Report of the 2013 Independent Review Panel (IRP) on the Long-term Operations Biological Opinions (LOBO) Annual Review

Prepared for: **Delta Science Program**

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Panel Members:

James J. Anderson, Ph.D., University of Washington
James A. Gore, Ph.D., (Panel Chair) University of Tampa
Ronald T. Kneib, Ph.D., (Lead Author), RTK Consulting Services & University of Georgia (Senior Research Scientist Emeritus)
Mark S. Lorang, Ph.D., University of Montana
John M. Nestler, Ph.D., Fisheries and Environmental Services & USACE Engineer Research and Development Center (Retired)
John Van Sickle, Ph.D., U.S. Environmental Protection Agency Western Ecology Division (Retired)

Scope and Intent of Review: This report represents findings and opinions of the Independent Review Panel (IRP) assembled by the Delta Science Program to inform the National Marine Fisheries Service (NMFS) and the U.S. Fish & Wildlife Service (USFWS) as to the efficacy of water operations and certain regulatory actions prescribed by their respective Long-term Operations Biological Opinions' (LOBO) Reasonable and Prudent Alternative Actions (RPAs) as applied from October 1, 2012 through September 30, 2013 (Water Year 2013).

This year's annual review focused primarily on: (1) implementation of NMFS's RPAs for Shasta Operations in connection with the activities of the Sacramento River Temperature Task Group (RPA Actions I.2.1 – I.2.4), (2) new approaches to loss estimation of Chinook salmon, steelhead and green sturgeon at the Skinner Delta Fish Protective Facility and Tracy Fish Collection Facility (NMFS Opinion Term and Condition 2a), and (3) the USFWS RPAs related to Water Operations in connection with protection of delta smelt from December through June of the 2013 Water Year (RPA Action 1).

The federal government shutdown in early October 2013 affected the timely provision to the IRP of an official written report on Water Operations related to protection of delta smelt, and so comments and recommendations on this aspect of the original charge to the panel was amended to be at the discretion of the IRP; the IRP included comments and recommendations on delta smelt in its 2013 report.

After reviewing a required set of written documents (Appendix 1), the IRP convened at a public workshop in Sacramento, CA on 6-7 November 2013. The first day of the 2-day workshop provided a forum for the IRP to consider information on water operations, activities and findings related to RPA Actions related to Shasta Operations and effects on aspects of the early life history of winter-run Chinook salmon in the Sacramento River, the development of loss equations for listed anadromous fishes associated with Delta Water Operations, and a retrospective consideration of Delta Water Operations as related to delta smelt protective actions early in the 2013 Water Year (WY). On the second day the IRP deliberated in a private session beginning at 8:30 a.m. in order to prepare and present their initial findings at the public workshop at 2:00 p.m., after which there was an opportunity for agency representatives, members of the public and the IRP members to comment and otherwise exchange impressions and information. Subsequent IRP communication and deliberations were conducted via email and conference calls in the course of drafting this final report.

EXECUTIVE SUMMARY

The review panel recognizes the unique challenges and constraints faced by all of the agencies attempting to balance existing commitments and mandated coequal goals of (1) providing a reliable water supply for California and (2) protecting, restoring and enhancing the Delta environment and associated Central Valley ecosystems. The agencies charged with this daunting task continue to cooperate and integrate activities, at least to some degree, but polarity of focus remains evident. Perhaps this is to be expected in an environment where so much is at stake, socio-economic pressure is intense, and so little is precisely predictable.

The dry 2013 water year (WY) presented an even greater challenge to achieving specific RPA targets than was the case in 2012 and confirmed concerns expressed in previous IRP reports (Anderson et al. 2010, 2011, 2012) that some physical targets may not be routinely achievable. After four years of operating under the RPA actions, observations are available for a small sampling of both wet and dry years. The 2013 WY began with the promise of a wet or normal year but ended dry with low reservoir storage due largely to a sparse snowpack and one of the driest January-May periods in the past 90 years.

Although it still remains too early to make definitive assessments of long-term effects on listed species populations, signs linking specific RPA actions to improved conditions remain elusive. A science review panel is not required to confirm or refute that prescribed physical/numerical targets such as temperature compliance points and incidental take are met in any given year. Rather, as noted by all of the previous OCAP/LOO IRPs, the current LOBO IRP emphasizes the continued need to explicitly link the success or failure of meeting physical targets prescribed in the RPA Actions to the biological/ecological responses of the listed species. This is the only way that the intended goals (e.g., protection of listed species) of RPA Actions can be assessed in a scientific context.

The IRP was encouraged by a perceived continued movement toward research aimed at linking the survival and behavior of fishes to water operations on the Sacramento River as well as at the Delta Pumping Facilities. Inclusion of more ecological and behavioral responses of the fish populations or life stages targeted by the RPA actions continues to be recommended as multiple years of observations become available to support a more comprehensive evaluation of the co-equal goals. Despite recent efforts to improve loss estimates from water operations in the Delta, the IRP remains concerned with the assumptions and statistical approaches applied in the evaluation of listed fish species loss estimates associated with the pumping facilities. In particular, direct and indirect losses due to entrainment into the pumping facilities and the variance estimates associated with those losses may be substantially underestimated, and are not well-connected to population size estimates. Given that loss estimates are essential for establishing levels of incidental take, accurate estimates of losses relative to the size of the at-risk populations would certainly be worth the effort required to obtain them.

As noted in previous years, the regular evaluation of realistic goals and objectives is as much a part of an adaptive management strategy as are decisions to alter actions when justified by novel observations and response data that deviate from expectations. The dry 2013 WY provided another opportunity to consider how it is not too soon to step back and consider whether the intentions of habitat restoration efforts are tracking toward expected outcomes. If effects of water operations and protective actions on populations of listed species are not detectable following a series of either "good" or "bad" water years in the future, concerns about whether or not fine-tuning of water operations can contribute substantively to the survival of native species will persist.

The IRP again appreciated the opportunity to concentrate on a focal subset of RPA actions this year but noted some concerns about progress, biological responses and consequences in applying the many other prescribed actions within the watersheds. Promised improvements intended to reduce fish losses at the pumps, expand spawning and rearing habitat, preserve cool water reservoir storage and advance temperature model development are reportedly progressing but remain behind schedule.

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INTRODUCTION

Historically, the challenge of meeting water needs for much of California's growing human population has been met by engineering water storage and delivery systems that have profoundly changed the landscape and flow regimes of riverine and deltaic ecosystems associated with California's Central Valley. These and other anthropogenic alterations over time have been accompanied by profound changes in aquatic flora and fauna, including a persistent decline in native fishes. Consequently, some species have been afforded protection under the Endangered Species Act (ESA) and government agencies have been charged with developing ways of protecting these populations from further jeopardy associated directly or indirectly with water operation projects in the region.

Recent formal legislative recognition that water and other habitats should be managed to restore and enhance the ecosystem as a coequal goal with providing a reliable water supply to California (Delta Reform Act) provided an ambitious and novel conceptual approach to water management within the region. Ultimately, the ability to meet this mandate appears to rest largely on adjusting existing water operations within the context and constraints of a system developed and engineered to primarily achieve one of these goals – a reliable water supply in a region where precipitation is highly variable in both space and time. This constrains the options for meeting the aforementioned co-equal goals largely to modifications in water operations that amount to frequent serial adjustments in reservoir releases and export pumping from the system so as to avoid jeopardizing protected fish populations while continuing to ensure the availability of water for other human uses.

Background on the LOBO RPA review process**:** NOAA's National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS) have each issued Biological Opinions on long-term operations of the Central Valley Project (CVP) and State Water Project (SWP, hereinafter CVP/SWP; Long-term Operations Biological Opinions) that include Reasonable and Prudent Alternatives (RPA) designed to alleviate jeopardy to listed species and adverse modification of critical habitat. NMFS' Opinion requires the U.S. Bureau of Reclamation (USBR) and NMFS to host a workshop no later than November 30 of each year to review the prior water year's operations and to determine whether any measures prescribed in the RPA should be altered in light of new information (NMFS' OCAP Opinion, section 11.2.1.2, starting on page 583). Amendments to the RPA must be consistent with the underlying analysis and conclusions of the Biological Opinions and must not limit the effectiveness of the RPA in avoiding jeopardy to the ESA listed species or result in adverse modification of critical habitat.

The purpose of this annual review of the Long-term Operations Biological Opinions (LOBO) is to inform NMFS and USFWS as to the effectiveness of operations and regulatory actions prescribed by their respective RPAs in the 2013 Water Year.

Since the Long-term Operations Opinions were issued, NMFS, USFWS, USBR, U.S. Geological Survey (USGS), California Department of Fish and Wildlife (CDFW) and the Department of Water Resources (DWR) have been performing scientific research and monitoring in concordance with the implementation of the RPAs. Technical teams and/or working groups, including the geographic divisions specified in the NMFS' Long-term Operations Opinion, have summarized their data and results following implementation of the RPA Actions within technical reports. The data and summary of findings related to the implementation of the RPAs provide the context for scientific review regarding the effectiveness of the RPA Actions for minimizing the effects of water operations on ESA listed species and critical habitat related to the operations of the CVP/SWP. A subset of these technical reports was presented for consideration by the 2013 LOBO IRP (see Appendix 1).

General charge and scope for the 2013 LOBO IRP: Annual reviews prior to 2012 considered all of the RPA Actions but in 2013, as in the previous year, the panel's charge focused on a subset of the operations and RPAs.

This year's annual review included:

(1) Temperature management opportunities and constraints in WY 2013 as assessed by the Sacramento River Temperature Task Group (SRTTG);

(2) Proposed modifications to Term and Condition 2a of the NMFS Long-term Operations BiOp, which required USBR to develop alternative methods for the quantification of incidental take of listed salmonid species and green sturgeon at the Federal and State export facilities;

(3) A retrospective analysis of water operations and delta smelt protective actions taken in WY 2013.

The specific scope of the 2013 LOBO review was defined by questions posed to the 2013 IRP by the technical teams/task groups that presented materials for review. This IRP report addresses each of the questions posed from a scientific perspective, and provides additional observations, opinions and recommendations where, in the panel's opinion, they seemed potentially useful to agency staff for consideration in real-time decision making.

***Acknowledgements*:** The members of the IRP appreciate and acknowledge the efforts of the agency and technical team representatives and contractors who prepared the written materials and delivered the workshop presentations on which this report is based. Each year we are cognizant that much of the material has to be compiled, analyzed and organized in a relatively short time, and that this year the federal government shutdown in October 2013 was a particularly difficult challenge for the federal agencies involved. Despite the many competing demands on the workshop participants, the materials were presented professionally, concisely, and largely on schedule. The panel wishes to express a special thanks to the Delta Science Program management and the entire staff for providing the organization and logistical support to facilitate our task. In particular, Lindsay Correa (Senior Environmental Scientist), as usual, expertly attended to a wide variety of technical and provisional details in support of the IRP's efforts before, during and following the workshop. Similarly, George Isaac ably assisted us through a number of administrative issues.

LOBO IRP COMMENTS ON RPA ACTIONS IN WATER YEAR 2013

General comments and observations

The IRP begins this annual review with a familiar mantra to encourage the development of scientifically defensible connections between satisfying the conditions of specific physical or numerical targets prescribed in the RPAs and ecological responses in the listed species populations. Meeting prescribed targets such as temperature control points within specific river reaches and prescribed levels of incidental take is not the same as succeeding in the intended overarching purpose of the RPAs. An annual science panel is not required to confirm whether or not prescribed targets are achieved but rather if achieving those targets can reasonably be expected to address the intended purpose of reducing or eliminating jeopardy to listed species associated with annual water operations. This requires a demonstrable connection between biological responses of the protected species and the RPAs. The 2013 panel's intent is not to suggest that previous IRP statements to the same effect have gone unheeded, but rather as a reminder to encourage the continued movement we have seen in this direction.

At the workshop in Sacramento, the panel was presented with a brochure that briefly described the California Data Exchange Center and Flood Emergency Response Program. Presumably, this was offered in response to previous IRP recommendations (Anderson et al., 2011, 2012) to develop of a web-based collaborative tool that encouraged multidisciplinary collaboration and a centralized data source for real-time management of water resources as applied to the LOBO objectives. The purpose of the program is to provide reservoir operations staff secure and rapid access to data from remote sensors and instrumentation that feeds into forecasting models intended to coordinate reservoir operations prior to and during flood emergencies. It was not surprising that such a system is in place, but it is unclear how easily it could be adapted to the purposes the previous IRPs envisioned.

Hydrologic summary of the 2013 Water Year (WY)

The 2013 WY presented a forecasting challenge for water operations in that precipitation early in the year held out a false promise of water availability later in the year. The early season precipitation was followed by the driest January to May period on record for the past 90 years. Although total precipitation for the WY was nominally less than 10% below average, it was the distribution of precipitation that presented the challenge for water management. Snowpack in the mountains did not persist much beyond April and there were early demands for irrigation water from some users with senior water rights.

Given the wealth of annual flow records available to various technical groups, it is important to have and use the results of a comprehensive analysis of rainfall patterns coupled to regional and global climatic patterns. Such an analysis should identify precipitation-related conditions under which regional aquatic biota have evolved and which also help to identify reservoir release patterns that can be used as part of an adaptive management strategy favoring the survival of those species [see, for example, recent studies conducted in the eastern United States; Maxwell et al. 2013, Sheldon and Burd 2013, and Sherwood and Greening 2013]. One requirement for restoring or maintaining habitat quality will be to recreate or simulate previously existing hydrographic cues important to the survival of listed species. A first step is to establish a relevant benchmark that characterizes important cyclic phenomena. These cycles may not be apparent simply by looking at random blocks of a certain number of years, but rather by viewing historical running averages of various lengths in order to detect predictable cycles of wet/dry periods. With increasing observations of linkage between long-term oscillations in oceanic temperature and/or changes in climatic trends (e.g., Werritty 2002, Hannaford and Marsh 2006, and Maurer *et al.* 2004), it is increasingly important to understand regional runoff patterns (Kelly and Gore 2008). Maurer (2007) and Cayan *et al.* (2008) have done extensive modeling of potential climate change scenarios and could offer insights into changes in runoff that might affect management decisions.

The IRP suggests that a review of annual flow records to detect any predictable patterns influenced by the Pacific Decadal Oscillation (PDO) as well as consideration of proposed scenarios for climate change in California will be useful exercises to “fine-tune” future management options. This objective can be easily accomplished [and may have already been completed] through analysis of running averages of monthly flow records over 10, 20, 30 and 50 year periods in order to detect oscillations that drive long-term forecasts of water availability. It is likely, for example, that 10-year oscillations will parallel the PDO and longer oscillations may reflect more complex phenomena but will allow the development of wet-period and dry-period forecasting and management strategies.

The very dry 2013 hydrologic year, particularly following on the heels of a previously dry year in 2012, is an opportunity to refine long-term forecasting and management strategies, as the inclusion of these years will result in a downward trend in estimates of available water and a more realistic expectation of achieving the co-equal goals of water supply and resource protection under less than optimal conditions.

The analysis of data describing physical habitat characteristics important in sustaining populations of ESA target species in this very dry year also presents an excellent opportunity to identify marginal habitats that may be limiting the successful recovery of these species, and how the characteristics of those habitats are affected by RPA actions.

Sacramento River Temperature Task Group 2013 Technical Report for the Long-Term Operations BiOps

As in previous dry years, when temperature compliance points (TCP) could not be met downstream, they were moved upstream. This year was no exception and the TCP of 56º F was moved upstream to Airport Road Bridge, where there is no temperature monitoring station to verify that the TCP is even being met. A surrogate station at Balls Ferry is used to estimate water temperature at Airport Road. Riverine temperatures are monitored in one dimension longitudinally at discrete points, which does not account for spatial variation in temperature along a cross-section of the river, with depth, or due to springs (hyporheic flows from the streambed or adjacent upland) or various levels of shade provided by riparian vegetation in off channel habitats. Monitoring the spatial variation in water temperature could provide useful, even essential, information for water management aimed at maintaining or improving survival of salmonid early life stages. Given the apparent difficulty with achieving TCPs between Balls Ferry and Bend Bridge, there appears to be a need to reconsider requirements for TCPs farther downriver of Clear Creek, particularly where there is little overlap with the location of salmonid spawning sites and early life stages. The fact that the vast majority of salmon redds are located upriver of Balls Ferry only serves to support a focus on what can be accomplished in terms of water operations to maintain suitable spawning and early rearing habitat in areas that are being used by fish. Cold water storage that is conserved rather than released in unsuccessful attempts to extend TCPs farther down river than necessary to insure survival of developing embryos and alevins where redds are located, can be used to improve survival of juveniles during the summer months by reducing both temperature stress and the risk of stranding; that is, it may be a useful exercise to determine the location of the TCP by the downstream extent of a predetermined majority of potentially successful redds in both main-stem and secondary channels. See Appendix 3 for details of a heuristic model that should help to demonstrate this point.

The IRP suggests that the question of changing compliance points from a daily average temperature to a 7-day average daily maximum (7DADM) needs to be evaluated in the context of how it affects the location of the TCP as well as survival of salmonid early life stages. The current management scheme, based on daily average temperature, is potentially suboptimal because the location of the TCP is too far downstream, which then reduces the water available to address other mortality processes, e.g. redd dewatering and juvenile stranding (See Appendix 3). If the 7DADM metric effectively moves the TCP farther downstream (relative to the current average temperature location) and so requiring additional water, then the standard could be detrimental to both total fish survival and flexibility of Shasta operations. Alternatively, if the TCPs are allowed to change locations based on the availability of cold water resources, changing them from a daily average temperature to a 7DADM could even result in the TCP moving upstream. Therefore, until a model is developed and applied to consider tradeoffs in water allocations the IPR believes the effects of the temperature standard on fish is uncertain.

As noted by previous OCAP and LOO panels, decisions to augment or constrain water releases need to consider the coupling of hydrology and biology, including spatio-temporal impacts on adult selection of redd locations as well as survival of egg through early juvenile life stages. Some of these relevant issues are discussed in Appendix 5.

The Effect of TCD Hydraulic Operational Criteria on Storage of Cold Water

Constraints on Shasta operations that affected the use of the cold water resource within the reservoir were evident in WY 2013. According to the technical report:

"Because of the low storage and elevation at Shasta Reservoir this water year, Shasta Temperature Control Device (TCD) operational criteria limited Reclamation's flexibility with the TCD gate configurations. This reduced the temperature operation efficiency for a period in June 2013. In June, Reclamation was required to open all the middle shutters sooner than desired to meet hydraulic operational criteria. This was based on

the Shasta TCD operation manual, which states at water surface elevation 1010 feet, all middle gates are to be open to maintain proper submergence of the penstock intakes."

We note that operations to meet temperature criteria in June of 2013 (page 9) could not be optimized because of these operational restrictions. It may be useful to evaluate the likelihood of critical depletions more than 30 days in advance so that water deliveries can be scheduled over a longer time period and hence avoid the hydraulic operational criteria that have the net effect of forcing the inefficient use of cold water storage. In this recommendation, we assume that the need to invoke this operational criteria decreases with reductions in powerhouse discharge.

Use of HEC-5Q for Long Term Temperature Forecasts

The IRP understands that the quantity of cold water storage primarily in Shasta Reservoir, but also in Trinity and Whiskeytown Reservoirs determines the downstream extent of Sacramento River habitat that meets the temperature requirements of early life history stages of fall and winter-run Chinook salmon. Effective use of the cold water resource over an annual operational cycle to maximize survival benefits for fish requires accurate predictions and monitoring of: (a) reservoir stratification dynamics, (b) selective withdrawal characteristics of the reservoir outlets, and (c) water temperature dynamics of the upper river. The IRP was informed at the LOBO workshop that HEC-5Q was used to develop water flow and temperature management scenarios for consideration. HEC-5Q is a standard modeling tool developed by the Corps of Engineers to evaluate alternative operational plans. It can be used for short-term optimization (optimum blending of water from different reservoir strata to meet an immediate downstream temperature target) when combined with selective withdrawal capability. It can also be used for long-term optimization (i.e., determine release quantity and water temperatures to optimize reservoir storage) to meet long-term downstream temperature criteria. We have several comments related to the use of HEC-5Q to support water temperature management in the Sacramento River.

First, as with all models, there are tradeoffs between model accuracy and run-time. Models useful for optimization must be relatively simple to minimize the time required for multiple runs to converge on an optimal operation given a specific optimization function. We assume that the need for reduced run-time factored into the decision to use this model. However, some of the attributes of HEC-5Q that make it useful for long term operational optimization also increase the error of its predictions. While calibration details for the modeling were not provided, based on experience and expertise represented on the IRP, there are multiple sources of uncertainty that may affect the accuracy of the forecasts by as much as 2-3º C. Increased error in model forecasts increase the risk that incorrect water management decisions may be made. In the case of the HEC-5Q application, we note three attributes of the HEC-5Q application that likely affect forecast accuracy:

- The model was updated with meteorological conditions at 6-hour time-steps instead of 1-hr or even 3-hr updates. While longer time periods between updates will likely not affect prediction accuracy of reservoir stratification, they will likely affect the accuracy of river temperature predictions, particularly at lower flows or during high temperatures when salmon early life stages are most susceptible to temperature effects.

- The reservoir dynamics were simulated with a 1-D representation (vertical) whereas stratification and water quality dynamics within reservoirs are typically 2-D (longitudinal and vertical) although situations may occur were a full 3-D representation may be required. As a consequence, calibration parameters in a 1-D model must be adjusted to ranges outside of values that have physical meaning to “force” the 1-D model to calibrate to reality that is usually at least 2-D, if not 3-D. The amount of error associated with use of a 1-D model to simulate a reservoir depends upon the extent to which the 1-D assumption is violated.

- The river was simulated with a 1-D representation (longitudinal). This is likely the smallest source of error and may be negligible depending upon how the temperature calibration was performed. For example, if the riverine part of the HEC-5Q model was calibrated to accurately simulate low flow, summer time conditions then the simulations may be of acceptable accuracy. However, if the model was calibrated to minimize residuals (i.e., differences between predicted and observed water temperatures) over an annual cycle then the simulation accuracy may be reduced for the time periods that are most critical to salmon early life stages. In addition, the report mentions a number of ungaged and unmonitored tributaries downstream of Keswick Dam that may seasonally affect water temperature. The methods used to synthesize tributary flow and temperature should be reviewed to optimize forecast accuracy.

Next, while there is nothing inherently wrong with HEC-5Q we note that it is an older legacy model that, to our knowledge has not been updated for more than a decade. For purposes addressed in this review, a more current model such as CE-QUAL-W2 or a dedicated temperature model that can be run to support real-time operations (CE-QUAL-W2 can also be used for this purpose) may be more appropriate. Interestingly, CE-QUAL-W2 has been applied to Shasta Dam and the IRP wondered why it was not used to support management decisions that are based on downstream temperature and stage dynamics.

There seems to be suboptimal communication between field survey teams monitoring redd dewatering and juvenile stranding and group members who simulate water temperatures. Model selection and calibration should be coordinated within the SRTTG such that future temperature modeling and forecasting are configured, calibrated and optimized to accurately predict temperatures at TCPs located at different distances downstream of Keswick dam during critical salmon early life stages or alternatively to identify a TCP based on the distributions of redds.

Temperature modelers may wish to calibrate to extreme values/conditions in the Sacramento River instead of using standard methods to reduce deviations (differences between measurements versus predictions) over an annual cycle. That is, the ability to simulate temperatures around 40^{O} F is less important than the ability to accurately simulate temperatures around 55^{O} F. This can be done easily during calibration by weighting more heavily (e.g., doubling them) residuals associated with critical time periods when temperatures approach detrimental levels.

Another question of interest is also affected by the details of model calibration. The LOBO workshop presentation by Brycen Swart (NOAA Fisheries) included temperature measurements summarized as average daily water temperature versus a seven day running average of daily maximums (7DADM). There is typically about a 2^{O} F difference between the two temperature statistics which is likely consistent with the expected error in the river water temperature predictions from HEC-5Q. The selection of an acceptable maximum temperature measure that avoids deleterious effects on early salmon life stages, while minimizing demands on water resources, should include input from river water temperature modelers to ensure model accuracy during the months and flow conditions considered to be most critical to salmon survival.

The IRP noted that the extensive water temperature data collected by the California Department of Fish and Wildlife (CDFW) in connection with monitoring salmon redds did not appear to be integrated into the temperature modeling studies conducted by the BoR. It would have been useful to compare the measured temperatures obtained by the CDFW during redd dewatering/stranding studies to the predictions made by HEC-5Q to get a better idea of the differences between predicted and observed water temperatures.

NMFS seemed most interested in how water releases affected seasonal variation in water depth as it pertains to redd dewatering and juvenile stranding. HEC-5Q (or a future model) can output both stage and depth. The IRP considered ways that the output of both stage and discharge estimates could be coupled to survival of early life stages associated with dewatering/stranding of redds and juveniles (see Appendix 3 of this report).

Better Integrating Long-term Forecast Simulations with Real-Time Operations

Reservoir operations currently appear to be based on relatively long-term simulations derived from data and hydrologic models from the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC) but many of the issues addressed by the Sacramento River Temperature Task Group (SRTTG) require short-term remedies using real-time operations at Shasta, Trinity, and Whiskeytown Reservoirs. The SRTTG seems to be largely operating in a reactive adjustment mode as a means of meeting RPA targets. For example, TCPs in any given year are reset depending on the availability of cold water storage in reservoirs, but ultimately are expected to meet 10-year running average expectations at multiple riverine locations (Clear Creek, Balls Ferry, Jelly's Ferry and Bend Bridge). In WY 2013, a 56º F TCP was set at Airport Road Bridge, where there is no RPA requirement to meet any 10-year running average success criterion. The SRTTG annually recommends a TCP point that, given available cold water storage, is feasible for the longest river reach that could provide salmonid spawning habitat regardless of where active spawning is occurring. Long-term forecast simulations were apparently inadequate to support more strategic use of the cold water resource during the dry 2013 WY, if in fact there even were a more effective way of managing reservoir operations. Inter-annual variability in the seasonal amount and spatial distribution of precipitation in the region presents a serious forecasting challenge.

It appears that the real-time operations needs of the SRTTG and the long-term forecasting of USBR are not well interfaced, and perhaps there is an opportunity here to collaborate on development of an integrated long-term forecasting and real-time operations capability. For example, the present *ad hoc* temperature monitoring system does not include a station at Airport Road Bridge. This could easily be remedied and such collaboration would increase the accuracy of temperature forecasts and provide increased lead time prior to water crisis situations thereby potentially increasing the efficiency with which the cold water resource can be managed to enhance survival of salmonids as suggested in Appendix 3 of this report.

Critical elements of an improved real-time monitoring system would include at least: (a) one or more automatic temperature profilers within Shasta Reservoir to describe temperature stratification patterns near the dam; (b) real-time temperature reporting sondes located at points within the Sacramento River channel and significant tributary mouths; (c) real-time calibrated reporting stage monitors, and (d) a dedicated high resolution temperature forecasting model that can be used in near-real time to forecast and evaluate downstream temperatures, stages, and discharges based on different scenarios of dam releases, release temperatures, and range of anticipated meteorological conditions. The real time model, coupled with reporting temperature and stage monitors, will help ensure that the cold water resource within the three reservoirs is used as efficiently as possible to protect fish and allow flexibility in water operations.

Establishing a real-time modeling capability requires additional information. For example, transects of channel and flood plain morphology at key locations at known spawning habitats should be surveyed if such information does not presently exist. Annually collected low flow light detection and ranging (Lidar) data for the reaches below Keswick dam to Red Bluff diversion dam (see Fig. 1 in Revnak and Killam 2013) could be used to develop a Digital Elevation Model (DEM) to feed into existing hydraulic models. The DEM in conjunction with stage-discharge and temperature relationships could be used to evaluate the likelihood of stranding and dewatering over all discharge regimes and as spatial distribution of spawning and rearing change from year to year.

In addition, the IRP supports continued and expanded monitoring of redd dewatering and juvenile stranding and suggests that the teams place temperature/water level sensors in redds and important juvenile rearing habitats. This will allow a retrospective analysis of modeling and application of water flows intended to benefit the species of interest over their riverine life cycle stages. Then the important question of how many fish benefit from the water management can be addressed so that informed decisions can be made to maximize protection of salmon redds and low flow juvenile salmon habitat. With this type of assessment informed decisions about moving TCP can be made in keeping with RPAs, which are aimed at protecting fish not simply meeting TCP goals.

Consideration of River Water Temperature Dynamics

In general, the SRTTG seems to consider river water temperatures in a simplistic way as though water temperatures are laterally and vertically homogeneous within the river corridor. It would be desirable to measure the spatial variability of temperature and water level relative to critical spawning and rearing habitat, including secondary channels (see Appendix 5). Future temperature dynamics studies within the river corridor should include monitoring temperatures in the main channel, secondary channels, hyporheic (within the gravel) zones, secondary channels, and tributaries.

Loss Estimation for Listed Anadromous Species

The technical team (TT) uses Jahn's (2011) simple model to estimate fish loss*:*

$$K = G\text{-}H = H/S\text{-}H$$

where K =loss, G=entrainment, S=survival proportion, and H=salvage.

Given that entrainment cannot be measured directly, there appears to be no other means of estimating loss except from observed (expanded) salvage and an assumed survival rate, even though this may compromise the accuracy of the total loss estimate if entrainment (or losses associated with it) are large or highly variable. Setting the entrainment issue aside for now, the IRP also had several concerns with the implementation of the loss model and with estimates of its uncertainty:

a) characterizing S as a fixed parameter leads to underestimates of total loss,

b) characterizing the uncertainty of *S, H, G, and K* by standard errors understates their true variability,

c) Equations 8 and 9 of Jahn's (2011) error propagation method are incorrect, and

d) Jahn's (2011) model fails to account for probable losses associated with zero salvage, further negatively biasing its loss estimates.

See Appendix 2 for a more detailed explanation of the concerns and some recommendations for resolving these issues. Appendix 2 includes several suggested ways to reduce the bias of the loss estimates and increase the realism of their uncertainties, including: a) modeling S to realistically vary over short time scales (daily, weekly), b) estimating annual loss as the sum of daily losses, c) treating G and K as random variables whose uncertainties are estimated via Monte Carlo simulation rather than closed-form error propagation, and d) using a Bayesian method to estimate the probable losses associated with zero salvage. Finally, we suggest statistical strategies for making RPA-triggering decisions based on daily loss estimates, in the face of high uncertainties in those estimates.

Delta Water Operations and Delta Smelt Protective Actions

The seasonal distribution of precipitation in the Central Valley watersheds in WY 2013 resulted in a distinct "first flush" event, which has not been as discretely discernible in previous years. The Smelt Working Group (SWG) thus had some information to alert them to a potential trigger for spawning migration that could place some portion of the pre-spawn adult delta smelt population in a location that would make them susceptible to entrainment into the pumping facilities. By mid-December delta smelt were appearing in salvage and the USFWS determined that OMR flows should be constrained under RPA Action 1. This was the first time that Action 1 had been applied to protect pre-spawn delta smelt and when negative OMR flows were reduced, the number of salvaged delta smelt declined, totaling 86 between December 12 and January 1. The continued presence of delta smelt in the central and south Delta led to the implementation of continued – albeit more relaxed - constraints under subsequent RPA Action 2 in January, which was associated with another 146 delta smelt in expanded salvage, for a total of 232 by February 2, 2013. This level of take remained below the revised allowable incidental take value of 362 for WY 2013.

Recent efforts to understand the population dynamics of delta smelt using an individual-based modeling approach (Rose et al. 2013a, b) have suggested that multiple factors (e.g., temperature, stage-dependent growth rates, entrainment into water operations, etc.) are important in determining the inter-annual abundance of this species in the estuary but the importance of key factors may vary among years (i.e., wet versus dry). However, Rose et al. 2013a also cautioned that their model was not designed to forecast future delta smelt population abundance.

The IRP continues to believe that discerning behavioral responses of delta smelt to tidal oscillations (e.g., Feyrer et al. 2013) and perhaps associated turbidity changes is crucial for understanding delta smelt movements and spatial dispersion, which has potential consequences for affecting the level of fish entrainment at the Delta pumping facilities. Reliance on salvage to estimate delta smelt mortality associated with water operations remains a concern of the IRP. New information about potential losses associated with entrainment at the pumping facilities (e.g., Castillo et al. 2012) suggest that the determination of allowable incidental take even from extended salvage estimates may underestimate actual facility impacts on this species.

The IRP also continues to believe that the use of particle tracking models may not adequately capture the behavioral responses of delta smelt to important migration cues. Reliance on turbidity measures associated with discrete "first flush" events to predict delta smelt migration is risky because these events vary in intensity and annual occurrence. Furthermore, delta smelt tend to be distributed within the water column during incoming tides and move to the bottom and shallow channel edges during ebb tides (Feyrer et al. 2013) as a means of maintaining their position within the estuary.

Lacking convincing evidence to the contrary, it seems counter-intuitive that an annual species such as the delta smelt would have evolved to depend for its survival on temporally unreliable environmental cues to trigger migrations associated with crucial life cycle events such as spawning or selection of nursery locations. Perhaps turbidity cues are more obvious to the smelt than to human observers, but the smelt are not making decisions about water operations.

See Appendix 4 for a discussion of delta smelt behavior and a potential approach for developing preemptive actions to reduce entrainment.

IRP RESPONSESTO QUESTIONS DEFININGTHE SCOPE OF THE 2013 LOBO ANNUAL REVIEW

Responses to questions regarding Sacramento River Temperature Task Group 2013 specific questions

1) **How well did implementation of the RPA actions meet the intended purpose of the actions?**

When the intended purpose of an RPA action is to meet a very discrete objective, it is relatively easy to decide if the intended purpose is met. For example, Action I.2.2.A requires USBR to convene a group to consider a range of fall actions if the end of September storage is 2.4 MAF or above. This was the case in WY 2013, so this action met its intended purpose in WY 2013. Other examples are not so clear, especially when only certain portions of the intended purpose are either met or not achieved. For instance, part of Action 1.2.4, which deals with the development and implementation of a Keswick release schedule, requires that USBR fund an independent modeler to report on temperature management and recommend refinements by March 2010. This has yet to occur, so the intended purpose of this portion of Action 1.2.4 has not been met.

Determining the successful implementation of other aspects of Action 1.2.4 may depend on whether one perceives the intended purpose of the actions as meeting a physical target or having a desirable biological effect on salmonid populations. It continues to be difficult, if not impossible in dry years (such as WY 2013), to meet TCPs as one moves farther downriver, but based on modeling water temperatures and using a surrogate monitoring station at Balls Ferry, it appears that an average daily temperature of 56º F can be maintained at Airport Road Bridge. However, this has yet to be demonstrated with *in situ* measurements.

TCPs are also intended to be measured on the basis of a 10-year running average at multiple locations, but this is only the fourth year they have been in place. Thus, it is not possible to determine if TCPs are even meeting their intended site-specific targets. One complication with using Airport Road Bridge is that it was not one of the original locations specified in the RPAs and there is no temperature monitoring station at that location, which will make it difficult to include in a 10-year running average. Finally, the link between RPA actions and survival of salmonid early life stages remains elusive, but see Appendix 3 of this report.

Aspects of other RPA actions (e.g. I.2.3.A) were clearly the result of compromises that seemed to favor water operations over the requirements of the fish populations, at least as viewed by the fish agencies. While the fish agencies expressed a desire to maintain Keswick releases at 4500 cfs to avoid dewatering redds and stranding juvenile Chinook salmon, releases were ramped down from December through mid-February to 3800 cfs. While this was 550 cfs higher than desired by USBR, it was 1250 cfs lower than what the fish agencies considered necessary for salmonid protection. In such an instance, it is impossible to make an assessment as to whether or not the intended purpose of an RPA action was met.

2) **How effective was the process for coordinating real-time operations with the technical team's analyses and input as presented in the NMFS' Long-term Operations BiOps?**

Six meetings were convened to discuss cold water reserves that could be allotted to maintain TCPs and desirable river stage levels in the Sacramento River. However, there is little evidence to suggest any of the operations had a significant positive or detrimental effect on Sacramento Chinook populations (dewatering of some redds notwithstanding), nor was any evidence presented on how water transfers from Trinity to Shasta Lakes might be affecting salmonids in the Trinity River. Consequently, the IRP was unable to provide an objective answer to this question. Meetings were held, technical teams provided input and USBR made water operation decisions that were affected by considerations extrinsic to those that were part of the process to which the question pertains.

3) **Were the scientific indicators, study designs, methods and implementation procedures used appropriate for evaluating the effectiveness of the RPA actions? Are there other approaches that may be more appropriate to use?**

No. Spatial variation in water temperature and river stage needs to be better addressed within the context of impacts on salmonid spawning habitat and early life stage impacts of water operations. Deployment of water level loggers and temperature probes in spatial arrangements that are relevant for addressing the question of how flow regulation impacts fish is seemingly a requisite first step. Modeling alone may not solve the problem without accurate on the ground measurements.

Currently the ability to meet the TCPs is a central measure of the effectiveness of the RPA Action I.2.1. The IRP postulates that a more effective measure might be developed by integrating information on the spatial/temporal distributions of salmon during critical freshwater life stages into the TCP decision. Instead of meeting a TCP, consider a model-derived estimate of salmonid freshwater survival. As demonstrated in Appendix 3, such a measure might improve fish survival and flexibility in storage water operations. The IRP understands moving away from the current TCP measure would affect reservoir operations. Given the implications, the IRP suggests that NOAA form a working group to consider this issue.

4) How can implementation of RPA actions I.2.1. – I.2.4. be adjusted to more effectively meet their objectives?

Aquatic biota key to local geophysical dynamics and geospatial complexity. These factors are not reflected in the RPA actions, with the result that the river corridor of the upper Sacramento River is treated as a homogeneous system. By default, management actions are restricted to adjusting flow and release rates in attempts to meet a TCP based on storage of cold water in the upstream reservoirs. Substantial opportunities for salmon recovery and conservation may be realized by considering geophysical dynamics and geospatial complexity. For example, 29 of 45 redds pictured in Revnak and Killam (2013, Appendix D) were located in secondary channels. Environmental conditions (particularly temperatures) in the secondary channels can be substantially different than those in the main channel. Also, substantial numbers of juvenile Chinook were either stranded or in jeopardy of stranding in secondary channels and marginal riverine habitats. Although total juvenile abundance was not monitored, these shallow marginal habitats and secondary channels are certainly used by juvenile salmon. NMFS should consider adjusting RPA actions 1.2.1 - 1.2.4 so that redd location and juvenile abundance are better related to temporal and spatial patterns in habitat quality (e.g., water temperature, depth, and velocity pattern) at the scale salmon life stages respond to their environments (see Appendix 5).

In the SRTTG report and presentation at the LOBO workshop in Sacramento, there was a proposal to change the nature of the temperature compliance points from daily average values to 7DADM. There may be good biological justification for considering this depending on how sensitive early life stages are to brief exposures to suboptimal, or even lethal, temperatures. There is some evidence that the 7DADM may better protect salmon early life stages from negative effects of temperature spikes than does an average daily temperature TCP. However, the specific temperature of a TCP based on daily maxima was not suggested. If the intent is to use the same value (56º F), the effect of using the 7DADM would be to move the current TCP (daily average temperature) downriver at considerable cost in cold water resources with little improvement in early life stage survival if the distribution of redds continues to remain upriver of Airport Road Bridge. Alternatively, if the intent is to set a higher temperature (i.e., > 56º F) for a daily maximum-based TCP, there may be little or no effect on location of the current TCP, or it could even move upstream. In any case, it is important to consider inter-annual variation in cold water storage and the trade-offs associated with adopting a 7DADM TCP (or a different duration of running average) as the preferred maximum thermal threshold for insuring survival of salmon early life stages. These trade-offs are considered by the IRP in Appendix 3 of this report.

Responses of 2013 IRP to questions regarding Chinook, steelhead and green sturgeon loss estimation at the Delta Pumping facilities

1) **Are the technical work team's proposed equations for estimating loss supported by current science?**

Mostly. However, the direct application of the equations to annual salvage creates a bias. Overlooking the losses associated with inserted zeros creates additional bias in the loss estimates. Additional modeling research may be needed to devise the most accurate (least biased) loss estimates.

2) **Are the technical work team's proposed equations for estimating annual loss confidence intervals scientifically appropriate?**

No. Uncertainty has been modeled in terms of standard errors (SE) of fixed parameters. This approach greatly understates the true uncertainty. Also, an error propagation method was used to estimate the SE of loss from the SEs of survival and salvage. Two of Jahn's (2011) equations (8 and 9) for this propagation are incorrect. The IRP proposes modeling salvage, survival, entrainment and loss as random variables, and estimating the mean and standard deviation of daily and annual losses via Monte Carlo simulation instead of closed-form error propagation.

3) **Which, if any, of the proposed terms in the technical work team's equations introduce the greatest uncertainty? How might these formulations be improved in the future?**

The greatest uncertainty is due to the survival proportion, and to the lack of direct measures of entrainment. The IRP suggests additional research to better characterize whole-facility survival, as a function of season, flow, temperature and other relevant factors. Appendix 2 of the present review report includes a Bayesian model for loss estimation which has the ability to incorporate independent knowledge about entrainment, if and when such knowledge becomes available.

4) Which, if any, data inputs in the technical work team's equations are likely to reduce accuracy in their estimates?

The current assumptions about zero data values for salvage leads to a negative bias in daily and annual loss estimation. Appendix 2 suggests a correction for this bias. The unrealistic assumption of a single, fixed value for survival creates an additional negative bias for annual loss.

5) Are ongoing studies sufficient to gather data needed to calibrate coefficients and terms in the loss equations? What changes to ongoing studies or recommendations for future studies are needed to gather data to measure coefficients and values in the equations' terms?

The concept of coefficients that can be calibrated, and of model parameters with standard errors, is not a realistic framework for modeling survival rate, entrainment, and loss. Realistically, these quantities vary widely and unpredictably over time. The IRP suggests viewing these quantities as random variables and modeling their distributions, as is done by Cramer Fish Sciences (2013). A careful synthesis of previous mark-recapture experiments that estimate whole-facility survival (e.g., Clark et al. 2009), along with additional novel experiments, may be the most effective path to estimate survival distributions and to model the effects of factors that control survival. In addition, research aimed at directly measuring entrainment is encouraged. Even if resulting measurements are crude, they can increase the accuracy of loss estimates via the Bayesian model described in Appendix 2.

6) Given the importance of the hypothesized relationship between water velocity and facility efficiency for salmonid salvage, what scientific study designs and methods might be appropriate to investigate how this relationship could be incorporated into whole facility survival estimates?

Given the limited potential to manipulate exports for the purposes of conducting controlled experiments aimed at establishing a relationship between water velocity and whole facility survival rates, controlled flume studies may provide a portion of the answer. However, it will be difficult to simulate realistic conditions that capture all of the variables that determine whole facility survival. For example, the effects of predator fields associated with the facilities would be particularly difficult to simulate. In order to accurately determine whole facility survival rates, it is important to determine whether or not there is even a relationship between salmonid salvage and entrainment survival (mortality). Perhaps this could be addressed with carefully designed mark-recapture experiments conducted over multiple but relatively short-term periods of controlled water export pumping that would not interfere with total exports. For example, low and high water velocity runs could be alternated in experimental runs such that average weekly (or monthly) exports were unaffected while monitoring the recapture (in salvage and escapement – i.e., *sensu* fish overcoming the influence of entrainment flows and migrating out of the area) of marked fish released at the point where they would be initially entrained into the pumping facilities.

7) **What additional studies should be seasonally, annually, or semiannually completed to increase the accuracy of estimates of loss for green sturgeon?**

So little is known about the life-history of the green sturgeon that any studies shedding light on this species' responses to physical habitat variables (velocity, depth, substrate, cover, and complex hydraulics), particularly during its early life stages are likely to be useful.

8) **How well is the genetic information used in the technical work team's equation for estimating loss of winter run Chinook?**

With the information provided, it is difficult to determine the effectiveness of the genetic information.

9) **What sampling design provides the most accurate approach for characterizing the presence of genetic winter run Chinook salmon occurring inside and outside the Delta model winter-run size category?**

The IRP was not provided with alternative approaches to consider and is reluctant to suggest novel sampling designs at this time. However, the ability to separate cohorts associated with different salmon runs from overlapping size distributions seems to be at the core of this issue. There are algorithms and software packages that may assist in separating these cohorts with an assignable probability of goodness of fit (e.g., legacy software MIX Program v. 3.1, and the more current mixdist; for details see http://ms.mcmaster.ca/peter/mix/mix31.html and http://cran.r-project.org/web/packages/mixdist/mixdist.pdf). In practice, fitting mixed distributions can be more of an art than a science, but the more information that one has at the start, the better the chances of successfully distinguishing cohorts among mixed size distributions. In this regard, the genetic information available on winter-run Chinook salmon could be applied in retrospective analyses to test the accuracy of this approach.

Responses to questions regarding the retrospective analysis of water operations and delta smelt protective actions taken during December – June of WY 2013

1) **How well did implementation of RPA Action 1 meet the intended purpose of the Action?**

The information necessary to answer this question is incomplete. The outcome in the absence of the Action cannot be determined. The answer also depends on the intended purpose of the Action.

If the intent was to prevent exceedence of the allowable incidental take of delta smelt, then the answer is a qualified "maybe" because incidental take was not exceeded. However, this conclusion should be viewed in light of observations from previous years when incidental take limits also were not exceeded even though Action 1 was not implemented. Take limits were not exceeded in any of the past four water years and Action 1 was not implemented in three of the four years. Consequently, there is no apparent association between the implementation of Action 1 and whether or not the calculated allowable incidental take is exceeded. What might have happened if Action 1 was not implemented in WY 2013 is simply conjecture.

If the intent of Action 1 is to protect the delta smelt population from impacts of water pumping operations, there is little on which to base a judgment. Incidental take is calculated from historical delta smelt salvage (Cumulative Salvage Index, CSI) and no clear relationship has been demonstrated between salvage and total mortality of pre-spawn adults attributable to pumping operations. For example, if recent studies (e.g., Castillo et al. 2012) are any indication, entrainment mortality may be substantially greater than previously envisioned. That is, salvaged delta smelt may represent a very small percentage of actual "take" (loss) associated with water operations. Also, allowable incidental take is calculated using a measure of estimated relative population size (i.e., the Fall Midwater Trawl Index) that may not be reliable. The Fall Midwater Trawl was not designed to collect delta smelt and any assumed relationship between the abundance index based on those collections and the actual size of the smelt population is questionable at best. This is interesting in light of the fact that larger salvage values in the past can determine the current allowable take limits. For example, this year the allowable take of adult delta smelt (not including losses other than extended salvage) was originally calculated as 305, but an error discovered in the value for salvage in the 2006 WY resulted in a revised allowable take value of 362, an increase of nearly 20% based on a revised single value of salvage from seven years ago.

2) How can implementation of RPA Action 1 be adjusted to more effectively meet its objectives?

Without knowing the effectiveness of RPA Action 1 (see answer to the previous question) it is difficult to suggest a means of improving effectiveness. At the LOBO Workshop in Sacramento this year, earlier implementation of Action 1 was proposed as a means of providing preemptive protection for delta smelt while at the same time allowing for greater subsequent water exports; essentially, the proposal was to increase efficiency of delta smelt protection. The IRP agrees, in concept, that a more aggressive and preemptive implementation of Action 1 is worth developing. See Appendix 4 for a discussion of delta smelt behavior and movements that the IRP offers as straw-man guidance in the development of an improved implementation procedure for Action 1 that may provide more preemptive protection for pre-spawning adults.

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APPENDIX 1 – Materials for 2013 IRP Review

Review Materials Available to the 2013 LOBO Independent Review Panel

I. The following documents were provided in electronic format as required reading by the IRP prior to the 2-day workshop in Sacramento, CA on 6-7 November 2013:

1) Sacramento River Temperature Task Group 2013 Technical Report for the Long-Term Operations BiOps Annual Science Review

2) Chinook, Steelhead, and Green Sturgeon Loss Estimation for Skinner Delta Fish Protective Facility and Tracy Fish

II. The following document was provided to the IRP with a delay resulting from the federal government shutdown in early October 2013 and, as a consequence, it was left to the discretion of the 2013 IRP to address in the annual review:

1) Retrospective Analysis of Water Operations and Delta Smelt Protective Actions Taken in Early Water Year 2013

III. ***The following additional reports were made available in electronic format for supplemental use in providing historical context for the IRP***:

- Jahn, A. 2011. An Alternative Technique to Quantify the Incidental Take of Listed Anadromous Fishes at the Federal and State Water Export Facilities in the San Francisco Bay-Delta Estuary. Kier Associates, Ukiah California. Prepared for National Marine Fisheries Service, Central Valley Office. (http://www.kierassociates.net/Kier%20Assoc_OIA%20TO%203062_Incidental%20take%20at%20the%20Delta%20pumps_final.pdf)
- American River Group (ARG) Annual Report of Activities
- Stanislaus Operations Group (SOG) Annual Report of Activities
- Delta Operations for Salmonids and Sturgeon Group (DOSS) Annual Report of Activities
- Interagency Fish Passage Steering Committee (IFPSC) Annual Report of Activities
- The Smelt Working Group (SWG) 2013 Annual Report of Activities

Additional background information from the Science Program website was also available, including the RPA Summary Matrix of the NMFS and USFWS Long-term Operations BiOps RPAs and reports for previous IRPs.

APPENDIX 2 – Accuracy and Precision of Loss Estimates for Chinook Salmon, Steelhead and Green Sturgeon at the Skinner and Tracy Fish Facilities

The draft (Sept. 30, 2013) of this loss estimation report (hereafter "LER") describes an approach for estimating annual loss, and its uncertainty, of anadromous fish species at the two pumping facilities.

To estimate annual loss and its uncertainty, LER used the general loss model of Jahn (2011), with some changes in values of model parameters. The IRP has several statistical concerns and suggestions related to the Jahn (2011) approach, as detailed below. As a result of these concerns we believe that the underlying statistical model for loss estimation requires further research and development.

Jahn's (2011) simplified model for estimating loss:

For a single species and one pumping facility, Jahn's (2011) loss model is:

$$K = G - H = H/S - H \tag{1}$$

where:

K = Total number of fish lost over a time period.

H = Total expanded salvage over the period, equal to the sum of the 2-hourly expanded salvages within the period.

$G = H/S$ = Total number of fish entering the facility ("entrained"), whose survivors were salvaged during the period.

S = Survival proportion for the period, defined here as the proportion of entrained fish that navigate the facility and enter the holding tanks alive during the salvage period.

Comments on loss estimation:

1. Equation 7 of Jahn (2011) has an unrealistic assumption

Jahn's (2011) Equation 7 (hereafter Equation J-7) estimates the standard error of G (hereafter, SE(G)), as a function of S, H and their standard errors. Equation J-7 is an application of a widely-used error propagation method, often called the "delta method" (Rice 1988).

The IRP has two principal concerns about Jahn's (2011) interpretation of Equation J-7:

a) Equation J-7 gives an approximate, not an exact, estimate of SE(*G*). The approximation can be poor, especially for a highly nonlinear function like *G* = *H/S*, unless random values of *S* vary closely around their mean value.

b) Jahn (2011) assumes that the covariance between *H* and *S* is 0, hence his omission of the covariance term from Equation J-7. Jahn (2011) makes this assumption because there is no obvious way to estimate the covariance. However, salvage is the causal result of survival operating on entrainment, that is, *H*= *G*S*. Thus, there must be a sizeable, positive covariance between *H* and *S*. Setting this covariance to zero will result in the estimated SE(*G*) being too large, as Jahn (2011) notes. Although this strategy is conservative from a policy perspective, it is nevertheless unrealistic and merits further research.

2. **Equation J-8 is incorrect.**

The correct expression is (Rice 1988, p. 124):

$$SE(K) = \sqrt{\left(SE(G)\right)^2 + \left(SE(H)\right)^2 - 2COV(G,H)} \qquad (2)$$

Thus, the correct value of SE(*K*) is probably larger than the incorrect estimate given by Equation (J-8). Again, there is no estimate for the covariance, COV(G,H). However, since *G*= *H/S*, one would certainly expect *G* to covary positively with its numerator, H. Thus, it is unrealistic to assume that COV(*G,H*) = 0.

The unknown covariance in Equation 2 can be avoided by applying the error propagation method to the full loss expression, that is, to *K* = (*H/S* – *H*). From the formula for the approximate variance of any function of two random variables (Rice, 1988, p. 146), we can derive

$$SE(K) \approx \sqrt{\frac{(1-S)^2}{S^2}\left(SE(H)\right)^2 + \frac{H^2}{S^4}\left(SE(S)\right)^2 - 2\frac{H(1-S)}{S^3}COV(H,S)} \qquad (3)$$

Equation 3 replaces the incorrect, 2-step estimate of Equations J-7 and J-8. As the "≈" indicates, the error propagation method gives only an approximate estimate of SE(*K*).

Equation 3 still contains the unknown, and non-negligible, covariance, COV(*H,S*). However, as Jahn (2011) did with Equation J-7, setting this covariance equal to 0 gives a conservative (largest possible) estimate for SE(*K*). If the technical team continues using the error propagation method to estimate SE(*K*), then it seems appropriate to abandon Equations J-7 and J-8, in favor of Equation 3, while making some reasonable assumption about the value of COV(*H,S*). Below, we suggest how to estimate the uncertainty of annual loss without using the error propagation method.

3. Equation J-9 is incorrect.

The correct formula is (Rice, 1988, p. 124):

$$SE(K_{total}) = \sqrt{\left(SE(K_1)\right)^2 + \left(SE(K_2)\right)^2 + 2COV(K_1, K_2)} \tag{4}$$

In this case, it may be reasonable to assume that COV(K_1,K_2) = 0, signifying that loss estimates from the two pumping facilities are mutually independent. Equation 4, rather than Equation J-9, should be used to calculate the SE of the total loss estimate. Below, we suggest an alternative approach for estimating K_{total} and its uncertainty.

4. Time scale for loss estimation.

Jahn's (2011) approach applies Equation 1 to estimate the total annual loss, and its uncertainty, as follows: First, accumulate daily (or 2-hour) estimates of expanded salvage over the year, to estimate total annual salvage (*H*). This *H* estimate, along with a single value of *S*, are inserted into Equation 1 to yield a point estimate of total annual loss. Jahn (2011) then uses Equations J-7 to J-9 to estimate the SE of annual loss, based on the point estimates of *H* and *S* and their SE's.

However, the technical team also applies Equation 1 to daily salvage, thus estimating daily loss in real time, as described in CFS (2013). The daily loss estimate can potentially trigger an RPA action.

As an alternative to Jahn's (2011) approach, daily loss estimates could be summed over the year to estimate annual loss. An annual sum of daily loss estimates will be more accurate than Jahn's approach, for two reasons. First, a daily loss estimate more accurately represents the loss "process" experienced by individual fish, which spend only a few days to a few weeks moving through a pumping facility (e.g., Clark et al. 2009, Table 16). Second, daily loss estimates enable one to model *S* more realistically, as a random variable with substantial variation over time. With the present LER approach, summed daily losses will exactly equal their annual loss estimate, because the daily and annual estimates use the same, single value of *S*. However, if *S* is more realistically assumed to vary on a daily basis, then the two approaches will generally yield quite different annual loss estimates.

To demonstrate this, we carried out a Monte Carlo simulation using the framework of CFS (2013), in which daily salvage and daily survival proportion are modeled as random variables:

A. Expanded salvage statistics from Table (J-12) were rescaled to model daily salvage as a negative binomial random variable, with mean and standard deviation (not standard error) of 0.94 and 2.51 fish, respectively. It was assumed that the Table (J-12) data extended over 180 days (the actual period length is unclear from the table).

B. Survival proportion for any week was modeled as a normally-distributed random variable, with mean = 0.33 (Jahn's (p.20) high estimate)) and standard deviation (not standard error) of 0.10 (Clark et al. 2009, Table 12).

C. We generated 100 data sets, each with 180 daily values of salvage and survival proportion, by taking independent random samples from the distributions in A and B.

D. For each data set, the total 180-day loss was estimated in two ways:

  a) The 180 daily salvages were summed to estimate whole-period salvage. Then Equation 1 was applied, with S = sample mean of the 180 daily survival proportions. This simulates Jahn's (2011) approach, yielding an estimate of total loss over 180 days.

  b) The 180 daily losses were estimated by applying Equation 1 to the random daily values of salvage and survival proportion. Daily losses were then summed over 180 days to estimate total loss.

Results: Figure A2.1 below plots the 100 pairs of estimates of the total 180-day loss. A single point on the plot shows 2 estimates (a and b) derived from exactly the same set of 180 daily salvage values and 180 daily survival proportions. The straight line is the 1-1 line.

As the plot suggests, the annual sum of daily losses usually exceeded the Jahn-model loss. In fact, this occurred for 93 of 100 synthetic data sets, and by a mean exceedance of 142 fish. The annual sum of daily losses also had greater variability (SD=323 fish) over the 100 data sets than did annual loss from the Jahn model (SD=68 fish).

For each data set, the total salvage (180-day sum of daily salvage) was identical for both estimation methods. Thus, the differences in Figure A2.1 are due entirely to the effect of allowing S to vary daily, rather than assume a single mean value of S for the 180-day period. The negative bias in the Jahn estimate, relative to the summed-daily-

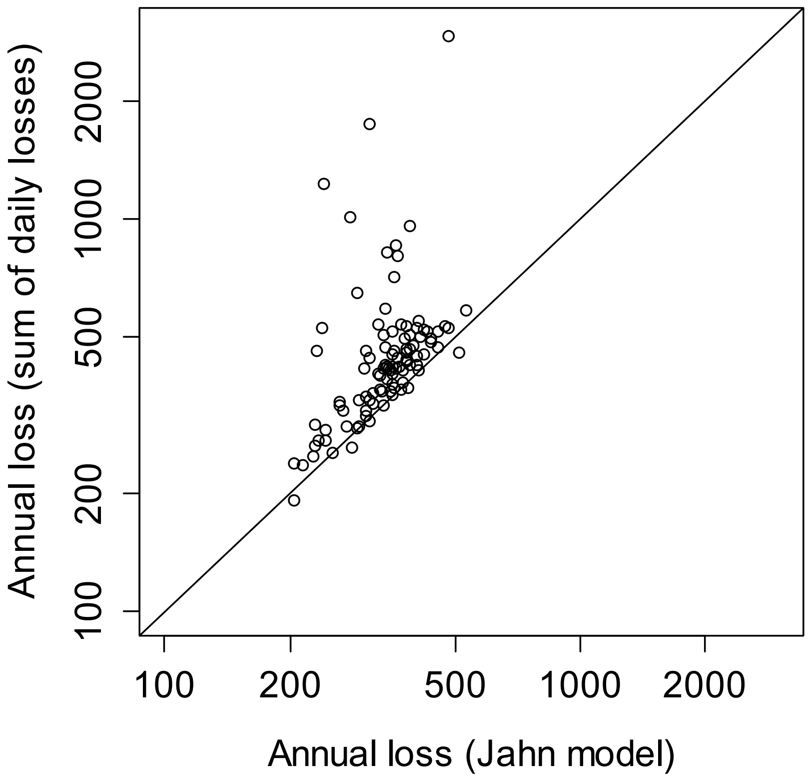

Figure A2.1. Plot of annual loss calculated as sum of daily loss estimates versus annual loss estimated from the Jahn model

loss estimate, can also be theoretically predicted from the nonlinear role of *S* in Equation 1 (Jensen inequality: Mood et al. 1974). Thus, a pattern somewhat like Figure A2.1 will be seen regardless of the particular distributions and the shorter time scale (daily, weekly, monthly) that is used to model survival and salvage.

Figure A2.1 does not reveal which of the annual loss estimates (Jahn model versus summed daily loss) is closest to the true annual loss. However, summed losses from shorter time periods (daily? weekly? biweekly?) should be more accurate than Jahn's whole-period loss estimate for the reasons given above.

5. **The Jahn (2011) model does not account for probable losses associated with zero observed salvage.**

Jahn (2011, p.8-9) inserts zero-count values of salvage into the raw 2-hour-sample data set for selected 2-hr sampling periods, during which fish might well have entered the facility, based on factors like season, flow, and recent nonzero salvage. This seems to be a sensible approach. However, Jahn assumes that these inserted zeros do not contribute to the annual or daily loss estimates. We believe that this approach overlooks the probable fish loss that is associated with zero observed salvage, resulting in underestimates of loss.

Suppose a particular 2-hr sampling period has zero salvage (H=0). According to Equation 1, $G = H/S$. Thus, the Jahn (2011) approach also assumes that a zero salvage estimate for the period is the result of zero entrainment (G=0) associated with that period. And, it is true that if G=0, then H must be 0. However, it is also possible that some small, nonzero number of fish could have been entrained (G>0), and all of them were ultimately lost, resulting in H=0 for the period.

For example suppose G = 3 fish are entrained, and assume that S = 0.20, that is, 20% of entrained fish survive. For a small number of fish, S is more accurately interpreted as a survival probability, that is, each entrained fish has a 20% probability of surviving. Assuming independence of individual fish, the probability that none of the 3 fish survives is equal to the probability that all 3 are lost, which is given by:

$$\text{Prob (0 survivors)} = (1-S)^3 = 0.8^3 = 0.51 \qquad (5)$$

In other words, there is about a 50% chance that all 3 entrained fish will be lost, resulting in a salvage of 0 fish. Jahn's model fails to account for this possible loss.

One might argue that Jahn (2011) accounts for the zero-salvage probable losses by allowing them to contribute to an increased standard error in annual salvage, and hence to an increased standard error of annual loss (SE(K)). However, Jahn (2011) uses SE(K) to construct a two-sided, symmetric confidence interval around the point estimate of K. But in reality, the zero-salvage probable losses create a one-sided bias -- their omission can only create an underestimate of annual and daily losses.

We can estimate the probable loss associated with zero salvage. Equation 5 is an example of calculating Pr(H=0 | G=3), the conditional probability of obtaining zero salvage, given that 3 fish were entrained. However, we now need to calculate the conditional probability that 3 fish were entrained, given that the observed salvage was zero, that is, Pr(G=3 | H=0). From Bayes Theorem, we get:

$$Pr(G = m \mid H = 0) = \frac{Pr(H=0|G=m)Pr(G=m)}{\Sigma_j Pr(H=0|G=j)Pr(G=j)} \qquad (6)$$

These probabilities can be calculated for entrainment values of m = 0,1, 2, … fish . Then the probabilities can be used to calculate the mean and variance of the number of entrained fish, given that zero salvage was observed. In Equation 6, Pr(H=0 | G=m) = $(1\text{-}S)^m$. In Equation 6, Pr(G = m) is the prior probability that m fish were entrained. Without a basis for estimating these priors, a standard approach is to assume they are equal. Under this assumption, Pr(G = m) = Pr(G=j), so these terms cancel out of the numerator and the denominator of Equation 6, leaving:

$$Pr(G = m \mid H = 0) = \frac{(1-S)^m}{\Sigma_j (1-S)^j} \qquad , m = 0,1,2\ldots \qquad (7)$$

For m greater than about 30 fish, these probabilities are negligible, so we only calculate the first 31 probabilities (including that for m = 0).

Once the probabilities of Equation 7 are calculated, the expected number (mean) of entrained fish, given zero salvage, is calculated as:

$$\text{Mean}(G \mid H=0) = \Sigma_m \, m \, \Pr(G=m \mid H=0) \qquad (8)$$

A similar equation can be written for the conditional variance of G, given that H=0.

Equations 7 and 8 were calculated using an assumed survival proportion (probability) of S = 0.1, then the calculation was repeated for S = 0.2, and again for S = 0.3. This yielded expected entrainments of 7.8, 4.0, and 2.3 fish, respectively. In other words, every 2-hr period of inserted-zero salvage results from an average of between 2.3 and 7.7 fish becoming entrained and then lost, assuming survival rates in the range 0.1 – 0.3.

These expected losses are not accounted for by the Jahn estimates, and they could add up to many fish on an annual basis. The IRP recommends that the mean value of this probable loss be calculated for all inserted-zero salvages in the data set, and added to daily and annual loss estimates.

Finally, we note that the Bayesian approach (Equations 6-8) can just as easily be used to estimate loss from nonzero salvage values. That is, one can use Equations 7 and 8 to calculate the mean and variance of entrainment, G, given any value for salvage. Then $K = G - H$. Replacing $G=H/S$ with the probability calculations of Equations 6-8 avoids possible discretization errors, when H is a small number of fish. In addition, the Bayesian method allows for improved accuracy, if future research or monitoring can provide direct estimates of entrainment, that is, of Pr(G = m). The IRP suggests that the technical team explore the use of the Bayesian method, via Monte Carlo simulation (see below), to estimate all daily and annual losses, and their variances.

6. Statistical modeling framework for loss estimation

The IRP strongly suggests changing the statistical framework for estimating daily and annual loss. The current framework assumes that annual survival proportion, salvage, and loss can be modeled as single-valued parameters, with their uncertainties characterized by SE's. This framework may seriously understate the true uncertainty of estimated loss, because it understates the true uncertainty in survival proportions. Survival uncertainty is more accurately represented by Table 5, for example, in which Chinook survival proportions were observed to vary by a factor of 60 over 8 mark-recapture trials. In another experiment (Table J-6), Chinook survival rates through CVP louvers varied by a factor of 10 across replicate mark-recapture trials conducted within a two-week period. We believe that these magnitudes of variability, rather than the SE of mean survival, should be represented in the uncertainty of loss estimates. Moreover, in some cases, Jahn (2011) is driven to stating placeholder values, and /or guestimates (Table J-4; "high", "medium", "low"), for survival rates, because the true survival rates are so very uncertain. The assignment of SE's to such speculative survival rates is not credible, because the SE's do not represent the high uncertainty that prompted the speculation in the first place.

We suggest that survival proportion, and hence loss, instead be modeled on a short time scale (daily?) as random variables. The CFS (2013) report gives examples of how to model the probability distributions of these random variables. Daily loss, and hence annual loss estimated by the sum of daily losses, would also be random variables characterized by their estimated means and standard deviations. This strategy can incorporate the realistic variability of survival proportion that is observed in mark-recapture experiments. We believe that the random-variable framework would provide more accurate estimates of loss and its uncertainty.

7. Computing the annual loss and its uncertainty

If the technical team pursues these suggestions, then the computation of annual loss and its uncertainty is no longer so simple. For example, we have suggested that survival rates and loss be modeled on a daily basis, as random variables, with daily loss then summed over the year. In addition, loss-estimation factors such as prescreen and louver components of survival, cleaning adjustments, Chinook ESU classification, and serial correlation of salvage all have their own uncertainties to contribute. Finally, the probable zero-count losses should be added to daily and annual losses.

With these added complexities, it becomes impractical, and perhaps impossible, to estimate the standard deviation of loss using closed-form error propagation (e.g., Equation 3).

For this reason, the IRP suggests using Monte Carlo simulation to estimate daily and annual loss and its uncertainty. For a single day, the observed salvage could be taken at face value, as a number known without error. Then randomly select 100 values of S from its assumed probability distribution. For each *S*-value, calculate *G* from *G=H/S*, or else calculate the conditional mean of *G* from the Bayes equations. Next, add any zero-salvage corrections to the *G* values. Finally, inserting the 100 *G*-values into Equation 1 gives 100 estimates of daily loss, *K*. This yields a probability distribution of *K* for the day, whose mean and variance can be calculated. Summing the means and variances of loss for the year gives the statistics of the annual loss distribution. From such statistics, one can construct approximate confidence intervals or exceedance probabilities for daily and annual losses.

The above scheme assumes that daily expanded salvage is known without error. An option would be to obtain the daily salvage from a measurement error model, which would have the same intent as Jahn's Equations J-4 to J-6

A well-conceived and well-documented Monte Carlo script would offer a flexible computing environment for exploring a broad spectrum of quantitative scenarios about the numerous factors that contribute to fish losses. The script(s) developed for CFS (2013) would probably be a good starting point.

Finally, the major challenge of a Monte Carlo approach is how to represent the causal dependence of salvage on survival in a random-variable context, in other words, how to model the covariance between these two variables. This problem pervades the application of Equation 1 or of Equations 6-8, whether one uses closed-form estimates (Jahn 2011) or Monte Carlo estimates for uncertainty.

8. Making an RPA-triggering decision, based on highly-uncertain daily losses

During the Nov. 6-7 panel meetings, the technical team requested advice on interpreting higher, more-realistic variances of daily losses, such as those seen in CFS (2013) and in our simulation scenarios (Comment 4). Specifically, how can a highly-uncertain daily loss estimate be meaningfully compared to an RPA- triggering threshold?

To illustrate the problem, suppose that an RPA is supposed to be triggered if the daily loss exceeds 15 fish. And suppose that the expanded salvage on a certain day is 12 fish. Monte Carlo application of Equation 1 to this salvage value, using the random survival assumptions of Comment 4, yields an estimated loss distribution with a mean of 31 fish and standard deviation (SD) of 21 fish. This high SD, relative to the mean, is due to our assumption of high daily variability in the survival rate. Now, suppose that we calculate a 2-sided, 90% confidence interval (CI) around the “best” point estimate of loss (the mean), yielding 31 ± 1.64*21 = [-3, 65] fish (assuming Normality). This CI extends far below the trigger level of 15 fish, indicating that the true loss might not have exceeded the trigger, even though the mean estimated loss (31 fish) is more than double the trigger level. With such a wide CI, it is very difficult to decide whether the trigger was exceeded.

Two possible strategies for making a sensible trigger-exceedance decision in the face of such high uncertainty are:

a) Make the trigger-exceedance decision based on a 7-day moving average of daily loss, rather than an individual daily loss. The 7-day moving average has a standard deviation equal to $SD/\sqrt{7}$, which implies that CI width will be reduced by a factor of $\sqrt{7}$ = 2.6. This increased precision may be adequate to develop a more useful CI for estimated loss. The moving average smooths out any apparent daily spikes in loss, but such spikes are highly questionable anyway, because of the high variance in estimated loss..

b) Use a one-sided (rather than two-sided) confidence interval, and relax the confidence level. As before, assume that a day’s loss is normally distributed with mean = 31 and SD= 21. The trigger decision depends only how small the true loss might be, not on how large it might be. Thus, we can construct a 1-sided, lower confidence bound for the true loss, and compare this bound to the trigger level. Reducing the confidence level will also help shrink the lower bound towards the mean. For example, a lower one-sided 75% confidence bound for loss is given by 31 – (0.67*21) = 17 fish. In other words, we can be 75% confident that the true loss was at least 17 fish. Because this exceeds the trigger of 15 fish, the RPA could be activated. The key strategic idea here is the need for managers to tolerate a reduced level of confidence (e.g., 75% rather than 90% or 95%) in decision rules, due to realistically high uncertainties.

APPENDIX 3 – Forecasting storage water release for temperature control and limit stranding and dewatering

The IRP was asked to answer the question, “What other tools are available to help forecast and manage storage and releases levels so we are not annually running into the issue of dewatering redds and stranding juveniles?” The short answer is that models are available or can be developed to predict the effect of storage water decisions on fish survival.

We suggest that both simple and detailed models are useful for management. Heuristic models that illustrate interactions of processes in terms non-dimensional parameters are useful for demonstrating the nature of the water allocation tradeoffs. Detailed models calibrated to the existing system and linked to physical models are needed to characterize the interaction of management actions and fish survival. The development of management models will involve considerable effort and require a team approach. However, a simple model that illustrates the processes can be relatively straightforward. Below we develop a simple or heuristic model to illustrate the system variables. Surprisingly, simple models may also have value in actual management as tools to inform managers that ultimately must make decisions based on judgments.

<u>Heuristic Optimal Temperature Compliance Point Model (hOTCP)</u>

This example model illustrates the approach of expressing the tradeoff storage water releases for cooling redds vs. releases for stage control to limit dewatering of eggs and stranding of juveniles. Currently the water storage is allocated to maintain a temperature control point in the Sacramento River during egg incubation stages. The model example illustrates the tradeoff of allocating storage water for egg and juvenile stages.

The model is intended to illustrate overall survival benefits that can be achieved during the egg vs. juvenile stages using available cold water storage in a trade-off to control temperature benefiting egg/embryo survival early on and later to reduce stranding during the juvenile stage. However, the concept is applicable for simultaneous actions involving temperature and stage controls to address redd dewatering as well as juvenile stranding.

For this illustration assume the effect of water releases on the survival of eggs and juveniles are independent. Then including a survival term for the background survival independent of reservoir operations, the total survival from egg through the juvenile stage is

$$S_{total} = S_{egg} S_{juv} S_{other} \tag{3.1}$$

Assume all redds upstream of the temperature compliance point (TCP) have 100% survival and redds below the TCP have 0% survival. This assumption is allowed because other mortality effects are captured in S_{other}. For a more realistic representation of temperature, the effect of temperature on mortality can be included but the essential dynamic should not be significantly different from eq. 3.1.

Assume the density of redds decreases exponentially with distance x from the face of Keswick Dam as

$$\rho(x) = \frac{1}{\lambda}\exp\left(-\lambda x\right) \tag{3.2}$$

where λ expresses the shape of the distribution of redds along the river. Note that the function fits well the observed distribution of redds. The survival of eggs in the river that depends on reservoir releases is a function of distance downstream as

$$S_{egg}(x) = \int_0^x \rho(x')dx' = 1 - \exp\left(-\lambda x\right) \tag{3.3}$$

where x is a distance equal to or less than the maximum temperature compliance point (TCP) defined as x_0. Typically x_0 is forecast prior to the beginning of the season and represents the maximum distance downstream at which temperature can be maintained below the critical maximum required to insure egg survival during incubation season.

Define the total preseason forecast of storage volume available for fish as v_0 and assume the maximum TCP location has a linear relationship with v_0 as

$$x_0 = \alpha v_0 \tag{3.4}$$

Here the relationship between TCP and volume is highly simplified but the form represents the basic property that more water is required to maintain a TCP further downstream. Because we assume the volume of water used and TCP location are linearly related in this model, the relationship between storage volume v_x and another TCP further upriver can be expressed as

$$x = \alpha v_x \,. \tag{3.5}$$

Having simplified egg survival as either 0 or 100% we can disregard egg incubation time and variations in storage water during incubation, so water storage after incubation can be described as

$$v_1 = v_0 - v_x = v_0\left(1 - \frac{x}{x_0}\right) \tag{3.6}$$

This remaining volume v_1 is thus available for other uses independent of temperature control. For our example, assume the remaining fish storage water is allocated for stage control to avoid juvenile stranding. The volume could also be allocated during the incubation period to minimize redd dewatering.

The more water available for river stage control, the less mortality from river stage effects. However, because of the nonlinear properties of flow and river elevation, the effect of storage volume decreases with volume amount. We can capture the general diminishing effect of additional flow on river elevation with an exponential function as

$$S_{juv} = 1 - \mu e^{-\beta v_1} \tag{3.7}$$

where μ is the maximum juvenile mortality if no storage water releases were available to target stranding and dewatering events and β characterizes the efficiency of water releases on reducing dewatering and stranding. Note that a brief analysis of the relationship between spawning and dewatering flows for fall-run Chinook salmon (Appendix B, Table B1 in Sacramento River Temperature Task Group 2013 Technical Report) indicates that an exponential relationship describes the impact of flow reduction on dewatering. Because both dewatering and stranding are processes driven by flow effects on river stage, we expect that eq. 3.7 is adequate for representing the effect of flow on stage-dependent mortality processes.

Combining the above equations the total survival over the two life stages is

$$S_{total}(x) = \left(1 - e^{-\lambda x}\right)\left(1 - \mu e^{-\beta v_0 (1 - x/x_0)}\right) S_{other} \tag{3.8}$$

where $x \le x_0$.

We simplify the equation first by normalizing the compliance point x to the distance of maximum temperature compliance x_0 giving

$$y = x/x_0 \tag{3.9}$$

such that y has the range $0 \le y \le 1$. Next, combine the parameters. The extent to which the available volume of storage water is capable of protecting the population of redds can be characterized as

$$a = \lambda \alpha v_0 . \tag{3.10}$$

That is, increasing the parameter *a* by an increase in any of the component terms increases the protection of the redds. For example, a larger λ implies the redd distribution is closer to Keswick dam so less storage water is required to cool the egg distribution. A larger v_0 implies more water is available to cool the redds. Note that *a* is a non-dimensional coefficient that can be estimated by fitting the distribution of redds scaled to the maximum temperature compliance point x_0. That is, in principle *a* can be estimated from the redd distribution, the amount of storage water available and the hydraulic properties of the system.

The second term defines the extent to which storage water can protect redds and juveniles from dewatering and stranding. It is defined as

$$b = \beta v_0 \,. \tag{3.11}$$

In principle *b* can be characterized from information on the hydraulic properties of the system and the location of redds and juveniles. An increase in *b* can be achieved by any combination of increased efficiency (β) and available coldwater storage (v_0). The IRP suggests that the efficiency term might be estimated from currently available information such as is illustrated in Appendix B, Table B1 in Sacramento River Temperature Task Group 2013 Technical Report.

With these non-dimensional parameters the total survival as a function of the TCP at distance *y* is

$$S_{total}(y) = S_{egg} S_{juv} = \left(1 - e^{-ay}\right)\left(1 - \mu e^{-b(1-y)}\right) S_{other} \tag{3.12}$$

Note that the value of S_{other} is not important because it does vary with storage reservoir operations.

The distance of the TCP that yields the optimum total survival is defined by $dS(y)/dy = 0$ giving

$$\frac{dS_{total}(y)}{dy} = \frac{ae^{b}}{\mu} - be^{(a+b)y_*} + \left(b - a\right)e^{by_*} = 0 \tag{3.13}$$

Note in Fig. A3.1 the total survival of eggs quickly approaches the asymptote of 100% survival and essentially tracks the cumulative distribution of redds downstream of Keswick Dam. Water not allocated for temperature control is allocated for stage control to reduce egg dewatering and juvenile stranding. Therefore S_{juv} is greatest when *y* = 0 and decreases progressively with increasing y because water not allocated to temperature control is allocated for stage control. The curvature of the total survival curve to the right of the optimum depends on the effectiveness of storage water for stage control activities.

Eq. 3.13 may be useful for management if it identifies the optimal distance for the temperature control point that balances survival of eggs and the survival of juveniles. Furthermore, the optimum allocation of storage water for temperature control is

$$v^* = y^* v_0 . \tag{3.14}$$

The salient point is that the optimum TCP and volume of water allocated for temperature control is likely to be generally less than the volume of water that is used under the current RPA. Figure A3.1 illustrates this point by applying the model to WY 2013 in which the location of the TCP was set at Airport Road, which gives x_0 ~ river mile 17.

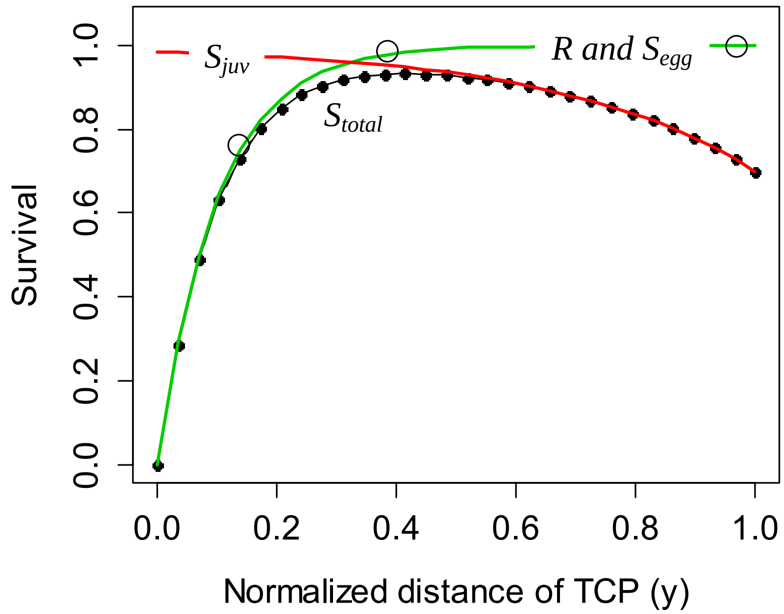

Fig. A3.1. Model output showing relationship between egg (S_{egg}), juvenile (S_{juv}) and total survival as a function of temperature compliance points (*y*) based on eq. 3.12. The large circles depict cumulative redd density *R* at the normalized TCP location. Optimum TCP is *y= 0.41 for this scenario.**

We estimated the parameter *a* using the redd density information for winter run Chinook from Table 2 in Sacramento River Temperature Task Group Annual Report of Activities 2013. From eq. (3.3) the cumulative distribution of percent redd vs. distance is

$$\mathrm{R}(y) = 1 - \exp(-ay) . \tag{3.14}$$

where $R(y)$ is the cumulative redd distribution as a function of normalized distance y. Knowing the distribution $R(y)$ we estimate the parameter giving a = 10 for WY 2013. We have no estimate of parameter b but in principle it is straightforward because its components can be estimated; v_0 is simply the total amount of storage water available for fish and β be estimated from river stage information and juvenile distributions.

Analysis indicates that the shape of survival vs. the TCP location is sensitive to the parameter *a,* but is less sensitive to *b* (Fig. A3.2). However, it is important to note that the survival over a range of TCP locations is relatively flat with any selected value of *b* such that the optimum TCP is relatively insensitive to *b* even though the optimum TCP location is sensitive to changes in *a*. Fortunately, *a* potentially can be estimated with some confidence while for *b*, an accurate estimate is not as critical for finding the optimal TCP location.

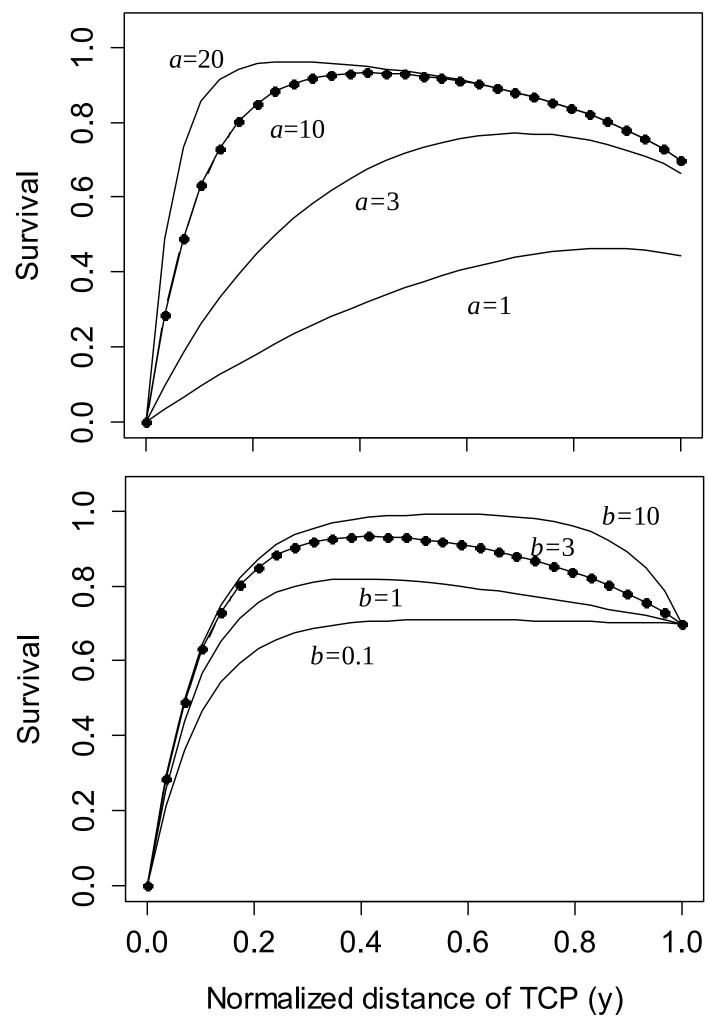

Fig. A3.2. Sensitivity of survival (S_{total}) with TCP distance *y* for differing values of *a* and *b* where base parameter values are sane as in Fig. A3.1.

For WY 2013 we assume b = 3 and μ = 0.3 then solving eq. (3.13) using the *uniroot* function in the R statistical package, the normalized optimum TCP location is y^* = 0.41. Thus, based on the Airport Road TCP (~ river mile 17) used in 2013 the model indicates the optimum TCP was at river mile 7. An exploration of the sensitivity of y* to variations of μ and b will give a measure of the uncertainty in the optimum. The salient points of this analysis are that it is feasible to estimate a TCP that optimizes survival across the two life stages and the optimum is likely to require less water than is used to meet the current TCP. Thus, it is possible the RPA can be adjusted to increase both fish survival and water operations flexibility.

Management - Optimal Temperature Compliance Point Model

A management model to forecast water release impacts could be developed in the basic framework of the heuristic model, but include spatial and temporal distributions of fish, river temperature and stage. The relationship between water releases, river stages and temperature would be input from a hydraulic model. The redd distribution could be characterized by redd survey information, not the distribution parameter λ in the heuristic model. The management could also use realistic temperature survival and growth models to characterize emergence timing and survival of eggs.

If detailed information were available on the distributions and environmental characteristics of redds and juvenile nursery grounds then management of a TCP location could be replaced by a management that optimizes survival across fish sites. The sites would include individual redds and juvenile habitats. Storage water releases would then seek to optimize the survival across the sum of sites and therefore the fish population itself.

Conclusions of Model Analysis

The heuristic model developed here illustrates that higher fish survival and greater flexibility in reservoir operations might be obtained by using a forecast model that accounts for the tradeoff of water allocations for different mortality processes and life stages. The model suggests that survival may be increased about 10%, which is moderate. However, the model also suggests that this improvement in survival might be attained with 50% less water than is currently used in maintaining TCPs defined by the RPA. Such a saving of storage water would be substantial for water years in which the location of the TCP extends significantly downstream of the majority of the redds. The IRP has in past reviews encouraged further integration of water operations with biology, and the model presented here illustrates the potential benefits of such an approach.

Appendix 4 - Delta smelt movements relevant to implementation of RPA Action 1

The underlying motivation for a preemptive Action as posed to the IRP in Question 2 involving RPA Action 1 is to reduce pumping flows prior to the fish entering the Old and Middle River environment, thus allowing the pre-spawning migrants to pass into the western and northern regions of the Delta without being drawn into the negative flow of the OMR. Developing an effective preemptive action requires understanding the behavior of delta smelt to their environmental cues during the migration. Below we address this issue, discussing alternative theories of delta smelt migration as based on the past and recent publications on delta smelt.

A working hypothesis of delta smelt movement

Delta smelt live in low salinity zones of the estuary and migrate upstream to spawn (Sommer et al. 2011). Previously it was believed that the fish migrated between the western and eastern portions of the delta. However, recent studies suggest that the life cycle is more complex. The adult population appears mostly as diffuse loci in and adjacent to the northern Delta's open waters from which individuals undertake landward movements to spawn (Murphy and Hamilton 2013). While the centroid of the adult population is located near the X2 low-salinity boundary (Feyrer et al. 2011) delta smelt are also found in Liberty Island, Yolo Bypass (Sommer and Mejia 2013) and as far north as Knights Landing (Vincik and Julienne 2012). The historical population distribution included the eastern and southern regions of the delta but currently these areas are largely without delta smelt (Murphy and Hamilton 2013).

Salinity and turbidity are key environmental variables that affect distribution of delta smelt, but the relative significance of these variables has been under debate in the literature (Sommer and Mejia 2013). Other variables have been identified as important including tidal velocity (Sommer et al. 2011), which correlates with other properties such as turbulence (Rippeth et al. 2001). How delta smelt respond to environmental variables is critical to developing a preemptive Action 1 to divert the movement of delta smelt in the OMR during their pre-spawning migration. Here we develop a straw-man or working hypothesis on the important variables to consider in designing an Action. We begin with a discussion of models or theories of delta smelt movement.

Two basic models have been proposed for how environmental variables affect delta smelt migration. One model identifies kinesis in which a fish moves with random and directed movements along a water property gradient, e.g., salinity. The rate of movement depends on the differential between an optimal salinity and the fish's local salinity. Residence of delta smelt in the X2 region is achieved by setting the optimal salinity at the X2 salinity. Movement toward freshwater in the landward pre-spawning migration is produced by lowering the optimal salinity for pre-spawning adults (Rose et al. 2013a). In essence, to switch between X2 residence and pre-spawning migration the optimal salinity level is changed and the delta smelt swims toward lower salinity water upstream. The model describes the general life cycle distribution of delta smelt and was implemented in an individual based model to explore processes controlling population levels (Rose et al. 2013a). However, it was not strictly intended to be an accurate representation of the mechanisms of migration. The IRP suggests the concept of kinesis is not conceptually wrong, but it must be applied over the small scale at which delta smelt perceive their environment, not at the large scale on which it has been applied previously.

A second model describes movement in terms of tidal surfing, or tidally mediated migration, in which upstream movement is achieved by the smelt moving into higher velocity regions of the water column during the flood tide and lower velocity regions during the ebb tide. This model has more biological realism than the kinesis model and can reproduce the distributions and movement rates of delta smelt, but as currently applied (Sommer et al. 2011) it does not address the mechanisms controlling the tidal cycle movements between high and low velocities. More important, the tidal surfing model is mute on how a fish distinguishes between ebb and flood tides – an essential ability for tidal surfing. While knowing how fish distinguish and respond to hydrodynamic properties has scientific appeal, the knowledge is important for developing delta smelt protection since any action can only modify the hydrodynamics and thus the link to fish behavior is essential.

While both models can reproduce delta smelt distributions, the mechanisms are different and designing a preemptive Action 1 based on an incorrect model of delta smelt behavior may neither produce desired results nor be cost effective. However, the selection of which model is more realistic is not difficult because the kinesis model, as previously applied, has been largely rejected. A plan proposed in 2009 to divert delta smelt from the Central Delta with a gating system in the central delta (Two-Gates project www.usbr.gov/mp/2gates/docs/index.html) was based on delta smelt kinesis to salinity and turbidity fields. However, a review of the plan identified significant problems with the kinesis movement model (Anderson et al. 2009) and the project was eventually withdrawn (www.c-win.org/two-gates-project-expedient-delta-conveyance.html).

In contrast, recent studies provide clear support for the tidal surfing model. A SmeltCam, which visually identifies free moving fish, revealed that in the lower Sacramento River in November 2012 delta smelt were dispersed over the water column during the flood tide and in the lower velocity regions near the bottom and side channels on the ebb time (Feyrer et al. 2013). The authors noted that the conditions were associated with the upstream migration of delta smelt to areas where spawning ultimately occurs during spring. The study essentially documented the fine-scale delta smelt distribution prior to the ‘‘first flush’’ and their upstream migration. Other studies have also documented delta smelt asymmetric behavior over tidal cycles. The pre-spawning migration velocity of delta smelt can be produced in a model with particles moving from the upper to the lower 10% of the water column between the flood and ebb tides (Sommer et al. 2011). In Suisun Bay, delta smelt feed predominantly on the flood tide in the day (Hobbs et al. 2006). To maintain residence in the dynamic low salinity zone of the western delta other species exhibit vertical migrations that are coordinated with the tides (Bennett et al. 2002). Thus, solid evidence (in the San Francisco Bay Delta system and many studies elsewhere not discussed) supports a model of tidally coordinated movement and indicates that tidal surfing is sufficient to produce the observed migration velocities and distributions of adult delta smelt and other species.

However, the tidal surfing model by itself does not describe how an animal coordinates movement with the tide. Perhaps the parsimonious perspective is to assume that delta smelt seek to maintain position in a favorable local environment, e.g., they seek a range of turbidity (small-scale kinesis), which because of estuary hydrodynamics occurs mostly on flood tides. Some support for this mechanism comes from (Hasenbein et al. 2013) who observed that delta smelt feeding performance was highest between 12 and 120 NTU and diminished otherwise. Also, higher levels of salinity stressed delta smelt. If delta smelt seek a favorable turbidity range when available, do not respond to turbidity when the level is low, and avoid higher levels of salinity, then a relatively simple correlation of small-scale distributions of turbidity and salinity with velocity profiles may be sufficient to explain movement behavior of delta smelt.

If delta smelt seek local regions of optimal turbidity then understanding movement in a tidal system reduces to correlating the optimal attraction regions with tidal velocities. Here studies indicate that turbidity levels are highest on the flood tides in the Carquinez Strait connecting San Pablo and Suisun Bay (Ganju and Schoellhamer 2008), in the Sacramento River above the confluence with the San Joaquin (Feyrer et al. 2013) and in channels of Cache slough in the northern Delta (Morgan-King and Schoellhamer 2013). These are all areas with significant delta smelt populations.

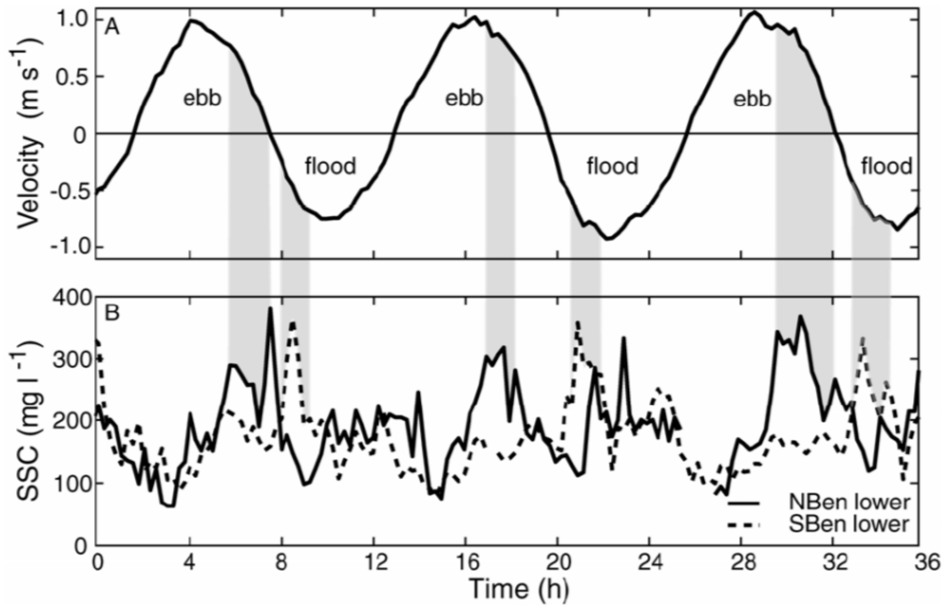

Figure A4.1. Water velocity and suspended sediment concentration (SSC) in Carquinez Strait and Suisun Bay. Carquinez Strait connects San Pablo Bay and Suisun Bay. Grizzly and Honker Bays are shallow areas of Suisun Bay. Sites NBen and SBen are located on piers of the I-680 Bridge. Depth is referenced to mean lower low water [from Ganju and Schoellhamer 2008].

Fig. A4.1 illustrates the asymmetrical patterns in turbidity across a tidal cycle in Carquinez Strait. In general, the pattern varies spatially, with flow and sediment availability such that the correlations of flood and high turbidity are expected to increase and decrease depending on conditions. Under the hypothesis that tidal surfing requires a high flood tide/turbidity correlation, then the propensity for movement against the mean flow will vary according to the estuarine physics. The flood/turbidity correlation is likely to be strongest in the western Delta and backwater sloughs because of tidal asymmetry in these environments (Morgan-King and Schoellhamer 2013). Strong tidal asymmetry and a high flood/turbidity correlation also would be expected during first flush events. In regions with low correlations, delta smelt movements should be more random. Furthermore, when turbidity throughout the water column is below the threshold for attraction, we expect that delta smelt would not seek higher velocity regions on either flood or ebb tides. Again, their movements would become random and we expect the net movement of the delta smelt would follow the mean flow.

While we frame the hypothesis in terms of tidal-scale changes in turbidity, we suggest the underlying mechanisms act at the scale of the fish’s immediate environment. At the perceptive scale of the fish, optimal turbidity may occur in the low velocity regions near shore and bottom on the ebb tide, while on the flood tide the optimal turbidity is associated with higher velocities, which generally occur throughout the water column. Also note that the mechanism may involve asymmetric patterns of small-scale turbulence over the tidal cycle. Fish can detect micro-turbulence in the water column (Chagnaud et al. 2008) and because turbulence induces resuspension of sediment, turbidity and turbulence may both appear to have an effect on delta smelt movement.

In summary, our working hypothesis is that tidal surfing behavior results because over the tidal cycle delta smelt seek water with intermediate turbidity, which depending on the asymmetry of the tidal cycle, tends to be in low velocity regions on the ebb tide and high velocity regions on the flood tide. Furthermore, the strength of tidal asymmetry varies spatially and seasonally so that delta smelt movements are expected to vary spatially and seasonally in a similar manner to the variability in tidal asymmetry.

As was indicated at the LOBO workshop, the USFWS seeks to fine-tune actions to protect delta smelt. The IRP realizes that considerable progress has been made in understanding delta smelt movement, but suggests that the best possible protection program requires explicit consideration of the small-scale physical properties to which fish respond. Below is a brief description of a straw-man program to test the hypothesis that delta smelt exhibit taxis to abiotic attraction zones that form and dissipate over the tidal cycle resulting in dispersion, retention or upstream tidal surfing depending on the bathymetry and flow of the local environment.

Program Hypothesis: By altering tidal asymmetry in critical channels and times, delta smelt movement towards pumps can be reduced.

Program Elements:

1. Characterize delta smelt responses (feeding, predator avoidance, taxis) to abiotic factors and identify an envelope of attraction, plausibly defined by ranges of turbidity, salinity and light levels. Example work: Hilton et al. (2013) and Hasenbein et al. (2013).
2. Characterize delta smelt distribution over tidal cycles. Example work: Feyrer et al. (2013), Bennett et al. (2002).
3. Characterize attraction envelope location and velocity properties over tidal cycles. Example work: Shchepetkin and McWilliams (2005), Ganju and Schoellhamer (2008; Morgan-King and Schoellhamer (2013), Jones et al. (2008).
4. Model delta smelt movement by linking behavior, attraction envelope and hydrodynamics. Example Goodwin et al. 2006, ROMs and DSM2 hydrodynamic models.
5. Using the model, identify hydraulic conditions that initiate upstream delta smelt movement and develop actions to disrupt delta smelt movement into inner delta.

Appendix 5 – Additional considerations- secondary channels of the Sacramento River

Most redds and stranding sites are associated with either secondary channels or smaller scale features (e.g., margins and geomorphically complex features of the main channel; Figs. A5.1 and A5.2). Secondary channels may be one of the most important options for river restoration because they appear to be a potentially important habitat resource for conservation and recovery of fall- and winter-run Chinook.

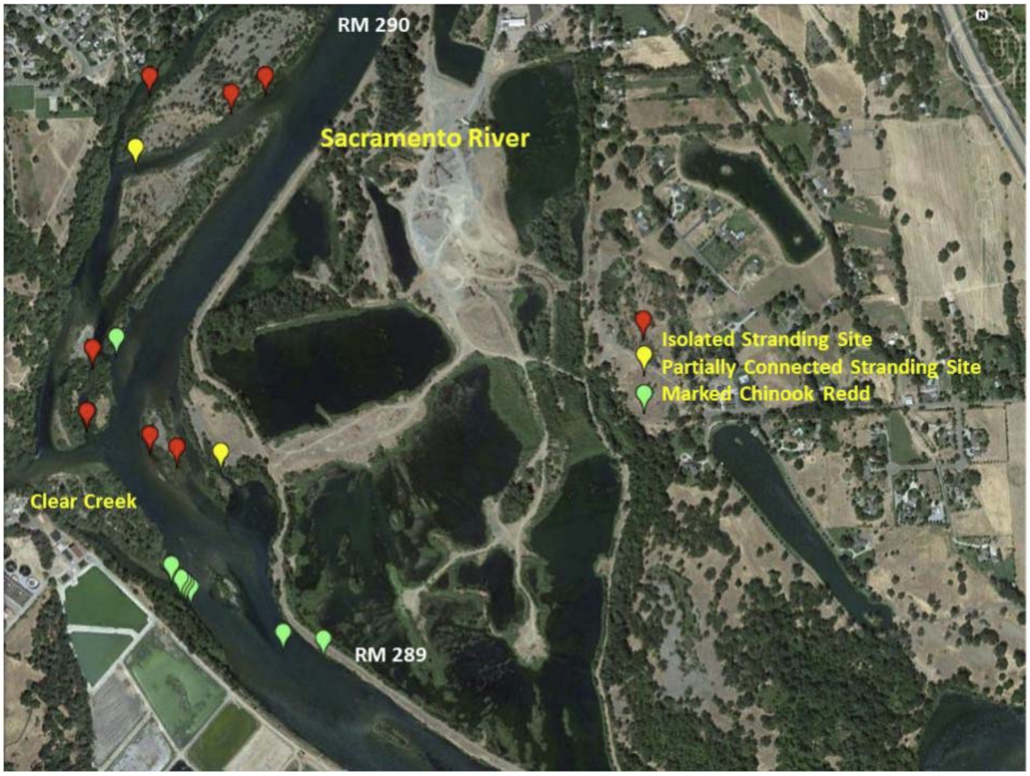

Figure A5.1. Strong association of stranding sites and redds with secondary channels in Sacramento River near Clear Creek. From Appendix D of Revnak and Killam (2013 RBFO Technical Report No. 01-2013).

Figure A5.2. Strong association of stranding sites and redds with secondary channels in Sacramento River near Highway 44 Bridge. From Appendix D of Revnak and Killam (2013 RBFO Technical Report No. 01-2013).

Existing and recently formed secondary channels should be identified and described by hydrogeomorphic variables such as average depth, width, length, and substrate type. Secondary channels so described can be sorted over a range of flows important to different salmon life stages. A description of their persistence should also be noted to address potentially important management issues. For example, have there been changes in the secondary channels through time, particularly since the closure of Shasta and Keswick Dams?

The IRP noted the presence of at least 8-9 secondary channels and more may be identified with a rigorous census that could even detect channels recently abandoned either from channel migration or avulsion processes. At least two important general categories of secondary channels can be identified – fully connected (both ends connect to the Sacramento River throughout the hydrograph) and partially connected (connected at the lower end only under low flows) – although other categories may also be discovered. Secondary channels that become disconnected at the upstream end and then become spring brooks because channel-bed elevation intercepts the top layer of the unconfined groundwater table may be particularly important juvenile rearing habitat (Stanford et al 2005,). Hyporheic water inputs are important in many rivers of the arid western U.S. because warm river water that flows from the open surface main channel into the underlying bed sediments is cooled before remerging as surface flow in the form of a spring brook (Hauer and Lorang 2004). Secondary channels that intercept both hyporheic and regional groundwaters may be particularly valuable cool water refugia for salmon during times when cold water storage in Shasta Dam is limited. Partially connected secondary channels may be the cool water temperature refugia of last resort for salmonid early life stages under stressful temperature conditions.

Secondary channels are typically highly dynamic hydrogeomorphic features that can experience more dramatic hydrologic changes (fully wetted to dry conditions) than the main channel (Hauer and Lorang 2004, Lorang et al. 2013). The rates of change will likely not be constant. They will depend upon patterns of in-channel sediment dynamics, bank erosion, interaction with large woody debris, fluctuating water levels, succession of riparian vegetation and hydrologic events that cross geomorphic threshold levels (i.e., those discharges that mobilize and transport sediment) and do so for a sufficient duration to accomplish geomorphic work (i.e., cut-and-fill alluviation channel migration and avulsion) (Lorang et al. 2013, Nestler et al. 2012). The existing geomorphic complexity and inferred temporal dynamics suggest that future side-channel management plans must be carefully considered and developed.

As a precautionary note, channel modifications made by means other than natural processes may have major unintended consequences (Stanford et al. 1996). The diversity and productivity of salmonid rivers depends on maintaining a “shifting mosaic of habitat” (Stanford et al. 2005). For example bank erosion is often viewed negatively especially if mobilized sediments bury redds immediately downstream. However, those sediments are also key elements for the creation of new gravel bars that support the rejuvenation of riparian vegetation. Caution must be exercised when in-channel modifications are made to enhance production of single species because such actions may add a suite of stressors to other species which can result in a feedback loop to indirectly affect the species of concern (Tockner et al. 2010). The net effect of a single species focus is to reduce the diversity and persistence of the aquatic community as a whole (Tockner et al. 2010). In-channel modifications will only be successful through careful consideration of how they may affect natural first order hydrogeomorphic drivers for biogeochemical processes which are secondary response variables and hence tertiary drivers of food web dynamics within the river ecosystem. Simply having potential habitat visible from an aerial photo or mapped from the ground does not insure successful juvenile production unless that habitat structure provides the necessary habitat quality.

If secondary channels are recognized as important elements in future strategic efforts to protect and enhance salmonid populations in the Sacramento River, they should be incorporated as part of a holistic adaptive management approach that explicitly focuses on the geophysical processes that shape the dynamic abiotic and biotic structure of the entire riverine ecosystem at multiple spatial and temporal scales. One of the most efficient ways to promote desirable ecosystem structure and functionality is to allow natural processes to self-maintain (Stanford et al. 1996).

Adaptive Management of Secondary Channels

Program-level restoration of secondary channels to serve as temperature refugia for salmonid early life stages may face difficult technical challenges and management issues. The SRTTG could take a formal collaborative adaptive management (AM) approach to restoration and conservation of secondary channels and similar small-scale habitat features in the Upper Sacramento River. An AM approach should include development of goals and objectives, guiding principles (e.g., self-maintenance), and conceptual models that describe how secondary channels contribute to salmon conservation and recovery. The conceptual models should be of sufficient detail and completeness that critical sources of uncertainty can be identified. These sources of uncertainty can then become the foci of studies that systematically improve the efficacy of management plans.