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June 20, 2011

Gina Ford
Delta Science Program
980 Ninth Street, Suite 1450
Sacramento, CA 95814

Dear ~~Ms. Ford~~ Gina:

Attached is the Final Report and supporting documentation for CALFED Grant No. 1042. There are two documents that are listed in the references section as still being under preparation as of the date of this submittal. These documents are:

- Modeling and Statistical Analyses for CALFED Science Grant No. 1042
- Spatial Analysis of Fall Midwater Trawl Trends for Delta Smelt

These documents will be submitted no later than June 30, 2011. The reason for the delay is that the write up of this analysis and results took longer than expected. There was also additional analysis that was conducted that required additional time to document. I understand that the Final Report submission will not be considered complete until receipt of these documents, and I will work to get these to you as soon as possible. Thank you again for your patience in completion and submittal of the Final Report.

We appreciate the opportunity that has been provided to conduct this research through CALFED and the Delta Science Program. If you have any questions, please contact me at (925) 688-8282.

Sincerely,

Brett J. Kawakami

Brett Kawakami
Water Resources Specialist

BK:wec

Attachment

The Consequences of Operational Decisions on Water Quality: Reconciling Delta Smelt, Salmon, and Human Needs
CALFED Bay-Delta Program Grant No. 1042

Final Report

This Final Report documents the work performed under Delta Science Program (formerly CALFED Bay-Delta Program) Grant No. 1042 and summarizes the key findings. More detailed descriptions of the analyses can be found in the technical memoranda and reports prepared under this Delta Science Program Grant, and referenced at the end of this report.

This Final Report consists of Project Findings and Conclusions, followed by a task by task description of the specific activities and deliverables produced.

Findings

We found that the spatial distribution of delta smelt in the San Francisco Bay-Delta during the fall, as measured by the Department of Fish and Game Fall Midwater Trawl (FMWT) survey, has shifted up-estuary over the past two decades. The shift is most pronounced in fall months following wetter water year types. Delta smelt are known to be sensitive to salinity, and this observed geographic shift correlates with a noted increase in fall salinity levels from historical levels. We provide evidence that the higher salinities are attributable to 1) higher fall exports, linked to export reductions in spring necessitated by D-1641 regulations; and to 2) a decrease in Sacramento inflow attributable to higher upstream diversions for rice field stubble decomposition. We did not find substantial evidence that cold water management for Chinook salmon during the summer played a role in higher fall salinity. The change in fall delta smelt distribution, linked to a possible degradation of fall habitat, has been proposed as a potential causal factor in the decline in delta smelt abundance. We illustrate that the changed spatial distribution patterns do overlap with lower volumes of quality habitat.

To test the validity of the widely used FMWT Index in measuring relative abundance, we evaluated the 14 FMWT Index Areas, each of which is a set of aggregated stations over which catch is averaged. We determined that, with one exception, stations within the same Area exhibited similar patterns of catch and salinity, and were therefore appropriate units for statistical analysis. We identified four FWMT Areas as the most important for describing catch patterns, and each Area has a unique pattern of catch with respect to salinity. We have noted a change in these patterns over time when comparing similar water year types. To determine if there were trends that were masked by the station-aggregated Area method used to calculate the FMWT Index, we recalculated the FMWT Index using individual catch data and individual station volumes. The recalculated index was similar to the existing FWMT Index and captured the same changes in delta smelt abundance. This showed that the existing FMWT Index does a reasonable job of establishing a consistent metric of relative abundance, given the limitations of the data collection.

We show that there are distinct patterns of FMWT catch, as confirmed by spatial statistical cluster analysis. These patterns are associated with regional salinity patterns and show consistent variation with salinity levels.

The FWMT Areas provided convenient boundaries for defining salinity and delta smelt regions. Using the catch relationships with salinity, we defined bounds of salinity for "suitable" habitat. This allowed us to define the range of delta smelt fall habitat for a set of salinity conditions. Similar relationships have been used by other researchers.

Using hydrodynamic and water quality modeling, we explored the feasibility of different operational scenarios to restore salinity to lower levels. First, with DSM2 fingerprinting, we confirmed that the source of fall salinity increases was from the seaward boundary, which is heavily influenced by outflow levels. We then examined two scenarios for increasing fall outflow – reservoir releases and export reductions. We found that upstream fall releases from Shasta reservoir would lower salinity and restore larger volumes of suitable habitat. However, we found that such releases could also impact the cold water pool, leading to increased temperatures during subsequent summer periods, and that these increases could lead to potential impacts on key measures of abundance for winter-run Chinook salmon. Decreases in exports would be another alternative of increasing net Delta outflow (NDO) without the attendant cold water storage effects. We looked at export reductions based on lower fall E/I ratios. Limiting fall E/I ratios was effective in lowering salinity during wetter years to a level conducive to expansion of delta smelt habitat. However, decreases in exports absent other mitigating measures would affect water supply deliveries.

To understand the broader implications of water management operations on Delta water temperatures, we developed a conceptual model of temperature in the Delta. This model introduced the idea of a Dynamic Equilibrium Temperature (DET). An important finding was that the Sacramento River does not actually achieve DET by the time that it reaches the northern edge of the Delta. The implications are that although temperature management of the Delta may not be practical, changes in water operations upstream do have the potential to change temperatures within the Delta.

Using existing operational and fisheries data, we were able to draw important conclusions regarding relationships between salinity and delta smelt, and the influence of water operations on each. This, coupled with the application of hydrodynamic, water quality and temperature models, allowed us to explore the feasibility of solutions for returning conditions to those more conducive to higher delta smelt abundance.

Below is a summary of the findings of this research and an accounting of the hypotheses that were tested.

Summary Table of Findings
Fall salinity has increased due to an increase in exports and increased upstream diversions
Delta smelt fall distribution has occurred further upstream in recent years than in the past, especially when comparing falls occurring after wet and above normal previous year water types.
Delta smelt fall distribution is highly correlated with salinity
The FMWT Areas are statistically appropriate station aggregates, with the exception of Area 13, which should be partitioned in two sub-areas
Releases from the upstream Shasta reservoir can lower salinity levels and increase fall habitat volume, although there are potential temperature impacts in the subsequent summer temperature season for Chinook salmon
Fall export reductions based E/I ratio are an effective method for lowering salinity levels and increasing fall habitat volume; however, they would have impacts on water supplies.

Hypotheses Tested

This research was initiated based on a number of hypotheses. The results of testing these hypotheses are summarized below:

Hypothesis Tested		
Hypothesis	**True/ False**	**Rationale**
Changes in reservoir operations, including temperature control on the Sacramento River in the summer, have changed seasonal salinity patterns	F	Temperature control releases occur within the normal range of operations. The key aspect of temperature control is preserving the cold water pool to last throughout the season.
Changes in exports have changed seasonal salinity patterns	T	There have been increased fall exports resulting from the requirement to reduce spring exports. This has led to decreased outflow and increased salinity.
Changes in upstream diversions have changed seasonal salinity patterns	T	Increased diversions to flood rice stubble have caused lower inflow in the fall.
The Fall Midwater Trawl Areas can serve as reasonable station aggregates	T	The current FMWT areas do capture the important variations in salinity and delta smelt catch.

Conclusions

This research has demonstrated that changes in water management and regulatory standards have altered the hydrodynamic and water quality landscape in the San Francisco Bay-Delta during the fall period. A distinct change in the relationship between natural flows and management operations is apparent in the years coinciding with the delta smelt decline. These altered patterns have led to changes in spatial distribution of delta smelt, when accounting for water year types. The historical record of delta smelt seems to imply a narrowing of abundance during dryer periods with recoveries occurring during wetter periods, when delta smelt can occupy a higher volume of quality habit. Our analysis suggests that the fall months following wetter year periods since 1980 have produced higher salinities and further upstream delta smelt distribution comparable to dryer years which may have not allowed the same recovery.

Measures to alleviate increased fall salinity include additional reservoir releases and export reductions. Releases from Shasta Reservoir could impact temperature control operations for winter run Chinook salmon and lead to reduced survivability. Export reductions tied to a more conservative E/I ratio would also be an effective means to return regional salinity to levels that would provide expanded delta smelt habitat in the fall. Each measure could have impacts on either reservoir storage or on water supplies.

Besides salinity, water temperature is another parameter that may influence delta smelt abundance. Temperature control in the Delta may be impractical due to the complexity of atmospheric forcing and local meteorological conditions. However, water management operations on the Sacramento River may have some effects on delta temperature because of the fact that equilibrium temperature is not always reached at the northern edge of the delta. The potential influence of water operations could be factored into consideration of this temperature sensitive region.

Restoration of endangered species within the San Francisco Bay-Delta will require a coordinated effort to ensure that water management operations are optimally structured to meet the potentially conflicting needs of these species, as well as providing for the best human use of the Delta as a resource as well. This study provides insights on how some actions might affect the system.

Task Descriptions and Deliverables

This section provides a list of specific accomplishments and deliverables by task.

1. Task 1 – Project Management

The original principal investigator, Dr. Marianne Guerin, left Contra Costa Water District (CCWD) in 2008 and was replaced by Dr. Brett Kawakami. A Technical Advisory Committee meeting on July 31, 2007 resulted in several recommendations to help focus the proposal. A summary of the TAC meeting notes with commentary from the TAC members and the presentation Dr. Guerin gave were included as background information on CCWD's first invoice to CALFED. Periodic reports were transmitted to CALFED and later the Delta Science Program by the principal investigators.

2. Task 2 – Statistical Analysis: Spatial

2.1. Dataset Compilation

Cramer Fish Sciences (CFS) compiled relevant biological survey data as well as associated water quality and physical habitat conditions. The data were obtained from agency websites, direct contact with district biologists and centralized database warehouses. In August 2007, Boedicea P. Fox and Jody Brauner Lando of Cramer Fish Sciences prepared a report on "**Delta Smelt Abundance and Habitat Data**" for Contra Costa Water District, which documents their compilation of data and was accompanied by spatially explicit geographic information system (GIS) files and associated datasets. The data collected and organized in this effort was further utilized in the subsequent tasks in the Project.

2.2. Cluster Analysis

CFS examined the long term data for the Fall Midwater Trawl (FMWT) and Summer Townet (TNS) surveys to evaluate the habitat preferences for delta smelt in the San Francisco Estuary. This analysis is documented in the July 2009 technical memorandum on "**Spatial and Temporal Analysis of Delta Smelt Abundance and Distribution: Fall Midwater Trawl and Summer Townet Survey**". CFS conducted a spatial autocorrelation analysis that revealed that delta smelt show differences in clustering (areas of high abundance) depending on the time of year when comparing the analyses for the FMWT and TNS. They generally observed greater abundance during the FMWT (concentrated at Suisun Bay, near Chipps Island and the Lower Sacramento River), although during the TNS, elevated abundances were also observed at Suisun Bay and the Lower Sacramento River. There was some evidence which would suggest different clustering patterns between years of low and high abundance; however, it is uncertain to what extent these findings might be unduly influenced by confounding factors.

2.3. Evaluation of FMWT Spatial Aggregates

One of the objectives of this research was to determine if the current Fall Midwater Trawl (FMWT) method for combining station data into FMWT Areas is a legitimate way to aggregate survey data, and if the Areas represent statistically appropriate units for further analysis. CCWD

evaluated these issues in the **"Spatial Analysis of Fall Midwater Trawl Trends for Delta Smelt"** prepared by Brett Kawakami**.**

The FMWT index is calculated by taking average catch from all stations within an Area and then multiplying this average by a weighting factor that theoretically reflects the volume associated with that Area. A main assumption is that the relative Area weights are reasonable. By averaging the data from all stations within an Area, the FWMT Index calculation method effectively assigns each station with the same volume. To determine if this assumption might affect the FMWT Index, the Index was recalculated using individual station data and station-specific volumes and it was determined that the trends were essentially the same. We also plotted the FMWT index values against raw catch totals and found similar trends between the two. Although the FMWT Index suffers from other issues that limit it from being a precise measure of absolute abundance, it does provide an adequate relative measure of abundance, particularly since it has such a long term record.

A research goal was to test the suitability of the FMWT Areas for use as reasonable clusters for spatial statistical analysis. The suitability will depend on whether the individual stations within each Area show consistent patterns of salinity and catch within that area. There were three questions that were posed to answer this question:

- Are there significant differences in salinity patterns between spatial clusters (FMWT Areas)
- Are there significant differences in salinity patterns over time?
- Are there significant differences in delta smelt densities with space and time as covariates?

Salinity data among stations within the same Area does follow the same trend and reflects the general pattern of salinity in that vicinity during the survey period. This makes sense as the FMWT stations are grouped generally by proximity. Stations higher up-estuary have lower salinity than those more seaward. One inherent limitation of the FMWT data on the fine scale is that is does not represent a snapshot in time. Salinity at each station can change significantly over the course of a survey due to tidal fluctuations. In spite of this, on the whole, the FMWT data did capture seasonal and annual variations in salinity.

We explored the relationships between FWMT catch and salinity by plotting cumulative catch by FMWT Area with salinity. We found that the relationship was not fixed and there were distinct variations between FMWT Areas. With the exception of one FMWT Area, we conclude that the Areas as defined did sufficiently capture the relationships for the stations therein. It was determined that Area 13 could further be subdivided into two areas – downstream and upstream, each of which showed unique patterns of catch versus salinity. We defined an upper bound of salinity to utilize for evaluation of suitable habitat in our subsequent modeling scenarios.

2.4. Delta smelt distribution response to salinity

We found that spatial patterns of FMWT distribution are strongly driven by salinity. Salinity patterns in the western Delta are largely a function of outflow. Salinity patterns are defined mainly by the extent of salinity intrusion, as measured by X2, which is the distance from the

Golden Gate (in km) to the 2 parts per thousand salinity contour line. As X2 increases, salinity intrusion increases. To determine the relationship between delta smelt distribution and salinity, we calculated a geographic "center of mass" for each FWMT survey. It was found that there was a significant relationship between the center of mass of delta smelt distribution and X2 position which indicates that delta smelt distribution is strongly influenced by salinity. There is a clear relationship between delta smelt distribution and X2.

Dr. Guerin (the initial principle investigator) prepared an unpublished manuscript titled "An analysis of the effects of the regulatory regime and water management operations on *Hypomesus transpacificus* (delta smelt) abundance in the San Francisco Bay-Delta estuary". This paper analyzed different statistical relationships between TNS data, FMWT data, western Delta salinity and San Joaquin River flows at Vernalis. The work suggests that the abundance of Delta smelt was strongly correlated with salinity in the western Delta. This can either mean that higher salinities in the fall in the western Delta provide habitat for the introduced clam species, *Corbula*, which in turn out-competes the Delta smelt for food, or that the factors causing higher salinities in the fall, such as decreased Delta outflow and increased fall exports, have also impacted Delta smelt abundance.

3. Task 3 – Research Historical Reservoir Releases and Operational Data

Dr. Denton produced two documents summarizing his analyses, as well as well-documented electronic data files in support. One major focus of his work concerns examining the causes behind the Fall salinity shift since 1993. The second major focus was preparation of normalized data files to extend Noah Knowles' analysis of management influences on freshwater inflows and salinity.

3.1. Historical Data Analysis

Dr. Denton analyzed the timing, source and volume of flow releases from Shasta Dam and Keswick to met temperature requirements on the upper Sacramento River for the protection of Chinook salmon**.** Dr. Denton also examined other possible factors contributing to the observed shift in Delta salinity in the fall, such as operation of the Head of Old River temporary barrier and the other South Delta temporary barriers, shifts in timing of south-of-Delta export operations, and operational changes for flood management.

3.2. Basis for Increase in Fall Salinity

Dr. Denton produced two documents summarizing his analyses of the causes behind the Fall salinity shift in the western Delta since 1993. Two factors appear to have contributed to the increase in Fall salinities since 1993-1995: (1) operation to meet either net Delta outflow (NDO) or Rio Vista flows consistent with D-1641; and, (2) Variation in export/inflow (E/I) ratios. Both of these factors are linked with to an increase of exports in the fall. It appears that the major changes that have occurred are the changes in NDO in the months of October and December. NDO is much lower for a given water year type (as represented by the total Sacramento Runoff) in the months of October and December.

There has been a considerable increase in the E/I ratios in September, October and November, consistent with an increase in exports. D-1641 requires that the 3-day average ratio of exports to inflow be less than **65%** from July through January. The SWP and CVP have been operating to this 65% limit to a high degree since 1995, unless other standards such as minimum monthly Delta outflow or the Rock Slough chloride standard were governing. Prior to about 1992, E/I ratios were increasing in the spring, but since 1992 these have reduced because of regulations implemented after 1992.

3.3. Principal Components Analysis

Dr. Denton collated unimpaired flow data, DAYFLOW flow data, and reservoir data for the major tributaries as background for this task, and delivered an electronic copy of all of the files and analyses to CCWD. The normalized data was to be used to perform an empirical orthogonal function (EOF) analysis following the method developed in Knowles' 2002 paper on management influences on freshwater inflows and salinity. Knowles separated out a Baseline flow effect, a Reservoir effect and a Delta Withdrawal effect. On review, this initial dataset calculation for reservoir effect needed to be reconsidered. Knowles missed New Bullards Bar flow data, representing Yuba River flows, in his original analysis. CCWD conducted a Principal Components Analysis (PCA) on the data collated by Dr. Denton and showed that were distinct differences in the relationships between unimpaired flows, reservoir releases and exports in recent years. The results are documented in **"Modeling and Statistical Analyses for CALFED Grant No. 1042** prepared by Brett Kawakami.

4. Task 4 – Statistical Analysis: Delta Smelt

As described under Task 2, the existing FMWT Areas are suitable for aggregation of stations spatially. The Areas can serve as convenient boundaries for both salinity and delta smelt regions. A main difference observed with FMWT catch is that upstream regions are inhabited at higher frequency when salinity intrusion is more pronounced. Although delta smelt are still found with some frequency down-estuary as salinities increases, higher salinity is a driver for a general move up-estuary in the center of mass of delta smelt distribution. To understand the relationships between regional salinity and delta smelt occurrence, further statistical analysis was conducted.

4.1. Generalized Linear Mixed Models

The relationships between water quality factors and delta smelt distribution as indicated in the FMWT and the STN were explored using Generalized Linear Mixed Models (GLLMs) and are documented in the TM prepared by CFS titled "**Spatial and Temporal Analysis of Delta Smelt Abundance and Distribution: Fall Midwater Trawl and Summer Townet Survey**". GLLMs are useful for accounting for some of the inherent limitations found in fish survey data.

Those analyses uncovered significant spatial patterns in delta smelt abundance and raised concerns of sampling and analytical bias. The authors also investigated the relationship between several measures of water quality that are known to play an important role in fish ecology, and which have previously proved important in predicting the occurrence and distribution of delta smelt in the San Francisco Estuary (e.g., Moyle et al. 1992; Moyle 2002; Bennett 2005). Overall, they observed that specific conductance, water temperature, and Secchi depth were

important predictors of delta smelt abundance; however, their results suggest that the importance of these measures may differ depending on the time of year and sampling method employed. While all three of these measures were significant in predicting delta smelt abundance in the FMWT, only temperature and Secchi depth were significant in predicting relative abundance in the TNS analyses.

A relationship was not developed between the FMWT and TNS. Recently, Dr. Richard Deriso, in his legal declarations in the current delta smelt litigation pointed to the importance of the stock recruitment relationship. In other words, this year's summer townet survey will dependent upon the availability of adults in the fall, as represented by the FMWT. Deriso normalized the summer townet survey data by dividing by the previous year's FMWT Index. Thus, fall abundance, as measured by the FMWT, may influence subsequence abundance as measured in the TNS.

In January 2009, Jody B. Lando and Boedicea P. Fox of Cramer Fish Sciences completed a technical memorandum entitled "**Exploratory Analysis of Delta Smelt Abundance and Distribution: Spring Kodiak Trawl and 20 mm Survey**" prepared for the California Urban Water Agencies. Past studies analyzed the same datasets (Moyle et. al 1992, Swanson et. al 2000, Bennett 2005, Miller 2005, Freyrer et al. 2007), but did not account for the spatial/temporal component of the Delta smelt abundance relative to water quality conditions. Lando and Fox (2009) acknowledged the challenges of using catch per unit effort (CPUE) in regression analysis (Ricker 1975). In reality large and persistent measurement errors result in low accuracy, particularly for environmental variables. These problems are exacerbated at low population levels, such as those for delta smelt. The authors aggregated the period of record for each station and explored station-specific patterns in the most abundant years (2000 and 2004). The spatial effect of station location was reflected in their hotspot analysis and in their regression results. Both station and year were statistically significant for the SKT and 20 mm surveys.

The authors also found that Secchi depth and temperature were statistically significant for both the Spring Kodiak trawl and 20 mm survey, and electrical conductivity was significant for the 20 mm survey. This differed from earlier studies of delta smelt abundance because of the inclusion of spatial and temporal effects, as well as the use of negative binomial regression analysis. It was also cautioned that regression models illustrate associations (i.e. between delta smelt and environmental conditions), but they do not imply causation, e.g., they do not prove that turbidity, temperature and conductivity directly result in specific delta smelt abundance.

5. Task 5 – Concept Development and Synthesis of Results

Syntheses of results were documented in the semi-annual reports, in poster presentations and in this final report.

5.1. Summary of Presentations

In October 2008, Brett Kawakami, Richard Denton, and Greg Gartrell (representing CCWD and Richard Denton & Associates) presented a poster at the CALFED Science Conference titled: "**Investigation of the Basis for Increases in Delta Fall Salinity**". The authors concluded that

due to a combination of factors, reductions in NDO since 1984 have led to increases in fall salinity. Major water management factors that were identified included (a) a shift in exports from spring to fall caused by SWRCB water rights decision 1641 requirements; (b) decreases in Sacramento River inflow from rice field diversions and reduced Shasta releases; and, (c) other potential factors that were to be examined in future research as part of this project.

On September 29, 2009, Brett Kawakami, Emily Corwin, Jody Lando, Kristopher Jones, Brad Cavallo, and Greg Gartrell (representing CCWD and Cramer Fish Sciences) presented a poster at the State of the Estuary conference titled: "**Spatial Analysis of Fall Midwater Trawl Trends for Delta Smelt**." The poster reported on their analysis of FMWT trends from a spatial perspective using GIS tools and spatially explicit statistical methods. They found delta smelt FMWT distribution falls within distinct patterns (clusters) based on water year type, inflow, and time period, and that the estuarine habitat indicator X2 is a fairly reliable indicator of spatial patterns. Their DSM2 simulations suggested that increases in Sacramento River inflow can return salinity distributions to those historically associated with downstream delta smelt distribution in the fall.

In September 2010, Brett Kawakami, Brad Cavallo, and Greg Gartrell (representing CCWD and Cramer Fish Sciences) presented a poster at the Sixth Biennial Bay-Delta Science Conference titled: "**Evaluation of Potential Conflicts between Protection of Winter-Run Chinook Salmon and delta smelt**." The authors noted that maintaining adequate in-stream temperatures during the summer for salmon and maintaining sufficient outflow to provide adequate salinity habitat for delta smelt in the fall may result in potential water management conflicts. The authors presented a side by side comparison of the benefits and impacts of summer temperature and fall outflow management on both species. The authors concluded that temperature releases conducted within the realm of normal anticipated operations do not affect ability to maintain the estuarine habitat indicator X2. In some years, temperature control could be improved without affecting ability to maintain fall X2. They concluded that reductions in Shasta storage may increase summer temperatures.

6. Task 6 - DSM2 Modeling

DSM2 modeling was performed to determine salinity patterns and to determine the effects of various scenarios on salinity patterns. The results are documented in **"Modeling and Statistical Analyses for CALFED Science Grant No. 1042".**

We examined three scenarios: 1) upstream releases on the Sacramento River; 2) upstream releases on the San Joaquin River; and 3) export reductions. We ran simulations over the historical period 1990-2006. We found that each scenario could be successful in achieving regional salinity levels associated with periods of higher delta smelt abundance. Each of these scenarios would have operational implications that were not within the scope of this research. In addition, current and future operations will be different than historical. We also utilized the fingerprinting module within DSM2 to determine the source of fall salinity increases. It was confirmed that the fall salinity increases experienced at most FMWT stations originated from salinity intrusion from the ocean (i.e. the Martinez boundary in the model).

7. Task 7 - Temperature Analysis

In June, 2008, Dr. Mike Deas, Watercourse Engineering, Inc., completed a report for CCWD entitled "**Report: Summary of the historical reservoir release schedules for temperature control for Chinook salmon**." Dr. Deas identified temperature criteria, objectives, and targets for thermal management in main stem rivers below reservoirs for anadromous fishes. Dr. Deas noted that, up to that time, climate change had been largely absent from the available temperature management literature for the Central Valley. While it is very difficult to control Delta temperatures using releases from cold water pools behind the distant Central Valley main stem dams, temperature conditions in the Delta may respond to extant water operations (e.g., Sacramento and San Joaquin River flows, pumping) by affecting the volume of water present in the Delta at any particular time, the transit time through the Delta region, and the influence of tidal flows from downstream bay regions. Dr. Deas outlined criteria that apply region-wide in the Central Valley, as well as site-specific criteria for river systems where flow related temperature objectives exist.

7.1. Delta Water Temperature Conceptual Model

In December, 2010, Michael Deas, Eric Miao, Edwin Limanto, and Stacy Tanaka of Watercourse Engineering, Inc. completed a report for CCWD entitled "**Sacramento-San Joaquin Delta Water Temperature Conceptual Model".** The Delta water temperature conceptual model provides a baseline characterization of water temperature dynamics. The conceptual model does not quantify water temperature responses in the Delta, but provides a framework to form hypotheses about how the Delta's thermal regime responds to hydrology, meteorology, and/or other factors. Modeling results and the data suggest tidal and river influences affect in-Delta conditions regionally. During summer periods, the western Delta (from mouth of Suisun Bay to Rio Vista and Jersey Point) has the coolest temperatures due to the advection of a large source of cooler water from San Francisco and San Pablo Bays and the marine influence. The north, central and south Delta areas, with a complex array of channels and islands, experience the warmest water temperatures during summer. Diel temperature variations, which are clearly evident in river inflows to the Delta, are largely eliminated within the Delta as tidal influences begin to dominate the transport of water.

Due to the extended distance from Shasta Dam to the Delta and the multiple factors that potentially affect water temperature in the Sacramento River en route, temperature "control" in the lower Sacramento River would be neither feasible nor persistent. Similarly, the mainstem reservoirs upstream on the San Joaquin River and its major tributaries are either too distant or release relatively small volumes that water temperatures at Vernalis are at dynamic equilibrium temperature with little or no perceptible upstream influence. The authors hypothesized that water operations have probably affected temperatures in the Delta to some extent; however, active management of temperature in the Delta is most likely to be unrealistic.

The authors suggested a more comprehensive assessment of the available data will be needed before there can be a more quantitative assessment of in-Delta thermal conditions over the existing range of conditions.

7.2. Temperature modeling

Release of water in the fall from Shasta Reservoir could have potential impacts on cold water management for Chinook salmon. To explore this potential conflict, CCWD used the USBR Sacramento River Water Quality Model (SRWQM) to determine potential effects on downstream temperature. Using constant 1,000 cfs release, we found that additional fall releases would deplete cold water storage in Shasta Reservoir and could affect the ability to control temperatures during subsequent seasons. There were notable temperature increases, particularly in late summer. To understand the biological ramifications of these temperature increases, the output was used as input into a salmon population model by CFS.

8. Task 8 – Salmon Population Modeling

To determine the effects of temperature increases caused by upstream fall releases from Shasta Reservoir, the Interactive Object-Oriented Salmon Simulation (IOS) model was employed by CFS. The results of the model are documented in **"Modeling and Statistical Analyses for CALFED Science Grant No. 1042".** IOS can compare the relative impact of different flow, temperature, and water export scenarios on the winter-run Chinook population that spawns in the upper reaches of California's Sacramento River. The model found that based on the temperature increases determined by the SRWQM model, there was a significant decrease in egg to fry survival and number of returning female spawners which was the highest in critical and dry year periods. This indicates that upstream releases during fall for delta smelt may have potential impacts on winter run Chinook salmon in the subsequent year.

9. Task 9 – Visualization and Regional Analysis of DSM2 Output

Spatial visualizations of FMWT data and salinity were prepared to allow for visual inspection of regional trends and year to year variations. Results of the DSM2 analysis are provided in "**Modeling and Statistical Analyses for CALFED Science Grant No. 1042"**. A GIS database was also developed and populated. A set of maps that show FMWT catch by survey was generated and provided as an attachment.

Grant Reports and Presentations

Deas, M.L. 2008. Summary of the historical reservoir release schedules for temperature control for Chinook salmon. Watercourse Engineering, Inc.

Deas, M.L., Miao, E., Limanto, E. and S.K. Tanaka. Sacramento-San Joaquin Delta Water Temperature Conceptual Model. Watercourse Engineering, Inc.

Denton, R.A. 2007. Review of Operational and Regulatory Factors Causing Recent Changes in Delta Salinities in the Fall. 2007. CALFED Science Grant No. 1042.

Denton, R.A. 2007. Additional Analysis of Factors Affecting Fall Salinities. CALFED Science Grant No. 1042.

Fox, B.P., and J.B. Lando. 2007. Delta Smelt Abundance and Habitat Data. CALFED Science Grant No. 1042.

Fox, B.P. and J.B. Lando. 2009. Technical Memorandum: Exploratory Analysis of Delta Smelt Abundance and Distribution: Spring Kodiak Trawl and 20mm Survey. Prepared for California Urban Water Agencies.

Jones, K.S., Cavallo, B.J., and J.B. Lando. 2009. Technical Memorandum: Spatial and Temporal Analysis of Delta Smelt Abundance and Distribution: Fall Midwater Trawl and Summer Townet Survey. CALFED Science Grant No. 1042.

Kawakami, B.T. 2011. Modeling and Statistical Analyses for CALFED Science Grant No. 1042. CALFED Science Grant No. 1042 (under preparation).

Kawakami, B.T. 2011. Spatial Analysis of Fall Midwater Trawl Trends for Delta Smelt. CALFED Science Grant No. 1042 (under preparation).

Kawakami, B.T., Denton, R.D., and G. Gartrell. 2008. Investigation of the Basis for Increases in Fall Salinity. CALFED Science Conference, 2008.

Kawakami, B.T., Corwin, E.C., Lando, J.L., Jones, K. Cavallo, B., and G. Gartrell. 2009. Spatial Analysis of Fall Midwater Trawl Trends for Delta Smelt. 2009 State of the Estuary Conference, Oakland, CA.

Kawakami, B.T., Cavallo, B., and G. Gartrell. 2010. Evaluation of Potential Conflicts between Protection of Winter-Run Chinook Salmon and delta smelt. 2010 Delta Science Conference, Sacramento, CA.