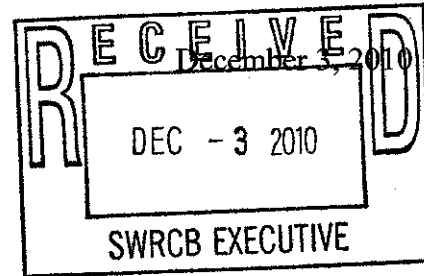| CITY AND COUNTY OF SAN FRANCISCO	OFFICE OF THE CITY ATTORNEY

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RECEIVED

December 3, 2010

DEC - 3 2010

SWRCB EXECUTIVE

Jeanine Townsend, Clerk to the Board
State Water Resources Control Board
P.O. Box 100
Sacramento, CA 95812-2000

Re: SJR Technical Report Comments

Dear Ms. Townsend:

On behalf of the San Francisco Public Utilities Commission, I submit the attached comments on the Board's *October 29, 2010 draft San Joaquin River Flow and Southern Delta Salinity Technical Report.* The attached comments were prepared by Ron M. Yoshiyama, who consults for San Francisco on fish biology. Mr. Yoshiyama will not be participating as a panelist during the Board's January workshop.

San Francisco does not believe the information and the tools in the draft Technical Report provide a scientific basis to modify the existing San Joaquin River flow objectives and program of implementation in the 2006 Bay-Delta Water Quality Control Plan. In particular, the draft Technical Report relies upon flawed modeling that has already been the subject of negative peer review. The draft Technical Report also fails to establish a foundation for a program of implementation.

San Francisco believes the Board must consider additional information to establish San Joaquin River flow objectives, including factors in and beyond the Delta that affect salmon and steelhead. Such factors include export pumping, predation, invasive species, the lack of wetlands and floodplains along the San Joaquin and in the Southern Delta, hatchery practices, toxics, hydraulics, in-Delta pumping, channel dredging, and ocean conditions. Consideration of such factors is necessary to appropriately determine the role of flow objectives and water quality conditions that may reasonably be achieved through the coordinated control of all factors that affect salmon and steelhead in the Delta. San Francisco agrees with the Delta Environmental Flows Group's conclusion that "a strong science program and a flexible management regime are critical to improving flow criteria."

Very truly yours,

DENNIS J. HERRERA
City Attorney

signed in original

Donn W. Furman
Deputy City Attorney

plus: attachment

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Ronald M. Yoshiyama,
Comments in Regard to:

State Water Resources Control Board

Draft Technical Report on the Scientific Basis for Alternative San Joaquin River Flow and Southern Delta Salinity Objectives (October 29, 2010)
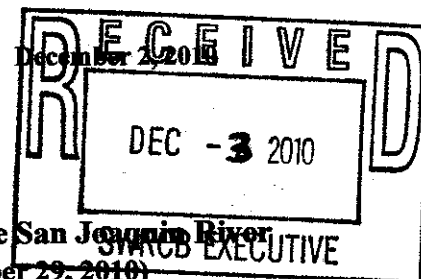
The following comments address several issues pertaining to Chinook salmon populations in the Tuolumne River and San Joaquin River basin, as included in or alluded to in the SWRCB's Draft Technical Report (hereafter, *"Draft Tech Rept"*), issued on October 29, 2010. These comments are intended to provide further information or to raise points that need clarification in order to better understand and more effectively manage the San Joaquin basin Chinook salmon resource.

At the outset it is unclear how many statements in the Draft Tech Rept regarding conditions in the Tuolumne River are relevant to determining the scientific basis for alternative San Joaquin River flow objectives. For example, whether it is efficacious to restore physical salmon spawning habitat in the Tuolumne is not relevant to determining appropriate flows in the San Joaquin River at Vernalis for those life stages affected by such flows. Nevertheless, some statements regarding the Tuolumne River will be addressed in the following comments since such statements appear in the Draft Tech Rept.

PART 1. SAN JOAQUIN BASIN AND LOWER TUOLUMNE RIVER CHINOOK SALMON POPULATIONS IN RELATION TO IN-RIVER AND DELTA FLOWS

(1.1) High Population Variability and the Risk of Extinction for the Tuolumne River Fall-Run Chinook Salmon

Draft Tech Rept page 54: *"In 2009 Mesick published a paper on the High Risk of Extinction . . . Based on this low escapement, the rapid nature of the population declines, and the high mean percentage of hatchery fish in the escapement, Mesick finds that the Tuolumne River's naturally produced fall-run Chinook salmon population has been at a high risk of extinction since 1990."*

The Mesick (2009) document was not published as a paper in 2009; it was an agency report submitted as an exhibit in the Clarifying Proceedings for the Don Pedro Project before Administrative Law Judge Charlotte J. Hardnett during December 2009.

The long-term record of in-river flows and associated salmon population levels (i.e., escapement) as shown in the Draft Technical Report Figure 3-6 indicates that the San Joaquin River basin salmon population has been highly unstable, showing prominent cycles since about 1950. The pronounced dips (population crashes) indicates an overall high risk of extinction during those periods of low spawner abundance. The cycles have occurred four times during the period of record. In that respect, the San Joaquin River basin population, including the Tuolumne River population, is in a tenuous state, but its risk of extinction is probably no greater than it has been during previous low points of the cycles. This is not to deny that the Tuolumne River

population continues to be highly vulnerable during the low phases, but the point is that the population's extinction risk is not something unique to the period after 1990.

Furthermore, the Tuolumne River salmon population actually showed a sustained degree of recovery soon after the six-year drought of 1987-1992 (TID/MID 2010) and the fact that the population reached an escapement peak of 17,870 spawners in the spawning-season 2000 is remarkable. During the six-year period 1997-2002, the annual spawning escapements in the Tuolumne River were just over 7,100 spawners in two years (1997, 2002) just above 8,200 in one year (1999) and close to 9,000 spawners in two years (1998, 2001) (TID/MID 2010).

The general assertion that the Tuolumne River salmon population is at high risk of extinction appears warranted in certain respects, at least in terms of several criteria defined in the general analysis of Central Valley salmonids by Lindley et al. (2007). The estimated numbers of natural spawners (in Mesick's Table 4) indicate, if taken at face value, that the natural spawning population has approached virtual extinction at least twice in recent history—i.e., very few natural spawners in 2007 and during the earlier period 1990-1995—and the actual numbers of fish that successfully reproduced during those "low years" is further obscured by the effects of demographic stochasticity and unknown rates for successful redd building, spawning and egg incubation. The estimated spawner numbers are "point estimates" with unknown degrees of error (e.g., unknown standard deviation). Presumably, the estimated natural escapements in Mesick's Table 4 are not meant to be taken literally but to show the substantial magnitude of the effects of straying hatchery fish in the Tuolumne River.

The basic result from Mesick's (2009) analysis is that there has been a continuous and substantial influx of hatchery fish from various sources in the Central Valley system into the Tuolumne River spawning population. That influx has varied in magnitude from year to year in regard to absolute numbers (e.g., less than 100 fish in 1981 and 1989-1995 to more than 2,000 fish in 1987, 1997 and 2000, and over 3,400 fish in 2002)--as well as in relative terms compared with the total escapement (e.g., less than 5% hatchery spawners in 1984 to 1986 up to 95% hatchery spawners in 1990, 56% in 1993, and 48% in 2002).

The implication from the estimated hatchery contributions to the Tuolumne River is that the naturally reproducing population dropped to extremely low and possibly virtual extirpation during two periods (1990-1995 and 2005-2008). If that is true, then it must be concluded that hatchery-origin fish from other locations served to rebuild the population after 1995 and probably will do so again after 2008. In other words, the Tuolumne River salmon population is heavily derived from hatchery fish of non-Tuolumne River ancestry. This fact is obscured by the CDFG's policy of regarding the progeny produced from parents that spawned naturally in the river as putative "natural" fish even if those parental spawners themselves were produced in hatcheries.

(1.2) Limiting Factors Analysis

Draft Tech Rept page 54: *"Mesick et al. reports that other evidence from rotary screw trap studies indicate that many more fry are produced in the Tuolumne than can be supported with existing minimum flows, and so, producing more fry by restoring spawning habitat is unlikely to increase adult recruitment."*

The specified minimum flows in most cases are not the same as actual flows that occur in the Tuolumne River, although the minimum flows define the "floor-level" of flows that must

occur over a series of flow ranges corresponding to different water-year conditions (e.g., dry, below-normal, above-normal, wet). The actual flow levels in the lower Tuolumne River often exceed the minimum specified flows and, therefore, provide incrementally greater amounts of juvenile habitat or promote greater juvenile growth and survival.

If juvenile survival or the amount of juvenile rearing habitat are markedly increased during wet years, then the amount of spawning habitat and corresponding production of fry may become the limiting factor in those years. Therefore, from a salmon management perspective, neglecting to improve and increase the amount of spawning habitat will be self-defeating in the long run because it would limit the population during wetter years (and perhaps other water-year types) when reproduction could otherwise be enormously increased and juvenile production and survival could become high enough to markedly bolster the population.

Furthermore, if a significant portion of juvenile salmon mortality is due to predation pressure by other fishes, then an excess production of fry could serve to satiate predator populations and ultimately allow a larger number of juvenile salmon to reach the smolt stage, hence increasing population production.

Draft Tech Rept:
"Mesick identified two critical flow periods for salmon smolts on the Tuolumne River: winter flows which affect fry survival to the smolt stage; and spring flows which affect the survival of smolts migrating from the river through the Delta." [page 55]

"Mesick et al. indicates that low spawner abundances (less than 500 fish) have occurred as a result of extended periods of drought when juvenile survival is reduced as a result of low winter and spring flows . . . " [page 54]

While the historic importance of spring flows is evident for connecting the San Joaquin rivers to the estuary and beyond, the function of winter flows is much less clear. Winter and spring flows are highly correlated since wet years, for example, produce both high winter and high spring flows. It is possible that the correlation of high winter flows with higher juvenile (or smolt) survival is partly, if not largely, spurious in non-flood years due to the collinearity of winter and spring flows. Although it is possible that there is a substantial functional relationship between winter flows and ultimate smolt production, the mechanism, if it exists, is far from clear. No studies have been done on the Tuolumne River to accurately quantify juvenile rearing habitat and juvenile survival corresponding to specific flow levels, although some preliminary rough estimates have been made (Mesick et al. 2008). The relative functional importance of winter flows and spring flows would be important to clarify because this issue has significant water management implications. For example, if spring flows turn out to be far more functionally important for salmon production than winter flows despite their high correlation, then it would be more effective to allocate relatively more flows during the spring than during winter in order to maximize smolt survival in the spring, given that the finite availability of stored reservoir water.

(1.3) Factors besides Lower San Joaquin River Flows that can affect Salmon Population Levels

Delta Factors in General

The potential effects of Delta conditions and their collective importance to Central Valley salmon populations are reflected by concerted research efforts to estimate juvenile salmon and smolt survival rates during their movements through the Delta and San Francisco Bay system and associated analyses to determine correlative factors that may affect the survival rates (e.g., Baker and Morhardt 2001; Brandes and McLain 2001; Newman 2008; San Joaquin River Group VAMP Report).

Brandes and McLain (2001:p.40) noted:

"All of the various races of chinook salmon in the Central Valley use the Delta as a migration corridor to the ocean and many rear there before emigration. The survival of juvenile salmon through the Delta is considered critical to year class success, as density-dependent mortality after Delta residence is believed to be minimal . . . Thus, for any given set of ocean conditions, increasing the number of juveniles emigrating from the Delta will increase the production of adults. Actions in the Delta to improve survival are considered important in increasing the production of these Central Valley salmon populations."

A number of studies have implicated several factors that may affect juvenile salmon survival in the Delta, but the relative importance of those factors depends on the statistical procedure or model(s) employed. Potentially significant factors include, for example, water temperature, position (open versus closed) of the Delta Cross Channel gate, ratio of pumping export to Delta inflow, predation, and the presence of the barrier at the Head of the Old River (on the San Joaquin side of the Delta).

Williams (2006:193) concluded in his review of smolt survival studies in the Sacramento-San Joaquin Delta:

"In summary, the main result of the CWT [coded-wire tag] studies seems to be that several factors influence the survival through the Delta of tagged hatchery fish, and of these, only water temperature stands out."

However, the limitations of post hoc statistical analysis of Delta factors have been recognized (Williams 2006, Newman 2008). Additional field experimental studies are needed to clarify the ecological processes that affect juvenile salmon survival in the Delta. In particular, acoustic tagging studies that have been recently initiated can provide detailed information on the migration paths of juvenile salmon and on the location and magnitude of mortality sources.

Mesick and Marston (2007) calculated partial correlation coefficients for the statistical relationships between recruitment levels of adult fall-run Chinook salmon in the San Joaquin basin tributaries and spring (mean monthly) flows in the Sacramento-San Joaquin Delta, and also between adult salmon recruitment and measures of Delta water exports. Among the models that included Delta water exports, there were 10 cases in which the partial correlation coefficients for the Tuolumne River population had negative values of -0.72 or greater magnitude--i.e., there were pronounced negative relationships between Delta export variables and Tuolumne River salmon recruitment.

In a recent conceptual overview of the San Francisco Estuary, and particularly the Sacramento-San Joaquin Delta, Moyle et al. (2010: p.15) concluded that the Delta has undergone profound structural and functional changes through the past century, becoming less variable and highly simplified as "a channelized conveyance system to export fresh water." Furthermore, "Suisun Bay and Marsh became essentially a brackish water system, with San Francisco Bay a largely marine system . . . Such prolonged stabilization, combined with a relatively rapid influx of alien species, has caused a *regime shift*. . . . that is also reflected in the overall low and declining productivity of the San Francisco Estuary compared with other estuaries worldwide." These broad changes have been highly detrimental to virtually all of the native freshwater and estuarine species, including salmon.

South Delta Water Exports

An issue of particular concern is the impact of water exports from the south Delta by the federal (Central Valley Project) and state (State Water Project) pumping facilities. The seemingly inevitable impacts of south Delta water exports in combination with other negative conditions for salmonids in the Delta and main tributaries was previously recognized in the CDFG's report to the State Water Resources Control Board ((CDFG 1987:p.3):

> "Under present conditions streamflow requirements for fall-run salmon below the major tributary reservoirs in this drainage are not adequate. All existing Licensees or Agreements [as of 1987] fail to provide acceptable streamflow levels for young salmon emigrating to the ocean. High water temperatures on the mainstem San Joaquin are a problem during emigration. The amount of water export in the South Delta during April, May, and June of above average, average, dry and critically dry years is high relative to the San Joaquin River inflow. Consequently, juvenile salmon survival is reduced by export-related impacts."

In contrast to that earlier assessment (CDFG 1987), the CDFG's subsequent evaluations of the influence of Delta exports have indicated that exports, along with ocean harvest, have relatively little effect on the Tuolumne River salmon escapements (CDFG 2005:p.7-8):

> ". . . The [CDFG] Department includes an analysis below that suggests that neither of these factors is controlling salmon escapement abundance fluctuation in the Tuolumne River . . . "
> ". . . Regressing the number of females, combined with Modesto flow with either export ratio (e.g., Vernalis flow divided by combined SWP/CVP exports) or ocean harvest, essentially does not improve the regression correlation at all."

The issue of the impacts of the south Delta water exports still has not been fully resolved. Curiously, the CDFG's regression of salmon escapement versus Vernalis flow/Delta export showed a negative trend. That is, salmon spawning escapements decreased as the proportionate amount of San Joaquin River flows (relative to exports) increased. Such a counterintuitive result suggests that the regression approach may not be the best quantitative tool for accurately assessing the flow relationships and requirements of anadromous salmonids in the Tuolumne River, although it still may be useful for providing insights if used in conjunction with other analytical approaches.

However, other assessments besides those of CDFG (2005) and Mesick et al. (2008) have surmised that Delta export operations exert substantial effects on the salmon smolts migrating through the Delta; e.g., Baker and Morhardt (2001: p.181):

"Smolt survival through the Delta may be influenced to some extent by the magnitude of flows from the San Joaquin River, but this relationship has not been well quantified yet, especially in the range of flows for which such quantification would be most useful. Salvage records show clearly that export-related smolt mortality is a major problem, but no relationship between export rate and smolt mortality, suitable for setting day-to-day operating levels, has been found. Survival measured in the Delta using paired releases of tagged smolts shows a twofold better survival for individuals that travel past Stockton via San Joaquin River rather than past the export facilities via Old River. Since more than 60% of the smolts usually go down Old River, any measure that decreased this percentage would be expected to benefit smolts, however such a benefit has yet to be demonstrated empirically."

Kimmerer (2008) estimated proportional losses of Sacramento River Chinook salmon due to entrainment at the water export facilities, the pertinent results of which are as follows.

"The proportion of fish salvaged increased with export flow, with a mean value around 10% at the highest export flows recorded. Mortality was around 10% if pre-salvage losses were about 80%, but this value is nearly unconstrained." (Kimmerer 2008:p.1)

"Even without estimates of indirect loss, the [direct entrainment] losses in Figure 10 are higher than expected based on management targets for the Delta"—[e.g., in regard to "take limits" for winter–run Chinook salmon at the export facilities] (Kimmerer 2008:p.20)

Kimmerer's (2008) analysis pertained to Sacramento River salmon but similar concerns also would apply, perhaps more so, to the San Joaquin basin salmon populations.

Newman (2008) recently completed a statistical reanalysis of results from four studies of coded-wire-tagged juvenile Chinook salmon in the Delta. The results in regard to export effects for two of the studies (viz., Delta Action 8 and VAMP) were somewhat ambiguous, if not conflicting (Newman 2008:p.3-4):

"Delta Action 8: There was a negative association between export volume and relative survival, i.e., a 98% chance that as exports increased, relative survival decreased. Environmental variation in the relative survival was very large, however;"

"VAMP: (a). The expected probability of surviving to Jersey Point was consistently larger for fish staying in the San Joaquin River . . . than fish entering Old River [which passes closer to the export facilities], but the magnitude of the difference varied between models somewhat; . . . (d) associations between water export levels and survival probabilities were weak to negligible."

Furthermore, the amount of Delta exports relative to San Joaquin River flows has been shown to be related to straying rates of Chinook salmon adults on their spawning migration (Mesick 2001). Specifically, Mesick (2001:p.159) concluded:

"The two-part investigation provided conflicting results. Reevaluation of the data collected by Hallock and others (1970) suggested that adult salmon that reared in the San Joaquin tributaries strayed when exports at the CVP and SWP pumping facilities exceeded about 100% of flow in the San Joaquin River at Vernalis and Vernalis flows were less than 2,000 cfs during the first three weeks of October. However, there is uncertainty about the origin of their study fish and data were collected in only four years."

"The evaluation of the recovery of coded-wire-tagged fish suggests a maximum of about 20% of adult San Joaquin salmon strayed when Delta exports exceeded about 300% of Vernalis flows for a ten-day period in mid-October. Although the accuracy of the estimated number of strays is questionable, the estimates correlate strongly with the ratio of Delta exports to flows at Vernalis and with Vernalis flows."

In general, the full extent of the effects of Delta exports on different salmon life-stages and on overall production of salmon populations in the Tuolumne River and other San Joaquin basin tributaries has yet to be clearly determined. Nonetheless, it is evident that the potential impacts of Delta exports on the salmon populations should continue to be evaluated.

(1.4) The Decreasing Effectiveness of Flows in Supporting Salmon Population Levels

Over the course of multiple decades extending back to the mid-20th century, there has been a simultaneous decline in the volume of in-river flows in the San Joaquin River basin and the effectiveness of given flow levels in maintaining the salmon population abundance. As noted in the Draft Technical Report (page 56, citing Hankin et al. 2010):

"The complexities of Delta hydraulics in a strongly tidal environment, and high and likely highly variable impacts of predation, appear to affect survival rates more than the river flow, by itself, and greatly complicate the assessment of effects of flow on survival rates of smolts. And overlaying these complexities is an apparent strong trend toward reduced survival rates at all flows over the past ten years in the Delta"

"In their own analysis of the VAMP data, the IRP (Figure 3-8) found that survival decreased as flows decreased, and that survival has been decreasing over time within each of four flow groupings (very low, low, moderate, high)."

The observed overall decrease in smolt survival rates regardless of flow levels (i.e., Figure 3-8 in the Draft Tech Rept) is important to recognize because it has profound implications for water management. It means that although increasing flow levels continue to improve smolt survival, the higher flows have become less effective over time—i.e., smolt survival continues to decline even in years when flows have been relatively high.

The progressive decline in the effectiveness of higher flows to improve smolt survival--or to improve salmon recruitment, which is correlated with smolt production--was previously noted by other researchers. Specifically, Figure 3 in the Limiting Factors Analysis by Mesick et al. (2008) and Figure 5 in the report by Mesick (2009; "The High Risk of Extinction for the Natural Fall-Run Chinook Salmon . . .") show that natural salmon recruitment in the Tuolumne River over a range of flows (0 to 8,000 cfs, February 1 to June 15, below La Grange Dam) has been

systematically lower for the recent period 1997-2004 than for the period 1980-1990. The observed drop in salmon production that occurred between those two time periods strongly indicates that some additional factor(s) besides instream flows must also be involved or that something about the salmon population or the environment has changed. There evidently has been a fundamental change in the overall situation between the two periods that has made it more difficult for higher flows to benefit the salmon population.

Much earlier, in a report to the State Water Resources Control Board, the CDFG (1987:p.40-42) pointed out noticeable changes in spawning escapement levels of Tuolumne River salmon associated with instituting the Central Valley Project (CVP) and, subsequently, the State Water Project (SWP) (CDFG 1987: p.40-42).

"Escapement estimates and streamflow data for the Tuolumne River are available back to 1938 . . . A comparison of the relationships between escapement and mean spring flow in the Tuolumne River during three time intervals more clearly defines how chinook salmon production has responded to changes in spring flows and water exports in the South Delta (Figure 15)."

"The Tuolumne River escapement generally represents 40% to 50% of the average total escapement in the San Joaquin drainage and therefore provides a fair indication of salmon needs. The declining trend in the slopes of these three relationships in Figure 15 is even more dramatic than similar relationships at Vernalis (Figure 13) and a reduced frequency of escapements exceeding 30,000 adults has occurred. The predicted Tuolumne River spring flows required to produce 30,000 adults has increased from approximately 1,000 cfs (exceeded in all but dry year scenarios during 1938-1945) to 6,000 cfs (now exceeded only in wet years) in 1967-84."

"The decline in frequency of escapements exceeding 30,000 adults was 83%, 35% and 11% during these three periods, respectively."

"Based on this and previous information provided:
A. In the absence of improved habitat conditions in the San Joaquin River and Delta, the full potential of Tuolumne River salmon production will only be in wet years when the Tuolumne River mean spring outflow exceeds 6,000 cfs.
B. Improved tributary flows during the smolt emigration period are important to salmon survival in the tributaries but factors downstream have diminished the positive effects of incremental increases in spring flows.
C. Improvements in emigration flows from the Tuolumne River would also benefit smolts from the Merced and Stanislaus Rivers."

The three graphs in the CDFG's (1987) Figure 15 show a substantial drop in spawning escapements (which are plotted versus spring streamflows) for the time periods—viz., between (1) the pre-water project period and (2) the period when the CVP began operating, and (3) a further apparent drop after the SWP began. Thus, the increasingly severe abrogation of the positive effects of spring tributary streamflows on salmon production by downstream (i.e., Delta) factors was clearly recognized by the CDFG more than two decades ago.

(1.5) General Function of Flows for Supporting Salmon Population Processes in the Lower Sacramento-San Joaquin Rivers and Delta

The lower San Joaquin River historically was and continues to be a migration conduit for various life-stages of anadromous salmonids. In the past, areas of the lower river and Sacramento-San Joaquin Delta also served as rearing areas but that function has been largely lost. In-river flows were the life's blood of the region's ecosystems—intersecting in complex ways with the tides, atmospheric conditions and physical habitats to mold and in some respects limit the biotic responses of the many species that constituted those ecosystems.

Flows serve several purposes in regard to salmonid populations and their habitats—e.g., by moderating water temperatures, transporting food items, providing a migration conduit for life-stages of the fish, and in some places by creating inundated floodplain areas that become feeding and rearing areas. However, varying flows affect those functions in complex ways that may have both positive and negative consequences for the salmonid populations. Very high flows may inundate extensive floodplains but could transport juveniles far away from those areas. Also, some potential floodplain areas along the lower San Joaquin River and south Delta are so physically degraded at the present time that their function as rearing areas would first require intensive restoration efforts that may take years to complete.

The determination of flow volumes that are required to sustain the life-history processes and population viability of Central Valley Chinook salmon and steelhead-rainbow trout (*O. mykiss*)—particularly in reference to the lower mainstem San Joaquin River during the springtime (April-May) period must address the following issues.

A) The function of flows in transporting salmonids, especially juvenile life-stages. A related issue is the relative importance of fry-outmigrants versus smolt-outmigrants in contributing to the adult population and the adequacy of downstream (low-elevation) rearing areas—i.e., floodplains and shallow Delta areas. These aspects are discussed in the following subsections.

B) Temperature-range requirements of salmonid life-stages. Temperature-related requirements are discussed at length in Part 2 of this commentary which presents an abridged review of published literature on salmonid-temperature issues, an interpretive synthesis of the information, and brief discussion on the potential adaptability of localized salmonid stocks.

C) Whether river flows from the San Joaquin River basin can overcome tidal influences to transport juveniles and smolts as quickly as possible through the Delta to more hospitable areas such as Suisun Marsh and around Suisun Bay

Fry-migrant versus smolt contributions to adult population production.

A recent study using otolith microchemistry has determined that juvenile fall-run Chinook salmon from the Central Valley system that emigrated downstream to saline areas as parr and fry, in addition to smolts, all contributed in varying degrees to the adult population (Miller et al. 2010). Out of 99 adult salmon that had emigrated from freshwater to the ocean in 2003 or 2004, 47% had entered brackish or ocean water as parr, 32% as smolts and 20% as fry. Hence, the study showed that parr and even fry that down-migrate early, as well as smolts, evidently contributed in some measure to the adult populations of Central Valley fall-run

Chinook salmon. This result means that the large numbers of fry and parr that have been observed to leave the tributaries in winter and early spring potentially could make important contributions to population productivity, at least in some years.

Because both years 2003 and 2004 were not especially wet water-years, the successful contribution by fry and parr emigrants of those year-classes means that high-flood years are not necessary in order for those smaller (than smolts) juveniles to survive and ultimately form part of the spawner population.

However, the study did not identify the specific natal rivers. Given the presently degraded condition of potential floodplain habitats in the lower San Joaquin River basin, it is questionable if any significant numbers of juvenile salmon from the San Joaquin tributaries have recently utilized those areas as rearing habitats. Hence, the present contribution to the spawning population by emigrant fry and parr that are transported from their respective tributaries during winter and early-spring high flows is very likely nil.

This point of uncertainty has major implications for flow management strategy for the lower San Joaquin River and San Joaquin part of the Delta because decisions must be made on whether to specify flow schedules with flows that facilitate downstream rearing of fry-parr emigrants (i.e., in low-elevation restored floodplains) or on flows that focus primarily on transporting older juveniles and smolts quickly through the inhospitable south Delta areas to suitable areas in the western Delta and upper San Francisco Bay estuary but only if it can be shown that older juveniles and smolts will outmigrate more quickly in response to higher San Joaquin River flows.

Juvenile rearing areas in the lower Sacramento River and Sacramento-San Joaquin Delta

Sampling studies by the U.S. Fish and Wildlife Service (McLain and Castillo 2009) have indicated that salmon fry are in fact present at high densities in certain parts of the northwestern Sacramento-San Joaquin Delta—i.e., particularly in the lower mainstem Sacramento River and Steamboat Slough which appear to be important rearing areas. Other areas such as the Liberty Island and Prospect Island marshes at the lower end of the Yolo Bypass also contained salmon fry at lower densities and could be important rearing or transition areas for juveniles that emanate from the Yolo Bypass floodplain (McLain and Castillo 2009).

In contrast, potential rearing areas in the San Joaquin River portion of the Delta are much more physically degraded and presently appear to offer very limited use to juvenile salmonids (Dr. P.B. Moyle, University of California, Davis, personal communication to R.M. Yoshiyama). Considerable effort and time will be required to rehabilitate areas in the San Joaquin portion of the Delta into productive, juvenile-rearing areas. Hence, flows specified for the lower San Joaquin River should take into account the high likelihood that fry emigrants from the San Joaquin basin tributaries—under present and near-future conditions—are destined to perish rather than contribute to the adult population at least for the foreseeable future.

Spring Flows and Floodplain Rearing Areas

Under present and near-future conditions in the lower San Joaquin River and south Delta, the primary issue of concern in relation to salmonid life-history protection would be the transport function of flows and associated water temperatures for later-stage juveniles and smolts during

April-May to ensure their successful transit through the south Delta to more hospitable areas in the western Delta and San Francisco lower estuary. In contrast, flows and temperature controls targeting early-stage juveniles during the February-March period to facilitate local rearing in the lower San Joaquin River and south Delta "floodplain" areas are not likely to be effective within the near-future (e.g., 10-20 years), given the highly degraded physical nature and limited potential usage of those areas. Hence, flows that are set to temperature constraints on early juvenile salmonids would not be relevant for this floodplain-rearing function until such areas are restored.

One hypothesized function of high winter and spring flows in the lower Tuolumne River is to inundate floodplain areas that would provide productive rearing areas for juvenile Chinook salmon, as has been found in the Cosumnes River and Yolo Bypass floodplains (Sommer et al. 2001, Jeffres et al. 2008). This postulated function deserves critical evaluation particularly in respect to the timing and required volumes of flows. However, the higher gradient sections of the lower Tuolumne River—i.e., those reaches that are considerably upriver of the Tuolumne-San Joaquin confluence—do not appear comparable to the low-elevation floodplain areas of the Cosumnes River (which lie on the Central Valley floor) and the Yolo Bypass floodplain that lies at the terminus of the Sacramento River in the north Delta.

In the Cosumnes River floodplain study by Jeffres et al. (2008, their Figure 3), the inundated floodplain areas remained almost as cold as the river during the last half of February and into the first week of March in 2004; and a similar but less clear pattern occurred in 2005. For the Tuolumne River, if large volumes of water are required to inundate the floodplains along the up-river reaches, then the water may be too cold to produce the warm flooded rearing areas particularly during February or even early to mid-March. The somewhat higher elevation floodplain areas in the up-river reaches of the lower Tuolumne River most likely would require later timing if such floodplain inundation flows are supposed to provide favorable (warmer, more food-productive) rearing conditions for salmon, assuming such action is even feasible.

Conclusions

The interrelated nature of flows, water temperatures and physical habitat configurations present challenges to the process of determining suitable flow levels for maintaining robust fish, wildlife and ecosystem functions. The complex topography of San Joaquin Delta channels can produce unexpected spatial temperature profiles (Monismith et al. 2009). The topographical and hydrological complexity of the Delta and ongoing in-Delta physical changes such as subsidence and inevitable levee failures (Hanak and Lund 2008, Mote et al. 2003) coupled with expected regional climate change (e.g., Mote et al. 2003) would seem to indicate that specifying a static set of flow levels may be overly simplistic and unrealistic. This does not mean that flow criteria and the associated temperature criteria are unnecessary; they are in fact critically needed but they should be tailored to respond appropriately over time to the dynamical nature of the system. Significant regional warming or catastrophic levee breaches could quickly render inflexible flow and temperature criteria moot.

To be truly useful for protecting salmonid populations and the aquatic ecosystem of the Sacramento-San Joaquin River and Delta, flow standards and associated temperature-based criteria (which are defined by the biological needs of the fish) will have to be closely integrated with knowledge of hydrological and ecological processes that change over multiple time-scales.

Finally, it appears that the optimal specification of in-river flows would vary from year to year, or over decades, depending on the availability and condition of useable fish habitats in different parts of the lower San Joaquin River and south Delta along with other factors such as overall water availability (i.e., water-year type), delta-export pumping allotments, pollution loads borne by the lower San Joaquin River, and the physical configuration of the Delta—which may be altered by levee breaches and future habitat restoration projects.

Failure to set river flows that are appropriately coordinated with the prevailing ecosystem conditions—in the present and near-future—will result in the ineffective use of water supplies while providing limited benefits toward the restoration of salmonid fisheries and the Delta ecosystem.

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PART 2. TEMPERATURE REQUIREMENTS OF SALMONIDS

(2.1) Introduction to Temperature Review

Among the many studies and reviews on temperature-related effects on Pacific salmonids, two of the most useful comprehensive assessments are those of Richter and Kolmes (2005) and the U.S. Environmental Protection Agency Issue Paper 5 ("EPA Issue Paper 5" by McCullough et al., 2001) from which much of the following information is drawn.

The EPA Issue Paper 5 specifically addresses the physiological effects of temperature on salmonids. It is one of five interrelated technical issue papers sponsored by the U.S. Environmental Protection Agency that formed the basis of the information used in developing the general guidance document on temperature standards ("criteria") for Pacific Northwest salmonids—viz., "EPA Region 10 Guidance" (EPA 2003). Hence, EPA Issue Paper 5 provides a more extensive and detailed source of information that portrays the variability of salmonid responses to temperature and the complex interaction of multiple factors that determine those responses. The review paper by Richter and Kolmes (2005) similarly relies heavily on the EPA Region 10 Guidance and EPA Issue Paper 5 and other issue papers, as well as on other broad temperature-related reviews. Richter and Kolmes (2005) provide concise summaries of the temperature restrictions of specific salmon species and steelhead trout; their Table 1 on "Upper optimal temperature criteria" essentially condenses the EPA's (2003) Region 10 Guidance Table 1 which summarizes the good versus bad temperature levels for salmonid life-stages. The Richter and Kolmes Table 1 presents the temperature thresholds (or criteria) as two types of averages: (1) the 7-day average of the maximum daily temperatures (7DADM), and (2) weekly mean (average) temperatures. The first average (7DADM) was originally recommended by the EPA (2003) and the second measure was proposed by Richter and Kolmes (2005) as "insurance" to detect and protect against longer-term environmental thermal changes. These average criteria are practical to apply in a regulatory sense; i.e., they are simple and understandable, but that does not necessarily mean that they would be practical or easy to achieve in the real-world environment.

In addition, the studies by Myrick and Cech (2001, 2004) are particularly relevant because they focus primarily on the thermal effects and requirements of Central Valley Chinook salmon and steelhead. Hence, the insights provided by the Myrick and Cech studies warrant special attention in regard to managing flows and temperatures to support Central Valley anadromous salmonids.

The earlier major reviews on the thermal requirements of Pacific salmonids are interrelated to various degrees because they cover much of the same literature, as reflected in the overall consistency of their final recommendations for thermal criteria. However, the variability in salmonid responses to thermal effects shown by those reviews warrants caution in strictly applying simple, single-value temperature criteria over broad spatial areas and extended time periods without due regard for the natural variability of environmental conditions within which the salmonids have evolved. With that caveat in mind, a selection of statements excerpted from the earlier reviews and papers is presented here. The information related to thermal constraints on Chinook salmon and steelhead-rainbow trout are compiled under the following categories: (a) general considerations, (b) growth and rearing, (c) smolting, and (d) adult migration. The last three categories are the life-stages that will be directly affected by flow and temperature criteria applied during the springtime (April-May) period for the lower San Joaquin River (at Vernalis).

(2.2) General Temperature Considerations

The following excerpts illustrate the complexity of temperature-related effects on salmonids that arises from the interplay of multiple factors and the sometimes conflicting demands on individual fish as they grow through their life-stages and traverse different habitats. The optimal or favorable temperature zones are not necessarily static boxes that the individuals occupy but, instead, are more like bubbles that may change in size and position as the individuals themselves move and change.

EPA Paper 5

(p.5) "Growth rate is a function of temperature but also of food availability . . . Food availability in the field is normally thought to be substantially less than that needed to provide satiation feeding. Consequently, if stream productivity restricts salmonid feeding to levels less than satiation, then lower temperatures are required to ensure optimum growth rates."
"Also, in order to provide the greatest population production capacity (contributing to biomass, abundance, and fecundity--all indicators of fitness and population long-term viability, it is important to provide the full range of natural potential temperature longitudinally. This means very cold headwaters, cold midreaches, and cold/cool lower reaches. This will produce, in general, lower than optimum growth in headwaters, optimum growth in midreaches, and lower than optimum growth downstream."

(p.5) "Preferred temperatures, optimum growth temperatures, and high disease resistance from common warm-water diseases . . . tend to be similar (Jobling 1981). Consequently, we are able to survey the literature about optimum growth temperatures, compare these temperatures with optima for other performances such as disease resistance or swimming ability, and find a temperature range that would satisfy growth objectives but also meet other key needs influencing survival."

(p.6) "These contrasting demands [of growing rapidly to attain large size at smolting versus growing at a rate to allow the appropriate timing of smolting] imply that it is important to achieve high growth rates during the growth season . . . "

(p.7) "Salmon and steelhead during the smolt phase have various degrees of sensitivity to elevated water temperatures . . . Temperatures that have been reported in the literature as impairing smoltification range from approximately 53.6-59°F (12-15°C) or more . . . Steelhead appear to be most sensitive during this stage, as opposed to their greater resistance to high temperatures during other juvenile stages. . . . Smolt migration during periods of high water temperatures can cause inhibition or reversal of the smoltification process or a termination of migration (i.e., return to freshwater residency for an additional year."

(p.13) "Laboratory results may need to be adjusted downward [for field management applications in order] to account for the influences of reduced food availability, competition, predation, and other environmental variables. Also, laboratory results may not reveal sublethal effects associated with an increased risk of warm-water disease and physiological stresses of smoltification under elevated water temperatures."

(p.13-14) "Streams with naturally low productivity or in which food availability is lower [due to altered conditions] than under natural conditions . . . can be expected to produce optimal growth

at temperatures that are lower by at least 3.6-7.2°F (2-4°C) and, under certain conditions, as much as 14.4°F (8°C) from temperatures producing optimal growth under satiation feeding."

(p.15-16) "[Disease occurrence and severity] . . . constant temperatures below 53.6-55.4°F (12-13°C) often reduce or eliminate both infection and mortality; temperatures above 59-60.8°F (15-16°C) are often associated with high rates of infection and notable mortality; temperatures above 64.4-68°F (18-20°C) are often associated with serious rates of infection and catastrophic outbreaks of many fish diseases."

Myrick and Cech (2001:iv):
"Central Valley steelhead can be expected to show significant mortality at chronic temperatures exceeding 25°C [77°F] although they can tolerate temperatures as high as 29.6°C [85.3°F] for short periods of time. It is important to note that both species [i.e., Chinook salmon and steelhead] begin to experience serious sub-lethal effects at temperatures below their chronic lethal limits."

(2.3) Juvenile Rearing and Growth

Richter and Kolmes (2005: p.30):
"Optimal rearing temperatures at natural feeding regimes are in the range of 12.2°C to 14.8°C for chinook salmon (Hicks, 2000). Garling and Masterson (1985) [and other researchers] . . . reported optimum growth temperatures, determined from feeding on full rations, that range from 14.8° to 20°C. Ration size in the laboratory and food supply in nature can have significant effects on optimal temperatures for rearing. Feeding rates below the satiation level, typical of field situations (Brett et al., 1982) were associated with reduced temperature optima for growth (Elliott, 1981). Brett et al. (1982) reported an optimal growth temperature of 19°C for chinook maintained in the laboratory at maximal daily ration. In the field, with a projected feeding level of 60% of maximal daily ration, Brett et al. (1982) projected an optimal growth temperature of 14.8°C. . . ."

"McCullough (1999) suggested using the growth optimum of 15.6°C for spring chinook salmon as the temperature standard, because temperatures lower than this cause no reduction in survival while temperatures higher than this begin to reduce growth and lead to increasing mortality rates. A synthesis of evidence from . . . led McCullough et al. (2001) to recommend an optimum production temperature of 10.0° to 15.6°C. Adjusting laboratory temperatures to naturally fluctuating stream temperatures, Hicks (2000) recommended that a 7-DAM [7-Day-Average-Maximum] of 14.2° to 16.8°C during the peak of summer provides for optimal growth conditions for chinook salmon. The Independent Science Group (1996) concluded that juvenile chinook rearing is optimal between 12°-17°C with most optimal at 15°C."

Myrick and Cech (2004: p.120):
"There have been two studies published on the effects of temperature on growth of SSJR [Sacramento-San Joaquin River] Chinook salmon races; one by Marine and Cech (2004) on Sacramento River fall-run fish, and the second by Myrick and Cech (2002) on American River fall-run fish. . . . The results of these two studies compare favourably with those conducted on two northern Chinook salmon races . . ."

"The studies referenced above suggest that the optimal temperature for Chinook salmon growth lies within the 17-20°C [62.6-68°F] range, provided that food is not limiting, and other factors, such as disease, predation, and competition have a minimal effect. However, it is unlikely that Chinook salmon in field conditions will feed at 100% satiation, and the effects of disease, competition, and predation should also be taken into account. Therefore, growth rates observed under field conditions are likely to be lower." ". . . Brett et al. (1982) determined that temperatures of 18.9-20.5°C [66.2-68.9°F] were optimal for juvenile Chinook salmon fed to satiation but salmon that fed at 60% satiation reached their optimal growth temperature at ~15°C [~59°F]. . . . This study underscores the importance of taking field conditions into account when trying to apply results from laboratory studies."

Richter and Kolmes (2005: p.35):
"Optimal growth for juvenile steelhead occurs in the range of 14° to 15°C [57.2°-59°F] (Hicks 2000); although in the laboratory, Wurtsbaugh and Davis (1977) found that steelhead growth could be enhanced by temperatures up to 16.5°C. Cech and Myrick (1999) tested winter-run steelhead at three temperatures (11°, 15° and 19°C) and high ration levels (82%-100% of satiation); they found a reduced but still high growth rate (exceeding 11° and 15°C) at 19°C as ration was reduced 12%. Hicks (2000) interpreted their data as suggesting a maximal growth rate between 15° and 19°C at more typical reduced ration levels. Grabowski (1973) tested three constant temperatures (8°, 15°, 18°C) and one varying regime (8°-18°C , mean 13°C) and found best growth at constant 15°C, and second best with varying temperature averaging 13°C.

"The recommendation by Hicks (2000) to fully protect juvenile rearing was 16° to 17°C. Sullivan et al. (2000) recommended the upper threshold for the 7-DAM temperature of 20.5°C for steelhead, assuming that a 10% reduction in growth is an acceptable risk level. McCullough et al. (2001) noted that Wurstbaugh and Davis (1977) found growth enhanced up to 16.5°C and that growth rate declined with increasing temperature until it was zero at 22.5°C.

Myrick and Cech (2001: p.v):
"The highest growth rates reported to date for Central Valley steelhead occurred at 19°C [66.2°F], but higher temperatures have not been test. Like chinook salmon, it is likely steelhead can grow at higher temperatures, but they become more sensitive to water quality and more susceptible to pathogens and predators at these temperatures."

EPA Issue Paper 5 (2001: p.29)
"On the basis of studies of growth at constant temperatures within the overall range 50-77°F (10-25°C), Myrick and Cech (2000) inferred an optimal growth rate between 57.2 and 66.2°F (14 and 19°C) . . ."

EPA Issue Paper 5 (2001: p.42)
"Wurtsbaugh and Davis (1977) studied growth of steelhead trout in laboratory streams under three fluctuating temperature regimes (natural cycle, natural +5.4°F [3°C], and natural +10.8°F [6°C]) in all four seasons and found that trout growth could be enhanced by temperature increases up to 61.7°F (16.5°C). . . . Gross food conversion efficiency decreased as temperatures increased from 61.2 to 72.5°F (16.2-22.5°C)."

"Final preferred and optimal temperatures for rainbow trout have been reported at 53.6-66.2°F (12-19°C) . . . and scope of activity and growth for juvenile fish are commonly reported to be optimal between 59 and 69.8°F (15-21°C) on a satiation diet . . . "

"Piper et al. (1982) set the optimal at 50-62.1°F (10-16.7°C), although Sadler et al. (1986) found that growth and food conversion efficiency were greater at 60.8°F (16°C) compared with 50°F (10°C). McCauley and Huggins (1975) found that large (150-250 g) rainbow trout had a preferred mean temperature of 62.1°F (16.7°C), and that the fish actively traveled at temperatures between 56.8 and 64.4°F (13.8-18°C) in a thermal gradient. Behnke (1992) suggested that the optimum temperature for growth and food assimilation in salmonids occurs between 55.2 and 60.8°F (13-16°C). Ferguson (1958) cites 56.5°F (13.6°C) as the final preferred temperature for rainbow trout, and Mckee and Wolf (1963, . . .) found 55.4°F (13°C) to be optimum."

"Dockray et al. (1996) found that [for rainbow trout] in a fluctuating temperature environment, temperature increases benefited growth up to daily maximum temperatures of 64.4°F (18°C), above which long-term growth was inhibited."

"De Leeuw (1982) found that stream temperature increases that raised the summertime maximum temperature from 53.6 to 61.7°F (12-16.5°C) were associated with an increase in growth rates [of rainbow trout] in three streams in British Columbia, Canada."

"Hokanson et al. (1977) found that a constant exposure of 63°F (17.2°C) produced the greatest growth rates in trout fed to satiation over a 40-d test period. Increased mortality was observed in temperatures above this growth optimum. They also noted that in fluctuating temperature experiments, growth was accelerated when the mean temperature was below the constant temperature optimum (63°F [17.2°C]), and growth was retarded by mean fluctuating temperatures above this optimum. The highest growth rate in the fluctuating temperature environment occurred at a mean of 59.9°F (15.5°C) (range of 53-66.7°F [11.7-19.3°C]). A statistically nonsignificant decrease occurred at a mean of 63.1°F (17.3°C) (range of 56.3-70°F [13.5-21.1°C])."

EPA Issue Paper 5 (2001: p.43)
"Cunjak and Green (1986) found that rainbow trout were able to compete better with brook trout at 66.2°F (19°C) than at either 46.4 or 55.4°F (8 or 13°C)."

"Bisson and Davis (1976) . . . found that streams with daily maximum temperatures of 60.8-73.4°F (16-23°C) had greater standing crops of trout than did streams with warmer maximum temperatures (78.8-87.8°F [26-31°C])."

"Frissell et al. (1992) studied the distribution of rainbow trout and found that although they could be found in water temperatures over 73.4°F (23°C), there was a general threshold response for age 1+ fish above 71.6°F (22°C) and for age 2+ fish above 69.8° (21°C)."

[Li et al. (1993, etc.)] noted that rainbow trout ". . . actively avoided waters warmer than 73.4-77°F (23-25°C)."

EPA Issue Paper 5 (2001: p.45)

"In northern California streams, juvenile steelhead were seen actively feeding in water temperatures as high as 75.2°F (24°C) (Nielsen et al. (1994). However, once temperatures reached 71.6°F (22°C), rate of foraging began to decline."

Summary. Collectively, the studies above appear to indicate the following temperature ranges that provide different degrees of suitability for juvenile growth and rearing.

	Optimal	Sub-optimal	Poor to Sub-lethal
Chinook salmon	15-19°C (59-66.2°F)	20-21°C (68-69.8°F)	>21°C (>69.8°F)
Steelhead	15-19°C (59-66.2°F)	20-23°C (68-73.4°F)	>23°C (>73.4°F)

(2.4) Smoltification and Smolt Migration

Richter and Kolmes (2005: p.27):

"High temperatures during the smolt phase can result in outright lethality, premature smolting, blockage of seaward migration, desmoltification, shifts in emigration timing resulting in decreased survival in the marine environment, and other stresses detrimental to fitness. Temperatures reported to impair smoltification are above a range from approximately 12° to 15°C or more . . . Spring water temperatures must not exceed 12°C for successful smoltification in steelhead . . . For spring chinook and coho this value is 15°C (Zaugg and McLain, 1976), and it may be higher for summer migrating fall chinook subyearlings (Zaugg and Wagner, 1973)."

Myrick and Cech (2001:v-vi):

"Both Central Valley chinook salmon and steelhead have high growth rates at temperatures approaching 19°C, however, in order for them to complete the parr-smolt transformation (i.e., become adapted to life in salt water), lower temperatures are required. . . . Steelhead successfully undergo the parr-smolt transformation at temperatures between 6.5 and 11.3°C [43.7 and 52.3°F], and show little seawater adaptation at temperatures above 15°C [59°F]. Cooler temperatures (<10°C) tend to increase their seawater adaptation."

Richter and Kolmes (2005: p.35):

"A variety of upper temperature thresholds have been reported for impairment of steelhead smoltification. Hoar (1988) reported temperatures higher than 13°C, Adams et al. (1975) reported higher than 12.7°C, Zaugg and Wagner (1973) reported higher than 13.6°C, and Zaugg (1981) reported 12°C."

Richter and Kolmes (2005: p.39):

"The extreme variability of habitat use by steelhead makes establishing a temperature criterion for their smoltification challenging. The 12°C criterion for a weekly mean temperature at the fourth-level hydrologic unit (HUC) watershed is consistent with Zaug and Wagner's (1973) gill ATPase activity data. Weekly mean temperature values of 15°C proposed as criteria for other salmonids

are well above the values having excessive physiological consequences for steelhead (Zaugg and Wagner, 1973). The results of Adams et al. (1975) and Hoar (1988), who reported impairment of smoltification at 12.7°C and 13°C, respectively, support the lower criterion for steelhead."

It is especially important to note the changing and somewhat conflicting temperature requirements of salmon and steelhead-rainbow trout as the individuals grow through the successive life-stages, as emphasized by Myrick and Cech (2001).

Myrick and Cech (2001: p.53-54):
"Steelhead smolt in a very narrow temperature range, ..."

"When steelhead smolting and optimal growth temperatures are considered within the framework of steelhead life histories, the biological rational for the observed differences is apparent. Steelhead grow best at temperatures of 15-19°C, yet these temperatures are unsuitable for smolting. However, because steelhead spend at least 1 year in freshwater, high growth rates during warm summer periods help them reach a suitable size (>160 TL, Zaugg, 1981) for smolting during the cooler winters. If river temperatures are kept below those optimal for growth during non-smolt periods, there is a risk that the steelhead will be [too] small to smolt, forcing them spend another year in freshwater. Conversely, if the river temperatures are managed year-round at a level that is optimal for growth (i.e., ~ 15-19°C, smolting rates and success will be reduced. What is needed for steelhead, and indeed for all anadromous fishes, is a flexible management plan that is tailored to their temporally changing needs."

Summary. Collectively, the studies above appear to indicate the following temperature ranges that provide degrees of suitability for smoltification and smolt migration.

Chinook salmon **Suitable: up to 15°C (59°F)**   **Unsuitable: >15°C**

Steelhead **Suitable: up to 12-13°C (53.6-55.4°F)** **Unsuitable: >13°C**

(2.5) Adult Migration

Richter and Kolmes (2005: p.27):
"Thermal blockages to adult salmon migration have also been identified. Migration blockages occur consistently in the temperature range of 19° to 23°C (McCullough et al., 2001). For chinook and sockeye salmon and steelhead in the Columbia River, 21.7° to 23.9°C has been cited as the temperature range blocking migration (Fish and Hanavan, 1948).

Richter and Kolmes (2005: p.31):
"Immigrating spring chinook in the Willamette River have experienced thermal blockages at 21°C to 22°C (when dissolved oxygen was 3.5 mg/l) . . . A temperature of 21.1°C blocked spring chinook in the Tucannon River (Bumgarner et al., 1997) and fall chinook in the Sacramento River were blocked at 19° to 21°C (oxygen ~5 mg/l) (Hallock et al., 1970). Temperatures between 21.7° and 23.9°C blocked migration in the Columbia River . . . Hicks (2000) recommended that daily maximum temperatures should not exceed 20° to 21°C in order to prevent migration blockage of adult chinook salmon."

Richter and Kolmes (2005: p.36):

"Stabler (1981) reported 21°C as the temperature blocking adult steelhead migration in the Snake River. Snyder and Blahm (1971) reported that temperatures of 23.9°C produced a migration barrier that remained until temperatures declined to 21.1°C. In a study of movement into and out of pools, Nielson et al. (1994) found that temperatures above 22°C generally elicited avoidance. Coutant (1970) reported an incipient lethal temperature at a constant 21-22°C for migrating steelhead adults. Fish and Hanavan (1948) reported that steelhead congregated in cool tributaries when the river's mainstream reached 21.7°-22.8°C."

"Based on the consistency of several studies, Hicks (2000 recommended that temperatures remain lower than 21° to 22°C (1-DAM) to prevent thermal barriers to migrating steelhead, and that water in which steelhead migrate or hold not exceed a 7-DAM of 16°C to 17°C."

Richter and Kolmes (2005: p.40):

"Adult steelhead migration is not blocked until 21°C (Coutant, . . .). Steelhead have been reported to make use of deep stratified pools as thermal refugia when midday ambient stream levels ranged above 22°C (Nielsen et al., 1994), or to congregate in cool tributaries when the mainstem reached 21.7-22.8°C (Fish and Hanavan, 1948)."

Summary. Collectively, the studies above appear to indicate the following temperature ranges that provide different degrees of suitability for adult migration.

Chinook salmon	**Suitable: < 20°C (68°F)**	**Migration blockage: 20°C or higher**
Steelhead	**Suitable: < 22°C (71.6°F)**	**Migration blockage: 22°C or higher**

(2.6) Tabular Summaries

Based on the preceding information, Table 1 below presents a combined summary of the temperature ranges that correspond to generally favorable versus unfavorable conditions for the life-history stages most affected by springtime flows and temperatures in the lower San Joaquin River and southern Delta. These assessments address only the warmer half of the temperature spectrum affecting the salmonids; i.e., colder temperatures than shown in the Table 1 will also be suboptimal or lethal.

For comparison, Table 2 represents the temperature criteria determined by Richter and Kolmes (2005; their Table 1) that provide sufficient protection to salmon and steelhead life-stage functions (e.g., spawning, rearing).

Finally, Moyle et al. (2007 and 2010) most recently determined the temperature requirements for life-stages of Central Valley fall-run Chinook salmon and California steelhead; those are partially reproduced in Table 3 below.

Table 1. Summary of temperature ranges representing different levels of suitability for Chinook salmon and steelhead life-history functions (spring period). The ranges were inferred from the information described in the text.

Juvenile Rearing	Optimal	Sub-optimal	Poor to Sub-lethal
Chinook salmon	15-19°C (59-66.2°F)	20-21°C (68-69.8°F)	>21°C (>69.8°F)
Steelhead	15-19°C	20-23°C (68-73.4°F)	>23°C (>73.4°F)

Smoltification	Suitable	Unsuitable	
Chinook salmon	Up to 15°C (59°F)	>15°C (>59°F)	
Steelhead	Up to 12-13°C (53.6-55.4°F)	>13°C (>55.4°F)	

Adult Migration	Suitable	Migration blockage	
Chinook salmon	< 20°C (68°F)	20°C (68°F) or higher	
Steelhead	< 22°C (71.6°F)	22°C (71.6°F) or higher	

Table 2. Richter and Kolmes (2005, from their Table 1): Upper optimal temperature criteria

Life Stage	7-Day-Average of Maximum Daily Temperatures	Weekly Mean Temperatures
Spawning and Incubation	13°C (55°F)	10°C (50°F)
Juvenile Rearing	16°C (61°F)	15°C (59°F)
Smoltification: Salmon Smoltification: Steelhead	16°C (61°F) 14°C (57°F)	15°C (59°F) 12°C (54°F)
Adult Migration	18°C (64°F)	16°C (61°F)

Table 3. Moyle et al. (2007, 2010) Temperature ranges for different categories of suitability for Chinook salmon and steelhead life-history functions.

		Sub-Optimal	Optimal	Sub-Optimal	Lethal
Adult Migration:	Chinook Steelhead	<10°C <10°C	10-20°C 10-20°C	20-21°C 20-23°C	>21-24°C >23-24°C
Adult Spawning:	Chinook Steelhead	<13°C <4°C	13-16°C 4-11°C	16-19°C 12-19°C	>19°C >19°C
Egg Incubation:	Chinook Steelhead	<9°C <4°C	9-13°C 5-11°C	13-17°C 12-17°C	>17°C >17°C
Juvenile Rearing:	Chinook Steelhead	<13°C <10°C	13-20°C 10-17°C	20-24°C 18-26°C	>24°C >26°C
Smoltification:	Chinook Steelhead	<10°C <7°C	10-19°C 7-15°C	19-24°C 15-24°C	>24°C >24°C

(2.7) Discussion: Interpretive Synthesis of Temperature Effects on

Chinook Salmon and Steelhead

The many studies and reviews on temperature-related issues of anadromous salmonids collectively indicate at least the following major points.

(1) There are ranges of temperatures--as defined by various averaging methods--that represent so-called optimal and sub-optimal conditions (also termed non-stressful and stressful) for salmonids, but there is no single, definite cut-off temperature that universally demarcates those two sets of conditions for a given life-stage. Such a rigid demarcation would be an artificial construct that does not truly represent the underlying biological processes. A primary reason is that fish generally show gradated physiological and biochemical responses to environmental stressors such as temperature, salinity and dissolved oxygen levels, among others.

(2) Another reason for somewhat different optimal versus sub-optimal temperatures shown by different studies is that temperature interacts in complex ways with other factors to affect the fish—e.g., internal factors such as size, age, and body condition of the individual and external factors such as food supply. Thus, salmon or steelhead-rainbow trout are able to withstand higher temperatures if there is an adequate food supply to offset the increased metabolic demands while allowing enough energy to be allotted to growth.

(3) The thermal responses of individual fish will change through time as the fish grow through different life-stages (i.e., ontogenetic change). Hence, the thermal requirements or sensitivities of a fry will differ from those of an older juvenile, which will in turn differ from those of a smolt. This point was noted by Dr. Peter B. Moyle in testimony to the Federal Energy Regulatory Commission (Moyle Testimony 2009):

"The temperature requirements of both Chinook salmon (Exhibit 1) and steelhead (Exhibit 2) vary considerably with life stage. Both also show considerable ability to withstand periods of unfavorable temperatures but have a fairly narrow preferred range for most activities. The extent of deleterious biological effects of suboptimal or sub-lethal temperatures upon the two salmonids depends upon various factors such as the length of exposure, extent of acclimation to warm conditions prior to the actual thermal challenge, availability of thermal refuges in deep pools, groundwater inputs, amount of food available to the fish, and perhaps genetic background. The complex interplay of various environmental and physiological factors with thermal tolerances of Chinook salmon and steelhead-rainbow trout result in statements such as the following: "Central Valley steelhead can be expected to show significant mortality at chronic temperatures exceeding 25°C [77°F] although they can tolerate temperatures as high as 29.6°C [85.3°F] for short periods of time. It is important to note that both Chinook salmon and steelhead begin to experience serious sub-lethal effects at temperatures below their chronic limits (Myrick and Cech 20001)." Trout and salmon in the lower Tuolumne River can also respond behaviorally to changing water temperatures and to the spatial pattern of thermal microhabitats, such as cool-water sources along the river below La Grange Dam, by seeking out areas with more preferred conditions (if they exist)."

(4) This ontogenetic change in thermal requirements of individuals ramifies through the entire cohort of young fish that were produced in that preceding spawning season, but it does so in a

complicated way because individuals differ in the dates when they hatched and in their developmental rates. Thus, various segments of the cohort will have somewhat different and even opposing thermal optima and constraints—viz., younger juveniles would do better at warmer temperatures that enhance growth rates but older juveniles and smolts require cooler temperatures that allow successful smolting.

Flow management, in turn, must balance the sometimes divergent needs of the population segments (i.e., age-groups within species) as they move through the lower San Joaquin River basin and Delta. Furthermore, temperature criteria may have to be set contingent on the prevailing environmental conditions, such as the availability of low-elevation floodplain areas for juvenile rearing. The proper application of thermal tolerance information on the salmonids will require an adaptive and realistic management approach as emphasized by Richter and Kolmes (2005: p.40):
"Definitive criteria for salmonid recovery should eventually define ways to incorporate spatio-temporal variability into them in a realistically complex fashion and have as their eventual goal a process that realigns the distribution of current environmental variables so that they overlay historic conditions rather than simply act as a floor or ceiling."

Adaptive and realistic flow management to maintain anadromous salmonids and other native fauna in the lower San Joaquin River basin and Delta also must consider the environmental ramifications of regional climate change, as Richter and Kolmes (2005: p.40) noted for the Columbia River basin:
". . . Projections for regional climate changes suggest summer flows will be decreased and water temperatures increasing (Mote et al., 2003). The complexity of any solution to the problem of salmonid survival will need to balance all of these considerations while achieving temperature regimes suitable for the persistence of salmon."

(5) While specific temperature standards are generally necessary and useful as guidelines for protecting salmonid and other aquatic resources, such standards by themselves are simplistic solutions to very challenging problems. The spatial and temporal variability of both the fish and the environment should be considered in an integrated fashion to maximize population production and survival while minimizing the attendant costs. It is the manner of application of such standards that will determine the degree of success or failure of salmonid resource management in California and elsewhere. This crucial point has been previously expounded by multiple authorities; e.g., (Moyle Testimony 2009: p.14)
"The complex temperature requirements of Chinook salmon and steelhead have been extensively reviewed and form the basis for the exhibit tables. They indicate that setting simple temperature standards for these fish may or may not help the species persist. As McCullough et al. (2009) state: "Standards of the past were based largely on incipient lethal and optimum growth rate temperatures for fish species, while future standards should consider all integrated thermal impacts to the organism and ecosystem." "

(2.8) Life-History Migration Timing

The salmonid life-stages that are most likely to be affected by San Joaquin River flows during the April-May period are juveniles and smolts of fall-run Chinook salmon and steelhead-rainbow trout (*O. mykiss*) and up-migrating adult steelhead—and eventually spring-run Chinook

salmon (i.e., down-migrating juveniles/smolts and up-migrating adults) if that run is successfully introduced into the upper San Joaquin River.

The life-history timings for different stages of Central Valley fall-run Chinook salmon and steelhead are as follows (based on Moyle 2002 and Moyle et al. 2007).

Fall-run Chinook Salmon

Adult up-migration:	Peak in September-October
Spawning:	Peak in October-November; sometimes through December
Juvenile rearing:	December-March
Juvenile-smolt down-migration:	Peak in March-April

Steelhead

Adult up-migration:	Peak in late-September to late-October
Spawning:	February-June
Juvenile rearing:	Year-round
Juvenile-smolt down-migration:	Late-December to beginning of May (peak mid-March);
	A second much smaller peak in the fall (Hallock et al. 1961)

These peak periods will require water temperatures that are conducive to the successful completion of the respective life-stages.

In regard to down-migrating juvenile life-stages, it is likely that at the present time only smolts and older juveniles that are near smolting will benefit from the April-May San Joaquin River flows. The younger stages that are transported downstream from the San Joaquin basin tributaries during that spring period do not appear to have adequate rearing areas in the lower San Joaquin River and Delta that would allow them to survive up to the smolting stage.

(2.9) Differences Between Populations in Local Adaptation to Warm Temperature

Although the anadromous salmonids as a group are coldwater-adapted and generally restricted by warm conditions (McCullough et al. 2001), there is reason to expect differences in the thermal tolerances of populations that inhabit areas with substantially different environmental conditions. There are two main reasons for this expectation: (1) different acclimation histories and (2) probably different heritable adaptations to local thermal stresses.

(1) **Acclimation history.** It is well documented from numerous studies in the aforementioned reviews that the acclimation history of individual fish strongly affects their ability to withstand thermal stresses. Different localities or regions often have characteristic environmental conditions—i.e., thermal regimes that vary on multiple time scales (daily, weekly, seasonal, etc.). Hence, the individuals that inhabit those areas will have been gradually acclimated to the corresponding thermal regimes and probably would differ in their sensitivities at least to certain additional thermal challenges—e.g., seasonal or episodic heat waves. The implication is that southerly located populations, for example, may be more able to withstand frequent temperature fluctuations that approach their upper limit of physiological tolerances than would more northerly populations. Hence, there may be some rationale for allowing more flexible temperature standards for protecting salmonids at more southern locations.

(2) **Heritable local adaptations.** Locally adapted populations are a major feature of biological diversity. There is no reason to believe that anadromous salmonids differ in this regard from other taxonomic groups of organisms. In fact, it would be very surprising if all Chinook salmon, or steelhead-rainbow trout, populations within the species had identical or highly similar thermal tolerances.

The existence of genetically based differences in high-temperature tolerances has been firmly established for steelhead-rainbow trout (*O. mykiss*) and they almost certainly exist as well for the various salmon species in the same genus (*Oncorhynchus*). As noted by McCullough et al. (2009: p.93),

"The genetic architecture that underlies temperature tolerance is better understood for rainbow trout than for other fishes. Genetic variation explains roughly half of the phenotypic variability in the upper temperature tolerance (UTT) of individual rainbow trout (Danzmann et al., 1999)."

Examples of within-species variation in thermal tolerances were cited by McCullough et al. (2009: p.99):
". . . For example, Beacham and Withler (1991) carefully interbred several generations of individuals from northern and southern British Columbia Chinook salmon (*O. tshawytscha*) stocks. Juveniles from the southern stock proved better adapted to survive high temperatures than the northern stock but seemed to reach a limit beyond which they could no longer achieve additional tolerance. Redding and Schreck (1979) observed that inland steelhead (anadromous rainbow trout, *O. mykiss*) populations, which experience higher average temperatures, tended to have a higher temperature tolerance but slower growth than coastal steelhead populations."

Some examples of relatively high thermal tolerances of anadromous salmonid populations in California are the following.

(a) **Northern California coastal steelhead.** Adult and juvenile summer-run steelhead used coldwater refuges (stratified pools) during the summers in the Middle Fork Eel River and (juveniles only) in Rancheria Creek, a tributary of the Navarro River. The steelhead used the coldwater pools when ambient stream temperatures exceeded 23°C [73.4°F]. The coldwater refuges were generally 3.5°C [6.3°F] cooler than the ambient stream temperatures—i.e., 22.5°C [72.5°F] and higher in coldwater pools.

"During this study, however, juvenile steelhead were seen actively feeding in surface waters with ambient temperatures up to 24°C" [in the Middle Fork Eel River] (Nielsen et al. 1994: p.621)

In Rancheria Creek, juvenile steelhead moved into cool stratified pools when ambient stream temperatures reached 23°C or more. However, on days when ambient stream temperatures remained at or below 22°C, the juveniles did not seek the cooler pool refuges.

(b) **Klamath River Chinook salmon.** Adult Chinook salmon were tagged with transmitters and archival tags in the Klamath River and their up-migration was monitored along with river temperatures (in 2004 and 2005). Strange (2010: p.1091, 1105) reported:
"Mean daily river temperatures upon initiation of upriver migration by adult Chinook salmon after a period of thermally induced migration inhibition ranged from 21.8°C to 24.0°C (mean = 22.9°C) [71.2-75.2°F (mean=73.2°F)]. During the first week (168 h) of migration, mean average body temperature was 21.9°C, mean average minimum daily body temperature was 20.6°C, and mean average maximum daily body temperature was 23.1°C [73.6°F]. Temperatures above these levels appeared to completely block migration in almost all circumstances."

"The temperatures at which adult Chinook salmon in the Klamath River basin were observed actively migrating approached or exceeded the highest ultimate upper incipient lethal values determined for any life stage of this species (Brett 1952). This finding demonstrates that Chinook salmon adults are capable of enduring, at least for a limited time period, potentially lethal instantaneous temperatures while continuing to migrate. While there is certainly a limit to the duration of exposure that can be endured, it is significant that although temperatures during the first week of migration equaled or exceeded the upper incipient lethal temperature for adult Chinook salmon (Coutant 1970), tagged Klamath River basin adults still had high rates of success in reaching spawning grounds. Cumulative exposure to deleterious temperatures, however, can lead to delayed mortality after arrival on spawning grounds; therefore, when comparing results from the Klamath River basin to numeric water quality criteria, it is important to distinguish between tolerable versus optimal thermal conditions for migration."

(c) **Upper San Joaquin River Chinook salmon** (historical population). The Chinook salmon (presumably fall-run) that formerly utilized the upper San Joaquin River, near Friant Dam, were considered by the California Fish Commission to be extraordinarily adapted to relatively warm conditions (Yoshiyama et al. 2001: p.94):

"Large numbers pass up the San Joaquin River for the purpose of spawning in July and August, swimming for one hundred and fifty miles though the hottest valley in the State, where the temperature of the air at noon is rarely less than eighty degrees, and often as high as one hundred and five degrees Fahrenheit, and where the average temperature of the river at the bottom is seventy-nine degrees and at the surface eighty degrees (CFC 1875, p 10; USFC 1876b, p xxv)."

"The Commissioners noted that during August-September of 1875-1877, the average monthly water temperatures for the San Joaquin River where two bridges of the Central Pacific Railroad crossed (at 37°50'N, 121°22'W and 36°52'N, 119°54'W) were within 72.1 to 80.7°F (considering both surface and bottom water) and maximal temperatures were 82 to 84°F (CFC 1877). The high temperature tolerance of the San Joaquin River fall-run salmon inspired interest in introducing those salmon into the warm rivers of the eastern and southern United States . . ."

It is important to note that in the preceding examples, the fish were observed in their natural environment under the prevailing temperature conditions rather than in laboratory situations—i.e., living proof of their abilities to exist at least at those times and places. These examples appear to represent exceptional levels of tolerance to relatively warm environmental temperatures. It would not seem credible to assume that all other Chinook salmon and steelhead populations have, or had, the same (genetic) capabilities to tolerate such temperatures—and probably few, if any, salmonid biologists would draw such an inference. Yet, that inference is merely the obverse side of assuming that all salmonid populations are essentially equally intolerant of elevated temperatures—i.e., that there is no significant local adaptation to different regional or temperature conditions.

Finally, Richter and Kolmes (2005: p. 40) have noted:

"A rich data set (e.g., Brannon et al., 2004) shows that in terms of thermal tolerances, disease resistance and physiological adaptation in general, salmonid stocks native to specific bodies of water may be better adapted to local conditions than are members of stocks originating in substantially different spawning habitats."

"Brannon et al. (2004) provide compelling arguments that temperature has been the dominant environmental influence responsible for the evolution of historical chinook and steelhead population structure in the Columbia River basin; if dominant in their evolution, temperature will surely be a dominant factor in their survival or extirpation."

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PART 3. CLIMATE AND OCEAN VARIATION AND ITS INFLUENCE ON CALIFORNIA CENTRAL VALLEY SALMON POPULATIONS

(3.1) Introduction to Climate-Ocean Factors

The broad influence of climate and ocean conditions on fish distribution and abundance has been long recognized by ecologists, oceanographers and fisheries scientists. However, it often is difficult to delineate the exact factors and mechanisms that regulate fish populations, even for intensely studied species such as salmon. The role of climate-ocean variables in driving pronounced population fluctuations is exemplified by the recent sharp decline in Central Valley Chinook salmon and other West Coast salmon stocks and is of special interest because large-scale uncontrollable factors can severely affect the success of salmon restoration and ecosystem management programs.

It is useful to evaluate the potential influence of climate and ocean variation in regard to salmonid populations in the Tuolumne River and other lower San Joaquin basin tributaries because some recent assessments appear to have underestimated the influence of certain aspects of climate-ocean variability on those populations. For example, a recent analysis by the U.S. Fish and Wildlife Service concluded that except for the severely detrimental circumstances during 2005-2006, the coastal ocean conditions as represented by the average coastal upwelling index during April-August for the Gulf of Farallones had no detectable impact on adult salmon recruitment in the Tuolumne River (Mesick 2009 Exhibit No. FWS-50). There is a general lack of data on the direct effects of climate-ocean variation on San Joaquin basin salmon (and steelhead) populations and so it is important to continue evaluation of this topic as additional information is gathered in the future.

The purpose of this Part 3 is to provide updated background information on the influence of climate and ocean conditions on Pacific salmon species that bears upon the question of what factors have significantly affected of Central Valley Chinook salmon abundances, including Tuolumne River fall-run Chinook salmon, during recent decades. The intent is to provide evidence that the effects of climate-ocean variation on salmon are not restricted to rare and dramatic impacts but, instead, have occurred multiple times in the past (i.e., over many decades) and probably have had varying levels of impacts on salmon populations.

(3.2) El Niño: An Example of a Major Ocean Factor affecting Salmon

The large-scale patterns and temporal shifts of climate-ocean conditions are known to have significant and occasionally dramatic effects on marine ecosystems along the North American Pacific Coast. A well-recognized phenomenon is El Niño, which is broadly described as a reversal of the more usual coastal current patterns and the warming of sea surface temperatures (SST) that have variable but generally negative consequences for California-Oregon coast salmon and certain other fish populations (Mysak 1986, Johnson 1988). The particularly inimical 1982-1983 El Niño was one of the most extreme examples of a one-year El Niño event (Pearcy and Schoener 1987, Pearcy 1992). Hence, the frequency, intensity and duration of El Niño events—and also the basically opposite La Niña which is occasionally paired with El Niño

(Diaz and Kiladis 1992, Trenberth 1997)— often have major consequence for salmon populations.

Although the exact population impacts of El Niño or El Niño-like events on specific Central Valley fall-run Chinook stocks have not been determined, their effects on other salmon runs and species are clearly recognized, especially in Oregon and Washington. For example, Peterson et al. (2010: p.11) stated:

". . . the impact of El Niño events on survival of coho salmon is well documented (Pearcy 1992). For example, the large events of both 1983 and 1998 were followed by low adult return rates for coho salmon during 1983-1984 and 1999, respectively."

"Likewise, the extended period of El Niño conditions in 1977-1983 was accompanied by declines in adult coho returns during the same years. A second extended El Niño period during 1990-1996 was followed by extremely low returns of adult fish that migrated to sea as juveniles from 1991 to 1998. For spring Chinook, the two large (but brief) El Niño events resulted in lower-than-average smolt-to-adult return rates, but the lowest adult return rates were observed during the weaker but prolonged El Niño events of 1990-1998."

"Declines in adult Chinook salmon returns from 2004 to 2007 are likely related to the period of warm ocean and weak but persistent El Niño conditions during 2003-2006."

It should be noted that El Niño events originate in the Pacific equatorial region and spread northward (northern hemisphere) and southward (southern hemisphere). Therefore, any detrimental effects of El Niño events on salmon stocks manifested off Oregon-Washington waters would be even more pronounced along the California coast and on California salmon populations because the force of El Niño emanates from the south.

(3.3) The 1987-1992 California Drought and the Commonness of El Niño-La Niña Events

The six-year drought of 1987-1992 in California partly coincided with an unusual period of El Niño-like conditions during 1990-1995. The latter period was initially described as a single persistent El Niño event but was subsequently determined to have consisted of several closely spaced El Niño or El Niño-like events (Trenberth and Hoar 1996, Allan and D'Arrigo 1999). Based on an examination of extended instrument-based data series starting in 1876 and "proxy" data series (i.e., paleoclimate data from tree-ring analyses), Allan and D'Arrigo (1999) concluded that sequences of persistent El Niño (or La Niña) events—each lasting three years or longer— have occurred multiple times. The instrument-based data showed that persistent El Niño episodes have occurred four times and persistent La Niña episodes six times during the past 100-120 years of record. The recent persistent El Niño episode of 1990-1995 has been the longest such phenomenon in the instrument-based record (since 1876) but similar persistent El Niño episodes occurred in 1911-1915 and 1939-1942 (Allan and D'Arrigo 1999).

In comparison with the instrument-based data, the more extensive historical document-based records and paleoclimatic proxy (tree-ring) data similarly indicate that persistent El Niño episodes have occurred "around four or five times per century" (Allan and D'Arrigo 1999: p.115). The most historically consistent episodes—i.e., those that were corroborated between the

different historical sources and paleoclimatic proxy records--occurred during 1749-1751, 1791-1793, 1814-1816 and 1833-1835.

However, not all drought periods are associated with extended El Niño (or El Niño-like) episodes. For example, the persistent drought of 1928-1934 did not coincide with any significant El Niño events (cf., Stine 1994 and Allan and D'Arrigo 1999). Nonetheless, it is clear that either a drought or El Niño alone can have substantial negative repercussions on salmon populations. Regarding the 1928-1934 drought in California, Stine (1994: p.546) noted:

> "Until recently, the most severe and persistent drought of California's instrumental record occurred between 1928 and 1934 (the 'Dust Bowl period'), when Sierran runoff averaged ~70% of normal. That interval was matched in severity during the 6 years 1987-1992, reinforcing the notion of a maximum 6- to 7-year dry spell."

Stine's statement is notable because it points out that there have been two episodes of severe, persistent drought of at least six-year duration in California during the 20th century. That fact undercuts the strength of the resource agencies' argument that such repeated, extended droughts are highly unlike to occur--e.g., see Proposed Findings of Fact of Resource Agencies and Conservation Groups, October 21, 2009, page 46, point 3.23; citing Exhibit No. NMF-52 (NMFS Anderson Rebuttal).

(3.4) Recent Ocean Conditions

Ocean conditions during the past decade or so can be summarized as follows. A principal measure of El Niño conditions is the Multivariate ENSO Index (MEI) which reflects the strength of El Niño events (positive values) or La Niña events (negative values) along the North American Pacific Coast. In the years since 1998, MEI values were positive during April 2002-September 2005 and again beginning in spring 2009, thus signaling the occurrence of extended El Niño conditions (Peterson et al. 2010).

Another measure of climate-ocean conditions is the Pacific Decadal Oscillation (PDO) Index which is based primarily on sea surface temperatures. The PDO is considered to have two phases—i.e., a warm phase that is less favorable for salmon and a cool (or cold) phase that is more favorable. Generally, the cool-PDO phase is associated with stronger upwelling conditions and colder temperatures in coastal waters from California to Washington while the warm-PDO phase has opposite conditions. The PDO was in a cool phase during 1998-2001, in a warm phase in 2002-2005, in neutral phase in 2006 to mid-2007 and in a warm phase from September 2007 up through July 2009 (Peterson et al. 2010).

Thus, both the MEI and PDO Index indicated poor ocean conditions from 2002 through 2005. A significant point is that despite strong coastal upwelling during the following summer 2006 (Peterson et al. 2010), the coastal biological productivity remained poor when juvenile salmon entered the ocean in the spring and summer of that year (2006)—a situation similar to the low biological productivity observed during 2005 (MacFarlane et al. 2008).

Furthermore, Petersen et al. (2010: p.16) commented on the insufficiency of a single upwelling index to fully reflect ocean conditions such as sea surface temperatures (SST) and biological productivity:

"Knowledge of upwelling alone does not always provide good predictions of salmon returns. For example, during the 1998 El Niño event, upwelling was relatively strong, as measured by the CUI; however, plankton production was weak. This occurred because the deep source waters for upwelling were warm and nutrient-poor. Low levels of plankton production may have impacted all trophic levels up the food chain. Upwelling was also strong during summer 2006, yet SST anomalies only averaged -0.3 °C. On the other hand, upwelling was relatively weak during the summers of 2007 and 2008, yet these summers had some of the coldest temperatures in the times [sic] series, -1.0°C. These observations demonstrate that some care is required when interpreting this simple upwelling index. We hypothesize that although upwelling is necessary to stimulate plankton production, its impact is greatest during negative phases of the PDO."

Therefore, the caveat offered above by Peterson et al. (2010) must be considered in interpreting the correlation analysis between adult salmon recruitment in the Tuolumne River and the average summer Coastal Upwelling Index (CUI) that was conducted by Mesick (2009: p.27). Specifically, additional factors besides coastal upwelling strength undoubtedly contributed to the ambiguous pattern of adult recruitment variation reflected in Mesick's analysis (see Mesick 2009: Figure 15) but without more detailed information it is not possible to accurately determine how much each ocean-related factor had contributed to the pattern.

(3.5) Additional Factors to Consider in Assessing the Effects of Ocean Conditions on Salmon

The Spring Transition

In addition to the intensity and duration of the upwelling season, the date when consistent upwelling begins is a critical factor in affecting the productivity of the coastal ecosystem. The beginning of upwelling during the spring season is termed the "spring transition" and is considered to be "the most critical time of the seasonal plankton cycle" marking "when the ocean transitions from a winter downwelling state to a summer upwelling state" (Peterson et al. 2010: p.19).

The influence of the spring transition was described by Peterson et al. (2010: p.19):

"The spring transition marks the beginning of the upwelling season and can occur at any time between March and June. Generally, the earlier in the year that upwelling is initiated, the greater ecosystem productivity will be in that year. In some years the transition is sharp, and the actual day of transition can be identified easily, but in many years transition timing is more obscure. It is not uncommon for northerly winds (favorable to upwelling) to blow for a few days, only to be followed by southwesterly winds and storms. If late season storms are intense, they can erase any upwelling signature that may have been initiated, thus re-setting the "seasonal clock" to a winter state. This is what occurred during summer 2005."

Therefore, the spring transition in 2005 essentially had been delayed and explains to a large degree the exceedingly poor conditions encountered by salmon smolts that had newly

entered the ocean. The spring transition was also somewhat late in 2006 and in both 2003 and 2004, contributing further to the unfavorable series of years (2003-2006) (Peterson et al. 2010, their Figures 2, 3, 4 and 13). Studies have shown that the spring transition is correlated with hatchery coho salmon and spring-run Chinook salmon from Oregon (Peterson et al. 2010) but direct studies on California salmon populations have **not** been conducted.

It is evident that the spring transition date is highly variable and may significantly affect the survival success of young and adult salmon along the California-Oregon coast. Variation in the spring transition and possibly other factors (discussed by Peterson et al. (2010)) very likely explain at least partly why the USFWS (Dr. C. Mesick's) analysis found no detectable statistical relationship between the cumulative upwelling index (for May-June in the Gulf of Farallones) and natural salmon recruitment to the Tuolumne River (Mesick 2009; p.27 and his Figure 15). Much of the scatter in Mesick's graph (his Figure 15) of natural salmon recruitment levels in the Tuolumne River may have been caused by year-to-year differences in the spring transition date.

Peterson et al. (2010) further noted that the spring transition date could be defined in biological terms as well as by physical oceanographic terms. Rather than using the date when cold water (due to upwelling) first appears in coastal waters, the spring transition alternatively could be marked by the date when a "northern (cold-water) copepod community" first appears at a specified location (viz., "baseline station NH05")—termed the "biological spring transition." Peterson et al. (2010: p.36) gave the following rationale:

"We believe this date may be a more useful indicator of the transition in ocean conditions because it also indicates the first appearance of the kind of food chain that coho and Chinook salmon seem to prefer; that is, one dominated by large, lipid-rich copepods, euphausiids, and juvenile forage fish."

"Thus we suggest the potential feeding conditions for juvenile salmon are more accurately indexed using the northern copepod biomass and the biological spring transition date (as compared to an upwelling index, which is presumed to serve as an index of feeding conditions). We say this in light of the following two instances wherein the upwelling index alone fails to correctly indicate feeding conditions."

"First, during El Niño years, or years with extended periods of weak El Niño-like conditions, upwelling can still be strong (as in 1998), but can produce a warm, low-salinity, low-nutrient water type (rather than the expected cold, salty, and nutrient-rich water). Upwelling of this water type results in poor plankton production."

"A second example of upwelling as a misleading indicator occurred during 2005, when mean total upwelling levels from May to September were "average." However, the zooplankton community did not transition to a cold-water community until August (Table 6). Therefore, in spite of early upwelling, conditions for salmon feeding, growth, and survival were unfavorable throughout spring and most of summer 2005."

El Niño Modoki

Recent studies on El Niño (and La Niña) -like events have shown that a different type of El Niño exists and has occurred more frequently in the past two decades. This new type is called El Niño Modoki, or pseudo- El Niño, which is sometimes associated with a new type of La Niña,

La Niña Modoki. El Niño Modoki has different atmosphere-ocean characteristics from those of the conventional El Niño and different repercussions on both ocean and terrestrial conditions (e.g., air temperature and rainfall) (Ashok et al. 2007, Weng et al. 2007). El Niño Modoki and conventional El Niño events also lead to distinct temperature and rainfall patterns during the northern hemisphere winter in large regions well outside the tropics due to their different teleconnection paths to those regions (Weng et al. 2009).

The relatively warm atmosphere-ocean conditions in the tropical Pacific Ocean since 1979 have been more conducive to the formation of persistent El Niño Modoki episodes than for the conventional El Niño (Ashok et al. 2007). Hence, the more frequent El Niño Modoki events may have partly caused the unprecedented environmental conditions in recent decades along the North American Pacific Coast, particularly off California-Oregon. El Niño Modoki events were determined to have occurred in 1986, 1990, 1991, 1992, 1994, 2002 and 2004 (Ashok et al. 2007). The increased frequency El Niño Modoki events is consistent with, and possibly partly due to, the trend toward global warming (Ashok and Yamagata 2009).

The significance of more frequent El Niño Modoki events is that severe droughts in the western United States occur during El Niño Modoki summers, in contrast to wetter conditions during conventional El Niño summers (Weng et al. 2007). Thus, the likelihood of more frequent El Niño Modoki-associated droughts and higher temperatures poses increased challenges to salmonid populations in freshwater environments. Furthermore, these changes in the relative frequencies of conventional El Niño and El Niño Modoki episodes are only one aspect of the repercussions of the recent long-term global warming trend.

(3.6) Conclusions on Climate-Ocean Factors

Multiple aspects of climate-ocean conditions affect the California-Oregon coastal ecosystems that contain numerous salmonid and non-salmonid fish stocks. Those aspects span a wide range of temporal and spatial scales and they affect salmon populations in complex, interacting ways. Although ocean factors likely do not usually determine population levels as directly and as strongly as would environmental conditions in the Sacramento-San Joaquin Delta and in the natal rivers, the ocean nonetheless can significantly modify salmon population levels— probably at least once per decade.

Furthermore, the variation in ocean conditions that affect salmon (and steelhead) populations along the California-Oregon coast is not entirely reflected by the single measure of average summer upwelling activity in the Gulf of Farallones, although that variable is often a strong indicator of the suitability of conditions for young salmon newly arrived in the ocean.

The effects of ocean conditions ultimately intersect with those of freshwater and estuarine conditions to determine salmon population production levels, and so it is important to integrate ocean-related information into salmon management strategies whenever possible in order to optimize the outcome of management actions. For example, it would be questionable to intensify hatchery production of salmon or to provide very high instream flows during periods of severely unfavorable ocean conditions when the survival and growth of young salmon is very poor. However, that does not mean that proper management of freshwater conditions can be neglected during such periods. Rather, management efforts should be adjusted to optimize the effectiveness of instream flow and freshwater habitat management. Such adjustments may entail, for example, maintaining streamflows at sufficient but conservative levels to protect the populations while

focusing efforts on freshwater physical-habitat improvements. As ocean conditions revert to more favorable states, instream flows can be accordingly ramped up to maximize salmon output from the freshwater environment and take advantage of the higher productivity potential of the ocean.

It is clear that the overall trends in climate-ocean conditions—including El Niño-like events, multidecadal cycles and long-term global warming—collectively pose increased demands on water availability and thermally suitable habitats for salmonids in future years. Hence, it would be highly advisable to plan for frequent future episodes of drought or near-drought conditions in relation to water supply and fisheries management, rather than assuming that future conditions will generally be the same as those in the past half-century.

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