EXHIBIT TBI-3

BEFORE THE STATE WATER RESOURCES CONTROL BOARD

WRITTEN TESTIMONY OF

CHRISTINA SWANSON, PH.D.
EXECUTIVE DIRECTOR AND CHIEF SCIENTIST
THE BAY INSTITUTE

JOHN CAIN
DIRECTOR, CALIFORNIA FLOOD MANAGEMENT
AMERICAN RIVERS

JEFF OPPERMAN, PH.D.
SENIOR ADVISOR FOR SUSTAINABLE HYDROPOWER
THE NATURE CONSERVANCY

MARK TOMPKINS, PH.D.
PRINCIPAL ENGINEERING GEOMORPHOLOGIST
NEWFIELDS RIVER BASIN SERVICES

REGARDING FLOW CRITERIA FOR THE DELTA
NECESSARY TO PROTECT PUBLIC TRUST RESOURCES:
DELTA INFLOWS

PREPARED FOR:

THE BAY INSTITUTE
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NATURAL RESOURCES DEFENSE COUNCIL

EXHIBIT 3: DELTA INFLOWS

Overall Relevance of Delta Inflows to Developing Public Trust Flow Criteria

Summary points:

- *The amounts and constituents of Delta inflow are critical to the Delta's habitat availability, energy budget and water quality, inundating floodplains and maintaining turbidity levels and other conditions that influence public trust resources*
- *Migratory species depend on Delta inflow levels and patterns to facilitate transport up and downstream in the estuary and maintain adequate temperature conditions*

The timing, duration, frequency, and source of flows into the Delta have an important effect on the protection of public trust resources, independent of any consideration of flow conditions in areas upstream of the Delta that fall outside the scope of this proceeding. These inflows literally *create* the habitat in the Delta that public trust species use for spawning and rearing and the migratory cues and drivers that anadromous species use to travel between ocean, riverine, and headwaters habitats. The relative contribution of the inflows that cumulatively produce Delta outflows has enormous consequences for the habitats (e.g., floodplains, waters with sufficient flow and turbidity) available to species in the Delta.

Source inflows have a strong influence on the quality of Delta water, the productivity of the Delta ecosystem and the abundance, growth, and survival of fish that spend some portion of their life history in the Delta. Inflows carry fresh water, nutrients, sediment, and energy into the Delta. Pulse flow events transport turbid waters to the Delta; low and declining turbidity in the Delta, resulting from water storage and flood control projects upstream, appears to make native fish species (e.g., Chinook salmon) more vulnerable to predation from exotic predators. For example, research from other river systems (e.g. Gregory 1992; Gregory and Levings 1998) indicates that predation rates of juvenile Chinook salmon are very high when turbidity levels are as low as they are in San Francisco Estuary. Delta smelt larvae require turbidity to initiate feeding (Baskerville-Bridges et al. 2003). Distribution of juvenile delta smelt is strongly influenced by turbidity; thus, decreasing turbidity in the Delta may constrain the distribution of juvenile Delta smelt (Feyrer et al. 2007, *in review*; Nobriga et al 2008). In addition to providing a competitive advantage to non-native fish species (Nobriga et al. 2005), low turbidity provides better growth conditions for exotic submerged aquatic vegetation species, including as *Egeria densa*.

Adult and juvenile migrations of migratory species, including Sacramento splittail, green and white sturgeon, Sacramento and San Joaquin Chinook salmon, steelhead, striped bass, and American shad, are timed to correspond with flows that, among other things, provide:

- migratory cues (e.g. salmon find their natal streams by the "scent" of their natal river as transported by flows from that river),
- transport upstream (e.g. providing suitable water quality, depth and continuity of flows needed to cross barriers),
- transport downstream (e.g. providing the suitable water quality, depth and continuity of flows needed to cross barriers, and
- beneficial rearing habitats (through the wetting of streambank and overbank habitats and by mobilizing sediments that contribute to turbidity in the Delta).
- adequate temperature conditions on the lower San Joaquin River.

River flows into the Delta are positively correlated with each of these benefit categories. In addition, high flows in the spring prolong the duration of cool water temperatures (see below) that benefit emigrating salmonid juveniles, which are generally temperature-stressed in this ecosystem (Marine and Cech 2004; Myrick and Cech 2005).

The magnitude, timing, duration, and frequency of Delta inflows from various sources, have changed dramatically, particularly during the winter and early spring months. These reductions in flow have diminished the Delta's ability to support the viability of public trust resources as well as the public trust value of the Delta ecosystem itself (Figures 1, 2).

Figure 1: Ratio of actual San Joaquin River flow at Vernalis to unimpaired flow in the San Joaquin Basin during winter-spring for three time periods: 1930-1955, 1956-1987, and 1988-2009. Horizontal lines indicate the average for each period. Over time, the percentage of winter-spring runoff available in the San Joaquin Basin that has reached the Delta has declined.

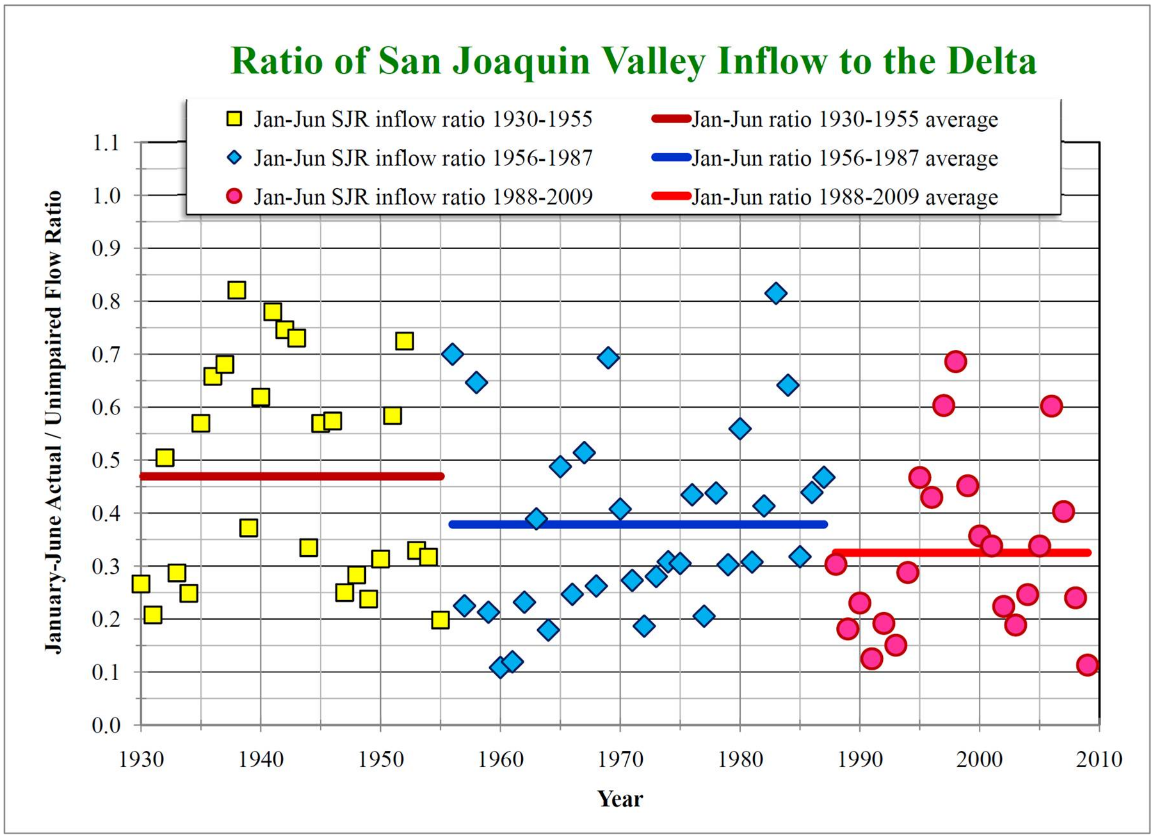
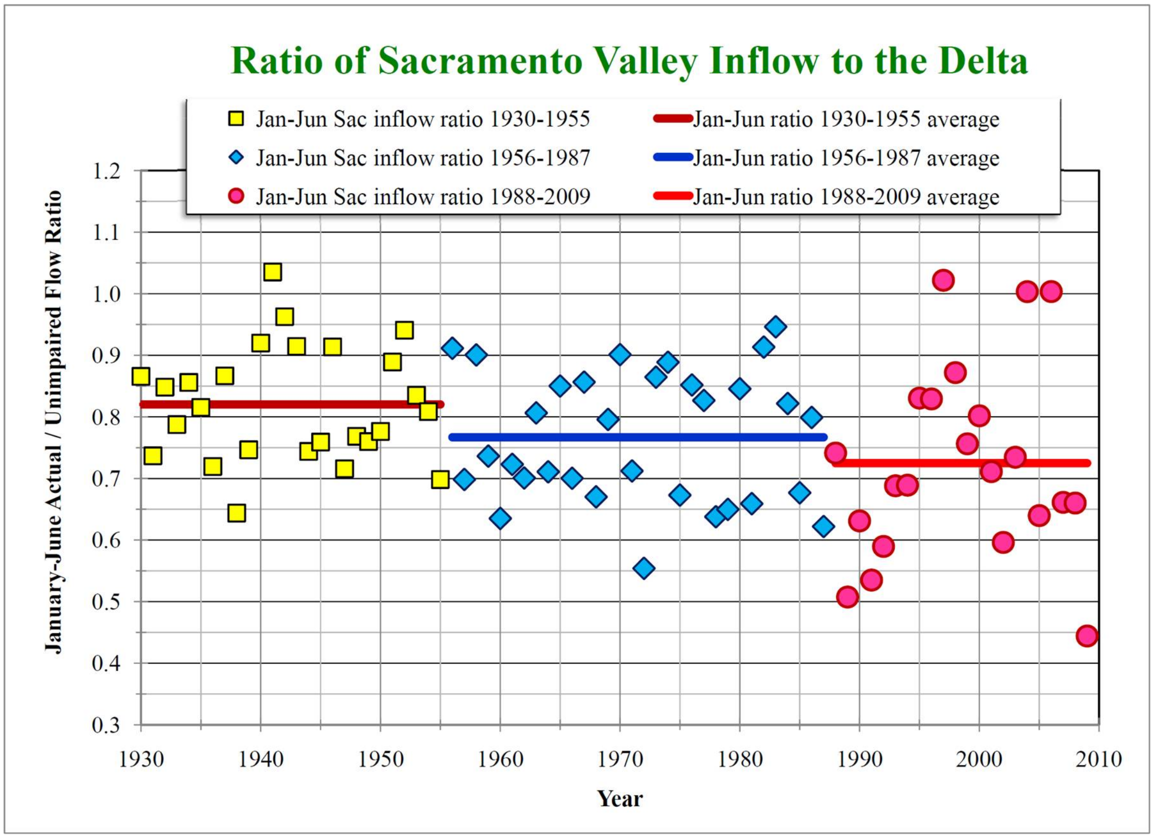


Figure 2: Ratio of actual Sacramento River flow at Verona to unimpaired flow in the Sacramento Basin during winter-spring for three time periods: 1930-1955, 1956-1987, and 1988-2009. Horizontal lines indicate the average for each period. Over time, the percentage of winter-spring runoff available in the Sacramento Valley that has reached the Delta has declined.



Williams et al. (2009) recently explored the effect of altered flow regimes on the functionality of floodplains along the Sacramento River, and found that due to channel incision and regulation from upstream reservoirs, long duration spring floods have been greatly reduced compared to pre-dam conditions. Currently, the benefits associated with floodplain inundation on the Sacramento River—food-web productivity and native-fish habitat—is mostly restricted to the Yolo Bypass, a large (24,000 ha) engineered flood bypass (Sommer *et al.*, 2001a,b, 2002).

Below, we provide inflow recommendations for both the San Joaquin and Sacramento River systems that protect specific public trust resources. Specifically, we focus on:

- The duration and magnitude of spring San Joaquin River inflows needed to provide adequate transport and physical habitat for outmigrating juvenile Chinook salmon and steelhead. These flows are needed to support the productivity (potential for population growth), abundance, and life history diversity of salmonids in the San Joaquin Basin and are quite likely to benefit other anadromous species in a similar manner.

- Year-round flows needed to alleviate low dissolved oxygen conditions in the lower San Joaquin River to preserve its functionality as a migration corridor and rearing habitat. These flows support the spatial diversity of a variety of migratory species which may otherwise be unable to use the San Joaquin or its tributaries for spawning.
- The magnitude and duration of winter-spring flows necessary to inundate floodplains in the lower Sacramento River and northern Delta. These floodplains provide critical spawning habitat for Sacramento splittail, important rearing habitat for migratory fish and bird species, food production that supports the Delta food web, and influx of turbidity to the sediment-starved Delta ecosystem.

Spring San Joaquin River Inflows

Summary points:

- *Flow conditions on the San Joaquin River are highly impaired, with extremely inadequate flow amounts, duration, variability, and water quality.*
- *These reductions in San Joaquin River inflows have heavily impacted all viability attributes of migratory species in the San Joaquin basin, and are a main driver of the serious decline of salmonid populations.*

The San Joaquin River is the common migration corridor for fall-run Chinook salmon and Central Valley steelhead that reproduce and rear in the Stanislaus, Tuolumne and Merced Rivers.[1] Seasonal flow conditions on the lower San Joaquin River (usually measured at Vernalis) affect the survival and passage of both upmigrating adult fish and outmigrating juveniles (Figure 3). For San Joaquin River fall-run Chinook salmon, San Joaquin River flow conditions affect all four viability criteria, including: a) abundance (measured as adult escapement); b) productivity (measured the population replacement rate of cohort return ratio); c) diversity (measured as the life history diversity of successful outmigrating juveniles); and d) spatial structure (measured as the presence and

[1] Before the late 1940s when the federal Central Valley Project began diverting almost all flow from the San Joaquin River at Friant Dam, fall-run and spring-run Chinook salmon and steelhead also reproduced and spawned on the San Joaquin River. Spring-run Chinook salmon have been extirpated from all rivers in the San Joaquin Basin but will be restored pursuant to the settlement of the Friant litigation.

ability to persist by these species in San Joaquin Basin rivers, the southern extent of their geographic range).[2]

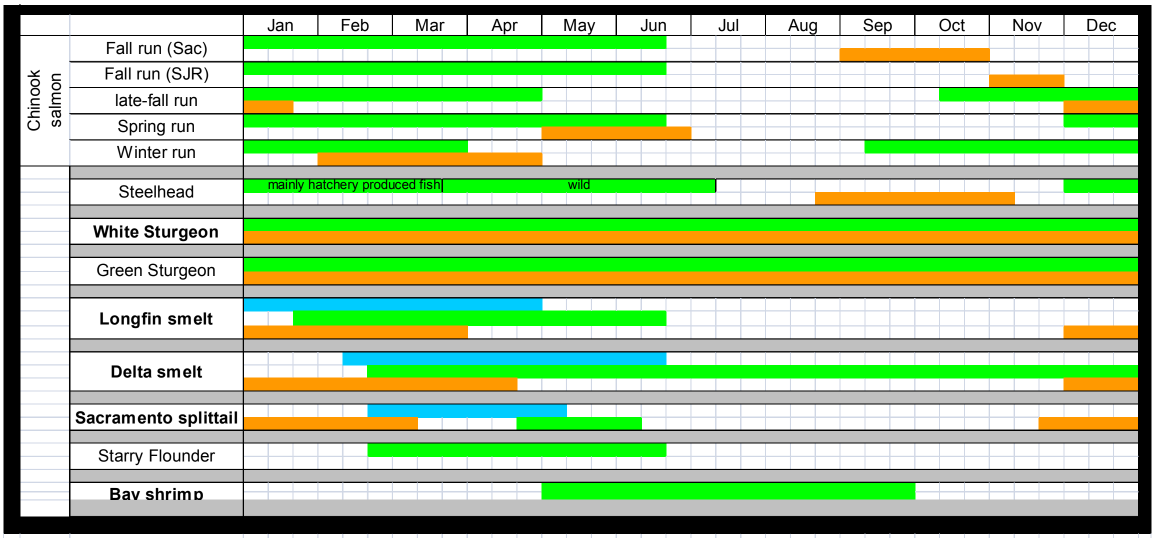


FIGURE 3: Approximate life history timing of native public trust species described in Exhibits 1-4. Life history timing varies with environmenal conditions in any given year and some individuals will complete their life cycle earlier or later than indicated in every year. Species in boldface are those for whom individuals or the entire population may reside in the Delta + Suisun Bay year-round.

Juvenile migration and rearing
Adult migration
Spawning

For adult salmonids migrating upstream through the Delta and into the San Joaquin River and its tributaries, adequate flow conditions are necessary to provide the migratory cue to guide these fish to return to their natal stream, tolerable water quality conditions (e.g., temperature, dissolved oxygen), and in-stream conditions to allow physical passage (e.g., water depth). For outmigrating juvenile salmonids, seasonally higher river flows, which occurred naturally as a result of precipitation and snowmelt, function as an environmental cue to trigger migration, facilitate transport of the fish downstream, and improve migration corridor conditions to inundate floodplains (e.g., where juvenile salmon experience improved growth and survival), reduce predation (e.g., increased turbidity levels reduce predation success on juvenile salmon) and provide tolerable water quality conditions (e.g., higher flows correspond to cooler water temperatures and reduced incidences of low dissolved oxygen concentrations). Each of these functions is extremely impaired by current conditions on the San Joaquin River (e.g., "Steelhead stressor matrix," NMFS 2009).

In managed rivers, successful upstream and downstream migration of anadromous fishes occurs only in years and during periods when flow conditions are managed at levels that

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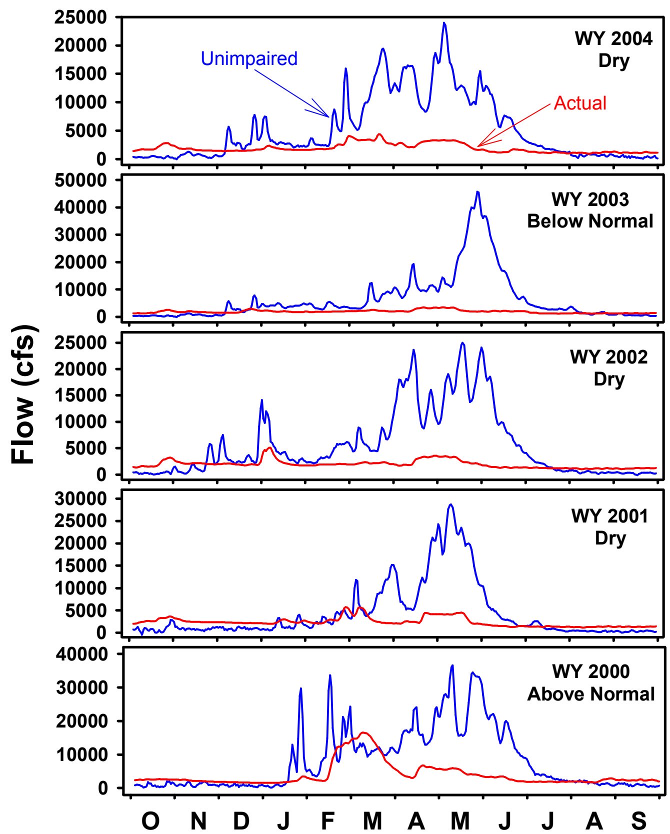
[2] There are insufficient data available for steelhead to quantitatively evaluate the effects of San Joaquin River flows on population viability criteria. However, given the broad similarities in the anadromous life histories and environmental requirements of the two species, it is likely that steelhead respond similarly to flow conditions that support or, conversely, are harmful for Chinook salmon.

support these behaviors. Flows on the San Joaquin River and all of its tributaries are highly managed and, on an annual basis, reduced by ~ 60-80% compared to estimated unimpaired runoff in ten of the past 20 years; in most years the river is essentially "flatlined" with nearly all of the seasonal snowmelt runoff captured and diverted at major dams on all the tributary rivers (Figure 4).

FIGURE 4

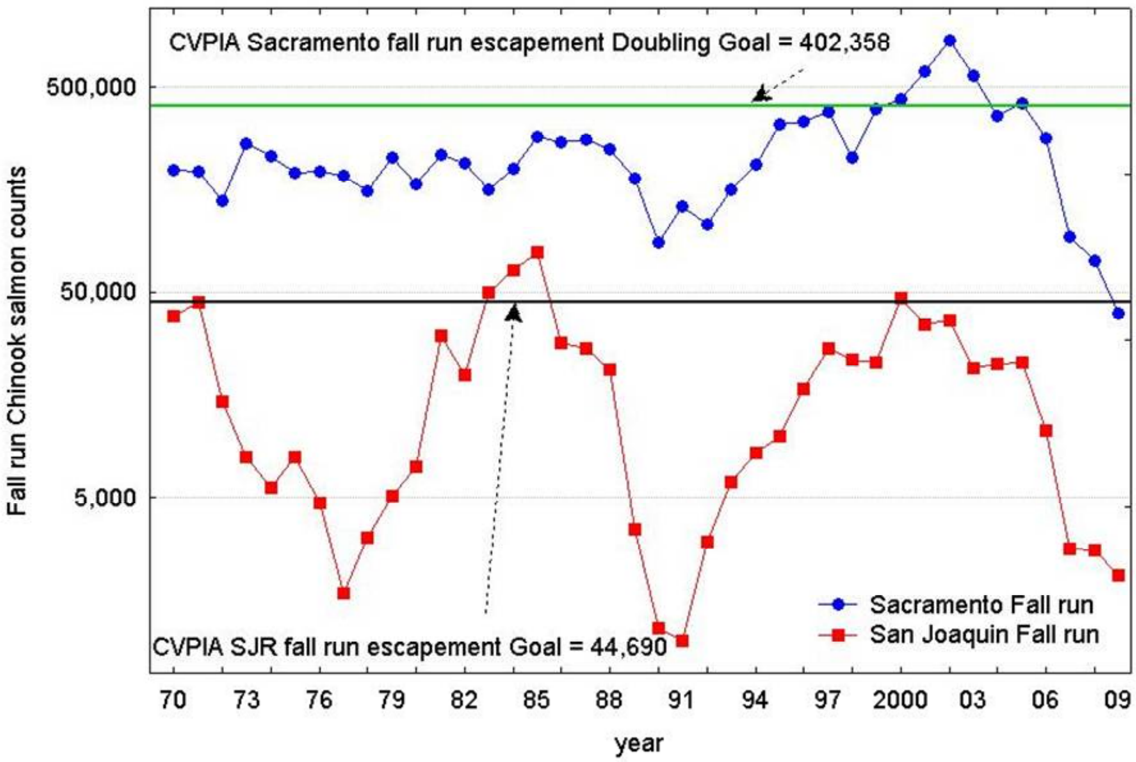
Comparison of daily estimated unimpaired San Joaquin Basin runoff (blue line) with actual daily San Joaquin River flows at Vernalis (red line) for five water years (200-2004). In most years and water year types, actual flows are reduced by more than 60% and the winter-spring flows from precipitation and snowmelt are virtually eliminated.

Data sources: California Data Exchange Center Full Natural Flows dataset and California Department of Water Resources, Dayflow.



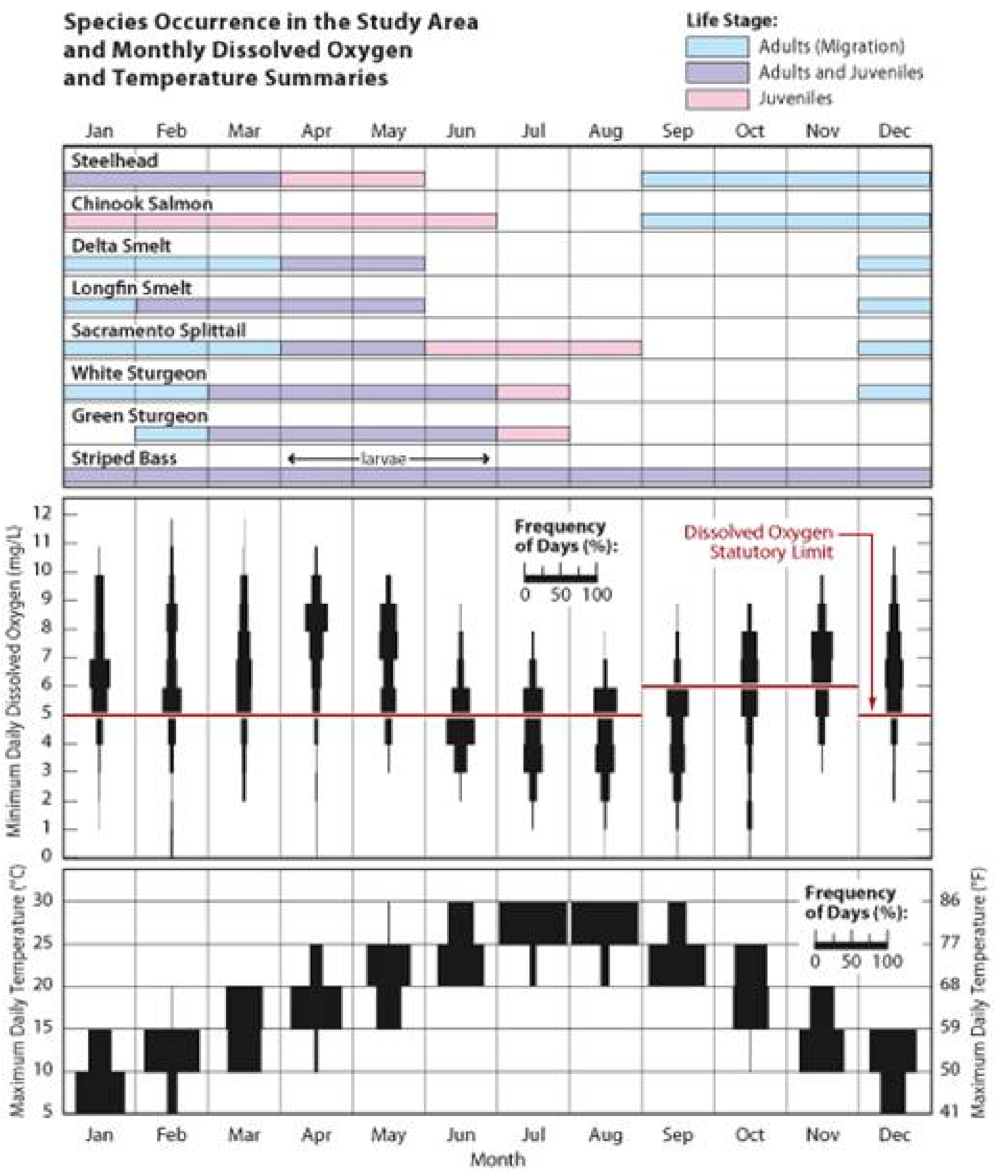
San Joaquin River flow conditions (as well as flows in all of its tributary rivers) are the primary environmental variable controlling production of salmon in the San Joaquin Basin according to comprehensive analyses of monitoring data, quantitative population models and other studies (USFWS 1995; CDFG 2005). Thus, the current highly altered flow conditions in the San Joaquin River and its tributary rivers are the major factor behind the current status of San Joaquin Basin fall-run Chinook salmon (declining and at near record low numbers in recent years; Figure 5) and Central Valley steelhead (listed as "threatened" under the federal ESA).

FIGURE 5:
Fall run Chinook escapement for Sacramento and San Joaquin systems, 1970-2009



In their detailed analysis and quantitative modeling effort, CDFG (2005) identified three aspects of San Joaquin River flows that control production of Chinook salmon in the basin: a) flow magnitude during the juvenile outmigration period; b) duration of the suitable outmigration flow conditions (i.e., duration of flow-mediated "window" for successful juvenile outmigration); and c) frequency of occurrence of suitable outmigration flow conditions. In addition, research and modeling has suggested minimum flow levels necessary to eliminate harmfully low dissolved oxygen conditions in the Stockton Deepwater Ship channel (located on the lower San Joaquin River) during Chinook salmon migration periods (e.g., Van Nieuwenhuyse 2002; Jassby and Van Nieuwenhuyse, 2005; CVRWQCB and CBDA 2006; Figures 3, 6); when dissolved oxygen is below suitable levels during salmon migrations, it may represent an impassable barrier and render the upper watershed in accessible for reproduction – a serious constraint on the spatial distribution of Chinook salmon.

FIGURE 6: Seasonal use of the Stockton Deep Water Ship Channel (SDWSC) by different species, occurrence of low Dissolved oxygen events, and frequency distribution of temperatures in the SDWSC.



Source: CVRWQCB and CBDA. 2006. Dissolved oxygen concentrations in the Stocktor Water Ship Channel: Biological and ecological effects model. Available at: http://www.sjrdotmdl.org/concept_model/bio-effects_model/lifestage.htm

Relationship between spring San Joaquin River inflows and life history diversity for public trust resources

Summary points:

- *Viable salmonid populations require both genetic and life history diversity.*
- *The natural salmon outmigration period is spread out over several months, allowing a viable level of within-population diversity.*
- *By constraining flows adequate for outmigration to a brief period, only a subset of individuals successfully migrate, and diversity is drastically reduced.*

Viable and sustainable populations of Chinook salmon and steelhead exhibit both genetic and life history diversity. Even within runs and populations (e.g., the fall run or a river-specific population) variation in the timing of upstream migration, spawning, and juvenile outmigration occurs and is an important contributor to the ability of the population and/or species to persist in the highly variable habitats and hydrological conditions typical of Central Valley watersheds (Lindley et al. 2007, NMFS 2009).

Juvenile San Joaquin River fall-run Chinook salmon typically outmigrate over a 3 – 4 month period, from March through June (CDFG 2005). Current flow objectives and operational conditions in the lower River during the spring period, which provide adequate flows during less than half of the juvenile salmonid outmigration period in nearly all years, are not sufficient to support and sustain the life history diversity of these public trust anadromous fish resources. Our recommendations for expanding the duration of flows that support juvenile emigration from the San Joaquin Basin are based on the observation that species which use the Delta as a migratory pathway to spawning and rearing grounds in the upper San Joaquin River normally migrate over an extended period that is much greater than 31 days long (Figure 3, 6, 7). The current 31-day pulse period of somewhat elevated flows (currently implemented as the Vernalis Adaptive Management Program, VAMP) often provides a short window of migration opportunities. Fish whose life history trajectory is not timed to capitalize on that narrow window are lost to the population – this constriction impairs population viability because, for instance, fish that would have migrated outside of the 31-day flow pulse period are not able to capitalize on temporally variable resources that may occur in the Delta or the ocean before or after that period.

Figure 2. SJR Smolt Out-migration Trends 1988 through 2004.

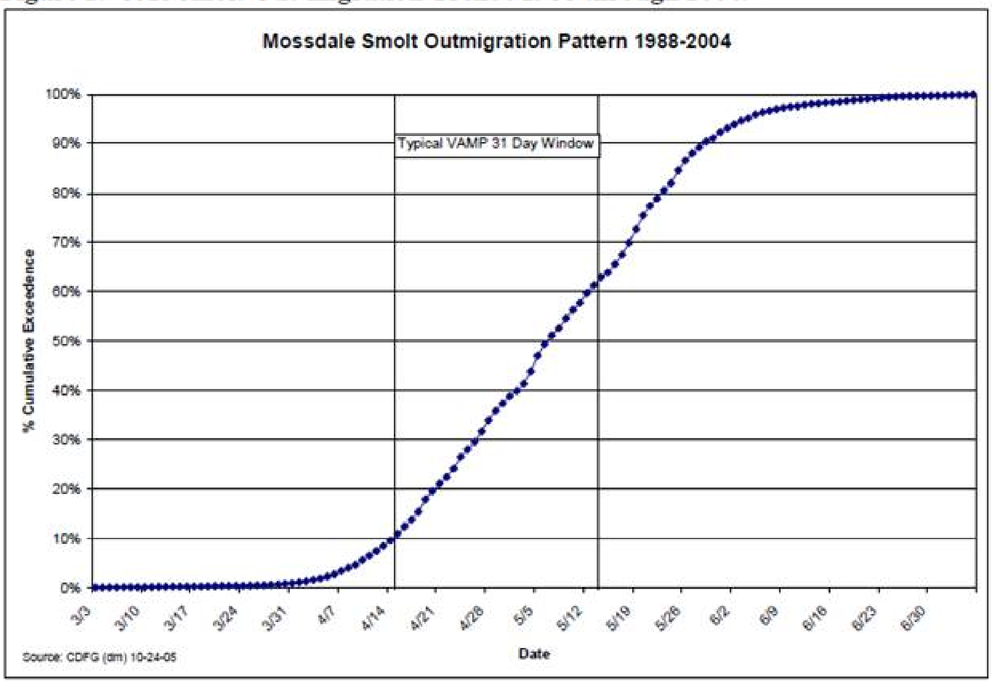


FIGURE 7

Cumulative passage of juvenile salmonids at Mossdale (Lower San Joaquin River), 1988-2004. Juvenile outmigrants begin moving out of the tributary rivers in March and reach the lower San Joaquin River in late March. Outmigration continues through June.

<u>Source</u>: Figure 2 from CDFG 2005

Flow management actions that function to artificially select for the survival of only a subset of a population reduce the life history diversity of the population (e.g. the timing and size of migrants) and the genetic diversity that may cause that life history diversity. For example, managed flow conditions that provide tolerable outmigration conditions during only a portion of the population's outmigration period reduce the diversity of the population by eliminating individuals with either genetic or life history characteristics for migrating at times other than the managed migration "window". Diverse migration timing contributes to population viability by insuring that at least some portion of the juvenile population is exposed to ecological conditions (in the Delta and beyond) that support growth and survival – if this were not the case, natural selection would have operated to reduce the natural variation seen in the within-run timing of Central Valley salmon life histories (Smith et al. 1995).

Methods for developing spring San Joaquin River inflow criteria to protect diversity of public trust resources

More than a decade of monitoring data for juvenile Chinook salmon and steelhead migrating from tributary rivers and down the San Joaquin River shows that migration occurs over a prolonged period during the later winter and spring, typically beginning in March and continuing through June (Figure 7). However, current flow management of the San Joaquin River provides a modest "pulse flow" for a 31-day period from mid-April to mid-May. Prior to this period and after it, flow conditions in all but wet years are poor, with average minimum required flows < 2000 cfs in almost all months and all years (SWRCB 2006). Monitoring data show that these low flow conditions are regularly associated with stressful or lethal elevated water temperatures and/or low dissolved oxygen concentrations that can preclude successful migration of juvenile (or adult) fish transiting the river at these times. For example, according to NMFS (2009b, p. 421), in the San Joaquin Basin, "(w)ithout a suitable pulse of cooler water moving downstream from increased dam releases…, juvenile salmonids would be unlikely to survive their migration downstream to the Delta, dying from excessive thermal exposure en route". According to CDFG (2005) current management of Vernalis flows provide tolerable conditions for migration to occur only during the VAMP and, because of the VAMP experimental design, in most years those conditions are not adequate to support Chinook salmon productivity in the San Joaquin River (see below). Analysis by CDFG (2005) showed that the greatest gains in San Joaquin salmon production were related to increasing the duration of the outmigration flow pulse from 30 days to 60 days and extending it through the months of May and into June. Additional incremental increases in the duration of enhanced outmigration flows further increased salmon production, although not to the same extent. The limited window of the 31-day pulse flow also constrains the timing and associated life history diversity of other migratory fish using the San Joaquin corridor, including white sturgeon and steelhead (Figures 3, 6; CVRWQCB and CBDA 2006).

One of the principal reasons that lower San Joaquin River conditions in the period after the typical VAMP implementation (i.e., after ~May 15) are intolerable to salmonids is elevated water temperatures. Inflow from the lower San Joaquin basin is essential to maintain suitable water temperature conditions in the lower San Joaquin and southern Delta for salmonids, particular during the spring outmigration period. Temperature is determined by a number of factors including reservoir releases, channel geometry, and ambient air temperatures, however, water temperature data from the Vernalis gauge shows that flows over 5,000 cfs in the late spring are necessary to provide water temperatures suitable for juvenile salmon and smolts (Cain 2003).

Recommendation: spring San Joaquin River inflows to protect diversity of public trust resources that use the Delta as a migratory corridor

Summary points:

- *Increase the duration of outmigration flows from 31 days in the driest years to 90 days in the wettest years.*
- *Provide sufficient flows to maintain a 65 degree average water temperature in the lower San Joaquin River in April and May of all years.*

Provide increased duration of enhanced flow conditions needed to support outmigrating juvenile salmonids in all non-critical water years (see below for recommended flow levels). Provide enhanced flows for at least 90 days (from approximately March 15- June 15) in 20% of years, at least 75 days in 40% of years (~March 15-May 31), at least 60 days in 60% of years (~April 1-May 31), at least 45 days in 80% of years (~April 15-May 31), and at least 31 days in all years (~April 15-May 15). To provide adequate temperatures in the lower San Joaquin River/southern Delta that avoid lethal effects and increase outmigration success of juvenile Chinook salmon and steelhead, provide flows sufficient to provide average daily water temperatures of 65°F (18.3°C) or lower from April 1 through May 31 in the lower San Joaquin River in all years. (In our analyses we have assumed 5000 cfs to be necessary to provide these conditions but, depending on air and water temperature conditions, flows less that 5000 cfs may be sufficient to provide adequate temperature conditions during some weeks in the April-May period.) These recommendations for the durations of enhanced flow conditions for outmigration are similar to those developed by CDFG (2005) using their quantitative San Joaquin Chinook salmon population model to achieve the SWRCB and Central Valley Project Improvement Act (CVPIA) salmon doubling goal.

Relationship between San Joaquin River inflows and abundance of public trust species

Summary points:

- *Far from achieving state and federal doubling mandates, San Joaquin Chinook basin salmon abundance has fallen so low that some tributary populations are at risk of extinction.*
- *Salmon abundance is strongly correlated to inflow levels 2.5 years prior; declining abundance has closely tracked consistently low inflows.*

State and federal law requires the doubling of natural production of Central Valley Chinook salmon populations relative to their average abundance during the 1967-1991 period (SWRCB 2006).[3] For San Joaquin Basin Chinook salmon, the doubling objective calls for annual escapement levels of approximately 37,000 fish.[4] In contrast, the average San Joaquin Chinook salmon escapement for the past ten years (2000-2009, representing returns from roughly three generations) was 20,257 fish, with the escapement numbers declining steadily during the past nine years to just 2,100 fish in 2009[5] (Figure 5). Most of the returning fish were counted on the Stanislaus River: in each of the past two years, less than 500 fish returned to the Tuolumne River and just over 500 fish to the Merced River. Based on these abundance numbers, the Tuolumne and Merced River populations of San Joaquin fall-run Chinook salmon are at increasing risk of extinction. Lindley et al. (2007), in their evaluation of extinction risk for Central Valley salmonids, determined that populations with less several hundred adults were at moderate to high risk of extinction.

Analysis of monitoring data for San Joaquin fall-run Chinook salmon abundance (measured as escapement, or the numbers of adult fish returning to the Stanislaus, Tuolumne and Merced Rivers) and San Joaquin River flows measured at Vernalis 2.5 years earlier during the spring (March-June), when the juveniles of that population cohort were migrating downstream, shows that abundance is significantly and directly related to flow magnitude: more adult salmon return to San Joaquin tributaries when flows during their juvenile outmigration period were higher than when flows were low (Figure 8).

[3] The original state law requirement for salmon doubling was enacted in 1988 as Cal. Fish and Game Code § 6902.
[4] This doubling figure is based on salmon escapement only in the Stanislaus, Tuolumne and Merced Rivers. Salmon production on the Mokelumne and Cosumnes Rivers is not included because these fish are not exposed to flow conditions on the lower San Joaquin River at Vernalis. In addition, the doubling goals are for "natural production" of Chinook salmon, thus excluding fish produced in hatcheries. However, in California hatchery-produced fish are not uniformly marked, therefore their contribution to the numbers of fish returning to spawn is difficult to determine. The doubling goal and the comparisons with recent escapement numbers used here (from California Department of Fish and Game's Grandtab dataset) are based on escapement counts that include fish that spawn in the river as well those collected to be spawned in river-based hatcheries; it makes no distinction for natural v hatchery produced fish.
[5] It is important to note that the commercial fishing season for Chinook salmon was closed during 2008 and 2009 – this closure has not produced a recovery of these public trust species.

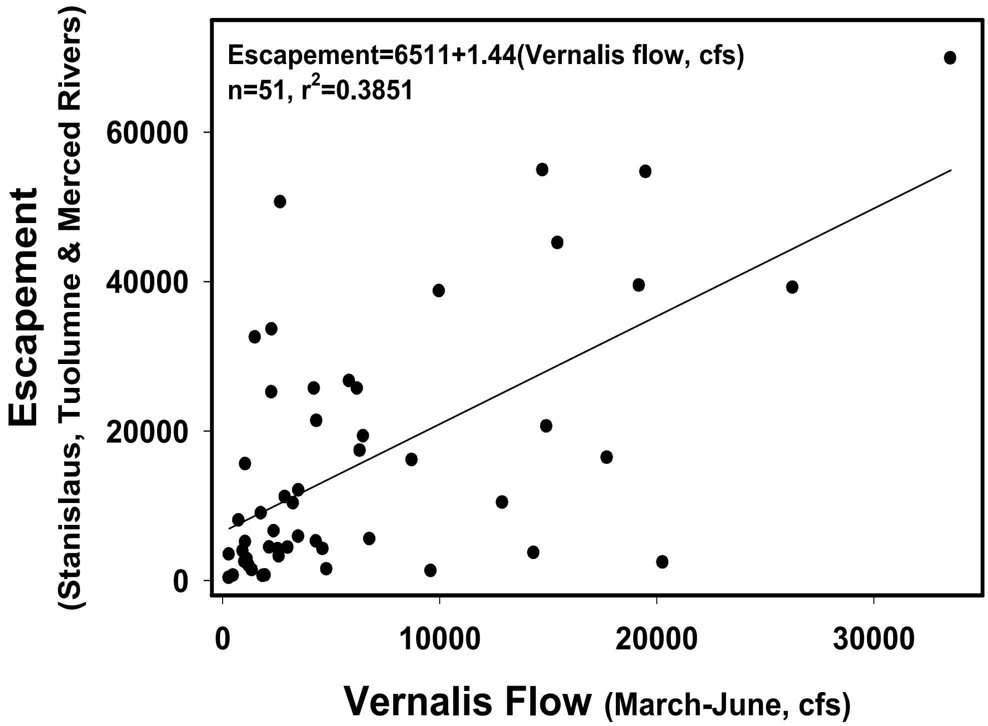


FIGURE 8:
Relationship between abundance (escapement) and springtime flow at Vernalis measured 2.5 years earlier, when the juveniles of each annual cohort were migrating downstream. Line shows linear regression (equation at top).

Sources: CDFG GrandTab file for escapement and CDWR Dayflow file for Vernalis flows.

Current springtime flow conditions on the San Joaquin River at Vernalis, with flows averaging less than 5000 cfs in almost all years, are inadequate to provide conditions necessary to support or sustain salmon population abundances, minimize extinction risk, or meet the salmon production objectives established by the SWRCB, Cal. Fish and Game Code section 6902, the CVPIA, or the public trust responsibilities for these fisheries.

Methods for developing spring San Joaquin River inflow criteria to increase abundance of public trust resources

Summary points:

- *Based on the abundance to prior flow relationship, average springtime inflows of 10,000 cfs or more are likely to achieve the salmon doubling goals.*
- *Periodic springtime inflows of 25,000 cfs are needed to achieve large-scale floodplain inundation on the lower San Joaquin as currently physically constrained.*
- *Inflows of at least 5,000 cfs are necessary to maintain minimum temperature conditions for migrating salmonids in April and May.*

In order to determine San Joaquin River flows into the Delta that would support abundance of fall run Chinook salmon, we analyzed the relationship between Vernalis flow and the absolute abundance of San Joaquin River Chinook salmon. We also evaluated the relationship between flows and floodplain inundation on the lower San Joaquin, particularly between Vernalis and Mossdale, and between flows and water temperature.

Our analysis of the effects of Vernalis flows on abundance showed that, in general, springtime flows that are less than 5000 cfs (average March-June) correspond to escapement numbers that are less than 10,000 fish (Figure 8). Average springtime flows of greater than 10,000 cfs appear necessary to produce annual escapements that meet the doubling objective.

For floodplain inundation, we found that, under existing channel conditions, flows of approximately 20,000-25,000 cfs at Vernalis were necessary to trigger substantial floodplain inundation. A review of the stage discharge curve at the Vernalis gauge combined with an evaluation of topographic maps adjacent to the river indicated that a flow of a minimum of 20,000 cfs and as much as 25,000 cfs is necessary to achieve broad scale inundation of floodplain along the San Joaquin River between Vernalis and Mossdale. A flow of 16,000 cfs at Maze Road upstream of Vernalis and the Stanislaus River confluence inundates large areas of the San Joaquin National Wildlife Refuge (PWA, 2001 – NEED CITE). An evaluation of floodplain inundation threshold on the tributaries by Cain (2003) documents that flows of 3,000-6,000 cfs (4,500 on average) are necessary to inundate various low-lying floodplains below the terminal reservoirs on the upper Stanislaus, Merced, Tuolumne, and San Joaquin rivers. A hydraulic study of the upper San Joaquin (JSA 1998) estimated bankful discharge of 4,500 for a substantial reach between Firebaugh and Bear Creek. In short, flows of 4,500 cfs from the mainstem and each of the three tributaries plus 2,000 or more from the coast range and other smaller streams result in inundation of riparian floodplains from the upper watersheds to the lower river between Vernalis and Mossdale.

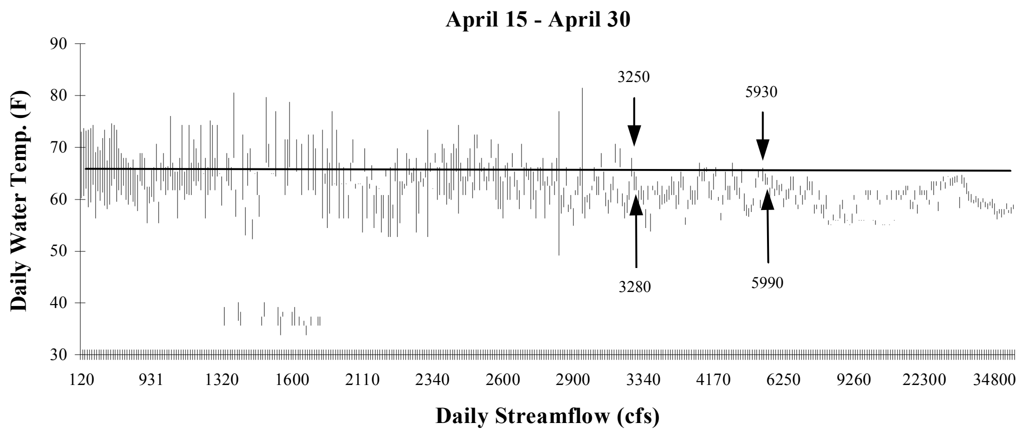
Salmonids in the Central Valley are generally temperature-stressed through at least some of their freshwater life-cycle (e.g. Myrick and Cech 2004, 2005). Inflow on the San Joaquin at Vernalis in the legal Delta is essential to maintain suitable water temperature conditions in the lower San Joaquin for salmonids, particularly during the spring out-migration period. Temperatures which produce mortality among Pacific salmon depend, to some extent, on acclimation temperatures -- higher acclimation temperatures produce higher Incipient Upper Lethal Temperatures (Myrick and Cech 2004). Baker et al. (1995) found that Central Valley Chinook salmon had an IULT between ~71.6- 75.2°F (22 - 24°C). Negative sub-lethal effects (those that may increase susceptibility to other mortality mechanisms) begin to occur at temperatures lower than the IULT. When fish have access to full rations, growth of juvenile salmonids increases with temperature up to fishes' physiological limits; however, when food supply is limited (as it often is under normal conditions in the field) optimal growth occurs at lower temperatures. Among juvenile fall run Chinook salmon from California's Central Valley population, Marine and Cech (2004) found decreased growth, smoltification success, and ability to avoid predation at temperatures >68°F (20°C). They also reported that fish reared at temperatures 62.6 - 68°F (17-20°C) experienced increased predation relative to fish raised at 55.4 - 60.8°F (13-16°C). The finding of decreased performance at temperatures above 62.6 °F (17°C) is consistent with several studies that suggest optimal growth and survival among Chinook salmon occurs at temperatures somewhat lower than 62.6 °F (17°C). Richter and Kolmes (2005) cite numerous studies of optimal rearing temperatures which report a range of 53.6-62.6°F (12-17°C). Optimal temperatures for steelhead juvenile growth occur between 59-66.2°F (15-19°C; e.g., Moyle 2002; Richter and Kolmes 2005). Temperature also mediates the impact of competition between species. For example, steelhead juveniles suffer adverse impacts of competition with pikeminnow at temperatures >68°F (>20°C) though no competitive impact is detectable at lower temperatures (Reese and Harvey 2002).

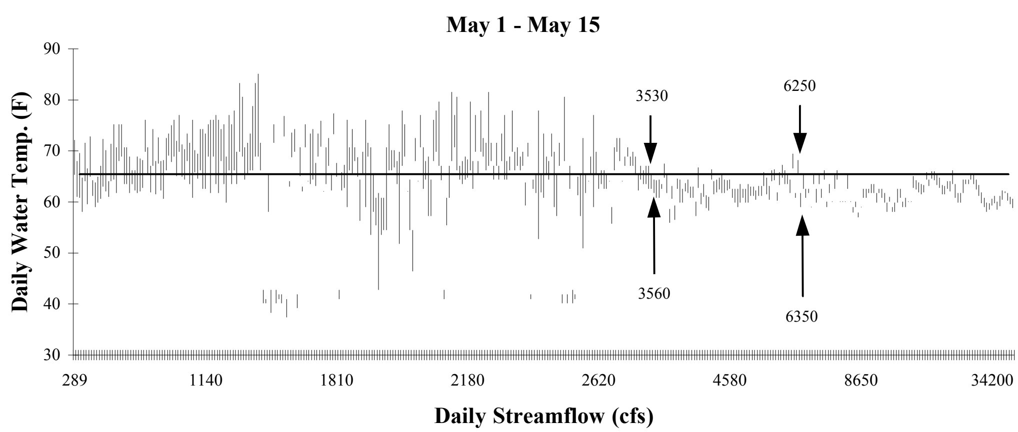
Elevated water temperatures inhibit the parr-smolt metamorphosis (smoltification) among salmonids. Marine and Cech (2004) found that Central Valley Chinook salmon rearing in temperatures ≥68°F (≥20°C) suffered altered smolt physiology and other studies from within this ecosystem suggested that negative effects of temperature on the parr-smolt transition may occur at temperatures <68°F (<20°C). Richter and Kolmes (2005) cited two studies that indicated negative impacts on Chinook salmon smoltification success at temperatures >62.6°F (>17°C). Steelhead juveniles are much more sensitive than Chinook salmon to elevated temperatures during the smoltification process (US EPA 1999). Richter and Kolmes (2005) and US EPA (1999) cited studies that present a range of temperatures, between 51.8- 57.2°F (11-14°C) that may inhibit steelhead smoltification. From these studies, we conclude that temperatures ≥68°F (≥20°C) are unambiguously detrimental to rearing migrating juveniles of Central Valley salmonid populations and that temperatures <~65°F (18.3°C) during the winter and spring migration periods are required to maintain the abundance of these public trust species.

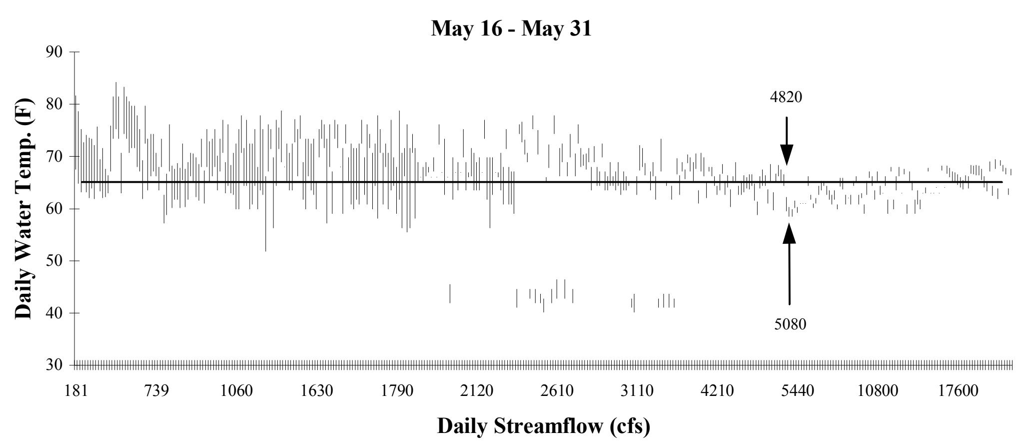
Temperature is determined by a number of factors including reservoir release, channel geometry, and ambient air temperatures. The variability of air temperature, particularly during the spring and fall when temperatures are rising and falling, makes it difficult to determine the exact flow release necessary to maintain water temperatures in the lower San Joaquin. A given flow may be sufficient during average meteorological conditions to achieve suitable water temperatures, but it may be inadequate during heat waves which periodically occur during the spring.

Water temperature data from the Vernalis gauge show that flows over 5,000 cfs in the late spring are necessary to provide water temperatures suitable for juvenile salmon and smolts. Cain (2003) evaluated water temperature data from Vernalis to determine what flow thresholds achieved suitable water temperature conditions in the past under a range of hydrologic and meteorological conditions during the six week period between April 15 and May 31. Figure 9 show the results of this analyses and indicate that temperatures during this six week period generally drop below 65^{o}F and always remain below 70 ^{o}F at flows above 5,000 cfs. Temperatures rise above 65^{o}F even at very high flows in some cases either due to unseasonably warm weather or water from inundated floodways far upstream.

Figure 9:
Water Temperature vs. Flow at Vernalis, April 15–May 31. The few data points for very high flows bet May 16 and May 31 appear to be associated with very wet years when large scale inundation of floodplains warm water contributions from the James Bypass occur, thus explaining the apparent rise in water temperatu very high flows.







<u>Recommendation: spring San Joaquin River inflows to increase abundance of public trust resources</u>

To increase Chinook salmon population abundance and meet population objectives, increase the frequency of springtime flows in the San Joaquin River that function to inundate floodplain and correspond to higher escapement numbers. Reduce frequency and duration during the outmigration period of springtime Vernalis flows that are less than 5000 cfs. Provide spring outmigration flows that exceed 20,000 cfs for at least two weeks in 60% of years and that average (for the duration of the enhanced flow outmigration period, see above) 10,000 cfs or more in 60% of years. To provide adequate temperatures in the lower San Joaquin River/southern Delta that avoid lethal effects and increase outmigration success of juvenile Chinook salmon and steelhead, provide flows sufficient to provide average daily water temperatures of 65^{o}F (18.3^{o}C) or lower from April 1 through May 31 in all years. (In our analyses we have assumed 5000 cfs to be necessary to provide these conditions but, depending on air and water temperature conditions, flows less that 5000 cfs may be sufficient to provide adequate temperature conditions during some weeks in the April-May period.)

Relationship between San Joaquin River inflows and productivity of public trust species

Summary points:

- *San Joaquin salmon populations will need to grow in order to attain a self-sustaining or viable level.*
- *Over the last decade San Joaquin salmon populations have experienced such severe negative population growth half of the time that mild positive growth in the other half is insufficient to prevent long-term declines.*
- *The number of adult fish returning to spawn has declined by more than 50% in every generation for most of the last decade, and population levels have crashed.*

Regardless of the absolute abundance recovery target for fall-run Chinook salmon (and for spring-run salmon when they are reintroduced to the San Joaquin), the population will need to *grow* to attain a level consistent with maintenance of the public trust. Species or populations with persistent negative population growth (i.e., population decline, or a cohort return ratio, CRR, that is less than 1.0), as well as populations with limited ability to respond to favorable environmental conditions with positive population growth, are less viable and at higher risk of extinction. Thus, spring flows from the San Joaquin River into the Delta must also be consistent with positive population growth of the San Joaquin River fall-run Chinook salmon population. Spring-run salmon have very similar juvenile emigration timing (Moyle 2002; Williams 2006) and should benefit from these recommendations as well.

The productivity of San Joaquin fall-run Chinook salmon, measured using the Cohort Return Ratio (CRR; the ratio of the number of adult fish that return to spawn in a particular year to the number of adult fish that produced them several years earlier) is significantly related to the magnitude of Vernalis flows during the spring (March-June) of juvenile outmigration (Figure 10). Based on the last 51 years, springtime flow conditions on the San Joaquin River at Vernalis have supported positive population growth in approximately half of those years. However the magnitude of negative growth in the remainder of years has been significantly more pronounced and, as a result, San Joaquin fall-run Chinook salmon escapement numbers have declined from an average of nearly 26,000 fish in the 1980s (i.e., 1980-1989) to barely 13,000 fish in the 2000s (2000-2008) (see also Figure 5). For the past six consecutive years (two complete generations of Chinook salmon), the CRR has been substantially less than 0.5 and abundance has fallen by more than 90%. Overall springtime conditions are therefore inadequate to increase San Joaquin fall-run Chinook salmon populations to meet management objectives or to support stable populations in the long-term.

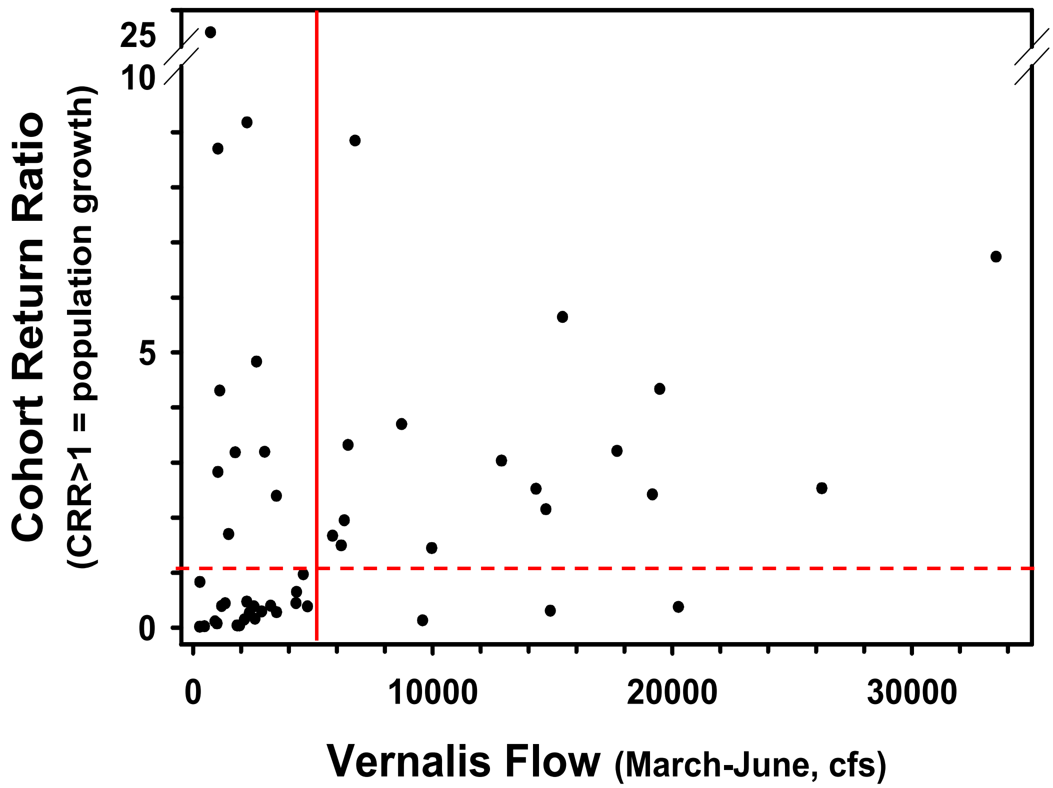


FIGURE 10:
Relationship between cohort return ratio and springtime flow at Vernalis measured 2.5 years earlier, when the juveniles of each annual cohort were migrating downstream. Horizontal dashed line shows cohort return ratio of 1.0. Vertical line shows average March-June Vernalis flows of 5,000cfs. In most years with Vernalis flows < 5,000cfs, the cohort return ratio was negative, indicating population decline. <u>*Sources*</u>: CDFG GrandTab file for escapement and California DWR Dayflow file for Vernalis flows.

Methods for developing San Joaquin River inflow criteria to improve productivity of public trust resources

Summary points:

- *Salmon population growth was negative in two-thirds of years when spring San Joaquin River inflows were below 5000 cfs.*
- *Population growth was positive 84% of years when inflows were in excess of 5,000 cfs.*

We analyzed both flow-productivity correlations and mechanistic flows (i.e., flows needed to provide tolerable water quality conditions during outmigration, results described in sections above) to identify spring Delta inflows from the San Joaquin River that would protect and enhance productivity of fall-run Chinook salmon.

We first used logit analysis to investigate the effect of average March-June Vernalis flows on productivity, measured as CRR, and found that Vernalis flows of approximately 4600 cfs corresponded to an equal probability for positive population growth (CRR>1.0) or negative population growth (CRR<1.0). Detailed review of CRR data showed that in 84% of years with average March-June flows greater than or equal to 5000 cfs, the CRR was greater than 1.0 (positive population growth), while in 66% of years with average March-June flows less than 5000 cfs, the CRR was less than 1.0, indicating a population decline (Figure 10). A slightly higher flow threshold, 6000 cfs or greater, yielded a similar proportion of years with positive population growth while slightly lower flows, 4000 cfs or lower, resulted in population growth in only 37% of years. This sharp change in the likelihood of positive versus negative population growth within a narrow range of flows suggests that the effect of flow on salmon productivity is strong and that springtime flows of approximately 5000 cfs represent an important minimum threshold for success of salmon in the San Joaquin Basin. Therefore, current minimum flows for Vernalis required by the SWRCB (SWRCB 2006 and the Vernalis Adaptive Management Plan), which are less than this level in most spring months of most water year types, would predictably result in more frequent occurrences of negative population growth for San Joaquin Chinook salmon.

<u>Recommendation: San Joaquin River inflows to improve productivity of public trust resources</u>

To provide conditions that will support positive population growth to increase abundance and achieve Chinook salmon population targets, increase the frequency of springtime flows in the San Joaquin River that correspond to more consistent positive population growth and which provide improved habitat conditions (e.g., floodplain inundation). Reduce frequency and duration during the outmigration period of springtime Vernalis flows that are less than 5000 cfs and/or are insufficient to produce tolerable water quality conditions.

Provide spring outmigration flows that exceed 20,000 cfs for at least two weeks in 60% of years and that average (for the duration of the enhanced flow outmigration period, see above) 10,000 cfs or more in 60% of years. To provide adequate temperatures in the lower San Joaquin River/southern Delta that avoid lethal effects and increase outmigration success of juvenile Chinook salmon and steelhead, provide flows sufficient to provide average daily water temperatures of 65°F (18.3°C) or lower from April 1 through May 31 in the lower San Joaquin River in all years. (In our analyses we have assumed 5000 cfs to be necessary to provide these conditions but, depending on air and water temperature conditions, flows less that 5000 cfs may be sufficient to provide adequate temperature conditions during some weeks in the April-May period.)

Year-Round San Joaquin River Inflows

Relationship between year-round San Joaquin River inflows and spatial distribution of public trust resources

Summary points:

- *Low dissolved oxygen conditions create a barrier to migration for San Joaquin basin salmonids, limiting access to upstream and downstream habitat areas.*
- *Inflows of less than 2,000 cfs are the largest contributor to low DO concentrations. Year-round San Joaquin River inflows should exceed 2,000cfs.*

The San Joaquin Basin and its tributary rivers are the southern extent of the geographic range for fall-run Chinook salmon, Central Valley steelhead (a federally listed distinct population segment), white sturgeon, and Sacramento splittail, among other species. Flow conditions that block passage or cause substantial mortality of upmigrating adults or outmigrating juveniles reduce the geographic range and spatial structure of these species by preventing the species from accessing and/or successfully using spawning and rearing habitat in the San Joaquin Basin tributary rivers. Furthermore, spring-run Chinook salmon will be reintroduced to the San Joaquin watershed pursuant to the San Joaquin restoration settlement. Improving flow conditions for fall-run Chinook salmon and steelhead will also benefit restoration of the spring-run Chinook salmon spatial distribution as well.

Flow- and water quality-related blockages to passage in the lower San Joaquin River have been documented for decades. Hallock et al. (1970) documented that low dissolved oxygen conditions in the lower San Joaquin delayed migration of fall-run Chinook salmon. Low dissolved oxygen conditions in this area have also resulted in mass mortality events for migrating salmon and steelhead. Sturgeon species are extremely susceptible to low dissolved oxygen conditions (Cech and Doroshov 2004) and conditions observed in the Stockton Deep Water Ship Channel would be likely to block their migrations.

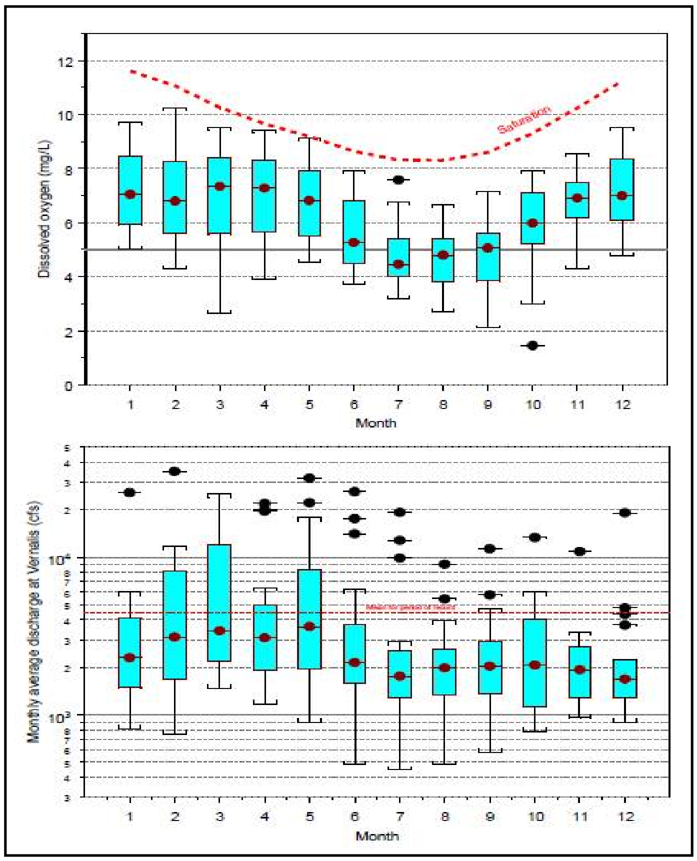
Current flow conditions on the lower San Joaquin River regularly result in harmful low dissolved oxygen concentrations and block passage and/or cause mortality of migratory fishes (Figures 6, 11). This effectively restricts these public trust species from accessing or using areas of their geographic range in the San Joaquin Basin and, by reducing the species' spatial structure, reduces their viability.

FIGURE 11

Top panel: Box plot of summary statistics for monthly average values of daily minimum DO in the ship channel at the Rough and Ready Island continuous monitoring station (DOmin), 1983-2001 (n=19/month).

Bottom panel: Figure 6 from Van Nieuwenhuyse, E. E. 2002. Box plot of summary statistics for monthly average discharge in the San Joaquin River near Vernalis (Qvern), 1983-2001.

<u>Source</u>: Figures 2 and 6 from Van Nieuwenhuyse, E. E. 2002.



Methods for developing year round San Joaquin Inflow criteria to improve spatial distribution of public trust resources

In order to identify San Joaquin flows that will support migration of fishes into and out of San Joaquin Basin rives and thus the spatial distribution of public trust resources, we used recent research studies and literature reviews to evaluate those flows necessary to reduce the migration barrier presented by low dissolved oxygen conditions at the base of the San Joaquin River. Water quality monitoring data show that dissolved oxygen concentrations regularly fall below the regulatory minimum promulgated to promote survival and passage of salmonids and other species (Figure 6; CVRWQCB and CBDA 2006).

Several recent studies (as well as quantitative modeling efforts) have demonstrated that low dissolved oxygen conditions most frequently coincide with periods of low flow and elevated temperature.[6] Based on Figure 11 and other data presented by Van Nieuwenhuyse (2002), low dissolved oxygen conditions most frequently occur during the spring and summer when flows are less than 2000 cfs and water temperatures are elevated. Although management of other variables in addition to flow will be necessary to completely alleviate this problem, Jassby and Van Nieuwenhuyse (2005) found that: "[r]iver discharge has had the biggest impact … on hypoxia"; their modeling demonstrated that increased management of other important factors would be far less effective without improvement of freshwater flows in this area.

Existing flow requirements for the lower San Joaquin River allow flow levels substantially less than 2,000 cfs for nearly all months in the year in every water year type (SWRCB 2006).

Recommendation: year-round San Joaquin inflows to protect spatial distribution of public trust resources that use the Delta as a migratory corridor.

San Joaquin River flows at Vernalis should exceed 2000 cfs in all months of all years. These flows will alleviate the potential for low dissolved oxygen conditions and are expected to have synergistic positive effects with other management responses to this problem (e.g., reduction in nutrient pollution and biological oxygen demand; Jassby and Van Nieuwenhuyse 2005).

Summary of recommendations for San Joaquin inflow criteria to protect viability of public trust public trust resources that use the Delta as a migratory corridor.

In Table 1 below we have combined and integrated our recommendations for year-round San Joaquin River inflows to the Delta that are needed to support public trust resources. The table expresses the flow criteria as a frequency distribution; the figure as a continuous hydrograph. For the springtime months (March through June), we provide a more detailed flow schedule to illustrate our recommended timing for enhanced flows for outmigration of juvenile salmonids (shown in the grey shaded cells) and floodplain inundation. The duration of the enhanced outmigration flow period and the average flow magnitude during that period is also shown.

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[6] Channel depth, nutrient loads and the biological oxygen demand also influence dissolved oxygen conditions in the Stockton Deepwater Ship Channel (CVRWQCB and CBDA 2006; Jassby and Van Nieuwenhuyse 2005).

Table 1. Schedule of springtime Delta inflows from the San Joaquin River recommended to protect public trust resources.

Frequency (% of years)	**July-February kcfs**	**March kcfs** (cells show 1st and 2nd parts of month)		**April kcfs** (cells show 1st and 2nd parts of month)		**May kcfs** (cells show 1st and 2nd parts of month)		**June kcfs** (cells show 1st and 2nd parts of month)		**Duration enhanced outmigration flow period (days)**	**Average flow during enhanced outmigration flow period**
	Recommended Flow (kcfs)										
100% (all years)	2	2	2	5	5	5	5	2	2	31	5
80% (dry years)	2	2	2	5	10	7	5	2	2	45	7
60% (below normal years)	2	2	2	20	10	7	5	2	2	60	11
40% (above normal years)	2	2	5	20	20	7	7	2	2	75	12
20% (wet years)	2	2	5	20	20	20	7	7	2	90	13

Winter – Spring Sacramento River Inflows

Relationship between winter – spring Sacramento River inflows and productivity of public trust resources

Summary points:

- *Winter – spring inflow levels are essential to maintaining connectivity between the Central Valley's rivers and floodplains.*
- *By inundating floodplains, inflows provide well-documented benefits to public trust resources, supporting high levels of ecosystem and species productivity and providing high quality spawning and rearing habitat areas.*

Floodplain connectivity (i.e. the magnitude, frequency, duration, and timing of a natural or artificial hydraulic connection between a river channel and its floodplain) is a critical element of a healthy river ecosystem (Bayley 1995). The ability of a river to overflow its banks and inundate its adjacent floodplain is an important influence on both river channel and floodplain form. Reduced floodplain connectivity can increase the frequency of hydrologic disturbance in river channels (Schiemer et al. 1999). Similarly, without the physical, chemical, and biological inputs delivered through floodplain inundation, the floodplain ecosystem becomes ecologically simplified. Floodplain connectivity also influences form and structure of riparian zones, which are important interfaces between terrestrial and aquatic ecosystems (Gregory et al. 1991) and components of the public trust. Distribution and composition of riparian plant communities reflect histories of both fluvial disturbance from floods and non-fluvial disturbances of upland areas, and geomorphic surfaces of the valley floor and hillslopes adjacent to channels provide the physical template for development of riparian communities (Gregory et al. 1991).

Bird populations are also affected by floodplain connectivity. In addition to its affect on flora, floodplain inundation creates habitat for numerous species of birds associated with wet habitats (dabbling ducks, diving ducks, wading birds, and shorebirds) and habitat complexity on the floodplain combined with the productivity of such environments make floodplains important habitats for terrestrial species as well. Sommer et al (2001) reported large populations of bird species from multiple ecological groups, including particularly high numbers of Swainson's Hawk, a species listed as threatened under the California ESA.

Many fish species also benefit from slow-moving, highly productive habits available on inundated floodplains. Several studies document benefits to larvae and juveniles of many fish species using the Cosumnes River floodplain (Crain et al . 2004, Ribeiro et al. 2004); similarly, Sommer et al (2001) identified 42 Delta fish species (15 native species) on the Yolo Bypass. In particular, Sacramento blackfish and Sacramento splittail appear to specialize on floodplain habitats, breeding and rearing primarily in these shallow, ephemeral, highly productive habitats (Sommer et al. 1997; Sommer et al. 2001; Sommer et al. 2002). Splittail are considered obligate floodplain spawners; thus their abundance is largely a function of the frequency and magnitude of floodplain indundations in the Central Valley (Moyle 2002; Sommer et al. 2002; Moyle et al. 2004; Feyrer et al. 2006). Also, Central Valley Chinook salmon juveniles rear on floodplains, growing faster and suffering less mortality than in nearby river habitats (Sommer et al. 2001, Limm and Marchetti 2003; Jeffres et al. 2008). Each of these endemic fish populations contribute to the food web throughout the Delta – in other words, the increased production of fish on the floodplain and export of those fish to the larger estuary represents a food subsidy to the upper parts of the estuarine food chain.

Just as increased fish production exported from a floodplain enhances the Delta foodweb, invertebrate and photosynthetic prey items produced on a floodplain are exported downstream as well (Schemel et al. 1996). Food limitation is one of the leading candidates for a driver of declines of native fish throughout the Delta (Jassby and Cloern, 2000; Sommer et al. 2007). Central Valley floodplains can produce high levels of phytoplankton and other algae, particularly during long-duration flooding that occurs in the spring (Sommer *et al.*, 2004; Ahearn *et al.*, 2006). Some of this food productivity and other essential resources is exported to the estuary at-large (Benke 2001; Junk et al 1989). Algae provide the most important food source for zooplankton in the Delta (Muller-Solger *et al.*, 2002) and these zooplankton are a primary food source for numerous Delta fish species. Floodplains may export zooplankton as well; zooplankton density can be 10-100 times greater in a floodplain compared to the river (Grosholz and Gallo 2006). Consequently, a potential benefit of floodplain restoration is an increase in the productivity of food webs that support Delta fish species (Ahearn et al. 2006).

The basis for developing flow criteria for winter – spring Sacramento River inflows is discussed in greater detail in Exhibit AR-1, submitted by American River on behalf of our organizations.

Methods for developing winter – spring Sacramento River inflows to increase productivity of public trust resources.

Summary points:

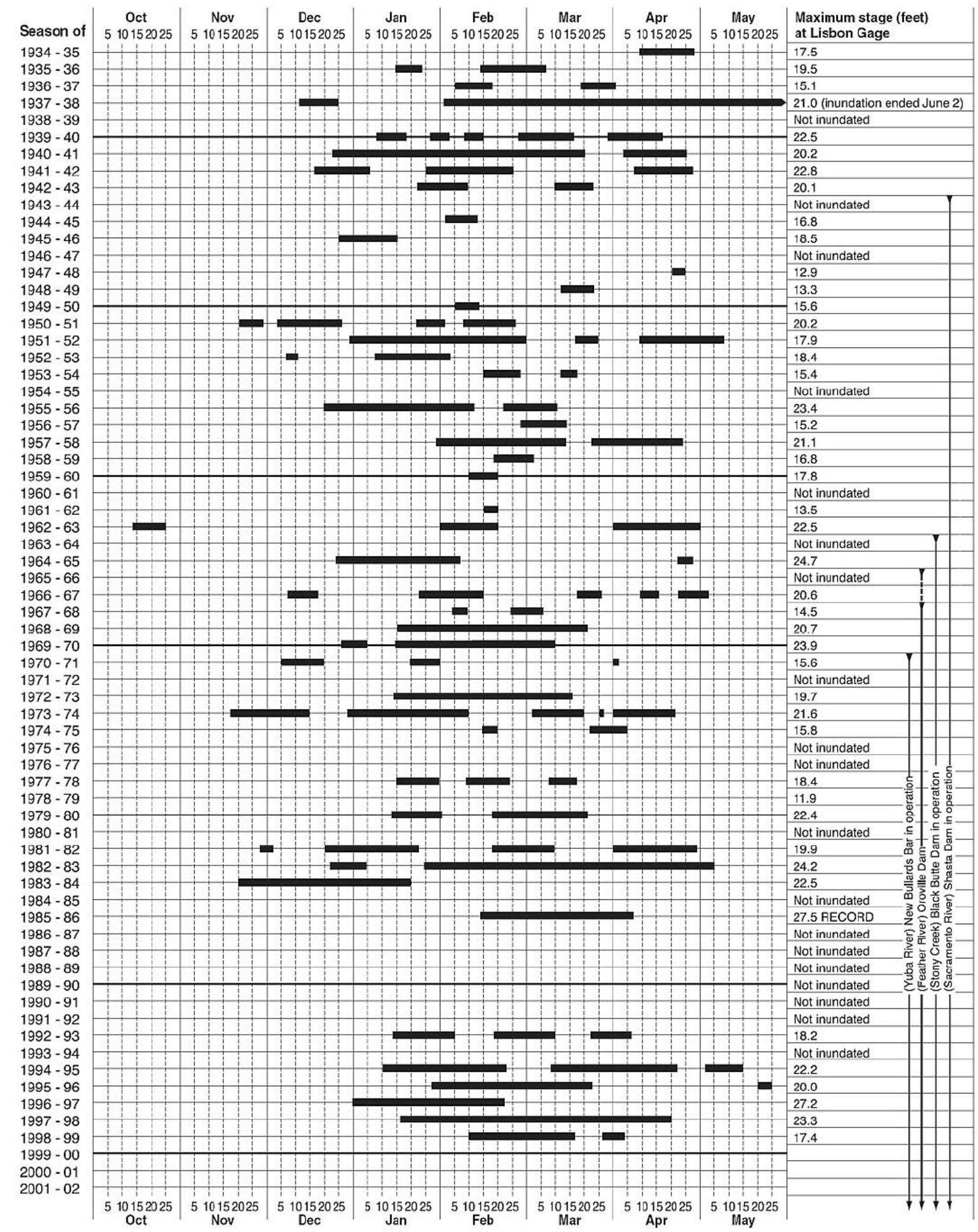
- *Late winter and early spring floodplain inundation coincides with Sacramento River Chinook salmon outmigration and splittail spawning periods and optimal seasonal conditions for food production.*
- *Splittail require a minimum at least 30 – 45 days of functional floodplain habitat for spawning success.*
- *River inflows must not only overtop riverbanks but also be sufficient to maintain desired flow conditions within the area inundated floodplain for 1 – 3 months.*

The prerequisite for an ecologically functional floodplain is hydrological connectivity between the river and floodplain (Amoros, 1991; Tockner and Stanford, 2002). Connectivity drives all hydrologic and geomorphic processes on the floodplain. Connectivity can be achieved through multiple pathways including lateral overflow as river stage rises, through breaks in natural or constructed levees, and through sloughs or side channels into a flanking flood basin. Water on the floodplain can then perform geomorphic work (erosion and deposition), facilitate the exchange of organisms, nutrients, sediment, and organic material between the river and floodplain, and provide a medium in which biogeochemical processes and biotic activity (e.g., phytoplankton blooms, zooplankton and invertebrate growth and reproduction) can occur. Thus, timing, duration, and frequency of flows necessary to inundate floodplains are the key flow characteristics for controlling floodplain productivity.

We used the published literature to determine the magnitude, timing, duration, and frequency of flows necessary to inundate the Yolo Bypass in a manner that would benefit food productivity and productivity of Sacramento splittail and Chinook salmon. These are the best-studied public trust resources known to benefit from floodplain inundation. Other benefits of floodplain inundation are believed to be covered by flows sufficient to support these contributions to the Delta aquatic community

Timing: Winter and spring months are the most valuable periods for floodplain inundation. Floodplain productivity (and export of food resources to the surrounding ecosystem) in the spring benefits from increasing light and temperature regimes. Phytoplankton productivity increases with temperature (Cushing and Allan 2001, Sommer et al. 2004). Although this relationship has a threshold beyond which increasing temperatures will retard phytoplankton growth, under the common conditions of floodplain inundation in the Central Valley this can be considered a straightforward positive relationship as those threshold temperatures typically are well above ranges found in the Delta. Flooding too late in the spring can be counterproductive. Historically, flooding of the Yolo Bypass was uncommon after May 1 (Figure 12, EDAW 2001).

Figure 12.
Periods of inundation at Lisbon Weir showing timing, duration, frequency, and magnitude of Yolo Bypass inundation.



Data compiled from records of DWR stream gaging station 'Yolo Bypass near Lisbon". Datum: 0 = 0 feet U.S.E.D. Period of record: 1914-present. Assumed overflow of Bypass at stage above 11.5' on the Lisbon gage. Source: State of California, Department of Water Resources.

Source: Yolo Basin Foundation 2001

Flooding in the winter provides the opportunity for all runs of Sacramento River Chinook salmon to benefit from inundated floodplain rearing habitat (Figure 3; Moyle 2002; Williams 2006). Whereas research regarding Chinook salmon growth and survival on floodplains has focused on the Sacramento fall run Chinook salmon (Sommer et al 2001) and the different runs are distinguished by life history differences (Smith et al 1995; Moyle 2002; Williams 2006), it is possible that different runs may experience different costs and benefits on inundated floodplains. However, the Yolo Bypass historically flooded most commonly during February and March (Figure 12; EDAW 2001 – NEED CITE) and given that this period covers the migration period of all Chinook salmon runs, and most of the splittail spawning season (Figure 3), it is highly likely that late-winter inundation of the Yolo bypass has significant benefits on the productivity of these species. Migratory waterfowl would also benefit from increased availability of floodplain habitat in the late-winter and early spring.

Duration: Both phytoplankton and periphyton require a minimum duration of inundation for growth and reproduction. Phytoplankton productivity is initially positively correlated with residence time (Ahearn et al. 2006, Schemel et al. 2004, Sommer et al. 2004); phytoplankton concentrations are low during inundation events when residence time is low, due to both dilution and displacement. However, high velocity flows (with very low residence time) can flush phytoplankton from the floodplain and transport them downstream; if residence time is shorter than phytoplankton growth rate, then biomass accumulation will not occur (Schemel et al. 2004). For reference, on the Cosumnes River, Ahearn et. al. (2006) found that phytoplankton productivity peaked 2-5 days after disconnection – that finding reflects residence time, velocity, and other factors particular to that study.

Continuous inundation is necessary for successful spawning, incubation and initial rearing of larval splittail. Splittail eggs require 3-5 days to hatch (Moyle et al. 2004) after adults find the floodplain and begin to spawn. Larval and juvenile splittail will remain on the floodplain while conditions are appropriate. Benefits of inundation to splittail abundance probably do not begin to occur until inundation duration exceeds 30 days. Emigration from the floodplain appeared to be related to fish size as most YOY leaving the Yolo Bypass were between 30-40 mm in length. This size range suggests that a duration sufficient for fish to reach this size will be optimal (Feyrer et al. 2006). Spawning success may also be improved by longer duration flooding that allows adults time to feed on earthworms on floodplains prior to spawning. Thus the optimal duration will allow for adults to enter floodplains, feed and spawn, for eggs to incubate and hatch, and then provide sufficient duration for the YOY to reach 30-40 mm in length – maximum benefits to splittail abundance from floodplain inundation probably occur when inundation duration exceeds 45 days. Benefits to splittail continue to accrue with greater durations of inundation as splittail may continue to spawn and benefit from floodplain connectivity; the strongest year classes of splittail occur in years with continuous inundation of floodplains (e.g, Yolo Bypass, Cosumnes) during March and April (Moyle et al. 2004).

Frequency: Generally, natural floodplains are inundated to some extent once every ~1.5 years -- larger inundation events are less frequent. However, Central Valley floodplains are generally isolated from their rivers by flood control structures. These structures (e.g. levees) can be modified to allow more frequent flooding at lower flows. Given the severe declines in most anadromous and estuarine pelagic fish species in the Delta and the significant benefits provided by inundated floodplains, a high frequency of inundation (e.g., yearly or nearly every year) may be required, at least until the Public trust values supported by floodplains are restored.

Magnitude: We evaluated two questions associated with magnitude: *What is the magnitude of flow in the Sacramento or Feather Rivers necessary to inundate the bypasses*? and *What is the magnitude of flow in the bypasses necessary to create large areas of suitable floodplain habitat that will produce benefits to the public trust*?

Table 2 below lists inundation thresholds for multiple locations along the river. Flow thresholds were developed from a review of reports, hydrologic data, and topographic maps to estimate the floodplain inundation thresholds. The inundation threshold, however, is not enough to push a substantial amount of water down the bypasses. For example, achieving 5,000 cfs on the Yolo bypass requires an additional 12,000 cfs above the 23,100 cfs inundation theshold.

Table 2: Inundation thresholds for floodplains and side channels at various locations along the river. Inundation threshold refers to the discharge when flood waters begin to inundate the floodplain. Target discharge is the amount of water necessary to produce substantial inundation and flow across the floodplain assuming that the modifications identified are performed immediately. Without recommended structural modifications (e.g. notching of the Fremont Weir), greater flow rates will be required to inundate the floodplain.

Location	Stage	Inundation Threshold (cfs)	Target Discharge (avg. cfs)	Gauge Location	Source
Freemont Weir					
existing crest	33.5	56,000	63,000	Verona	USGS
proposed notch	17.5	23,100	**35,000**	Verona	USGS
Sutter Bypass					
Tisdale weir	45.5	21,000		Colusa	NOAA; Feyrer
Tisdale with notch					
Lower Sutter Bypass	25	30,000	**30,000**	Verona	USGS
Upper Sacramento					
meander belt side channels	various	10,000	**12,000**	Red Bluff	USGS

Recommendation: Winter – spring Sacramento River inflow criteria to increase productivity of public trust resources

- *Sacramento River inflows ranging from 27,5000 to 35,000 cfs should occur every year or twice in every three years to create and maintain floodplain habitat in the Sutter and Yolo bypasses for 15 to 120 days between December and May. These inflow criteria should be sufficient to maintain the desirable areal extent of floodplain inundation during this period.*

Table 3 identifies flow criteria for various year types at four key sites based on flows necessary to maintain inundated habitat in the Yolo bypass for varying durations depending on year types. These flows would probably result in inundation of the Sutter bypass as well, particularly if the Tisdale or Moulton weirs were also notched.
Table 3 illustrates duration and timing targets to provide floodplain inundation flows for 15 to 120 days between December and May 30 into the Sutter and Yolo Bypasses to provide rearing habitat for salmon and splittail, spawning habitat for splittail, improved migration corridor opportunities for downstream migrants, and foodweb productivity benefits. Reservoir releases should be timed to coincide with and extend duration of high flows on less regulated rivers and creeks such as the Yuba River which still exhibits a somewhate natural hydrograph. The duration target is fixed for each year type, but actual

hydrograph timing of hydrograph should vary across the optimal window depending on hydrology and to maintain life history diversity.

TABLE 3: Floodplain inundation flow magnitude, duration, and timing targets in years with different hydrology. The frequency of flooding should be maximized (i.e. once per year at least) even though flooding in critical and dry years may be low magnitude and duration. Flow volumes assume structural modifications to allow inundation at lower flow rates than is currently possible.

Floodplain Inundation Flow Targets

	Dec	Jan	Feb	March	April	May	Average c.f.s.	Days	MAF
Inundation Target Window									
Wet (80 - 100 percentile)							35,000	120	8.3
Normal wet (60 - 80 percentile)							32,500	90	5.8
Normal dry (40 - 60 percentile)							30,000	60	3.6
Dry (20 - 40 percentile)							27,500	30	1.6
Critica (0 - 20 percentile)							27,500	15	0.8

Duration and Timing
Table 3 illustrates duration and timing targets to provide floodplain inundation flows for 15 to 120 days between December and May 30 into the Sutter and Yolo Bypasses to provide rearing habitat for salmon and splittail, spawning habitat for splittail, improved migration corridor opportunities for downstream migrants, habitat for migratory waterfowl, and foodweb productivity benefits. Reservoir releases should be timed to coincide with and extend duration of high flows that occur naturally on less regulated rivers and creeks. The duration target is fixed for each year type, but actual timing of inundation should vary across the optimal window depending on hydrology and to maintain life history diversity.

Frequency
At least one floodplain in the Sacramento system should be inundated every year for the duration and at the time required to enhance foodweb productivity and improve rearing habitat for every year class of salmon. It may be possible to do this while economizing on water by inundating relatively small areas in dry years and very large areas in wet years with minimal or no inundation in critical dry years.

Relationship between winter-spring Sacramento River inflows and spatial distribution of public trust resources

In addition to exporting biologically available carbon from floodplain habitats, inundated floodplains provide benefits to the Delta system by increasing the total area of Delta habitats. For example, Jassby and Cloern (Jassby and Cloern, 2000) reported that, when flooded, the Yolo Bypass essentially doubles the area of the Delta. In this way, floodplain inundation increases the spatial extent of the Delta ecosystem and thus supports the public trust benefits of the Delta ecosystem.

More specifically, organisms within the Delta can access the resources available in the bypass only during the periods of inundation. By distributing organisms over a greater area, floodplain inundation increases the spatial extent of populations during critical life stages (e.g. migrating salmon, spawning splittail); this increased spatial distribution insulates populations from localized catastrophes, reduces densities (and thus resource competition and vulnerability to virulent diseases), and increases the potential for organisms to capitalize on resources that would otherwise be unavailable. Furthermore, because aquatic organisms (in particular) are known to follow different life history paths based on their nutrition status and the conditions (e.g. temperature) under which they rear, floodplain inundation is likely to contribute to the life history diversity attribute of viability as well because it increases the diversity of habitats (temperatures, food resources, etc) encountered by different individuals in a population.

Recommendation: Winter – spring Sacramento River inflows to increase spatial distribution of public trust resources

The flow magnitude, timing, frequency, and durations identified above will also support the spatial extent attribute of viability for, at a minimum, Sacramento splittail, emigrating Sacramento River Chinook salmon, and migratory waterfowl[7].

[7] Reactivation of additional floodplains along the San Joaquin River and the Delta's east side tributaries will be needed to support spatial distribution needs of fall run Chinook salmon (and spring run, once they are re-established in the San Joaquin drainage).

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