Report of the 2012 Delta Science Program Independent Review Panel (IRP) on the Long-term Operations Opinions (LOO) Annual Review

Prepared for: **Delta Science Program**

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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 the water operations and regulatory actions prescribed by their respective Long-term Operations Opinions' (LOO) Reasonable and Prudent Alternative Actions (RPAs) as applied from October 1, 2011 through September, 30 2012 (Water Year 2012). This year's annual review focused primarily on implementation of NMFS's RPAs for Clear Creek (RPA Actions I.1.1 – I.1.6) and the Spring 2012 Delta Operations joint stipulation agreement for water operations and fisheries that was required to be executed in water year 2012 in lieu of NMFS's RPA Action IV.2.1.

After reviewing a required set of written documents (Appendix 1), the IRP convened at a public workshop in Sacramento, CA on 31 October - 1 November 2012. The first day of the 2-day workshop provided a forum for the IRP to consider updated information and new research findings and to discuss issues related to the application of RPA actions. 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 to comment and otherwise exchange impressions and information.

[1] Dr. Nestler will provide advice to the Panel on subjects relative to his expertise on eco-hydraulics and coupled hydrodynamics and fish behavior modeling. He is not tasked with written assignments for the report development.

Subsequent IRP communication and deliberations were conducted via email and conference call in the course of drafting this final report.

EXECUTIVE SUMMARY

The review panel appreciates 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 ecosystem from which water resources are derived for a multitude of human uses. We continue to commend all of the agencies charged with this daunting task for their efforts to date as they strive to cooperate and integrate activities directed at achieving this goal within the context of persistent change in environmental and socioeconomic conditions.

The dry 2012 water year presented a greater challenge to achieving specific RPA targets than was the case in the previous year and confirmed concerns expressed in Anderson et al. (2011) that some physical targets may not be routinely achievable. After three years of operating under the RPA actions, observations are available for a small sampling of both wet and dry 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. Nonetheless, as noted by the two previous OCAP IRPs, the current LOO IRP emphasizes the continued need to explicitly link the success or failure of meeting physical targets prescribed in the RPAs to the biological/ecological responses of the listed species.

The IRP was encouraged by a perceived movement toward research aimed at measuring the survival and behavior of fishes within a spatially-explicit landscape relevant to water operations. 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.

The regular evaluation of 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. It is not too soon to step back and consider whether the intentions of habitat restoration efforts are tracking toward expected outcomes. If positive effects on listed species are not detectable following a series of “good” water years in the future, concerns about the detectability of effects under less favorable conditions will persist.

Findings from recent research reported at the 2012 LOO Workshop corroborated previous expectations of nonconformity in behavior of salmonid smolts and passive particles within the context of water flows and routing through the Delta. Consequently, the application of passive particle models as a means of adjusting water operations to protect out-migrating salmonid smolts in real-time is not recommended. The IPR encourages a shift in the water management paradigm to include a more fish centric behaviorally and ecologically based perspective.

The IRP appreciated the opportunity to concentrate on a focal subset of RPA actions this year but wondered about progress, biological responses and consequences in applying the many other prescribed actions within the watersheds. The inclusion of maps for geographic orientation to the portion of the system under discussion was helpful to a degree and appreciated, but still fell short of expectations.

Finally, the time allotted at the workshop for panel deliberations (5.0-5.5 hrs) on the second day was again much appreciated and provided adequate time for the IRP members to organize thoughts and reach some consensus prior to presenting preliminary findings in the afternoon. We continue to encourage a similar time allotment for deliberation by future panels.

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INTRODUCTION

The Sacramento-San Joaquin watersheds and Delta comprise a complex system of distributaries, reservoirs, human-engineered channels, levees and a mix of agricultural and urban areas that have replaced former wetlands and floodplains. Significant structural alterations of the ecosystem date back to the mid-nineteenth century. Many of the anthropogenic changes in the Delta and its upstream tributaries were designed to store, redirect and convey water to meet human demands within the region, with little consideration for other biotic components of the ecosystem.

The chronic multi-decadal alteration of the natural ecosystem associated with meeting the demands of an increasing human population within and beyond the Central Valley watersheds have contributed to profound changes in the system's aquatic fauna, including a persistent decline in certain species of native fishes. Consequently, some of these jeopardized species have been afforded protection under the Endangered Species Act (ESA).

Within the historical context of engineered water resource management, 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) represents 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. If an appropriate combination of localized spatial and temporal deliveries of water cannot be found to maintain or restore the necessary ecological conditions to support the desirable species populations, the most feasible alternative may be to accept the ecosystem components that are sustainable within the constraints and limitations imposed by historical uses of the available limited resources.

***Background on the LOO 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 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 both Long-term Operations Opinions (LOO) is to present the responsible agency's biological opinion on whether USBR's and DWR's long-term operations of the CVP/SWP are likely to jeopardize the continued existence or adversely modify the designated critical habitat for the ESA listed species under each agency's jurisdiction. Because both Long-term Operations Opinions concluded that the long term operations of the CVP/SWP are likely to jeopardize the continued existence or adversely modify designated critical habitats, the USFWS and NMFS prescribed RPAs to minimize CVP/SWP operations related effects to the level where these effects do not appreciably reduce the likelihood of jeopardizing the continued existence of ESA listed species or adversely modifying critical habitat. The RPA in NMFS' Long-term Operations Opinion (2009 RPA with 2011 amendments) includes both broad and geographic division specific RPA Actions. The RPA Actions in both Long-term Operations Opinions provide specific objectives, scientific rationales, and implementing procedures.

Since the Long-term Operations Opinions were issued, NMFS, USFWS, USBR, U.S. Geological Survey (USGS), California Department of Fish and Game (CDFG) and the 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. However, not all technical reports were included in the official review materials to be considered by the 2012 LOO IRP (see Appendix 1).

In January 2012, Public Water Agencies (PWA), State of California and Federal agencies filed a joint stipulation regarding project operations during April and May 2012 in the litigation relating to NMFS' Long-term Operations Opinion. The parties stipulated that if a rock barrier were installed at the head of Old River, the CVP/SWP would operate within an adaptive range of Old and Middle River flows in lieu of operating to the inflow:export ratio specified in RPA Action IV.2.1 of NMFS' Long-term Operations Opinion.

At the request of USFWS and NMFS, the Delta Science Program (DSP) employed the services of an independent science review panel to assist NMFS and USBR in reviewing the effectiveness of the implementation of NMFS Long-term Operations Opinion RPA and documents associated with the implementation of the joint stipulation. The role of the Independent Review Panel (IRP) is to provide a technical review to the agencies involved in implementing NMFS' Long-term Operations Opinion RPA.

The intent of the annual review is to inform National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (USFWS) as to the efficacy of the prior year's water operations and regulatory actions prescribed by their respective Reasonable and Prudent Alternatives (RPAs), with the goal of developing lessons learned, incorporating new science, and making appropriate scientifically justified adjustments **to the RPAs or their implementation** to support water year 2013 real-time decision making.

General scope and charge to the 2012 LOO IRP: The previous two annual reviews have considered all of the RPA Actions but this year's panel charge focused on a subset of the RPAs primarily related to water operations and populations of Chinook salmon (*Oncorhynchus tshawytscha*) and Central Valley steelhead (*Oncorhynchus mykiss*) within portions of the San Joaquin and Sacramento watersheds and Delta.

This year's annual review deals with the implementation of NMFS' Long-term Operations Opinion's Clear Creek RPA Actions (I.1.1 – I.1.6) and the Spring 2012 Delta Operations in lieu of NMFS' RPA Action IV.2.1 per joint stipulation (Spring 2012 Delta Operations) for operations and fisheries for water year 2012 (October 1, 2011 through September 30, 2012) and considers:

(1) Whether implementation of the Clear Creek RPA actions met the intended purposes of the actions;

(2) The agency's responses to and implementation of independent review panel recommendations from the prior year's Long-term Operations Opinion Annual Review on the Clear Creek RPA actions;

(3) Study designs, methods, and implementation procedures used; and

(4) Recommendations for adjustments to implementation of the RPA Actions or Suite of Actions for meeting their objectives.

Five questions (some multi-part) were posed to the 2012 IRP panel and defined the scope of the panel's charge. This report addresses each of the questions posed and provides additional observations and opinions where they seemed relevant and potentially useful from a scientific perspective.

***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 that were the basis for this report. We recognize that much of the material had to be compiled, analyzed and organized in a relatively short time. Despite the many competing demands on the workshop participants, the materials were presented professionally, concisely, on schedule and often were responsive to the previous IRP's recommendations for format changes. The panel wishes to express a special thanks to the Delta Science Program, Peter Goodwin (Lead Scientist), Sam Harader (Program Manager) and the entire staff for providing the organization and logistical support to facilitate our task. In particular, Lindsay Correa (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.

LOO IRP COMMENTS ON RPA ACTIONS IN WATER YEAR 2012

General comments and observations

Some of the NMFS RPA actions and Joint Stipulation commitments have yet to be implemented or completed and so the 2012 IRP is unable to develop an opinion as to whether or not they have or will meet their intended purpose. These include:

(1) Action I.1.2. Channel Maintenance Flows from re-operation of the Whiskeytown Glory Hole spills to include mean daily spills of 3250 cfs for one day to occur 7 times in a 10-yr period. This action was targeted for implementation in winter 2013 and will likely be delayed until 2014, so once again was not implemented and cannot be evaluated.

(2) Action I.1.3. Spawning Gravel Augmentation was once again performed but there was little information available to evaluate whether it is meeting the intended purpose. The written report from the Clear Creek Technical Team (CCTT) contained a note to "[insert section here]" that may have been intended to provide salmonid or macroinvertebrate responses to the RPA. During the LOO 2012 workshop in Sacramento the CCTT indicated that the data were not currently available.

(3) Action I.1.4. Replacement of Spring Creek Temperature Control Curtain in Whiskeytown Lake. This action was completed by the Bureau of Reclamation in June 2011, but there was no test of its effectiveness that would allow an evaluation of the intended purpose of the action. Furthermore, the intended effect of the curtain was to lower water temperatures delivered to the Sacramento River and not necessarily Clear Creek, which was the focus of this year's annual review.

(4) Action I.1.6. Adaptively Manage to Habitat Suitability/IFIM Study Results. Although the IFIM Study is completed, results were not provided for evaluation, so the IRP is unable to formulate an opinion this year.

(5) In the Joint Stipulation Order (Case 1:09-CV-01053-LJO-DLB, Document 660, filed 01/19/12, p 6 and 7 of 11), DWR committed to developing a study for a pilot predator removal and control program to be submitted to NMFS and CA-DFG for review and comment and "if a rock barrier is installed (at the head of Old River), a predator monitoring study will evaluate predation associated with the installation and operation of the rock barrier". At the workshop there was some verbal mention of these activities having been carried out, but no data were provided to the IRP for evaluation.

Hydrographic analysis

Annual planning and decisions on water operations are based, in part, on qualitative categories (e.g., wet, above normal, below normal, dry and critical) of water availability derived from indices of unimpaired runoff measured during two periods within the year, with an adjustment for the previous year's conditions. However, the approach provides little room for forecasting conditions in an upcoming water year, except perhaps for an implicit expectation of a relatively dry year (i.e., 60% of the WY categories are less than "normal"). The ability to plan for alternative decisions on water use based on predicted near-term climate conditions (e.g., global patterns in sea water temperatures driving El Niño-Southern Oscillation events) would contribute to the improvement of real-time responses required to meet the intentions of RPA Actions.

Given the wealth of annual flow records available to various technical groups, it is almost imperative that a more concise analysis of rainfall patterns and overarching landscape-level climatic patterns be accomplished in order to create the most effective adaptive management strategy. One of the goals of restoring the system will be to recreate or simulate previously existing hydrographic cues; that is, an effective benchmark period must be created. In most cases, the previous 20 to 40 years are not useful tools. . The effect of climatic change and other phenomena make this arbitrary period an inappropriate target which sets target flows. 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 so that an effective benchmark target can be identified (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 Oscillation as well as proposed scenarios for climate change in California will be useful exercises to "fine-tune" future management options.

IRP responses to questions defining the charge and scope of the 2012 LOO annual review

The 2012 Annual Review focused on NMFS' Long-term Operations Opinion's Clear Creek RPA Actions (I.1.1 – I.1.6) and the Spring 2012 Delta Operations:

Implementation of actions

1) **How well did implementation of the Clear Creek RPA Actions and Spring 2012 Delta Operations meet the intended purposes of the actions?**

<u>Clear Creek RPA Actions</u>

There were six Clear Creek RPA Actions to consider this year, but some were not conducted (e.g., Action I.1.2, Channel Maintenance Flows) or the information necessary to determine whether the intended purposes were met was sparse or lacking.

Spring attraction flows (Action I.1.1) provided pulses of 400 and 800 cfs from Whiskeytown Lake instead of the minimum of two 600 cfs pulses described in the RPA Action. The intention of this action is to attract adult spring-run Chinook holding in the Sacramento River into Clear Creek. Although the pulses moved gravel downstream (a stated secondary purpose), the CCTT report (Page 5, para. 4) opined that fish monitoring results were inconclusive - just as they were in 2010 - due to low adult counts. The IRP agrees that the 2012 counts were disappointingly low. However, one can still statistically evaluate the effects of pulses on the counts. In 2012, nine fish were seen before the first pulse, 13 after the first pulse, and 39 after the second. If the pulses had had no effect, then one would expect these 61 fish to have been equally distributed among the three surveys, with about 61/3 = 20 fish seen in each survey. However, a chi-squared goodness of fit test (Zar 2010) rejects this equal-distribution null hypothesis ($P<0.001$, chi-squared = 26.1, df=2). Thus, there is evidence for a nonrandom difference in counts between the surveys, presumably (but not necessarily) due to the pulse flows. This same test, using "exact" P-values, can also be applied to the even-lower counts of 2010 and 2011.

Channel maintenance flows (Action I.1.2) were not performed and were once again delayed until 2014. Discharges of about 3000 cfs were common events in the past and discharges above 5000 cfs are most likely required to establish geomorphic threshold crossing events. A one day spike of 3,250 cfs will not complete much in the form of geomorphic work other than water some rocks and result in negative ecological impacts to Clear Creek. Small pulses of 400 to 800 cfs have stage increases of 0.5 - 1 ft at the confined location of the Igo gauging station. These would barely be measurable differences in terms of stage along the floodplain sites where most of the spawning and rearing habitat exists.

Spawning gravel augmentation (Action I.1.3) was intended to enhance and maintain previously degraded spawning habitat for spring-run Chinook and CV Steelhead. In 2011, 10,000 tons of gravel was placed at 5 sites in Clear Creek. Again there was no reliable metric to determine whether or not these augmentations are replacing or enhancing the quality of the spawning habitat for the targeted salmonid species or other fish and macroinvertebrate assemblages. Despite this lack of reliable metrics to gauge success, there is a clear intention to continue the spawning gravel augmentation project, with a concern expressed about the future source of gravel. The current plan is to use mine tailings that will be washed to remove the finer sediments containing mercury and potentially other contaminants and use a retention pond to permanently isolate those contaminants from the watershed. It is unclear how the quality of spawning habitat might be affected.

Replacement of the Spring Creek Temperature Control Curtain (SCTCC) (Action I.1.4) was intended to reduce adverse impacts of project operations on water temperatures for listed salmonids in the Sacramento River. The USBR replaced the SCTCC in Whiskeytown Lake on schedule in June 2011 at a cost of $3 million. However, unidentified “technical problems” with monitoring equipment apparently precluded pre-project monitoring to evaluate the effectiveness of this action. Effects, if any, of the SCTCC on temperatures in Clear Creek were not considered. However, in connection with the discussion on this temperature curtain, the IRP was informed that the Oak Bottom temperature control curtain (OBTCC) in Whiskeytown Lake was also damaged and in need of replacement or repair. While the agencies involved seemed to agree that the OBTCC should be replaced, no plan was advanced to test its effectiveness in meeting the intention of this action. It is unclear how the effectiveness of these temperature control curtains on water temperatures will be determined in either the Sacramento River or in Clear Creek.

Thermal Stress Reduction (Action I.1.5) was intended to improve conditions in Clear Creek for over-summering steelhead and spring-run Chinook during holding, spawning and embryo incubation. Seasonal temperature target maxima in Clear Creek at the USGS Igo gauge (about 6.5 miles downstream of Whiskeytown Dam) were set at 60° F during June 1 to September 15, and 56° F during September 15 to October 31. Thus far during 2009-2012, the temperature target was achieved consistently during the June to mid-September period, but frequently failed to be met during mid-September to October. In 2012, the temperature during this period exceeded the target maxima 69% of the time. During 2009-2011, temperatures exceeded the target 38% to 72% of the time. In prior years (2001-2008) temperatures at the Igo gauge exceeded the temperature target during September and October only 7% of the time. Once again there was mixed success in meeting the physical targets set by this RPA Action and no biological response data on which to base an opinion as to the intended effects on salmonids.

The Clear Creek Technical Team (CCTT) put forth a complex hypothesis that involved potential impacts of an interaction involving the Oak Bottom and Spring Creek temperature control curtains and the effects of “power-peaking” at generating stations above Whiskeytown Lake as a possible explanation for the failure to meet the conditions of Action I.1.5 during mid-September to October in recent years. There seemed to be agreement among the agencies that the Oak Bottom Temperature Control Curtain (OBTCC) was in need of replacement but there was no consensus regarding the role of power-peaking in current conditions.

There was a paucity of hard evidence provided to the IRP on which to form an opinion as to the scientific soundness of alternative hypotheses to explain the temperature observations at the Igo gauge.

Adaptively Manage to Habitat Suitability/IFIM Study Results (Action I.1.6) was intended to improve habitat conditions for spring-run Chinook and steelhead by adaptive management of flow conditions that favor salmonid survival. This Action is associated with what is perhaps the least definable objective. Also the IFIM Study which began in 2004 has been completed but reports on the findings were not available to the 2012 IRP. Consequently, there is no basis on which to develop an opinion as to the effectiveness of this RPA Action at this time.

Spring 2012 Delta Operations

There were three objectives to the Spring 2012 Joint Stipulation agreement:

(a) to provide for minimum protection of out-migrating juvenile steelhead by managing flow conditions in the Delta in a manner expected to allow salmonids to successfully exit the Delta;

(b) to increase water exports consistent with the protection mentioned in (1) above;

(c) to generate real-time tracking information in order to better understand how pumping rates, flows in Old & Middle Rivers, and juvenile steelhead migrations relate to one another.

The agreement called for installing a rock barrier at the head of Old River and managing flows in Old & Middle Rivers within an adaptive range of -1250 to -3500 cfs during April and -1250 to -5000 cfs during May. A predation study associated with the rock barrier was also required as part of a predator control study. The rock barrier was not completely impermeable and had several open culverts through which water and fish could pass into Old River.

In terms of meeting the intended purpose of the joint stipulation, increased water exports (a portion of Objective b) was achieved. Exports were ca. 57,000 acre ft greater than would have occurred under the NMFS RPA Action IV.2.1 (inflow:export ratio). The water provision side of the stipulation was achieved. While this was described as a "modest" increase in water supply, its significance should be considered within the context of the 2012 water year (WY) being categorized as "critical" and only upgraded to "dry" near the middle of May and the end of the joint stipulation period. NMFS determined that no further adjustments were needed as a result of the change in WY classification.

As for meeting the intended purpose of the biological portion of the agreement (protection of juvenile steelhead and clarification of the relationships between fish migration and inflows/exports), the IRP was unable to determine the level of success or failure for several reasons including the following.

The decision to install a rock barrier at Head of Old River (HORB) was based upon an assumption that it would not enhance predation on salmonid smolts; a previously tested non-physical barrier (bubble curtain) was shown to enhance the risk of predation mortality on smolts, which was the primary reason given for not using that approach.

Estimates of mortality used in setting the triggers for the number of tagged smolts that could be entrained by water operations depended on the assumption that the HORB did not enhance predation risk. Although testing that assumption was one of the conditions of the Joint Stipulation agreement, the 2012 IRP was not informed as to the outcome of any study to test predation associated with the rock barrier.

Furthermore, findings of the 2011 VAMP acoustic tag study, which estimated route-specific survival rates of tagged Chinook smolts, found that the highest survival rate through the Delta was via Old River. Most (64%) of the tagged smolts surviving to Chipps Island did so via artificial transport from the CVP holding tank. The HORB was intended to inhibit migration of smolts via Old River (the shortest route to the CVP holding tank) and as a consequence enhanced negative OMR flows, which may have encouraged higher smolt entrainment into the southern Delta via alternative routes. Data presented by the VAMP study showed that forcing smolts through the Delta by blocking the entrance to Old River decreased survival, presumably due to predation through the central Delta region.

The Spring 2012 plan for water operations focused on characterizing smolt movement with mean project operations, OMR flows, pump exports and I/E ratio. The plan appeared to be based upon the assumption that fish movements and survival would be correlated with measures of mean flow. However studies cited in the Tech Memo demonstrated weak correlations between smolt movement and particle tracking model studies and between project operations, OMR flows and smolt movement and survival. Studies available in the literature and many published in the region have demonstrated that fish movement across a wide range of taxa exhibit behavioral response to tidal oscillations. These behaviors facilitate either the retention of species in the Delta, or upstream/downstream movements necessary to complete their life cycles. The importance of tidal dynamics on smolt migration and interactions with predators and pumps received limited attention in the 2012 operations. When it was addressed it was in the context of tidal effects on passive particle movements.

It was emphasized by the 2010 OCAP IRP (Anderson et al. 2010, p 24) and confirmed by the Acoustic Tag Study conducted in April-May 2012 that steelhead smolts do not behave like passive particles and it was simply inappropriate to rely on the PTM to direct water operations intended to protect out-migrating juvenile steelhead. The effects on steelhead smolt survival could not be determined and this action cannot be described as providing any level of protection for steelhead.

The IRP believes that discerning behavioral responses of smolts and predators to tidal oscillations is crucial for understanding variation in salmonid survival within the Delta, and abundant information is available on the significance of tidal factors. Consequently, the IRP concludes that the best available information was not used in planning the 2012 Delta Operations.

2011 IRP recommended adjustments for Clear Creek Actions

2) **Where the 2011 Independent Review Panel made recommended adjustments to implementation of the Clear Creek RPA Actions,**
    a) **Were the adjustments made?**
    b) **How well did these adjustments improve the effectiveness of implementing the actions?**

The Clear Creek technical Team (CCTT) report and presentation frequently acknowledged the suggestions of the 2011 IRP. The recommended suggestion regarding gravel size in the spawning gravel augmentation program were followed but there were no biological response data upon which to base an opinion regarding whether or not this suggestion improved effectiveness of the action.

Although the CCTT agreed with the 2011 IRP's suggestion for improved temperature and flow modeling in the system, especially for Whiskeytown Lake, this has yet to be undertaken.

Also, the IRP suggestion to give a more natural hydrograph shape to the pulse release flows was not done. The 2012 IRP reiterates these last two suggestions.

Effectiveness of coordinating real-time operations with CCTT input

3) **How effective was the process for coordinating real-time operations with the Clear Creek technical team analyses and input as presented in NMFS' Long-term Operations Opinion [NMFS' 2009 RPA with 2011 amendments (pages 8-9)]?**

The CCTT Report lists topics associated with coordinated long-term operations on eight dates between December 15, 2011 and September 20, 2012 but there appeared to be no real-time operation effects related to analysis and input. However, there appeared to have been at least two incidents relevant to the implementation of actions. These were (a) a week-long period (June 3-11, 2012) during which warmer than intended water was released from Whiskeytown Lake due to an upper release gate being "inadvertently" left open, and (b) operations at the Redding power station which apparently is not under the control of USBR. The presentations from the CCTT and USBR made at the workshop in Sacramento on October 31, 2012 along with subsequent discussions with the IRP suggested that there may be a need for improved coordination between real-time operations and some of the RPA Actions intended to benefit salmonid populations in Clear Creek.

Indicators, study designs, methods and implementation procedures

4) **(a) Were the scientific indicators, study designs, methods, and implementation procedures used appropriate for evaluating the effectiveness of the Clear Creek RPA Actions and the Spring 2012 Delta operations?**

The approach in the Tech Memo was clearly articulated. Whether it was supported by the best available science prior to the study is less clear. In general, there can be little certainty as to the effectiveness of the indicators, study designs, methods and implementation procedures without reliable and accurate measures of biological responses.

Clear Creek RPA Actions

In general, the CCTT report tended to consider progress toward meeting RPA Action targets as a measure of success, which could be appropriate for actions intended to follow some expected trajectory over time (e.g., multi-year projects) but most actions are not defined in that manner.

A list of restoration goals have been created by the CCTT, but these goals must be continuously reviewed as studies are completed or different goals and endpoints are identified. These goals cannot remain static and the IRP urges the CCTT to review these goals annually to determine if the objectives and endpoints remain realistic. “River restoration” has been variously defined in the literature over the past three decades, ranging from “the complete structural and functional return to a pre-disturbance state” (Cairns 1991) to something less than ideal [“a return to an ecosystem which closely resembles unstressed surrounding areas”] (Gore 1985). Four overall targets can be identified (modified from Brookes and Shields [1996]):

Target	Definition	Management Approach
Full Restoration	Complete functional and structural return to an identified pre-disturbance conditions	Direct intervention, natural recovery, or enhanced recovery
Rehabilitation	Partial return to an identified pre-disturbance condition	Direct intervention or enhanced recovery
Enhancement	Any improvement in physical or biological quality	Mainly direct intervention
Creation	Development of a resource that did not previously exist, including “naturalization’ which creates a configuration of contemporary magnitudes and rates of riverine processes	Direct intervention

Gore and Shields (1995) argue that rehabilitation is probably the most likely obtainable target, yet the most expensive, while creation or abandonment of the project, is least expensive but most manageable. Targets continually shift in this broad spectrum of possibilities and the CCTT should consider modifying these targets as a component of their adaptive management strategy.

One of the goals of this project is the completion of the IFIM studies in order to create an adaptive management strategy. The successful completion of this study should allow the analysis of the appropriateness of other activities such as gravel augmentation and the achievement of restoration goals. It is imperative that the results of IFIM studies be reported. An adaptive management plan provides the flexibility that allows managers to respond to future change. These strategies must adapt to the actual results of the Clear Creek restoration plan as it progresses, yet one of the fundamental tools for the development of these strategies, after 16 years of restoration planning and work remains incomplete. The location, duration, and availability of habitat (as expressed as weighted usable area in PHABSIM or other habitat simulations]) over time under various operational scenarios can become a valuable planning tool.

Ultimately, completion of the IFIM study will require the correct choice of index period; that is, the previous historical records that best replicate natural hydrographs in the region, assuming that restoration of the hydrograph is, indeed, an acceptable restoration target. The choice of index period can be important as it must include a target condition prior to alteration *and* include the effects of regular climatic changes such as the Pacific Oscillation (see comparable work by Kelly and Gore, 2008, in the Southeastern US) and the effect of changing land use in PHABSIM predictions (Casper et al. 2011). For example, with changes in the Atlantic Multidecadal Oscillation, PHABSIM predicts a significant change in both fish and macroinvertebrate communities with each cycle (Warren and Nagid 2009) with shifts in dominant functional feeding groups and species composition, among macroinvertebrates, and top carnivores in the fish community. Such modeling results allow the focus of management strategies to shift as natural hydrographic conditions change.

During the CCTT presentation and later discussions at the workshop in Sacramento, it appeared that the team did not yet have an effective way to assess the effect of the temperature control curtains on temperatures of water releases from the reservoir into either the Sacramento River or Clear Creek. Also, there was a greater emphasis on relatively small (a few degrees) decreases in the temperature of the water released from Whiskeytown Lake rather than on stream water temperature when it reached targeted reach boundaries such as the Igo gauge, approximately 6.5 miles downstream or the lower reaches of Clear Creek approximately 12 miles from the dam.

Gravel augmentation has been a very active restoration activity in Clear Creek since 1996 (150,000 tons) and is planned to be continued into the future ($4.5 million). At this point there is insufficient data to support the ecological effectiveness of the gravel augmentation activities. It appears that two related responses follow this restoration activity. Spawning increases a couple percentage points and then just as rapidly declines (Fig. 9 CCTT 2012 report).

The CCTT 2012 report alludes to physical monitoring since 1996 and Figure 10 and 11 in that report show that pulse flows since 2009 have moved gravel in the Dog Gulch site just below Whiskeytown Dam, but there was less movement of gravel in the Peltier site just downstream. The IRP was unable to determine the type of data that were collected to distinguish the spread of gravel from the existing stream bed or how the magnitude of movement was assessed.

Spawning seems to occur very near the channel banks which may be a species preference or it could be that these areas had less gravel. At the 2012 LOO workshop, it was indicated that the channel was deeper at the edges as a result of how the gravel was placed and perhaps how the river flow encountered the gravel deposits. However, this only underscores the need to step back and quantitatively evaluate a set of metrics aimed at testing the restoration goals.

An independent 2005 review specifically of gravel augmentation practices in the Central Valley listed 20 unanswered questions concerning gravel augmentation practices (Lave et al. 2005.). One of the largest data gaps for Clear Creek, and most likely for the other sites, is linking threshold entrainment to discharge and routing/deposition of gravel through Clear Creek system.

The long-term future source of material for the gravel augmentation activities will come from mining tailings and hence there may be a potential to introduce additional mercury contamination to the system. The direct transfer of mercury - and other metals from sediments - through the aquatic food chain is a concern wherever past mining is prominent, such as in the Clear Creek basin. Fine sediments contain the higher levels of mercury then gravel and the fine bed sediments of Clear Creek have been shown to contain mercury levels 2 to 10 times natural background levels (Moore 2002).

Gravel augmentation seems to encourage spawning and hence the excavation of redds. There is also an expectation that gravel augmentation will result in favorable alterations of channel morphology. Both small- and large-scale morphological changes to the bed can result in an increased flow of hyporheic water through the surface sediment. Merz et al. (2004) reported on the possible benefits of gravel augmentation on spawning bed enhancement showing that it increases survival and growth of Chinook salmon embryos in the Mokelumne River. Other authors have shown the exchange of hyporheic water enhances the formation of riffle complexes with measurable impacts in terms of moderating riverbed water temperature (Grant et al. 2006a, b, Hanna et al. 2009). Brown et al. (2007) showed that spatial variation in sediment source resulting from flood transport of mine tailings along with temporal changes in hydrology, combine to dictate the role of the hyporheic zone in the transport and retention of arsenic.

In the lower reaches of Clear Creek bed sediments have mercury concentrations that are already above background levels and high flows that scour the bed reintroduce fine sediments into the flow. This coupled with gravel augmentation could be enhancing geomorphic change that in turn enhances hyporheic water flow through sites that encourage spawning soon after mobilization of the gravel. If so, gravel augmentation and flushing flows could be encouraging spawning in gravels where intra-gravel flow contaminated fines passed through incubating salmon embryos. The total net effect on salmon reproduction from the restoration activities of gravel augmentation coupled with flooding is unknown but it is not unlikely that gravel augmentation to encourage salmon spawning in an already highly contaminated creek bed could adding an additional layer of stress detrimental to the survival of the very species it is trying to help.

Indeed, Moore (2002) in discussing Clear Creek specifically states:

> *"Understanding the distribution of such widespread contamination is essential to river restoration, especially where dredging, filling, excavation, floodplain construction and changing sediment dynamics may lead to remobilization of contaminants from the riverbed/floodplain, making them more bioavailable. Specific river restoration efforts can also be stymied by bed-sediment contamination, especially those designed to increase/recreate fish spawning habitat. An example is the dependence of some salmonids on areas of upwelling through a gravel bed. If the bed is contaminated with mercury or other heavy metals, geochemical reactions within the bed can release contaminants to the water that irrigates fish eggs. This increased metal loading can decrease reproduction and productivity at spawning sites."*

The IRP recognizes that the plan is to wash the gravel used in the augmentation and remove the more heavily contaminated fine sediments, storing them in containment areas. However, this commits one or all of the agencies involved to the perpetual obligation of preventing the concentrated contaminants from entering the watershed.

The CCTT Report also included speculation about what may be learned through the use of both video and sonar. There are many "may"s here. The IRP suggests that CCTT members posit some specific, realistic outcomes from these two monitoring sources and think through exactly what conclusions could be drawn before investing substantial financial resources in video and sonar monitoring programs.

Spring 2012 Delta Operations

The study design for real-time operations using acoustic tagging material was inadequate to develop real-time operations. The operations were based on the arrival of fish at specific points in the inner Delta which were adjusted over the season because the fish arrived at the target points earlier than expected.

The general project operations have been managed in terms of the mean flows in OMR and in the San Joaquin River. This has been the fundamental approach for operations of the system for years but has resulted in inadequate protection for fishes. In part, this is because attempts to understand the movement and survival of fish through the Delta to date have not considered effects of tides, which are the dominant control on flow velocities and mean direction of flow.

Delta survival of steelhead, and especially Chinook, was extremely low based on tagging studies. Characterizations of survival in terms of river km or mean flow are inadequate because the rapid travel time and complex routing of fish through different reaches cannot be explained by these mean measures. The IRP suggests the travel, routing and survival of fish through the system needs to account for migrant behavior and the behaviors of the predators in response to the strong tidal influences in the Delta (see Appendix A2.2: Selective Tidal-Stream Transport).

The acoustic tagging experiment also had logistic and possibly methodological difficulties from the start, so reliability of the results is questionable for reasons that will be explained subsequently. Second, when difficulties were encountered, there was an attempt to use an “adaptive management” approach in real-time that only seemed to complicate the situation. Adaptive management requires that something be learned before adjustments are made, it was not intended to simply take another course when things are not going as intended in real time. There were two substantial examples of this:

(1) When the acoustic tagging study could not begin on April 1, the Particle Tracking Model (PTM) was substituted as a means of providing input into decisions regarding water operations for the purpose of protecting juvenile steelhead. As mentioned earlier, there was no means of determining whether or not this approach provided even minimal protection for out-migrating smolts.

(2) The original plan for the acoustic tag study was to run water operations in a manner that allowed OMR flows in the range of -1250 to -3500 cfs in April and -1250 to -5000 cfs in May. However, when the tagging study had logistical difficulties that delayed its start for 2 weeks a series of decisions was made that altered the experimental design.

After the first release of tagged smolts on April 16, when OMR flows of -3500 cfs were planned the number of tags entrained in the south Delta exceeded the trigger within 4 days and after a delay of 2 more days OMR flows were reduced to -1250 cfs through April 30. At this point, a decision was made to raise the trigger and switch the experimental treatment level to OMR flows of -5000 cfs instead of the -1250 cfs planned for May 1-15. Two days after release of the second group of tagged smolts the trigger was once again exceeded and, because of other constraints on water operations, flows were reduced to -1250 cfs for the remainder of the period (May 8-12) following a 5 day delay. The response was to raise the trigger once again and schedule operations to flows of -5000 cfs for the finally period as originally planned. Five days after the final release of tagged smolts, the highest trigger was exceeded and flows were reduced to -1250 cfs during May 23-28. Consequently, the apparent attempt at real-time "adaptive management" during this experiment resulted in a substantial alteration of the original experimental design that weakened the test for effects of flow on steelhead smolt survival and routing as follows:

Time Period	Original Plan	As Conducted – Spring 2012
April 1-15	-1250 cfs for 14 days	-1800 cfs Apr 1-7; -2500 cfs Apr 8-14; No Tags
April 16-30	-3500 cfs for 14 days	-2446 cfs for 7 days
May 1-15	-1250 cfs for 14 days	-2933 cfs for 7 days
May 16-31	-5000 cfs for 14 days	-5193 cfs for 7 days

Note that the changes implemented did not allow for any measurement of tagged smolt survival and routing under the lowest OMR flows (-1250 cfs) and the intermediate flow treatment level (-3500 cfs) was not achieved. Instead, two of the flow treatment levels were so similar (-2446 cfs and -2933 cfs) as to be functionally identical and there was no minimum flow regime included in the experiment as conducted. However, this did not seem to deter reaching the conclusion that there was no relationship between OMR flows and smolt entrainment to the interior Delta. This is too broad a conclusion to draw from the altered experimental design. It remains entirely possible that entrainment is related to OMR flows within any range between -2446 cfs and >0 cfs and becomes asymptotic at some threshold level of negative OMR flow.

Also, many of the study's initial conclusions are not adequately supported by the analyses because they fail to make use of statistical testing or confidence intervals. The analyses should be redone with greater statistical rigor, where possible. It is possible to test for evidence of a flow effect within the range of flow levels tested using the available data. We suggest recoding release groups 1 and 2 as "intermediate" OMR flow, and group 3 as "high" OMR flow. Then Groups 1 and 2 can be considered as independent replicates (n=2) of an "intermediate" flow treatment level, with Group 3 providing the only replicate (n=1) of a "high" flow treatment level.

Methodological issues with the acoustic tag study on steelhead smolts conducted under the 2012 Joint Stipulation Agreement.

The IRP recognizes that there were logistical, meterological and other difficulties beyond the control of the Department of Water Resources and their collaborators and contractors in conducting the Spring 2012 acoustic tag study. The LOO IRP also acknowledges that previous OCAP IRPs have consistently recommended studies to link biological responses and the physical targets in the RPA Actions. The attempt to move in this direction with the acoustic tag study was commendable and the following comments should not be interpreted as a criticism of those who attempted it.
As with most experiments, the credibility and reliability of the findings depends substantially on whether or not assumptions are reasonable or tested. The following were assumptions stated in the workshop presentation by Kevin Clark as applying to the Spring 2012 acoustic tag study:

(1) Tag detection probability at each location is high (>80%) and similar to the 2010 VAMP findings.

(2) Detection probability may vary among receiver arrays but not between release groups within arrays.

(3) No predator detection filter was required (i.e., all detections were assumed to be live steelhead, not tags carried by predators that had consumed tagged smolts).

(4) OMR flow differences between Group 3 and Groups 1 + 2 were sufficient to test the hypothesis that flows affect fish behavior.

(5) Sentinel hatchery steelhead and wild steelhead smolts behave similarly.

(6) Hatchery smolts released in the tidal portion of the San Joaquin River behave like river-run steelhead.

As to the first and second assumptions, the two studies used very different acoustic tags and receivers. The Joint Stipulation Study used VEMCO tags (V5) which transmit at 180KHz and VAMP uses Hydroacoustic Technology Model 795Lm tags which transmit at 307KHz. Both frequencies are suitable for use in freshwater but the detectable signal range of tags transmitting above 100KHz tends to be degraded with increasing salinity, turbidity, boat noise, etc. There was no mention of range tests conducted on the field arrays to verify this assumption. In tidal environments, one can also expect detection range to be affected by tidal movement and may differ at high and low tides (for a good example see Pautzke 2008). These assumptions can and should be tested. If environmental variation within the Delta affected the detection range of the receivers that resulted in a systemic bias, it could result in reduced tag detections being incorrectly perceived as mortality. When detection probabilities are < 100% and are not properly accounted for, survival estimates are expected to be biased lower (Drenner et al. 2012).

The third assumption conflicts with observations from the VAMP acoustic tagging studies (Vogel 2010, 2011) which now attempts to apply a predator filter that accounts for a considerable number of tag detections.

The fourth assumption was considered earlier. The two points representing treatment level flows in this experiment are relatively high and so the findings only apply to OMR flows that are more negative than -2446 cfs. There is a large range of flows more positive than this value within which a relationship between flow and smolt behavior could still exist. This is a severe limitation on the findings of the Joint Stipulation Study.

The fifth and sixth assumptions are unlikely true, as several studies have demonstrated differences in the behavior and survival of out-migrating wild and hatchery salmonid smolts (e.g., Chittenden et al. 2008; also see reviews by Melnychuk et al. 2010 and Drenner et al. 2012).

Several other potentially important assumptions were not mentioned. Among these were that: (a) tagging does not affect survival, (b) there was little or no mortality from handling, (c) tag expulsion was minimal, (d) the tag burden (weight of tag:weight of smolt) was appropriate and similar across groups, and (e) that tags did not affect swimming performance or predator avoidance.

In a recent review of tagging studies to examine the behavior and survival of salmonids, it was noted that only 10.6% of studies reported in the 207 papers assessed tagging and handling effects and only about a third of the studies even acknowledged them (Drenner et al. 2012). Given that one of the logistical challenges mentioned in the joint stipulation study was a paucity of experienced personnel available to implant acoustic tags, this could have been a potentially important source of mortality and tag loss in this study. Given the constraints to conduct the study in Spring 2012 under difficult circumstances, it may be impractical to expect such an assumption to be rigorously tested, but lacking evidence to substantiate this and other assumptions provides reason to doubt the accuracy of the findings.

Information on the size of smolts used in each group was not provided, but VEMCO V5 acoustic tags weigh an average of 0.65 g. Ideally, tag burdens of no more than 2% are recommended for most species, and burdens in excess of ca. 5% are generally not recommend for salmonid smolts (e.g., Adams et al. 1998), suggesting that appropriate smolt sizes for V5 acoustic tags would be > 13 g. There have been very few studies assessing the effects of tag burdens on the behavior and survival of salmonids (Drenner et al. 2012). However, early short-term swimming performance and higher predation rates have been associated with juvenile Chinook salmon carrying surgically-implanted transmitters for radio telemetry (Adams et al. 1998).

Statistical issues with the acoustic tag study on steelhead smolts conducted under the 2012 Joint Stipulation Agreement.

Data analysis issues were not specifically addressed in the charge to the 2012 LOO IRP but the IRP believed it was necessary to comment on this aspect of the recent studies because statistical rigor is crucial for objectively interpreting apparent patterns in the results. For example, Figure 5 in the "Status Report for 2012 Acoustic Telemetry Stipulation Study" shows cumulative detections at different receiver arrays. Cumulative distributions can exaggerate differences between time series counts. In the upper panel, the green and blue curves appear quite different, and yet the time series differ only by a few fish on days 2 and 3. Because the counts are low, it is important to place confidence intervals on these curves, before claiming they differ. In addition, with low sample sizes, it is more realistic to plot cumulative counts as a stair-step rather than a smooth curve.

These same comments apply to the cumulative count figures in the PowerPoint presentation (e.g., slide 31, 37, 39) given on this topic at the workshop in Sacramento on October 31, 2012. Because of low counts, the confidence intervals on the curves in these figures will likely all overlap substantially.

It would also have been useful to place confidence intervals on the estimated proportions in Figure 6 in the same Status Report, and in all other figures that display similar estimates (Zar 2010). To test whether proportions differed across the three junctions, the IRP suggests fitting a logistic regression model with probability of entering the interior Delta as the response variable, and junction and flow level as the explanatory variables. Recoding groups 1 and 2 together as "Intermediate flows", and group 3 as "Higher flow", it would be possible to test for the hypothesized difference between the 2 flow levels and reach a supportable conclusion, at least within the range of flows observed.

The boxplots in Figure 11 of the Status Report on the 2012 Acoustic Telemetry Study are unclear with respect to the sources of variation represented. The IRP was unable to determine the sample sizes in each case, but if small (n < 10), then boxplots can be misleading, and perhaps the data should just be plotted as distinct points. Also, this figure includes data from earlier releases ("six year release groups"), then release group ID's 1, 2, 3 and their relation to flow have no clear meaning.

At the top of p. 18 of the Status Report, "a generalized linear model with binomial error structure" was applied to tag detections at receiver array 9 compared to either array 12 or 14. The IRP did not understand exactly what was being tested by this model.

The 2011 VAMP acoustic tagging study of Chinook salmon smolts.

The 2012 IRP recognizes that evaluating the Vernalis Adaptive Management Program (VAMP) studies was not specifically within this year's charge. However, during the workshop in Sacramento (October 31, 2012) the IRP was presented an update from Rebecca Buchanan on the findings of the 2011 VAMP Acoustic Tagging Study which estimated survival of hatchery-reared acoustically tagged Chinook salmon smolts along different potential emigration routes from Mossdale to Chipps Island. Within the context of the workshop, it was difficult to avoid making comparisons between the VAMP and Joint Stipulation Acoustic Tagging Studies given the similarities in the intentions and objectives of the research projects.

The VAMP findings were that overall survival along all routes combined was less than 2% in 2011 and that survival was greater through the southern Delta than through the mainstem of the San Joaquin River. Also, plots of findings from three years of the VAMP acoustic tag study (2008, 2010 and 2011) suggested that higher river flows at Vernalis resulted in lower survival of smolts along the San Joaquin River route. These results contrast with those from earlier coded wire tag (CWT) mark-recapture estimates (analysis by Newman) which have been the basis of the NMFS Biological Opinion on salmonids and to provide the rationale for RPA Actions involving water operations in the Delta (see Report on Spring 2012 Delta Operations in lieu of Action IV.2.1 per Joint Stipulation).

In the VAMP 2011 tagging study, detailed route-specific survival rates tended to decrease in down-river segments and were greatest along the Old River route leading to the CVP tank from which tagged smolts were transported by truck to Chipps Island. The findings, if reliable, suggest that transport from collection facilities associated with water operations provides the best survival chances for Chinook salmon smolts in the San Joaquin watershed. Moreover, it suggests that the use of rock and/or other barriers at the head of Old River on the San Joaquin River that force smolts into the Delta interior where survival is less than 2% should be reconsidered. Indeed, it seems plausible from findings of recent acoustic tagging studies that higher smolt survival will be achieved through encouraging migration down Old River and towards the CVP tank.

The IRP is unaware of any current measure of smolt survival subsequent to transport and release at Chipps Island, but studies conducted in the Columbia River watershed have suggested that there was little evidence of “delayed” mortality associated with transport induced stress in spring Chinook smolts (Rechisky et al. 2012). The same study also suggested that survival to adulthood could still be impaired by early ocean entry as a result of transport. In the 2011 VAMP acoustic study, transported smolts reached Chipps Island in less than half the time (average of 2.6 days, n=24) as those taking an unassisted river route (average 6.3 days, n=8), so route-specific consequences for survival to adulthood remain uncertain.

The VAMP acoustic tagging program has been conducted annually since 2008 and so these studies have an experience advantage over the Spring 2012 Joint Stipulation Study (i.e., less likely to have experienced surgically-related sources of mortality and tag expulsion due to skill levels of personnel), but nonetheless are subject to many of the same criticisms regarding certain key assumptions, especially those related to array-specific detection probabilities under different environmental conditions. In fact, the use of HTI Model 795Lm acoustic tags, which transmit at a frequency of 307KHz would be expected to have an even smaller detection range in the tidal estuary than the VEMCO tags (180 KHz) used in the Joint Stipulation Study. Unless there have been array-specific range tests conducted across the entire environmental gradient that were not available to the IRP, there is reason to doubt the claim of high detection probabilities for every route and river segments between arrays, especially in tidal environments where salinity and perhaps turbidity are greater than in the freshwater reaches. A first step in addressing this issue would be to focus range detection tests on arrays associated with areas identified as mortality “hotspots” where survival was considered to be at or near zero.

There are a few other considerations that complicate comparisons between the VAMP acoustic tag studies and the CWT studies analyzed by Newman (2008). Perhaps the most important difference is that CWT studies depend on actual recaptures of tagged smolts so survival of individuals to the recapture point is a certainty. Acoustic tag studies – with the exception of smolts transported from the CVP tank – track tags and not smolts. The tags could be transported within predators that consumed smolts or could go undetected by a given receiver array due to imperfect detection probabilities.

Although there are filters that can be applied to adjust for these discrepancies, these are still estimates associated with a level of uncertainty.

Another difference between the CWT and acoustic tag studies is the route endpoint which was Jersey Point for the CWT studies and Chipps Island (over 10 miles farther down-estuary) for the VAMP acoustic tag studies. If smolt survival was low between Jersey Point and Chipps Island, it would help explain the difference in survival among the studies. However, the 2011 VAMP data are not consistent with this hypothesis given that smolt survival within that segment was estimated to be about 69% (see slide 22 in PowerPoint presentation by Buchanan et al., LOO Annual Review, October 31, 2012). Alternatively, differences may be due to inter-annual variation in smolt survival, which is known to be highly variable in other systems (e.g., Chittenden et al. 2010).

In any case, substantial uncertainties remain regarding the effects of water operations on the survival and behavior of out-migrating salmonid smolts. Conflicting findings of different studies and methodological issues associated with the approaches used to evaluate survival and routing behavior of out-migrating salmonid smolts have not yet provided a clear path to suggest that fine-tuning water operations will provide a successful means of maintaining or restoring salmonid populations that migrate through the southern Delta.

Clear Creek Technical Team Report specific questions

Were the approaches used to develop the recommended actions to reduce water temperatures scientifically appropriate?

The CCTT report provided a number of suggestions aimed at reducing water temperatures in discharges from the Whiskeytown Reservoir. The presumed effects of replacing the Oak Bottom Temperature Control Curtain (OBTCC) and power peaking on Clear Creek temperatures (Fig. 16 in the CCTT Report) were largely speculative and need to be verified through modeling, analysis of existing temperature data and controlled experiments, if possible.

Releases of colder water from lower in the reservoir as temperatures warm in the summer seems to be a common sense recommendation but still requires some verification with respect to the available volume of cooler bottom water in storage and how far downstream the intended effects on temperature are likely to extend under different climatic conditions, ranging from sunny and hot to cloudy and cooler.

What recommended adjustments to actions and implementation procedures for reducing water temperatures might be scientifically appropriate for the next year, while maintaining equal or greater protection for fish?

Any of the suggestions “might be” scientifically appropriate but require some objective testing to be certain. The IRP suggests that CCTT consider options for assessing the potential temperature-specific pools of water available, through modeling and real-time monitoring within Whiskeytown Reservoir and upstream.

Given that there seems to be consensus among the agencies in favor of repair/replacement of the OBTCC, the 2012 LOO IRP can see no reason to object but would strongly recommend that this action be conditioned on an evaluation of effectiveness that includes measurements before and after installation of a replacement curtain.

Spring 2012 Delta Operations specific questions

Was the approach to real-time operations, including the use of a rock barrier at the Head of Old River (HORB) and acoustic tagged fish for triggering real-time decisions, while providing equal or greater protection to out-migrating steelhead smolts under RPA Action IV.2.1, clearly articulated and supported by best available science in the NMFS February Tech Memo and supporting documentation?

The approach was clearly articulated in the February Tech Memo and supporting documentation but there was little basis for assessing the effects of the HORB on the intention of providing equal or greater protection for out-migrating smolts.

Survival models played a prominent role in decisions about the rock barrier and Old River flows, as evidenced in materials provided to the IRP. The models are also the kernel of the “HORB and survival exploration tool” spreadsheet. However, none of the material reviewed by the IRP discussed the uncertainties of these models, apart from the statement that survival estimates may be somewhat too high for present-day conditions (Report on Spring 2012 Delta Operations, Appendix D, pg. 3). Because of their management importance, the IRP believes it is critical to quantify and communicate the uncertainties of these models.

In addition, the IRP traced the constant survival estimates (flat lines in Figure 2 of the Report on Spring 2012 Delta Operations) back to the Newman (2008) report. However, the IRP could not locate the figure’s flow-dependent survival equations in that report, nor could we find the idea of estimating a weighted average (mixed model) of the flow-dependent and flow-independent models.

In Appendix C (Summary of expected benefits of the Spring 2012 Delta Operations Report), the interpretation of relative survival in OMR vs. San Joaquin was unclear. Smolt survival was apparently lower (again, no uncertainty estimates) in the San Joaquin in 2009-2010, with an acoustic barrier in place. And San Joaquin survival in 2008 was higher when no barrier was in place. Nevertheless, a rock barrier (HORB) was installed at the Head of Old River in 2012,"… based on a preponderance of the data". What data constitutes "a preponderance" of evidence is unclear. Perhaps all comparable through-Delta survival estimates, from all years, should be tabulated and presented with key environmental conditions (barrier presence, flows, tagging method, etc.), to reveal the true variation in survival estimates and possible reasons for that variation.

There were several reasons one could reasonably speculate that the effects of the HORB were detrimental to survival of smolts. Given that the VAMP acoustic tag study results have indicated that Chinook smolt survival through the Delta is substantially greater when smolts are transported to Chipps Island from the CVP holding tank, routing smolts via the shortest river segments to the holding tank would seem the best option for protecting out-migrating salmonid smolts.

The HORB inhibits passage along one of the shortest routes to the holding tanks from the upper San Joaquin watershed. Also, the HORB increases negative Old and Middle River flows and potential opportunities for smolts to become entrained along routes in the southern Delta, where survival is considerably lower.

Also, it has simply been assumed that the HORB does not result in enhanced predation mortality on smolts as was shown to occur with the non-physical barrier tested in previous years. All of the calculations and recalculations of route-specific mortality on acoustic tagged smolts that resulted in increasing the number of entrained smolts required to trigger real-time decisions for adjusting water operations were all based on the assumption that the HORB was not associated with increased mortality from predators or other factors. Lacking evidence to the contrary, it is difficult to conclude that the HORB provided equal or greater protection for smolts.

Finally, even after the triggers for tagged smolts were exceeded, there were frequently substantial lags of several days before pumping operations were reduced. Taken together, it is difficult to conclude that the approach taken in the Spring 2012 operations provided even minimal protection for out-migrating smolts. Negative effects of such artificial stresses may have even enhanced the higher natural mortality expected in a dry (or critical) water years such as 2012.

Were the weekly adjustments made consistent with the Tech Memo and supported by the available data and information, while providing necessary protections?

Weekly adjustments to operations appeared to be made within the season because the rapid movement of fish into the Delta was unexpected.

Is the overall approach of using acoustically tagged fish to adjust weekly operations scientifically supportable?

It was not clear to the IRP how water operations coordinated on the movement of acoustically tagged fish was protecting the passage of smolts. The study found that fish entrainment into the inner Delta was not related to pumping operations, suggesting that weekly adjustment of operations by fish movement is not scientifically supportable.

Were the scientific indicators (e.g., fish behavior or drivers of habitat conditions) used appropriate for evaluating the effectiveness of the Spring 2012 Delta Operations?

The lack of a relationship between fish movement and particle tracking model results and the lack of relationships between OMR inflows/exports and smolt movement/survival suggest that these were insensitive indicators for evaluating effectiveness of Delta operations on salmonids in Spring 2012.

Were the scientific indicators and methods used for classifying and detecting "smolt-type" vs. "predator-type" tags in real time appropriate for informing the Spring 2012 Delta Operations?

The Joint Stipulation study using acoustic tag did not determine if detected tags represented smolts or predators that had recently consumed tagged smolts. The approach to determining behavior relative to the tidal component may provide some classification regime. The 2012 IRP also noted that estimated survival - even without adjusting for predators (i.e., assuming no predation of observed tags) - was so low that the run may not be sustainable. Thus, although the classification of tag status is important, especially for identifying smolt movement patterns, the results may be of limited value in evaluating the impact of Delta operations on salmon and steelhead.

How well did the particle tracking model predict fish behavior relative to acoustically tagged data?

The acoustic tracking data as analyzed provide little information of fish behavior. However information in the tidal component of the particles may provide an approach to interpreting fish behavior. See Appendix 2 at the end of this report.

What are the most important analyses to complete for the 2012 data set? What scientific methods for analyzing voluminous response data (e.g., tag detections throughout the acoustic receiver array) and treatment conditions data (e.g., magnitude and direction of flow near specific receivers) might be more appropriate for evaluating the effectiveness of the Spring 2012 Delta Operations?

The question assumes that the 2012 data set is sufficiently reliable and contains important information extractable by analysis.

An important analysis is to evaluate survival and routing relative to Delta hydraulics including the mean and tidal flow components on a reach specific basis. See Appendices 2.1 and 2.2.

What scientific indicators and methods used for classifying and detecting "smolt-type" vs. "predator-type" tags in real time might be more appropriate for informing the Spring 2012 Delta Operations?

How to detect smolt-type vs. predator-type behavior is a subset to the larger issue of how tides affect predatory-prey interactions in the river and Delta. See Appendix 2.3 for further discussion.

What adjustments to the particle tracking models, as informed by the acoustically tagged fish studies, might be more effective for predicting fish behavior and informing future acoustic study design?

Information on mean and oscillatory (tidal) components of the flow over reaches and at reach junctions are likely to provide important information predator-prey and migration behavior as influenced by tides. See Appendices 2.3 and 2.4. However, the 2012 IRP reiterates the suggestion of the 2010 OCAP IRP that rather than making adjustments to the PTMs, a behavioral model for how species in the Delta respond to their local environment should be developed from first principles.

How should the experimental design be adjusted in future years to test key habitat drivers of smolt behavior and survival, and support weekly operational decision making?

Behavior-based fish movement modeling is gaining increasing acceptance as a potentially important tool in water and living resource management in the Bay-Delta and Sacramento River. Despite its potential, behavioral modeling is still a relatively new and developing technology whose optimum future use will depend on decisions made in the near-term. The IRP believes that actions need to be taken soon to help ensure that this technology contributes to future difficult management decisions.

Fish movement modeling and its many possible derivatives such as time-dependent or distant-dependent mortality forecasting should be considered in its broadest context. A useful way to understand fish movement modeling is to relate it to Computational Fluid Dynamics (CFD) modeling. CFD modeling is used to develop a virtual representation of a flow field which is then input to mathematical algorithms that attempt to capture sensory acquisition, sensory processing, and cognition.

Time varying, multi-dimensional CFD codes may be many thousands of lines long so that their connection to a behavioral model may be difficult and time-consuming. It is important for the region to formulate and address the strategic questions inherent in using fish movement models to address the many pressing questions faced by the region. Poor decisions made without fully understanding either the full range of possible modeling approaches, or before the full range of tentative uses are identified, can result in future performance or application challenges.

An effective way of addressing this would be through a series of technology workshops in which uncertainties in the optimum development and application of fish movement models can be identified and discussed. These workshops should include experts in fish movement modeling at different scales, fish tagging experts to answer questions about collection, calibration and validation of data, CFD modelers to answer questions concerning optimum hydraulic modeling, regional living resource experts to identify and refine potential applications, and living resource managers to describe important management questions that must be addressed. Each workshop should produce a guidance document that can be used to strategically develop behavioral modeling with specific application to the Bay-Delta watersheds.

The results of tagging studies to date (through the 2012 study), show little correlation between operations and fish movement, and so do not currently support using salmon to manage operations on a weekly basis. In Appendices 2.1 to 2.4 the IRP presents hypotheses on how migration and survival may be influenced by tidal oscillations in the river and Delta. If ongoing or future research identifies significant mechanisms affecting fish on tidal cycles, then managers might consider adjusting Delta operations on this scale. However, considerable work will be required to evaluate this hypothesis, and if supported, to design a tidally-based management program.

The 2012 IRP also raises the question of whether salmon populations are sustainable in the San Joaquin River (Appendix 2.5). While the IRP realizes that the Biological Opinion for the operations of the SWP and CVP is not charged with addressing the viability of the run, the IRP believes the question eventually needs to be addressed in this or another process.

5) How should multi-year data sets on NMFS' Long-term Operations Opinion RPA Action implementation be used to improve future implementation of the Clear Creek RPA Actions?

The hydrologic system that is used to control the flow of water in Clear Creek below Whiskeytown reservior is extremely complex, involving 3 reservoirs two tunnels, flow and temperature demands in the Trinity, Sacramento Rivers and power production for the City of Redding. In addition, water management in this river system must contribute to meething the co-equal goals of providing a reliable supply of water for human needs and provide for healthy ecosystem functioning. Componding the physical complexity is the high level of interagency involvement, communication and data sharing required to operate the system at peak potential. Moreover, decisions need to be made based on forecasting water supply months ahead of time.

Because of this complexity in system structure, opertational demands and interannual climate variation, it would be useful to develop an expert decision system to assist in making operational decisions on how water is routed through the system

Existing physical water routing models based on Computational Fluid Dynamics (CFD) could be developed in such a way as to link the hydrologic system of reservoirs, tunnels and river outflows to climate modeling and prediction output. This would allow for better strategic planning and action rather than relying primarily on reactive operation. One suggestion is to seek the input of an expert in this type of modeling to help guide an initial phase of investigation into models and feasibility.

A major problem addressed by the 2011 OCAP IRP (Anderson et al. 2011) was the need to enhance communication and data sharing through a common web-based clearing house along with easily accessible monitoring data to assess and ensure regulatory compliance. This same message has been voiced by all agencies, consultants, participipating scienctists, academic institutions and other review panels (Lave et al. 2005.). However, no progress in this direction seems to have been made. What is needed is a web-based collaboration tool that can buid multidisciplinary collaboration, centralize data and information, including development of robust yet easy to use search and display tools, that communicate complex information from large-scale modeling results and network sensors in a way that allows various stakeholders to view decisions and their effects. These tools exist and can be applied to resolve not only issues related to Clear Creek but the whole Central Valley system.

The IRP suggests that the Delta Science Program could facilitate a workshop where industry and academic leaders in this field can present their approaches and potential solutions to the agency partners. Perhaps the Clear Creek working group could provide a test bed model to start building such a web-based collaboration tool.

Another significant need for the Clear Creek group and restoration effort is that of an independent synthesis of all the restoration work and systems management to date. There has been 16 years of restoration effort in Clear Creek below Whiskeytown reservoir without an apparent synoptic review of that work. Instead, the CCTT continues to emphasize perpetual spawning gravel augmentation and changes to the timing and magnitude of reservoir releases without an objective assessment of what has been accomplished to date.

Temperature control in Clear Creek is directly related to the manner in which water flow is managed within the Trinity-Whiskeytown reservoir complex. A temperature control curtain has been replaced in Whiskeytown reservoir near the Spring Creek Tunnel intake and is expected to force more cold water toward that outflow. However, there has not been any data to corroborate that assumption. It is not known how this repair action has or could impact temperature control actions in Clear Creek through operation of the upper and lower intake gates at the Glory Hole intake tower. However, water temperature measured at the Whiskeytown outflow while water intake was shifted between the upper and lower intakes indicates that changes in water temperature outflow can be achieved (Figs. 6 and 16 of the CCTT 2012 report). Indeed, even a mix of water (refered to as middle gate) from both intakes shows an immediate change in water temperature that brackets the entire temperature regime from May to November measured over the past 12 years (Fig. 16, CCTT 2012 report). This suggests that water temperatures in Clear Creek can be controlled to benefit spring-run Chinook and steelhead, but it remains to be seen how far downriver temperature reductions can be maintained.

What is not clear from the CCTT 2012 report is how to assess the potential to achieve this in different water years and whether cooler temperatures in Clear Creek can be extended below the Igo gauging station throughout the summer.

Two planned pulsed flows of 400 cfs and 800 cfs from Whiskeytown reservoir were released in May and June of 2012 with the intent of attracting spring-run Chinook salmon into the upper reaches above Igo. Snorkel data conducted before and after the pulsed flows showed that Chinook salmon moved upstream but it was unclear that they did so in response to the pulsed flows. Reaching such a conclusion would require comparable snorkel surveys without pulsed flows, which could not be done simultaneously.

The 2012 LOO IRP reiterates the suggestion of the 2011 OCAP IRP that if pulsed flows are going to be released they should follow a more gradual rising limb with a longer smooth falling limb.

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APPENDIX 1 – Materials for IRP Review

Review Materials Available to the 2012 LOO 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 31 October -1 November 2012:

1) Draft 2012 Clear Creek Technical Team Report for the Coordinated Long-Term Operation BiOp Integrated Annual Review

2) Spring 2012 Delta Operations in lieu of NMFS' RPA Action IV.2.1 per joint stipulation
   - Appendix A: Joint stipulation
   - Appendix B: RPA Action IV.2.1
   - Appendix C: Summary of expected benefits from alternative operations
   - Appendix D: NMFS Technical Memorandum issued March 16, 2012
   - Appendix E: Tabular summary of Spring 2012 operations and cumulative tag detection data
   - Appendix F: NMFS Determination for Operations per Joint Stipulation During April 1-7, 2012
   - Appendix G: NMFS Determination for Operations per Joint Stipulation During April 8-14, 2012
   - Appendix H: NMFS Determination on April 12, 2012
   - Appendix I: NMFS Determination on April 27, 2012
   - Appendix J: NMFS Determination on May 4, 2012
   - Appendix K: NMFS determination on May 11, 2012
   - Appendix L: Water supply impacts of operations under Joint Stipulation relative to RPA Action
   - Head of Old River Barrier and survival exploration tool

3) Preliminary Report (Phase 1 Analyses) for the 2012 Acoustic Telemetry Stipulation Study

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

- Smelt Working Group (SWG) Annual Report on the Implementation of the Delta Smelt Biological Opinion on the Coordinated Operations of the Central Valley Project and State Water Project ("OCAP" Biological Opinion) Water Year 2012
- Sacramento River Temperature Task Group (SRTTG) Annual Report of Activities
- 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
- Report of the 2011 Independent Review Panel (IRP) on the Implementation of Reasonable and Prudent Alternative (RPA) Action Affecting the Operations Criteria And Plan (OCAP) for State/Federal Water Operations (December 9, 2011)
- Federal Agencies' Detailed Response to the 2011 Independent Review Panel's Report (June 20, 2012)
- Report of the 2010 Independent Review Panel (IRP) on the Reasonable and Prudent Alternative (RPA) Actions Affecting the Operations Criteria and Plan (OCAP) for the State/Federal Water Operations
- Joint Department of Commerce and Department of the Interior Response to the Independent Review Panel's (IRP) 2010 Report of the Reasonable and Prudent Alternative (RPA) Actions Affecting the Operations Criteria and Plan (OCAP) for the State/Federal Water Operations
- NMFS' 2009 RPA with 2011 amendments
- USFWS Biological Opinion on the Long-Term Operational Criteria and Plan (OCAP) for coordination of the Central Valley Project and State Water Project (pages 279-282 and 329-356)
- RPA Summary Matrix of the NMFS and USFWS Long-term Operations Opinions RPAs
- National Academy of Science's March 19, 2010, report
- VAMP peer review report
- State Water Board's Delta Flows Recommendations Report
- NMFS RPA, Appendix 2-B, Task 4: Green Sturgeon Research
- 2011 OCAP Review Materials, Background Information and Presentations (http://deltacouncil.ca.gov/science-program/2011-ocap-review-materials-background-information-and-presentations)
- 2010 OCAP Annual Review Materials and Presentations (http://deltacouncil.ca.gov/events/science-program-workshop/workshop-ocap-integrated-annual-review)

APPENDIX 2 – Framework for Addressing Salmonid Issues

Framework for addressing effect of Old and Middle River flows on reach-scale survival rate

A2.1: XT Survival Model

The current paradigm for characterizing movement of smolts through the Delta reaches relies on mean flow to characterize the movement and routing of fish. The tagging studies in 2012 and earlier years clearly indicate that this characterization is inadequate. Below is a mechanistic approach to consider smolt movement, routing and survival through the Delta in terms of the dynamics of encounters of predators and smolts as based on the XT survival model (Anderson et al. 2005).

The underlying equation characterizes survival in terms of both the distance traveled *x* and the time *t* to travel through a reach. The concept is that if smolt (prey) mortality over a distance is the result of predators then survival depends on both the mean travel time and the relative random velocity between the predator and smolt. Survival is

$$S = \exp\left(-\frac{x}{\lambda}\sqrt{1+\left(\frac{\omega}{U}\right)^2}\right) \tag{1}$$

where ω is the root mean-squared (rms) random component of velocity of the predator relative to the smolt, *U* is the mean velocity of the smolt through a river reach and *x* is the reach distance. The final term λ is the mean free-path length a smolt travels before a predation event and is defined

$$\lambda = \frac{1}{\pi r^2 \rho} \tag{2}$$

where ρ is the predator density per unit volume, and *r* is the predator-smolt interaction distance that on the average results in a predation event. The interaction distance *r* depends on the visual field of the predator and therefore depends on light levels and turbidity.

Because in Equation (1) survival depends on the ratio of two velocities to understand what controls survival, an understanding of the velocities is important. To illustrate their nature assume that the predators are territorial while smolts move with the water and exhibit selective tidal-stream transport (discussed in A2.2). Then the random predator-prey velocity ω is essentially the mean tidal velocity and the smolt velocity *U* is the reach length divided by the smolt's mean travel time through the reach. When $U/\omega > 1$, the mean smolt velocity is large compared to the tidal velocity so a predator gets only one chance at a passing smolt. However, when $U/\omega < 1$ the tidal velocity is larger than the mean smolt velocity and the tidal flow can bring the smolt into the predator's territory multiple times.

Figure A2.1 illustrates how smolt velocity and tides interact. Based on Equation (1), *x* and λ are constant for a reach so the shape of the survival curve depends only on U/ω. When U/ω is large, survival approaches its maximum value $S_{\max} = \exp(-x/\lambda)$ which depends only on reach distance, predator density and the capture distance, but not on either the smolt velocity or the tidal velocity. When U/ω drops below 1, (i.e., the tides become important) survival precipitously declines. Note that in total smolt survival depends on five variables, not simply smolt mean velocity. Furthermore, survival does not directly relate to particle velocity *V.* In other words, smolt velocity is only one of five variables affecting survival and the impact of particle movement on smolt survival is ambiguous.

The current operation schemes focus on controlling particle travel time which is controlled through project exports, the E/I ratio, and OMR flow. The 2012 stipulation study examined the survival and movement of acoustically-tagged steelhead in relation to project exports and OMR flows. The study demonstrated that under the conditions examined, fish travel time was not related to particle movement nor was route selection of the fish related to Delta operations. While the study to manage Delta operations considered smolt survival, with its focus on fish travel time, it did not consider other factors that control survival through reaches. In particular, smolt survival depends on the relative predator-smolt encounter velocities, as outlined above, and routing. Below we consider factors that determine fish migration velocity (Appendix 2.2), predator-smolt encounter velocities (Appendix 2.3) and fish routing (Appendix 2.4).

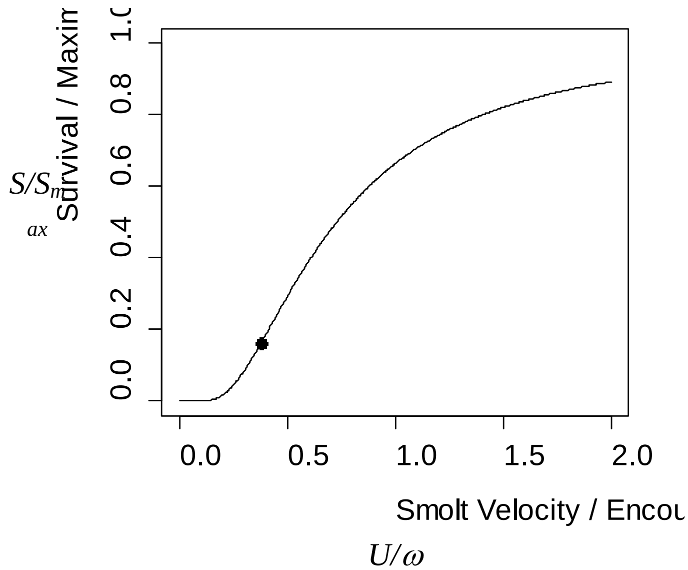

Figure A2.1. Relative reach survival depends on the ratio of the mean smolt migration velocity *U* to the relative predator encounter velocity ω. Maximum survival S_{max} depends on reach length *x* and mean free-path length before a predator encounter λ . Estimate of relative survival of fall Chinook from San Joaquin River to Chipps Island denoted by (●).

A2.2: Selective Tidal-Stream Transport (STST)

The stipulation study using acoustically tagged steelhead smolts clearly demonstrated particle and fish movements were poorly correlated. For example, calculated with hydraulic models, particles take 20 to 40 days to move through the Delta while observations on fish passage time are typically 10 days and can be less (Figure A2.2). It is well known that fish and zooplankton perform vertical migrations over the tidal cycle to remain in the Delta (e.g., Bennett et al. 2002, Kimmerer et al. 2002). Additionally many fish species (Gibson 2003), including salmon smolts (Moore et al. 1995) exhibit selective tidal-stream transport (STST) during migration. Here we illustrate the feasibility that salmon and steelhead smolts use STST to move quickly through the Delta.

> In selective tidal-stream transport (STST) an animal moves in and out of low velocity regions of the water column on selective parts of the tidal cycle to facilitate upstream or downstream movement. To speed downstream migration salmon smolts move into the higher velocity surface layer on ebb tides and lower velocity near shore regions on flood tides (Clements et al. 2012).

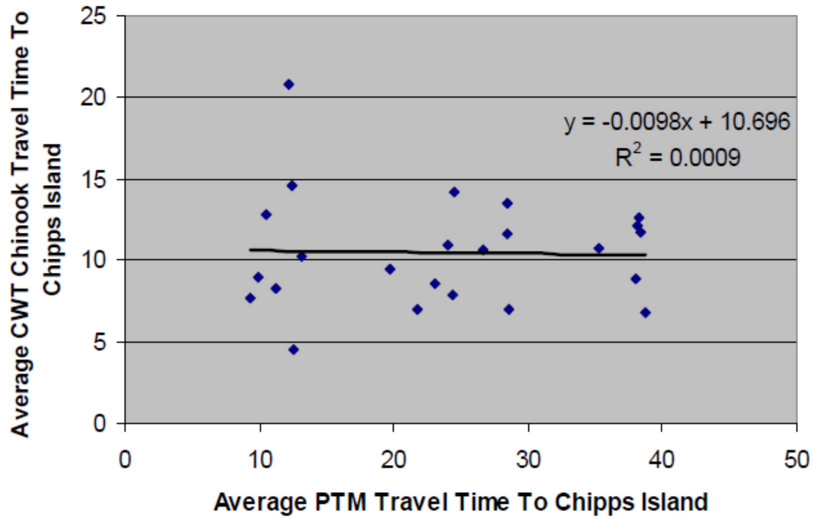

Figure A2.2. Release CWT Chinook salmon in the lower San Joaquin River and the associated Particle Model arrival time to Chipps Island in (LOO Annual Review 2012) Appendix H page H-24).

To demonstrate the feasibility that smolts use STST migrating through the Delta, assume the fish move with the ebb tide and hold in low velocity areas during the flood tide. The resulting across-ground velocity of a smolt can be expressed

$$U = V + \varphi v \qquad (3)$$

where V is the mean particle velocity experienced by the smolt, v is the rms tidal velocity and φ measures the contribution of STST behavior to migration. In the simplest view, φ is a measure of the fraction of the tidal cycle that smolts hide in low velocity regions. If $\varphi = 0.5$ then the smolts effectively hide in low velocity areas during the entire flood tide and drift downstream during the ebb tide. Values less than 0.5 indicate tidal selective movement occurs during only part of flood tide or that the smolts move into low velocity, but not zero-velocity areas on the flood tide. Figure A2.3 illustrates an idealized behavior where a smolt moves into a zero-velocity region during 3 hrs about the peak flood tide. Additionally, if STST is estimated over multiple reaches, φ represents an average of reach properties and behavioral responses.

Thus, Equation (3) hypothesizes that the difference between the observed smolt velocity and the mean particle velocity can be explained by the smolt STST behavior. To evaluate this hypothesis consider the difference in the estimated travel time of particles and CWT smolts traveling from the Lower San Joaquin River to Chipps Island (Figure A2.2) which gives T_{smolt} = 10 d, T_{ptm}= 25 d. Assuming the distance traveled by the smolts is approximately 2 x10^5 ft, then the average fish and particle velocities over the reach are $U = T_{smolt}/x$ = 0.23 ft/s and $V = T_{ptm}/x$ = 0.11 ft/s. Measurements of water velocity including tidal and mean flow indicate a typical maximum tidal velocity of 1 ft/s (Figure A2.4) which gives a rms tidal velocity of *v* = 0.7 ft/s. Then arranging Equation (3) to give $\varphi = (U - V)/v$ the STST index is φ = 0.17.

In other words the travel time of fish through the San Joaquin River can be explained by the fish exhibiting a moderate amount of selective tidal-stream transport.

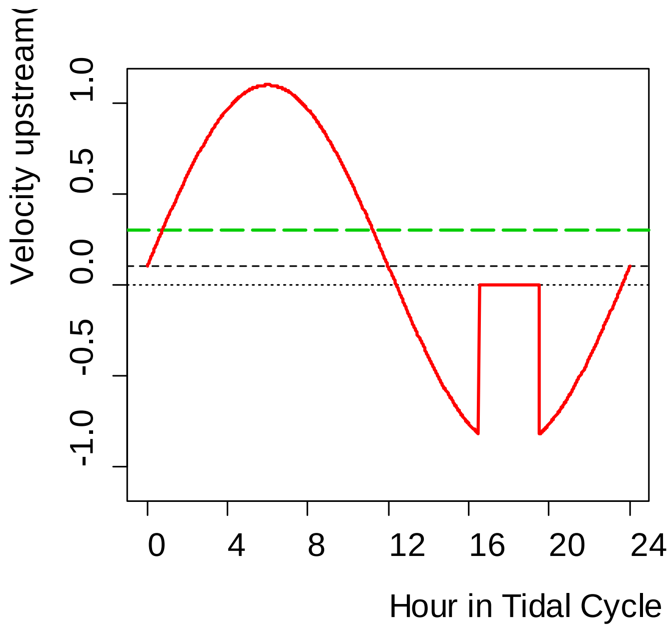

Figure A2.3. Illustration of selective tidal-stream transport. The reach water velocity is composed of a tidal component and residual (- - -) from the mean river flow. Smolt velocity (——) follows the water velocity until upstream velocity exceeds a threshold triggering fish to move into a low velocity area. The average smolt velocity over the tidal cycle (— — —) exceeds the average water velocity (- - - -).

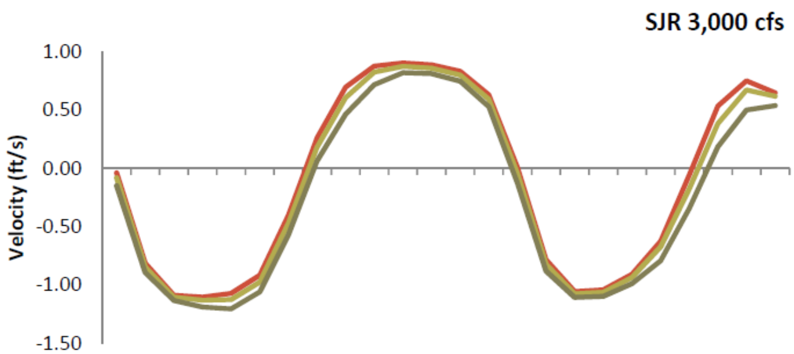

Figure A.2.4. Instantaneous average velocity values across 24 channel segments from the mouth of Middle River to Export facilities. Velocity data for each channel were taken from a single day (May 7, 2007) (LOO Annual Review 92012) Appendix A, page D-50).

Discussion of STST behavior.

The parameter φ quantifies STST behavior over the Delta and the correlation of φ with environmental conditions should provide insight to the mechanisms controlling fish migration behavior. For example, we might hypothesize that fish are able to detect the direction downstream by asymmetric changes in the environmental properties over a tidal cycle. The signal may include asymmetric patterns in the vertical or temporal distributions of turbidity and micro turbulence. For example, turbulence should be highest on the flood tide, possibly triggering movement into a low velocity region. Furthermore, in tidal rivers and estuaries the flood tide may move through progressively smaller cross-sectional areas causing the tidal currents to become progressively more asymmetric in both speed and direction (Wells 1995), which could facilitate detection of the tidal signal. Furthermore, if asymmetry in the channel configuration alters the signal triggering behavior then the complexity of the Delta may result in complex STST behavior. For example, fish moving from the San Joaquin River into Franks Tract may first experience a strong signal of tidal direction but once inside the track where the channel widens the signal may virtually disappear. With heterogeneity in STST signal strength we expect φ to vary over reaches and flow conditions.

Action.

The IRP suggests researchers evaluate the relationships of φ with differing environmental and hydraulic properties of the reaches. As a null hypothesis to the STST behavior, assume fish swim downstream independent of tidal conditions. In this case there would be no correlation of φ with Delta geometry. Note that the null hypothesis is also biologically possible if salmon navigate using the geomagnetic signals that indication location. However, even if fish use geomagnetic navigation they may do so in the context of STST behavior.

A2.3: Predator-Smolt Encounters

Equation (1) proposes that the importance of the downstream velocity of the smolts in determining their migration survival depends on the encounter velocity of the smolts to predators. Furthermore, the probability of encounters and predation events is expected to change over tidal and diel cycles and depend on the avoidance strategy of the smolts and the search strategy of the predators. While numerous studies have documented STST behavior, the panel is unaware of specific studies exploring predator-prey interactions in STST conditions. In a general sense, the smolt STST strategy is to move out of the Delta and avoid predators while the predator STST strategy is to remain in the Delta and encounter prey. Competing predator and prey strategies have been viewed as a predator-prey shell game that depends on the ability of the predator to adjust its strategy to the temporal flux of prey (Lima 2002). A recent study suggests a type of shell game may occur in Atlantic cod foraging on Atlantic salmon during their post-smolt estuary migration (Hedger et al. 2011). The cod exhibited a more focused foraging distribution during the smolt outmigration, but their distribution was not influenced by the tides, i.e. they held station against the tides. Delta predators may use a similar mechanism. We illustrate the implications of such strategies in the example below that combines the XT survival model and the STST hypothesis.

We begin by defining the random encounter velocity between predator and prey (Anderson et al. 2005) as

$$\omega = \sqrt{u_{smolt}^2 + u_{pred}^2} \qquad (4)$$

where u_{smolt} and u_{pred} are the rms random velocities of smolts and predators respectively. With STST behavior, relating smolt rms random velocity to acoustic tag observations may be problematic since in the model part of the tidally-correlated movement of the smolts is attributed to the mean movement. However, approximations of the rms random velocities can be developed based on assumptions of the behavior of predators and smolts. Assume that predators hold station during the ebb tide such that smolts pass through a gauntlet of predators, while on the flood tide the smolts are stationary and the predators move with the flow searching for prey. Assume the combined effect of these two strategies depends on STST behavior and the rms tidal velocity, which we take as a surrogate for the random search velocity of the predators. Then, the random predator-smolt encounter velocity might be expressed $\omega = (1-\varphi)v$ and the ratio of mean smolt migration velocity to the predator-smolt random encounter velocity is

$$\frac{U}{\omega} = \left(\frac{V}{v} + \varphi\right) \Big/ (1-\varphi) \qquad (5)$$

Using the example for travel time of CWT Chinook from the lower San Joaquin River to Chipps Island gives $U/\omega = 0.38$.. Including Equation (5) in Equation (1), survival over the reach is on the order of 16% of the maximum survival, S_{max} (Figure A2.1). If the maximum observed survival through the Delta is on the order of S_{max} = 20% then survival should be 3%, which is about what was observed in 2012.

The salient point is the XT predation model and selective tidal transport hypothesis together provide a mechanistic explanation for both the observed rapid movement and low survival of smolts in the Delta.

If smolts and predators exhibit distinct behavioral patterns relative to the direction and velocity of the water currents over tidal cycles then classification of smolt and predatory-type tags may require correlations of tag movement with the proximal water velocities. Distinct behavior patterns may be most evident on peak flow or slack water periods.

Action.

Much information is known about the behavior of organisms on tidal oscillations, but little is known about the effects of tidal oscillations on predator-prey interactions. The panel suggests that prior to additional field work in this area a workshop be held bringing experts together on tidal physics, foraging ecology and predator-prey theory. The panel suggests a mix of local, national and international experts comprise the workshop membership.

A2.4: Fish Routing

The 2012 joint stipulation study found that movement into the inner Delta appeared independent of the OMR flow which suggests that route selection is influenced by proximal conditions at the junctions of the channels. We hypothesize that routing is determined mainly by the response of the fish to the flow field as structured by the channel shape and the flow, which is comprised of the pure tidal flow and the residual flow generated by river flow and pump operations. Thus, it is reasonable to hypothesize that the behavioral factors that produce STST are also important in route selection at reach junctions.

The IRP proposes studying route selection at two spatial-temporal scales: a *reach scale* involving the asymmetric patterns of hydrodynamics of the tidal cycle and a *junction scale* that considers the flow structure over the scales directly perceived by fish during the passage through junctions. Frameworks for studying entrainment at reach and junction scales need to be based on working hypotheses of how hydraulic and behavioral factors interact to determine routing. Examples of reach and junction scale hypotheses are briefly outlined below. These are not intended to be complete or necessarily correct; their purpose is to illustrate general approaches and levels of detail that may be needed in designing analyses and frameworks at each scale. The panel encourages this two-pronged approach as a way to derive a working understanding of fish routing mechanisms while developing analysis that can draw on the existing, coarser scale data available through CWT and the finer scale acoustic tagging studies. As an aside, the panel suggests that mechanisms of STST and route selection in salmon will also have value for understanding the movement of resident Delta fish such as delta smelt and longfin smelt.

Reach scale analysis framework.

As an example of a reach scale routing hypothesis begin with the assumption that if smolt STST occurs in reaches it also occurs in junctions. Based on the STST hypothesis detailed in Appendix 2.2 smolts exhibit asymmetric behavior to selectively move downstream by moving into low velocity regions when triggered by signals indicating a flood tide. Note also, that reversal of OMR flows may disrupt and confuse this signal. The strength of the STST should be reach specific and might be quantified by φ (Equation 2) characterizing the fraction of a tidal cycle over which fish seek lower velocity regions. For a working hypothesis, assume that routing at a reach junction depends on the reach-specific φ, the junction hydrodynamic v, and the junction geometry, expressed here as cross-sectional area A (Figure A2.5). Then an equation expressing the fraction f of fish routed through reach 1 might be written

$$f_1 = \frac{\varphi_1 v_1 A_1}{\varphi_1 v_1 A_1 + \varphi_2 v_2 A_2} \qquad (6)$$

and fraction passing through reach 2 becomes $f_2 = 1 - f_1$. The important feature of this framework is that routing involves three factors, behavioral, hydraulic and geometric properties. The challenge is to formulate measures that are mechanistically meaningful and measurable. Three trial hypotheses/analyses (developed in conversation with R. Buchanan) are outlined below:

Hypothesis 1: assume φ_i from reaches Equation (3) applies to Equation (6) and the $\varphi_i A_i$ is the junction volume transport averaged over a tidal cycle.

Hypothesis 2: assume reach-specific φ_i and v_i represent rms velocities.

Hypothesis 3: assume φ_i is junction-specific and must be characterized by correlating fish and water movements with the junction.

Again, these approaches are presented to illustrate an approach for conducting analyses based on underlying transport mechanisms.

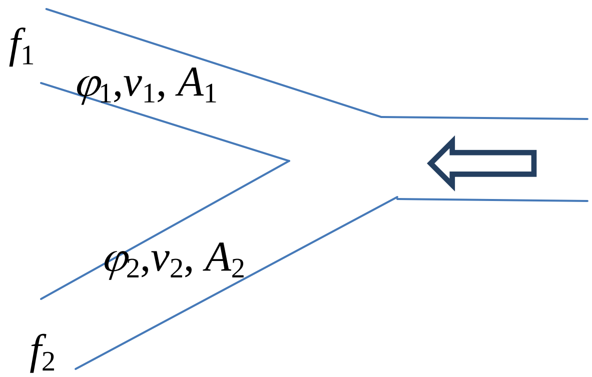

Figure A2.5. Reach routing model based on STST behavior and tidal dynamics.

Junction scale analysis framework.

An alternative, higher resolution, approach is available through the melding of computational fluid dynamics models with models of the rheotactic response of fish. Such studies are being carried out in the Sacramento River by David Smith of the Army Corps of Engineers Cognitive Ecology and Ecohydraulics Research group el.erdc.usace.army.mil/emrrp/nfs/index.html. A description of ecohydraulics to study fish routing derived from the research groups follows:

> The Eulerian–Lagrangian–agent Method (ELAM) provides a framework to analyze fish habitat occupancy as a function of environmental change. We create a 'virtual reality' of the environment and then analyze/forecast habitat occupancy as a function of discharge, channel morphology, habitat complexity, and water quality using a fish habitat selection algorithm coupled to a particle–tracking model (PTM). We model the cognition, adaptation, and learning of fishes along with their physiological sensory capabilities instead of using habitat suitability criteria or reach–scale habitat classification (e.g., pool, riffle, run, shear zone, etc). Reach–scale habitat occupancy patterns are resolved from responses to physical and chemical stimulus at the microhabitat scale. Thus, we can forecast fish response to changes in river channel morphology derived from hydrographic manipulation or construction of engineered structures. Traditional habitat suitability criteria and reach–scale habitat classifications limit flexibility and the level of fidelity that can be used in analysis of a restoration project. The ELAM approach is a "plug–and–play" tool that supports management decisions in a theoretically– and mathematically–rigorous manner (el.erdc.usace.army.mil/emrrp/nfs/fishhabitat.html).

For further discussion, see the response to question “How should the experimental design be adjusted in future years to test key habitat drivers of smolt behavior and survival, and support weekly operational decision making?”

A2.5: Is the San Joaquin River a salmon sink?

The low Delta passage survival of fall-run Chinook and steelhead on the order of 1-3%, begs the question as to whether the San Joaquin River can support salmon populations in the future or whether it is a sink habitat receiving adult Chinook from other Central Valley rivers. The high stray rate of the hatchery raised fall Chinook (e.g., Mesick 2001) may suggest natural production in the system is not being maintained or will not be in the future with increased Central Valley warming by climate change. The IRP recommends that this possibility be consider through an analysis of source-sink population dynamics of the Sacramento/San Joaquin populations.