DailySOS) that was developed for SWRCB evaluation of the proposed Delta Wetlands project operations has been modified to include San Luis reservoir operations, simulate the effects of 1995 WQCP objectives on allowable exports, estimate water supply effects from additional pumping limits to reduce the salvage of selected fish species, and provide estimates of environmental water that might be obtained from "relaxation" of fixed objectives (i.e. higher E/I ratio, reduced X2 outflow).

The DailyOPS (Operations Possibility Simulation) model simulation uses the historical daily Delta inflows (i.e., DAYFLOW records) for any selected recent year of record (i.e. 1981-1995). The daily historical data can be adjusted to match the monthly average DWRSIM results for a particular month, by adding the difference between the DWRSIM value and the historical average value. The DailyOPS model allows the user to specify a wide range of monthly Delta objectives, such as those included in the 1995 WQCP. For example, the allowable export pumping capacity can be changed to represent increased Banks pumping capacity. QWEST flow requirements can be imposed, and DCC gate can be closed during a month by simply changing a model parameter.

The allowable Delta exports that would satisfy each of the specified objectives are calculated for each day so that the effects of changing individual Delta objectives can be easily investigated. The daily model calculates daily X2 requirements and export/inflow ratio limits, for example, and determines adjustments in export that would be required to satisfy these specified objectives, assuming historical (or adjusted) inflows. DailyOPS calculates the allowable export that would have been possible if there had been additional export water supply demands or south of Delta storage facilities. The daily demands can be historical or a future adssumed demand (i.e., 6 MAF) pattern can be specified. San Luis reservoir storage is tracked because San Luis storage may limit exports during some periods.

The DailyOPS model simulated fish protection trigger(s) that can be specified as monthly density value for each of five species. Full pumping is allowed if the historical salvage density is less than the minimum specified value. Allowable pumping is reduced to a specified percentage of otherwise allowable pumping if the density is greater than the specified value.

The DailyOPS model allows the export limits to be specified and the E/I ratio to be relaxed on a weekly basis. The daily model tracks the EWA adjustments to the baseline conditions. Periods of relaxation in the E/I ratio or increased export limits will produce an EWA credit, with increased San Luis storage. Periods of fish triggers or lowered export limits will reduce the EWA account and may create an EWA debt (i.e., reduced San Luis storage).

The five upstream reservoirs that control Sacramento River inflow (i.e., Folsom, New Bullards Bar, Oroville, Shasta, and Clair Engle) were included in the EWA daily modeling. This allows the effects of potential changes in Delta exports to be "managed" by reducing reservoir releases to minimum required flows and holding water in upstream storage, unless the reservoir storage is already at flood control levels. These upstream reservoir management opportunities have not been fully explored in the EWA gaming simulations, and more efforts at coordination between Delta actions and upstream actions should be included in future gaming exercises.

Calculation of potential EWA benefits

Potential benefits of EWA changes in Delta hydrologic conditions (i.e., Delta inflows, outflow, DCC diversions, QWEST flow, Head of Old River diversions, and export pumping) are difficult to evaluate because there are multiple factors affecting fish populations and the effects of any single factor on fish survival cannot be experimentally determined.

Measurements of fish distribution and abundance (i.e. density) are the fundamental biological data that must be evaluated to estimate the potential benefits of EWA changes in flows and export pumping patterns. The timing of a species within the Delta (i.e., migration or spawning) is important because this controls the fraction of the population that is exposed to Delta conditions. The location of the population within the Delta is important because this controls the fraction of the population that is exposed to direct and indirect effects caused by changes in a particular flow or export pumping. Because the available biological data is generally incomplete compared with the daily hydrologic and water quality conditions, it is necessary to consider a wide range of possible assumptions about the relationships between hydrologic and water quality conditions and the resulting fish distribution and abundance patterns in the Delta. Some of the available biological information and assumptions are described in the following sections.

Historical CVP and SWP Salvage Data

The EWA gaming simulations have used the historical salvage density (fish/TAF) from the CVP and SWP pumping plants to estimate the baseline and EWA-modified salvage that would occur with EWA-modified export pumping patterns. Converting the historical salvage records to density provides a standardized measure of relative fish abundance near the pumps that is assumed to be independent of the pumping rate. However, this assumes that the changes in futurea allowable pumping would not change the basic fish occurance (i.e., timing) and abundance patterns. Under this assumption, the calculated salvage will vary directly with the pumping rate. The greatest number of fish can be protected by reducing the exports during periods with the greatest historical salvage density.

The pumping pattern may have a secondary effect on salvage density, if the fish population is not uniform throughout the Delta, and pumping draws more water with high fish density from the central Delta into the south Delta. This might occur for chinook density, for example, if the majority of the salvage originate from the San Joaquin River. Higher pumping may draw a greater fraction of the SJR chinook towards the pumps. This might also occur for delta smelt that have spawned in the central or north Delta and are drifting passively in the water column. Greater than historical pumping could increase the salvage denstiy, and less pumping may delay and reduce the salvage density. These possible changes in historical salvage density have not yet been incorporated into the EWA gaming calculations.

Chipps Island, Sacramento, and Mossdale Trawling Records

In addition to the historical salvage records, there are some available daily records of fish density from the Chipps Island trawling station. In more recent years, trawling at Sacramento and at Mossdale on the San Joaquin River have provided daily records during months with greaatest likelihood of chinook presence (the target fish species for these sampling efforts). This data should be included in the daily gaming simulation model to provide comparisons with the south Delta salvage density for chinook and other fish species.

Egg and Larvae Surveys

There are several years with relatively good egg and larvae surveys, conducted primarily to track the early development stages of striped bass, but providing information about the timing and relative abundance of several other common fish. Since the salvage records do not include fish smaller than a specific size, adjustment of export pumping based on historical salvage density may be missing opportunities to provide protection for younger life stages. Analysis of the egg and larval data may provide the required spawning temperature and growth rates needed to estimate the length of time for fish to grow to the minimum size reflected in the salvage density records.

Calculation of Factors Affecting Fish Density and Entrainment

The gaming simulations of the EWA has simulated the general effects of flexible pumping on daily allowable exports for a series of study years (i.e. 1991-1995). The major uncertainty in these gaming exercises, however, is in the expected response of the historical fish density to changes in exports, flows, salinity, and other habitat conditions. Progress in evaluating the EWA effectiveness will require that more of the fish data be brought into the EWA gaming simulations, to better understand the multiple factors leading to changes in fish abundance.

For example, the conditions leading to high salvage densities of delta smelt in recent years should be simulated to determine the likely interactions between spawning, inflows, and pumping on the observed delta smelt density patterns. This should be possible using the real-time data collected by DFG and USFWS with the 20-mm tows and summer tow-nets. Similar biological gaming of the high splittail salvage events in 1995 and 1998 should be conducted. Other biological reference data that should be incorporated in the gaming simulation are the DFG Mossdale trawling data and the USFWS Chipps Island and Sacramento trawling records.

The biological gaming could be simulated with an extension of the DailyOPS Delta operations model that included the MOVE (i.e., movement of organisms vulnerable to entrainment) module used for the CVPIA Programmatic EIS evaluation of habitat water quality. This daily model estimates the fraction of water that becomes mixed and transported throughout several Delta channel volume segments. The effects of Delta flows and export patterns on the fate of assumed fish spawning events or migration patterns can be approximated. For example, a fish spawning event can be simulated on a specified day in one of the Delta inflows (i.e. striped bass) or in one of the Delta volume segments (i.e. delta smelt). The movement of these simulated organisms can then be tracked for a sequence of days, and the transport towards the exports or out of the Delta towards Suisun Bay can be evaluated. These calculations might be used to provide a measure of biological benefits (i.e. percentage of an assumed population transported to Suisun Bay) that is achieved by EWA-adjustments in Delta flows and export patterns. The MOVE

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model results can be confirmed with more detailed calculations of the DSM2 particle tracking module. The effects of DCC closure and proposed Head of Old River gates are particularily important for estimating fish entrainment reductions.

The coded-wire tag (CWT) releases from San Joaquin River and Sacramento River locations may be used to calibrate the movement of chinook smolts towards Chipps Island and the export pumping. Correlating the daily trawl records with hydrologic parameters may be useful for identifying the factors that govern the travel time and pathways through the Delta. Chinook generally travel faster than net channel flows, but may be influenced by the tidal and net flow conditions.

Chinook Migration Survival Estimates

The Delta model used to guide the EWA gaming simulations currrently evaluates the effects on chinook migration survival with monthly calculations for the San Joaquin River and Sacramento River chinook races. Based on available coded-wire tag experiments, the San Joaquin River equation for assumed monthly chinook survival is:

Monthly survival = 0.00002 * Vernalis Flow (cfs) * [15,000 - Export (cfs)]/15,000

The SJR fall chinook population survival through the Delta is calculated by assuming that 45% migrate in April, 48% migrate in May, and 7% migrate in June. Increases in SJR flows and reductions in export pumping during these months have the greatest effects on the estimated chinook population survival through the Delta. For example, increasing the flow by 1,000 cfs will increase the assumed monthly survival by 2%. Reducing the export pumping by 1,000 cfs will increase the assumed monthly survival by a factor of 1.06 (i.e., 6% of the assumed monthly survival based on flow). Closing the HOR barrier is assumed to increase survival by 10% (equivalent to increasing flow by 5,000 cfs).

The Sacramento River migration survival is calculated for each run separately. The monthly distribution of the migrating population of winter run, spring run (juveniles and yearlings), late-fall, and fall run are specified for calculating the overal population migration survival. The Sacramento River assumed monthly chinook survival through the Delta is estimated as:

Monthly survival = 100%- DCC diversion % * [0.5 + 0.000034 * Export pumping (cfs)]

This equation assumes that fish remaining in the Sacramento River have a 100% survival, and only central Delta survival is affected by exports. For example, if the DCC diversion was about 50%, the maximum monthly survival would be 75% with no export pumping, and would be reduced to about 50% if the export pumping was 15,000 cfs (i.e., central Delta survival would be reduced to 0). Closing the DCC will increase the assumed survival because the DCC diverstion will be reduced to about 25%. Reducing the export pumping by 1,000 cfs increases the assumed survival of fish in the central Delta by 3.4%, so the assumed monthly survival increases by only 1.7% if the DCC is open and by only about 0.9% if the DCC is closed. Because the EWA adjustments in Delta inflows and export pumping are limited, the estimated improvements in Sacramento River chinook migration survival are relatively small.

Delta Export Entrainment Estimates

The daily Delta model calculates salvage estimates from the historical salvage density and the historic, baseline, and adjusted export pumping rates. Baseline and EWA adjustments in historical outflow will change the simulated salvage density for delta smelt and striped bass, because these fish are assumed to be distributed upstream of the X2 location. The assumed adjustment in historica salvage density is related to the movement of X2. The assumed salvage density is reduced if the X2 position moves downstream from the historic position, and is increased if the X2 position moves upstream from the historic position. A downstream shift in X2 will reduce the density by:

New density = Old Density * 0.9 ^ downstream movement of X2

Similar adjustments in historic salvage density of specific fish species caused by changes in other Delta flows could be included in the calculations. For example, changes in historic chinook salvage density and historic splittail salvage density should probably be adjusted if the Head of Old River barrier or tidal gate is simulated, because a majority of these fish are likely to enter the Delta by migrating down the San Joaquin River. However, assumptions about how to adjust historical salvage density for various changes in Delta inflows and channel flows (i.e. DCC or QWEST) have not yet been specified by the DNCT team, and are not included in the daily model calculations.

The goal of the EWA gaming simulations is to combine the most accurate respresentation of reservoir storage, river flows and Delta water management contraints with the best available biological data about fish abundance and distribution, so that EWA adjustments will provide the greatest possible benefits to important fish populations. More historical fish density data as well as improved calculations of the likely effects of flows and exports on the historical fish density patterns are both needed for future EWA gaming simulations.