EXHIBIT TBI-1

BEFORE THE STATE WATER RESOURCES CONTROL BOARD

WRITTEN TESTIMONY OF

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REGARDING FLOW CRITERIA FOR THE DELTA NECESSARY TO PROTECT PUBLIC TRUST RESOURCES: GENERAL ANALYTIC FRAMEWORK

PREPARED FOR:

THE BAY INSTITUTE
AMERICAN RIVERS
ENVIRONMENTAL DEFENSE FUND
NATURAL HERITAGE INSTITUTE
NATURAL RESOURCES DEFENSE COUNCIL

EXHIBIT 1:
GENERAL ANALYTICAL FRAMEWORK
FOR DEVELOPING PUBLIC TRUST FLOW CRITERIA

Basing Flow Criteria on Viability Criteria for "Umbrella" Species in the Delta

In this testimony, we recommend that the State Water Resources Control Board base its public trust flow criteria in the Delta on the maintenance or restoration of well-documented viability standards for public trust resources. Therefore, the approach taken in this testimony, which describes the general analytical framework, and Exhibits 2 – 4, which describe specific flow criteria, is to:

1. Identify the specific flow parameters associated with those viability criteria for one or more umbrella species in the Delta; and
2. Use the best available scientific information to develop specific recommended flow criteria that provide protection for public trust resources.

As used throughout the testimony of the Bay Institute et al. (TBI Exhibits 1-4), "best available scientific information" means the vast body of scientific data and literature currently available with regard to the Bay-Delta estuary and related fisheries and other public trust resources, with particular emphasis on the most recent data. As discussed on page 12, we recognize four related categories of scientific information which we have prioritized, but all of which are valid and appropriate for the Board to rely upon in developing public trust flow criteria.

Status of Public Trust Resources

Summary points:

- *Populations of the formerly most abundant pelagic fish species have fallen to record or near record low levels.*
- *Chinook salmon populations have also collapsed, devastating the California fishing economy, and other anadromous fish populations are at low levels as well.*

The Sacramento-San Joaquin Delta Reform Act of 2009 (Division 35, Part 1, Ch 1, § 85002) declares the Sacramento-San Joaquin Delta (Delta) to be a critically important natural resource for California and the nation, serving concurrently as both the hub of the California water system and the most valuable estuary and wetland ecosystem on the west coast of the Americas. The legislature has also declared this resource, held in trust for the people of California, to be in crisis (Division 35, Part 1, Ch 1, § 85001a). Numerous vertebrate and invertebrate species that qualify as public trust resources use the Delta and environs for spawning, rearing, as a migration corridor, or some combination of these. (The Delta ecosystem itself, its habitats and natural communities, is also a public trust resource). The brief overview of the condition of public trust fisheries resources in the Delta that follows is not meant to be a comprehensive assessment, but only to highlight current population status and trends for key pelagic and anadromous species representative of overall conditions for public trust fisheries resources in the Delta.

Overall, populations of important Delta fisheries have been greatly reduced from historic levels, are currently in decline, or both. The formerly most abundant pelagic fisheries have experienced dramatic declines in population abundance over the past decade, falling to record or near-record lows. Anadromous fisheries that rely on the Delta have either sunk to relatively low population levels or have declined significantly in recent years. These patterns indicate that the Delta is at risk for, or may in fact be in the process of, ecological collapse. Such a collapse would dramatically impact the suite of public trust values in the Delta, values that have been recognized to be of state, national, and global significance.

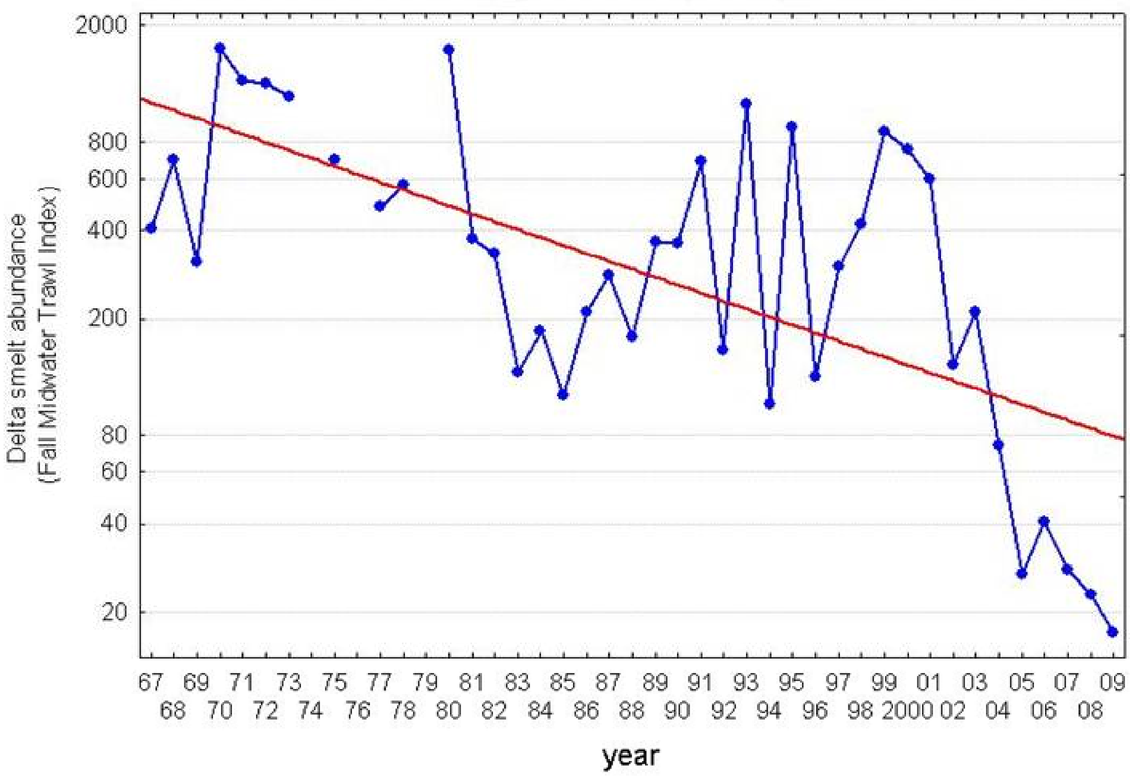
Pelagic fisheries: The Interagency Ecological Program (IEP), a consortium of nine state and federal resource agencies, has undertaken a decades-long fish population monitoring program in the Delta and San Francisco Estuary, developing one of the longest and most comprehensive data records on estuarine fishes in the world (Sommer et al. 2007). Important results of this research include: 1) the annual abundance of pelagic fish populations in the Delta are highly variable, 2) much of this variability is associated with hydrology and anthropogenic effects of water management operations in the Delta and its Central Valley watershed, and 3) beginning around the year 2000, populations of the four most abundant pelagic fish species in the upper estuary (the native delta smelt and longfin smelt, and non-native striped bass and threadfin shad) have experienced dramatic declines (Sommer et al. 2007). These recent declines have been widely recognized as an issue of significant concern, and have come to be referred to as the Pelagic Organism Decline (POD).

The POD is notable both for affecting populations of native and non-native species, and for population abundance estimates falling to record and/or near-record lows for the four most common pelagic Delta fisheries (DFG 2010). Using the federally-listed endangered delta smelt as an example, California Fish and Game fall midwater trawl abundance indices[1] set sequential new record lows in 2004, 2005, 2008, and 2009 (Figure 1)(DFG

[1] Available for delta smelt, longfin smelt, striped bass, and threadfin shad at: http://www.dfg.ca.gov/delta/projects.asp?ProjectID=FMWT

2010a). The recent low numbers of Delta smelt are the lowest in the period of record and represent well over a 90% decline compared to the delta smelt abundance indices in the years leading up to the species listing in 1993. The condition and trend in longfin smelt populations shows a similar pattern of decline, with the midwater trawl abundance index falling to new lows in 2007 and again in 2009. Population indices for juvenile striped bass and threadfin shad have also fallen to record or near-record lows (DFG 2010a, Sommer et al. 2007). For juvenile striped bass, nine of the ten lowest abundance index values have occurred since the year 1999. For threadfin shad, 2008 and 2009 were the lowest population index values on record. The precipitous population declines in these fisheries, once the most abundant pelagic fish species in the Delta and key indicators of ecosystem integrity, represent a significant threat to the Delta's public trust fishery resources.

FIGURE 1:
Decline of the Delta smelt (*Hypomesus transpacificus*), 1967-2009

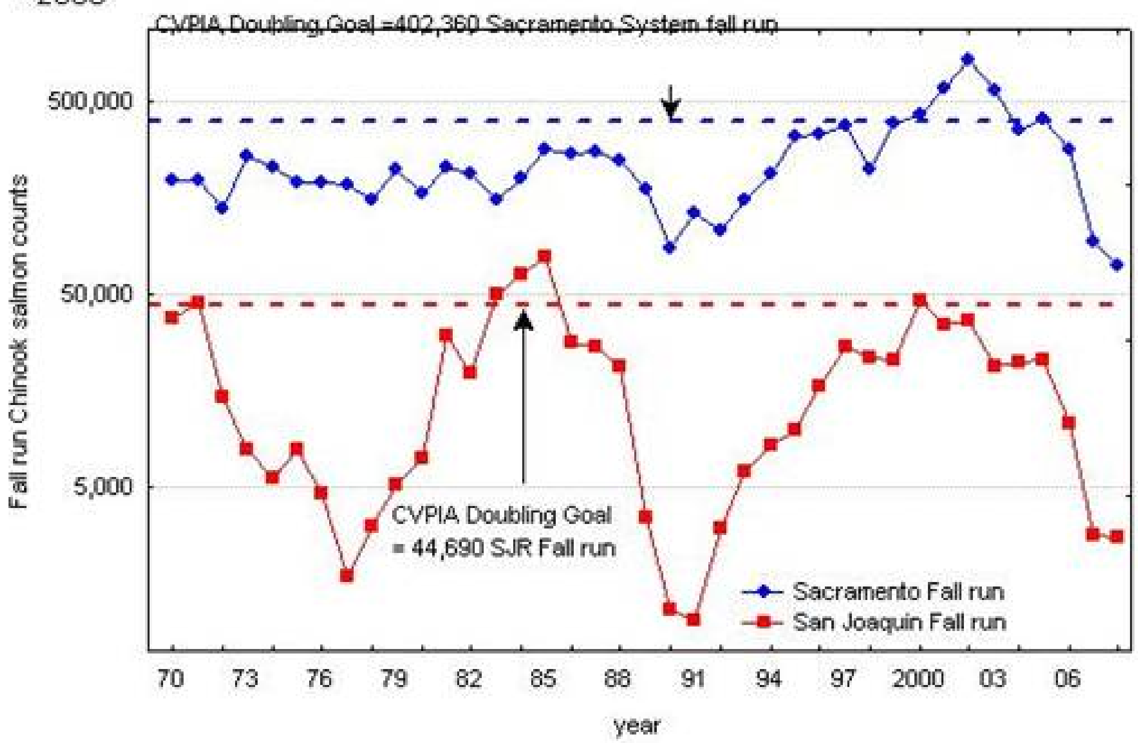


Anadromous fisheries: Overall, anadromous salmonids in the Delta have been significantly depleted from their historic population levels and the future of these important fisheries is an issue of significant concern. In April 2008 the Pacific Fishery

Management Council closed the salmon fisheries on the west coast of the US in response to the sudden collapse of the Sacramento River fall-run Chinook (SRFC) and other salmon populations (Lindley et al. 2009). The SRFC was by far the largest of the remaining Central Valley salmon runs that use the Delta for migration and rearing, and its collapse is in many ways representative of conditions for a majority of Central Valley anadromous fisheries: the long term degradation of riverine and Delta estuarine habitats resulted in a population vulnerable to collapse in the event of short-term perturbations (in the case of SRFC, a degradation of ocean conditions).

Populations of Central Valley anadromous fishes are generally in extreme condition. Abundance estimates for threatened Central Valley steelhead show a pattern of overall decline with populations at a moderate to high risk of extinction (NMFS 2009, Lindley et al. 2007). Chinook salmon (including fall/late-fall, winter, and spring runs) have low and/or declining populations. As discussed above, fall-run Chinook have experienced dramatic declines in recent years, falling to current historic lows (Figure 2). In 2009, a record low 39,530 natural and hatchery SRFC adults were estimated to have returned to the Sacramento River basin, far short of the conservation objective of 122,000 to 180,000 adult fish (PFMC 2010). The late fall run has experienced moderate declines since 2002 (Lindley et al. 2009).

FIGURE 2:
Fall run Chinook abundances for Sacramento and San Joaquin systems, 1970 -2008



Endangered winter-run Chinook populations have undergone a seesaw decline: falling precipitously from historic highs of as many as 230,000 fish in 1969 to historic lows of less than 200 fish in the 1990's, then experiencing a modest recovery to over 17,000 fish in 2006, only to fall again in 2007 and 2008 to under 3,000 individuals (NMFS 2009). Threatened spring-run Chinook are at extremely precarious population levels as well: From historic abundances of over 600,000 fish in the 1940's, they have declined in an erratic fashion with escapement in 2009 estimated at 2,506 fish (NMFS 2009, PFMC 2010).

As the fluctuating population levels described here demonstrate, Central Valley salmonid fisheries, which all rely on the Delta, are sensitive to both positive and negative environmental and anthropogenic influences and have the potential for significant recovery under suitable conditions.

Sturgeon (white and green) and American shad populations are also currently at low levels and/or experiencing declines. Both the white sturgeon and the threatened Distinct Population Segment of green sturgeon have experienced declines in recent years, although data limitations make accurate population estimates difficult (DFG 2010b, NMFS 2009).

Data are available on American shad abundance, with trawl data indicating that populations are declining in a pattern similar to what is being seen in the pelagic fisheries of the Delta: With the exception of a few good recruitment years (most notably 2003), American shad populations have seen record or near-record lows over the past decade, with three of the four lowest midwater trawl abundance indices being recorded in 2007, 2008, and 2009 (DFG 2010a).

Status of Flows Associated with Public Trust Resources

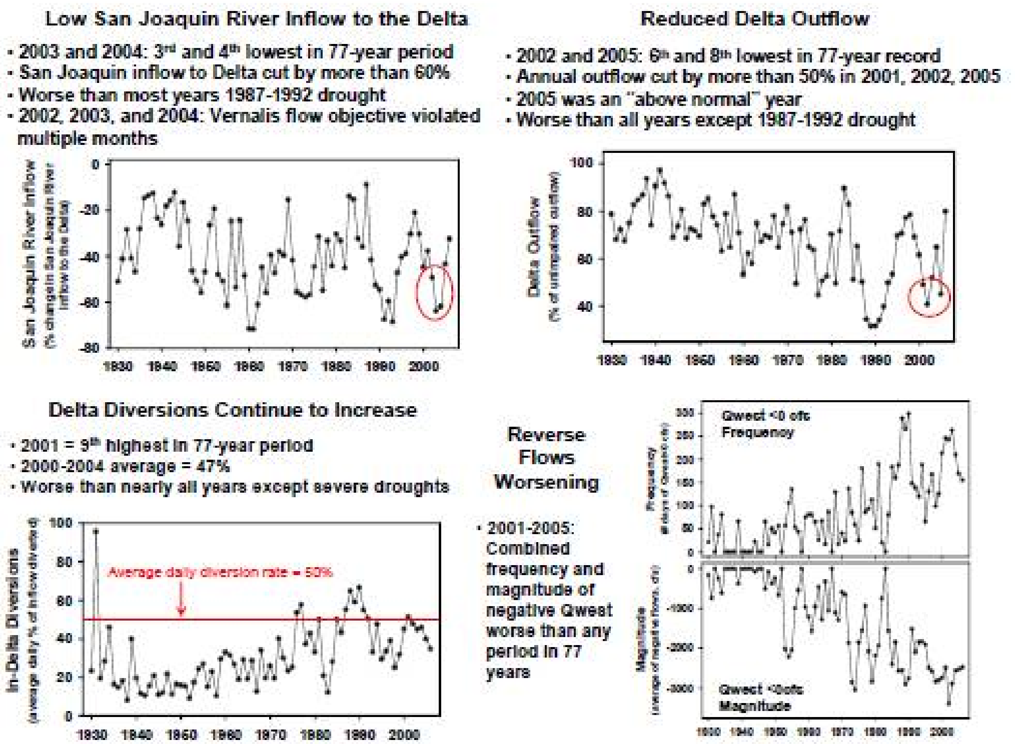
Summary points:

- *Delta flows have been dramatically decreased on an annual and seasonal basis and flow conditions further deteriorated in recent years.*
- *As Delta outflows have decreased by over 50% in some years, the Delta has become more saline and less variable.*
- *The health of Delta public trust resources has closely tracked Delta flows: As flows decreased, so did fish populations.*

The current Delta hydrograph (i.e., the timing, duration and magnitude of inflows, outflows and in-Delta circulation) has been dramatically altered over time by storage, diversions and exports. These alterations have had equally dramatic effects on the health of Delta public trust resources.

Figure 3 shows that freshwater flow conditions have worsened in recent years, despite the political attention focused on the Delta. Freshwater inflows from the San Joaquin basin into the Delta reached near record lows in several years during the 2000's, effectively flatlining the San Joaquin River (top left panel). Delta outflows were lower than for all years except the severe 1987-1992 drought, reduced by more than 50% in some years (top right panel). State and federal water project exports were higher than for nearly all years except during the 1987-1992 drought (bottom left panel). Finally, both the frequency and magnitude of reverse flows on the lower San Joaquin River were worse than for any period in the record, with negative Old and Middle River flows in more than 90% of years (bottom right panel).

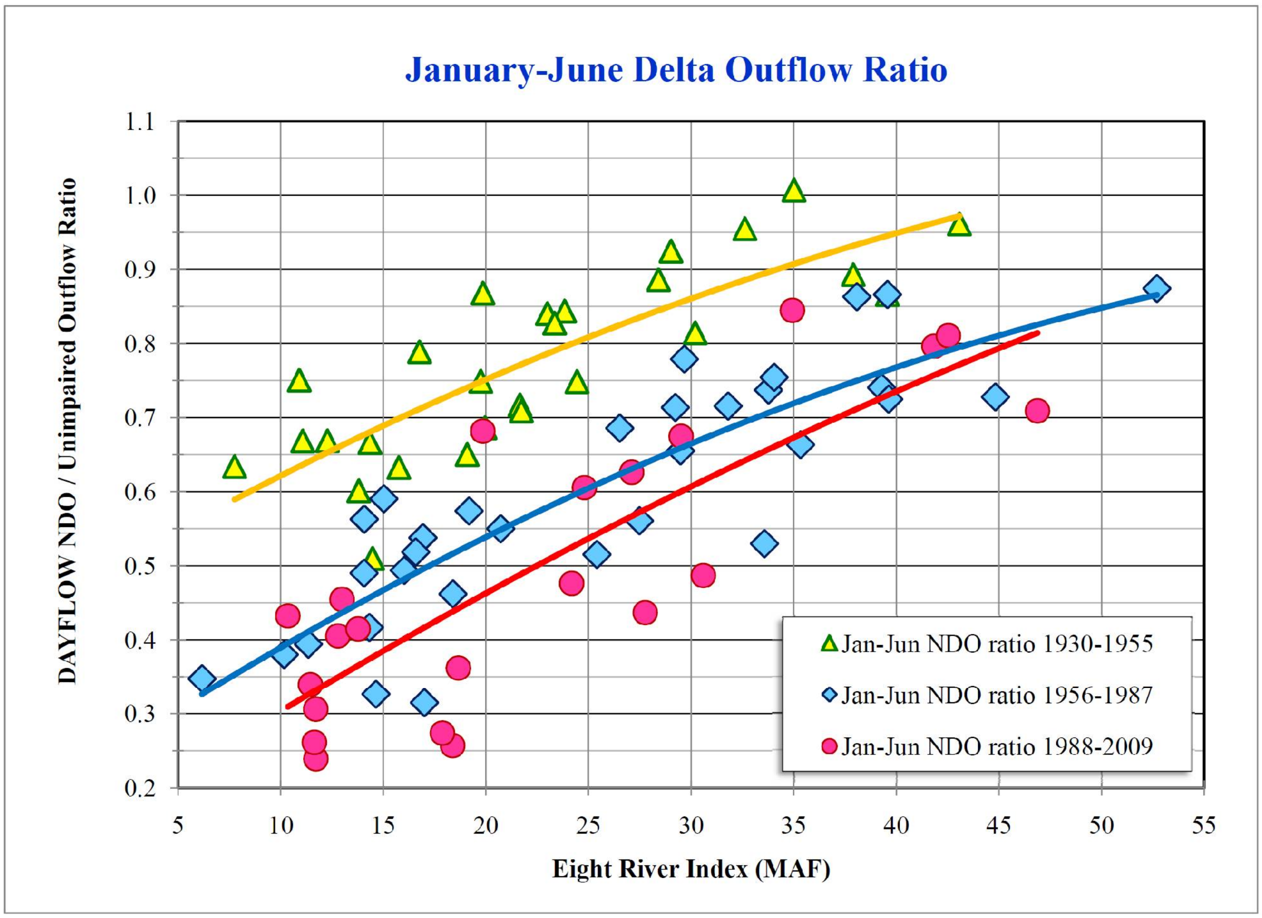
Figure 3: Four Indicators of Deteriorating Delta Flow Conditions



These four indicators from the Delta Flow Index show that freshwater inflows from the San Joaquin basin into the Delta reached near record lows in several years during the 2000s (top left panel), freshwater outflows from the Delta were lower than for all years except the 1987-1992 drought (top right panel), in-Delta diversion rates were higher than for nearly all years except during the 1987-1992 drought (bottom left panel), and both the frequency and magnitude of reverse flows on the lower San Joaquin River were worse than for any period in the 77-year record. Data source; California Department of Water Resources, Dayflow and Central Valley Unimpaired Streamflow dataset.

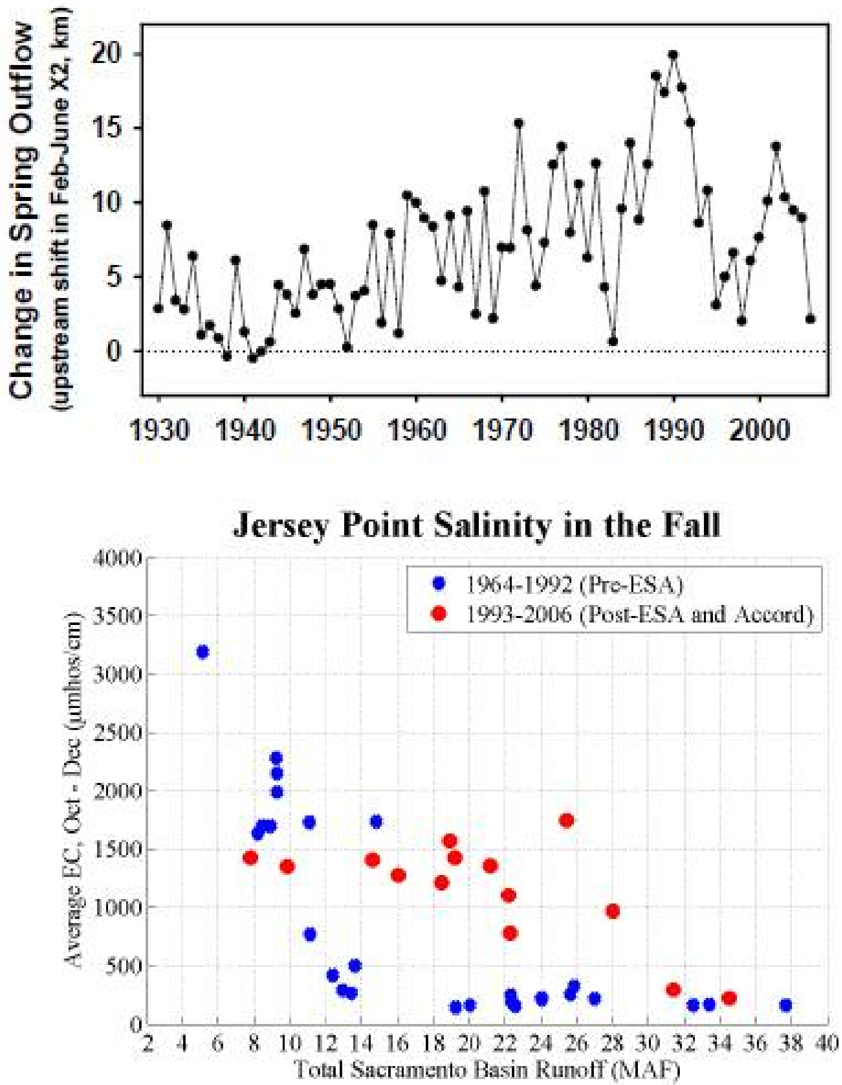
Delta outflow, one of the most critical drivers of ecological conditions in the estuary, is also a good indicator of overall flow conditions in the Delta (Figure 4).

FIGURE 4:
The ratio of cumulative January through June Net Delta Outflow (NDO) to unimpaired runoff as a function of the Eight River Index. The ratio decreases with decreasing water availability -- meaning NDO is disproportionately low under drier conditions. Fit lines show that the amount of water that makes it through the Delta as outflow has declined over the three time periods shown, regardless of hydrological conditions in the watershed. Values for unimpaired hydrology after 2003 were estimated using the historical relationship between unimpaired runoff and the eight river index (data from CDEC).



The Delta is more saline, not less, compared to historic conditions (Figure 5). As Delta outflows have decreased, the average location of X_2, the 2ppt isohaline indicator, has moved far upstream. Average X_2 location was 75 km or less from the Golden Gate before the 1970s but has moved upstream as far as 90 km since then, and seasonal variation has been reduced by up to 40%. Natural salinity fluctuation characteristic of variable estuarine conditions has decreased – because the Delta has become consistently more saline over time as a result of water development.

Figure 5:

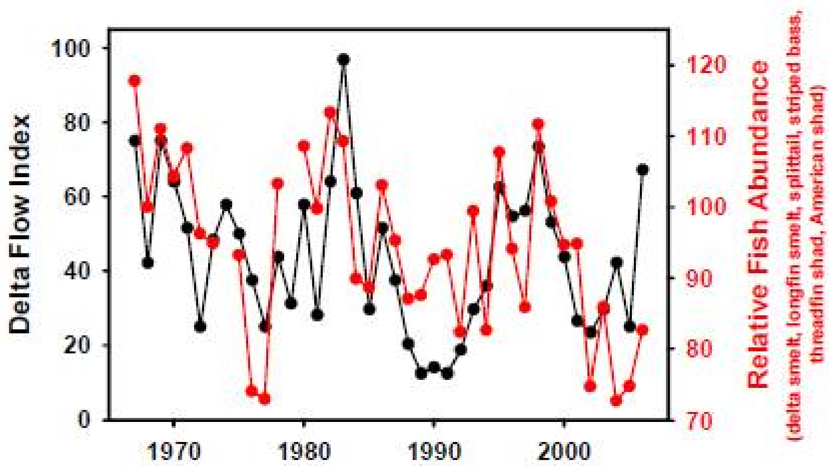


During the spring, reduced Delta outflows have shifted low salinity habitat, denoted by X2, far upstream (top panel: California Department of Water Resources, Dayflow and Central Valley Unimpaired Streamflow dataset). Similarly, during the fall reduced outflows have increased salinity (as electrical conductivity) measured at Jersey Point in all but the wettest years since 1993 (bottom panel; data source: Contra Costa Water District).

As Delta flows have been altered and reduced, the abundance of Delta fish populations has correspondingly declined. Figure 6 shows how closely the relative abundance of six regularly surveyed pelagic fish species tracks eight indicators of flow conditions in the

Delta, including inflows, outflows and in-Delta hydrodynamics. Delta flows exert a very strong influence on public trust resources, and as flows decrease, so do populations of these resources.

Figure 6:



Delta flow conditions, shown here as the multi-metric Delta Flow Index, are highly correlated with the abundance of multiple Delta fish species, shown here is the relative abundance (i.e., relative to their 1967-1976 average) of the six pelagic fish species surveyed by the Fall Midwater Trawl survey and for which abundance indexes are calculated. The Delta Flow Index aggregates the results of eight quantitative indicators that measured Delta inflows, outflow, channel hydrodynamics, and flow-related ecological conditions. Data sources: California Department of Water Resources, Dayflow and Central Valley Unimpaired Streamflow datasets, and California Department of Fish and Game, Fall Midwater Trawl Survey.

Viability Criteria

Protection of public trust resources requires maintaining or restoring the viability of public trust resources so that they may be maintained for future generations to use and enjoy. As we use it throughout the TBI testimony, "viability" means the maintenance of acceptable levels or conditions of four different biological characteristics that relate to the persistence of populations and estuarine ecosystems:

- **Abundance**
- **Spatial extent (or distribution)**
- **Diversity**
- **Productivity**

The characteristics of viability we use here are based on those defined by the National Marine Fisheries Service for "viable salmonid populations" (McElhany et al. 2000; Lindley et al 2007).

They are also generally accepted throughout the conservation science literature (e.g. Meffe and Carrol 1994).

Populations, species, and ecosystems must achieve acceptable levels of each of these characteristics in order to be relatively safe from extirpation and maintain viability over the long-term. For purposes of this proceeding, we present flow recommendations for "umbrella" species that are important keystone species in their own right, whose needs are likely to exceed those of other species in the same area at the same time. When the Board has the time and resources, it would be quite valuable to address more comprehensively the many distinct species and ecosystem attributes that need to be protected as public trust resources.

"Best Available Science:" Correlations and Causal Mechanisms

As directed in the legislation, this testimony employs the best available scientific information to quantitatively relate specific flow parameters to specific aspects of viability for one or more umbrella species, and combine the results of these analyses with information on extinction risk, management or recovery goals, and/or historical conditions to develop specific recommended flow criteria that provide protection for these species. Cumulatively, the flow criteria developed to protect these umbrella species are likely to benefit all or most other public trust resources. Nonetheless, we emphasize that there may be specific flows related to the viability of some public trust resources that we have not considered and are not addressed by the flow criteria recommended in this testimony.

Where there is an association between a known flow-dependent mechanism (e.g. floodplain inundation, entrainment) and a specific viability criterion, that relationship should be used to guide the development of flow criteria. Where mechanistic explanations are lacking – as is often the case – the numerous statistically significant (i.e., non-random) correlations between a specific flow parameter and a public trust resource, viability criterion should be used to establish flow criteria that protect the public trust. Where such correlations are not evident, flows associated with more productive historical periods should be used as flows in the historical period would represent the best available evidence of those needed to protect the public trust. In the event that baseline historical flow data is not available, unimpaired flows should be used to guide the development of flow criteria. We have used the first two methods to prepare the flow criteria proposed in this testimony. The Board should consider using information regarding historical conditions and unimpaired flows in addressing needs for protection of public trust resources not addressed in this testimony. The alternative, to assume that flows are unimportant because their functionality has not been determined, is unacceptable from either a scientific or a public trust protection basis.

It bears emphasis that correlations, historical conditions and unimpaired flows constitute important and scientifically sound evidence for purposes of developing public trust flow criteria, and should not be dismissed on the grounds that they do not reflect changing environmental conditions in a dynamic and highly stressed estuary. The fact is that causal mechanisms are modified by changing circumstances in the same way as correlations – indeed, if the statistical correlations between flow and viability characteristic change it is likely because the diversity and rank of importance among underlying causal mechanisms has changed. Nevertheless, where we employ statistical correlations between flow and viability to develop flow criteria, we use the significant relationships from the most recent period in which those correlations have been demonstrated in the published literature; in this way, we base our recommendations on the most recent known relationships between flow and public trust benefits.

Abundance

Summary points:

- *More abundant populations are less vulnerable to environmental or human disturbances and risk of extinction and reflect a higher level of protection of public trust values.*
- *The relationship between abundance and flow is one of the strongest and most persistent relationships observed in the San Francisco estuary.*

The number of organisms in a population is a common and obvious species conservation metric. For instance, endangered species recovery plans (USFWS 1995a; NMFS 2009) and plans to implement legislation mandating restoration of target species (USFWS 1995b) generally identify abundance targets against which conservation success may be measured. Populations or species with low abundance are less viable and at higher risk of extinction than large populations for reasons that include environmental variation, demographic stochasticity, genetic processes, and ecological interactions. Abundance is also correlated with and contributes to other viability characteristics including spatial extent, diversity, and productivity. In itself, however, simply increasing abundance of organisms (or any other single viability characteristic) is not sufficient to guarantee viability into the future.

Freshwater flow has a powerful, significant, consistent, and widespread positive effect on abundance and productivity of many fish species and their prey in the Delta and the upper reaches of the San Francisco Estuary. Studies documenting these relationships show statistically significant relationships, across orders of magnitude in abundance and flow, for numerous species (e.g., Stevens and Miller 1983; Jassby et al. 1995; Kimmerer 2002; Rosenfield and Baxter 2007; Sommer et al. 2007; Feyrer et al. 2007; Kimmerer et al. 2009). These studies incorporate data from across four decades and, in some cases, multiple sampling programs.

There are multiple potential mechanisms that may drive the relationship between freshwater flow through the Estuary and population response of numerous fish and wildlife species. Kimmerer (2002b) identifies 11 potential mechanisms and others may yet be identified. The mechanisms driving flow-abundance correlations are almost certain to vary by species and life stage. Although some effort has been made to evaluate different flow-related mechanisms (by comparing actual patterns to those expected from the operation of particular mechanisms; Kimmerer 2002a; Feyrer et al. 2007; Kimmerer et al. 2009), identifying particular mechanisms associated with abundance of each species and life stage is extremely difficult because of the challenges of working in an extremely large and complex environment, issues concerning the spatial or temporal scale at which different mechanisms operate (e.g. Nobriga et al. 2008), and our inability to conduct proper, controlled experiments on this (or any other) natural ecosystem. The difficulties associated with defining the mechanisms by which flow affects abundance of different species does not in any way undermine the central facts that (a) strong, persistent, multi-species flow-abundance correlations exist and (b) these correlations are very consistent with our knowledge of the biology of these species and estuarine ecosystem processes.

Where the mechanisms by which flows support abundance or other viability criteria are known, they may be valuable guides for developing flow criteria. For example, Sacramento splittail appear to benefit from the causal relationship between magnitude, timing, and duration of spring flows and the inundation of important floodplain spawning habitat (Sommer et al, 2002). Similarly, increases in growth and survival on the inundated Yolo Bypass of emigrating fall run Chinook salmon suggest that inundation of the bypass during the appropriate season will increase fall run Chinook salmon productivity (Sommer et al. 2001). Understanding this mechanism allows for flow recommendations that are targeted to produce beneficial effects for particular species by causing floodplain inundation for the appropriate duration, in the appropriate season, and with a desirable frequency of occurrence (*see* Exhibit 3).

The number of significant freshwater flow-abundance relationships (i.e. the number of species involved; e.g. Stevens and Miller 1983; Jassby et al 1995; Kimmerer 2002a; Feyrer et al. 2007; Kimmerer et al. 2009; Feyrer et al. *in review*) indicate that the correlations reflect a causal mechanism or suite of mechanisms that increase fish and invertebrate production as a result of increases in freshwater flow. These relationships are *extremely* unlikely to result from chance alone (that is the meaning of statistical significance) and it is also extraordinarily unlikely that the force driving abundance of so many estuarine species is independent of flows but just happens to fluctuate in concert with flows (i.e., a spurious correlation). As discussed above, where evidence regarding mechanistic relationships underpinning flow-abundance relationships is currently unavailable, flow criteria can and should be based on strong, persistent, and widespread statistical correlations between flow and abundance and other viability criteria

Several recent studies have noted “step-changes” (the displacement of the regression line by a constant value) in the freshwater flow-abundance relationships. Nonetheless, the correlations between freshwater flow and abundance are still strong and relevant. The statistical significance and slope (magnitude) of the flow-abundance relationships remain unchanged for many of the estuarine species studied (e.g. Kimmerer 2002; Rosenfield and Baxter 2007; Kimmerer et al. 2009). The freshwater flow-abundance relationships are usually "log:log" relationships, meaning that population responses are proportional to the order of magnitude of flow increases – these are powerful, high-magnitude effects. Two recent studies (Rosenfield and Baxter 2007 and Kimmerer et al. 2009) analyzed data from multiple sampling programs, collected over three to four decades, and found that the freshwater flow-abundance relationships were persistent, high-magnitude, and statistically significant. There have been significant physical and biotic changes in the San Francisco Estuary ecosystem over the past half-century (e.g. Nichols et al. 1990; Kimmerer 2004; Feyrer et al. 2007) and some of those changes (commonly called "other stressors") may have contributed to declines in the abundance of particular species that also have a flow-abundance relationship. Non-flow actions should be taken to respond to these changes where evidence supports alleviating other stressors in order to protect the viability of public trust resources.

However, non-flow actions cannot substitute for flow criteria for two major reasons.

First, despite the growing presumed or observed influence of other stressors in recent years, increasing flows still remain strongly correlated with increasing abundance. If these other stressors have had any effect on flow conditions (i.e., the step change in correlations), it would be to reduce somewhat the benefits provided at any given flow to flow-related public trust resources, implying that greater freshwater flow is needed than formerly to restore historical abundances of public trust species. In developing flow criteria we have recommended the *minimum* flows required to restore the viability of public trust species *if all other stressors are appropriately mitigated*.

Second, flows themselves can be powerful tools for addressing other stressors. For instance, higher peak flow events in the Delta can help control the spread of invasive species and reduce predation that increases when turbidity is low, and higher river inflows can reverse habitat loss and reduce predation by increasing the extent and duration of inundated floodplains.

Whereas mechanisms relating fresh water flow to estuarine secondary productivity are important research topics and potentially valuable management tools, freshwater flow requirements in the Delta have been and should continue to be based on the strong correlations between freshwater flow (e.g., as represented by X_2) and fish and wildlife populations, particularly where a mechanistic understanding of the relationship is still unknown. Jassby et al. (1995) documented many of the strong correlations between abundance and Delta outflow, and concluded:

> "[X_2] has simple and significant statistical relationships with annual measures of many estuarine resources, including the supply of phytoplankton and phytoplankton-derived detritus …; benthic macroinvertebrates …; mysids and

> shrimp; larval fish survival; and the abundance of planktivorous, piscivorous, and bottom-foraging fish. The actual mechanisms are understood for only a few of these populations." (Jassby et al 1995:272).

Kimmerer (2002b, 2004) provided excellent reviews of the complexity of the estuarine ecosystem and the potential for a variety of mechanisms to impact fish and wildlife resources that the Board has a responsibility to protect. He has since gone on to test (using correlative analyses) the likelihood that some of these mechanisms are actually at play. For instance, Kimmerer et al (2009) demonstrated that the relationships between freshwater flow and habitat volume for American shad and striped bass are consistent with their population response to flows – in other words, the relationship of freshwater flow to habitat volume or area may be a strong driving force for the population responses of these two species. For several other species (e.g. longfin smelt), the relationship between X_2 position and habitat volume may explain a portion of the population response to increasing freshwater flow. Whatever the causal relationships may be, he also found that the relationships between flow and abundance remained strong.

A mechanistic causal link between freshwater flow and population growth has not been definitively established for many public trust resources species. Absent such explicit data, scientifically sound flow criteria can and should be derived from strong, durable statistical correlations between freshwater flows and indicators of positive biological response (e.g. population size, population or individual growth rates). Waiting to implement flow regulations until researchers determine the mechanism underlying a causal relationship is unnecessary and has the effect of denying the existence of the correlation – an absurd approach – until a mechanism to explain it is demonstrated. We note that the absence of mechanistic explanations has not prevented aerospace engineers from developing airplanes (despite a complete lack of knowledge of the mechanisms underlying gravity) or prevented centuries of agricultural advances (which pre-dated our understanding of the biochemistry underlying inheritance via transfer of DNA).

We propose flow criteria for winter-spring outflows based on abundance criteria for longfin smelt, Bay shrimp, and starry flounder and criteria for fall outflows based on abundance criteria for delta smelt in Exhibit 2. We propose criteria for San Joaquin River inflows based on abundance criteria for Chinook salmon in Exhibit 3. We propose criteria for winter – spring Old and Middle River flows based on abundance criteria for Chinook salmon and Delta smelt in Exhibit 4.

Spatial extent (or distribution)

Summary points:

- *More widely distributed populations are less vulnerable to catastrophic events and risk of extinction.*
- *Flows affect spatial distribution by facilitating the movement of organisms in numerous ways and making suitable habitat available through floodplain inundation, salinity gradient, and other mechanisms.*

Maintaining or restoring spatial distribution of fish and wildlife species is a critical component of protecting these species and maintaining the public trust. The notion that spatial distribution is inversely proportional to extinction risk is axiomatic to modern conservation biology (e.g., MacArthur and Wilson 1967; Meffe and Carrol 1994; Laurance et al. 2002). Populations or species with limited or less varied geographic distributions are more vulnerable to catastrophic events, such as an episode of lethally elevated water temperature, disease, a toxic spill (such as the 1991 Cantara Loop metam sodium spill), drought, or other localized disturbances. The effect of geographic distribution on extinction risk is also apparent in the geographic attributes of extant freshwater fish species (Rosenfield 2002). Increased spatial distribution reduces susceptibility to localized catastrophes, predator aggregations, and disease outbreaks while simultaneously increasing the probability that at least some dispersing individuals will encounter habitat patches with favorable environmental conditions. The need to maintain adequate spatial distribution is regularly acknowledged in regulatory planning and decision-making regarding the Delta and its environs (e.g. USFWS 1995b; NMFS 2009).

Freshwater flows into, through and out of the Delta contribute directly to maintaining the spatial distribution of both resident and migratory species. Multiple mechanisms may contribute to this relationship (some or all of which may operate on different life stages of different species). Increased flows may transport larval and juvenile fish into, through, or out of the Delta (Kimmerer 2002b). For example, Delta inflows flows from the San Joaquin River are believed to contribute significantly to the survival and eventual return of salmonids migrating from the San Joaquin basin (CDFG 2005; *see analysis below*). Inadequate flows may also represent a barrier to migration; for example, freshwater flow rates are critical to preventing development of low dissolved oxygen in the lower San Joaquin River (Jassby and van Nieuwenhuyse 2005); episodes of low dissolved oxygen likely represent a barrier to fish migrations into and out of the San Joaquin basin (Hallock et al 1970; CVRWQCB and CBDA 2006). Thus, unless certain threshold flows into and out of the Delta are maintained, Chinook salmon and steelhead will not be able to reproduce in the southern part of the Central Valley – a severe restriction on their geographic range and major negative impact on the public trust.

In addition, freshwater flows through and out of the Delta appear to increase the area of habitat available to estuarine species and disperses fish into that habitat. Kimmerer et al. (2009) demonstrated that winter-spring outflows increased habitat for a number of estuarine dependent species with significant flow-abundance relationships. In particular, the flow-habitat relationships they found were of a scale capable of explaining the significant flow-abundance relationship for American shad and the flow-abundance and flow-survival relationships for striped bass. Feyrer et al (2007; *in review*) demonstrated a similar fall flow-habitat relationship that was consistent with spatial distribution of Delta smelt.

We propose flow criteria for fall Delta outflows based on spatial extent criteria for delta smelt in Exhibit 2 and observe that our winter – spring Delta outflow criteria to protect abundance of longfin smelt are also sufficient to protect the spatial distribution attribute of viability for longfin smelt larvae and juveniles. We propose flow criteria for winter – spring San Joaquin River inflows based on spatial extent criteria for Chinook salmon and for winter – spring Sacramento River inflows based on spatial extent criteria for Sacramento splittail, Chinook salmon and ecosystem public trust resource values in Exhibit 3.

Diversity

Summary points:

- *Species and populations that are both more genetically diverse and more diverse in life history patterns are more resilient to environmental change and less at risk of extinction.*
- *Maintaining the high variability in flows that characterize estuaries helps preserve the genetic and life history diversity of public trust resources.*

Natural diversity needs to be protected both within populations of specific public trust species and within the ecosystem as a whole. Natural diversity (e.g. life history patterns[2]) allows organisms to adapt to and benefit from environmental variability. This is an especially important characteristic in highly variable ecosystems such as the Delta. Flow criteria should also address the natural diversity of natural communities and other ecosystem attributes (e.g. seasonality, periodicity, duration, and richness).

Variability among individuals in a population increases the likelihood that at least some members of the population will survive and reproduce regardless of natural variability in the environment. For example, peak flows and associated environmental conditions (e.g. turbidity and salinity) have always been temporally variable in the Delta. Delta smelt and longfin smelt display protracted spawning periods in this ecosystem (Figure 7; Bennett 2005; Rosenfield and Baxter 2007; J. Hobbs, U.C. Davis, *personal communication*, December 3, 2009) and as a result, in every year some of their larvae hatch and metamorphose into juveniles at the appropriate time to capitalize on suitable environmental conditions. Similarly, for each run of Central Valley

[2] Although only genetically based traits are subject to evolution and not all diversity is genetically-based, it is a trait itself (genetically based or not) that confers the ability to survive and reproduce in different environments. Thus, in a conservation sense, flow criteria that protect natural diversity are protective of the public trust values whether or not the diversity is genetically based.

Chinook salmon, migration through the Delta occurs over many more months than the spawning/incubation period (Moyle 2002; Williams 2006); this suggests that historical environmental variability made migration success through the Delta and its environs, or the timing of ocean entry, less predictable than the timing for successful spawning/incubation upstream. Flow variability within the Delta is a natural part of the ecosystem and flow criteria should insure both the maintenance of appropriate variability[3] *and* the maintenance of the life history diversity that allows public trust resources to adjust to and thrive within that variability regime.

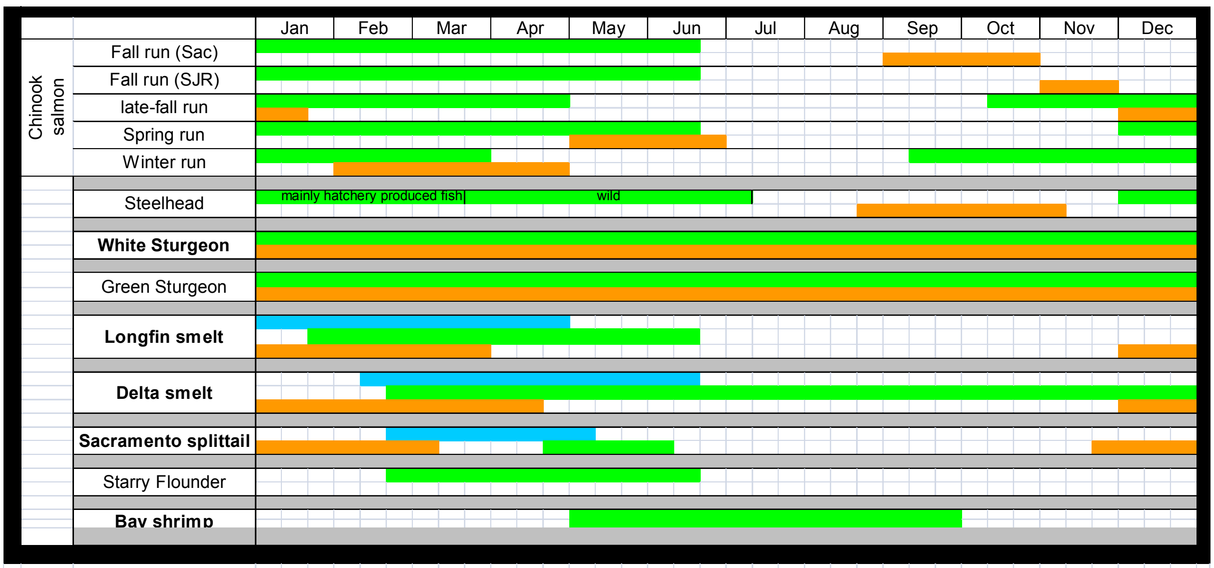


FIGURE 7: Approximate life history timing of native public trust species described in Exhibits 1-4. Life history timing varies with environmenal conditions in any given year and some individuals will complete their life cycle earlier or later than indicated in every year. Species in boldface are those for whom individuals or the entire population may reside in the Delta + Suisun Bay year-round.

While meeting abundance and spatial extent criteria contributes to natural diversity for species, communities, and the ecosystem as a whole, flow criteria may be necessary to directly address diversity needs for some public trust resources. For example, some water project operations impact life history (and potentially genetic) diversity in specific ways, beyond their measureable effect on abundance and distribution. Flow criteria that protect specific life-history attributes (e.g. early or late spawning individuals, particularly large individuals) provide additional protection to the population as these life-history variants are critical to a population's ability to capitalize on environmental variability.

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[3] Due to modifications to the estuarine ecosystem (e.g. invasion by numerous non-native species) "appropriate" variability may in fact be higher than historical. We support investigations of the timing, magnitude, frequency, and duration of variations in flow that will support native biological diversity in the face of pressures from invasive species. Potential increases in flow variability over historical norms for management purposes will emphasize the need to maintain life history and genetic diversity among Public Trust resources.

We propose flow criteria for winter-spring San Joaquin River inflows based on diversity criteria for Chinook salmon in Exhibit 3, and criteria for winter-spring Old and Middle River flows based on diversity criteria for delta smelt in Exhibit 4.

Productivity

Summary points:

- *A population's potential for population growth allows it to adjust to variable conditions in a dynamic estuary.*
- *Large-scale hydrologic alterations can reduce or even prevent population growth.*

The abundance, distribution and diversity of public trust resources cannot be adequately protected if human activities result in environmental conditions that regularly or chronically result in negative population growth (i.e., population decline), reduce the ability of depressed populations to recover, and/or cause the abundance, spatial extent, or diversity to fluctuate wildly.[4] Species or populations with persistent negative population growth, as well as populations with limited ability to respond positively to favorable environmental conditions, are less viable and at higher risk of extinction. In general, extraordinary population variability increases the risk of extirpation (May 1971) and should be avoided (e.g., Thomas 1990). For example, rapid and large declines in species abundance produce "genetic bottlenecks" that may constrain viability of a species for many generations even after abundance has recovered. Similarly, actions that impede a small population's natural ability to capitalize on the return of beneficial environmental conditions (e.g. loss of unoccupied habitat, decreased reproductive potential, mortality inversely proportional to population size) represent significant challenges to that population's viability as they impede recovery in other viability parameters. Additional measures that reduce anthropogenically-driven population variability are necessary to maintain productivity. Of particular concern are water project operations that increase the mortality of some species when environmental conditions (low Delta inflows and outflows) and population levels are already unfavorable.

We propose flow criteria for winter – spring Sacramento River inflows based on productivity criteria for the Delta food web, migratory birds, Sacramento splittail, and Chinook salmon in Exhibit 3. We propose flow criteria for winter - spring Old and Middle River flows based on productivity criteria for longfin and delta smelt and criteria for spring San Joaquin River inflow to export ratios based on productivity criteria for Chinook salmon in Exhibit 4.

[4] The estuarine environment is highly variable in nature (indeed, variability in some variables may define certain ecosystem processes) and we do not wish to suggest that this natural/historical variability should be constrained. However, human activities that contribute to unnaturally high variability or suppress the ability of populations to recover from periods of low abundance, distribution, or diversity endanger public trust resources.

TBI Recommended Flow Parameters for Purposes of this Proceeding

Summary points:

- *Flow criteria should be developed not only for Delta outflow. Delta inflows provide important ecological benefits for the estuary's many public trust resources.*
- *Along with information regarding bypass flows and other parameters, Sacramento River inflow criteria are also essential for evaluations of proposed new diversion and conveyance facilities in the North Delta.*
- *Criteria to limit reverse flows and other in-Delta hydrodynamic conditions are also needed to protect public trust resources, especially when flows are lower and population levels depressed.*
- *As a general rule, releases from upstream sources should be made proportionally to each stream and watershed to preserve ecological connectivity between the Delta and upstream watersheds and to avoid concentrating impacts on a subset of source areas.*
- *Flow criteria should, to the extent possible, be based on a "real curve" representing a continuous relationship between any particular hydrological condition and the flow parameter. Flow criteria that rely on discrete rules for different hydrological categories (e.g. wet year, dry year, critically dry year) produce unnatural flow patterns and generally result in actual flow levels that can be detrimental to the public trust.*

Public trust species use the Delta in a variety of ways according to their particular life history requirements, and are thus affected by different Delta flow parameters at different stages of their life histories. Figure 8 depicts the relation of numerous umbrella and other species to attributes of viability and flow parameters.

Viability Attribute	Flow Criteria			
	Delta outflows	San Joaquin River Delta Inflows	Sacramento River Delta Inflows	Delta Hydrodynamics
Abundance	**longfin smelt** **bay shrimp** **delta smelt** starry flounder Sacramento splittail striped bass American shad Eurytemora affinis (spring) *habitat abundance for estuarine species*	**fall run Chinook salmon** spring run Chinook salmon *Abundance of and transport to accessible cold-water riverine habitats and communities*		**SJR Chinook salmon** **Sacramento River Chinook salmon** **Delta smelt** *abundance of habitat for smelt species in the south Delta*
Spatial Extent	**longfin smelt** **Delta smelt** **striped bass YOY** starry flounder bay shrimp *transport both seaward and landward (e.g. gravitational circulation)*	**fall run Chinook salmon** **spring run Chinook salmon** steelhead white sturgeon green sturgeon Sacramento splittail longfin smelt Delta smelt *Distribution of productive cold-water riverine habitats and communities*	**fall run Chinook salmon** **Sacramento splittail** **spring run Chinook salmon** **winter run Chinook salmon** **late-fall run Chinook salmon** white sturgeon green sturgeon American Shad striped bass *increased distribution of floodplain*	longfin smelt Delta smelt fall run Chinook salmon (SJR) spring run Chinook salmon (SJR) *Spatial distribution of spawning and rearing habitats in the South Delta*
Diversity	*increased occurrence of juveniles seaward for freshwater spawners and landwards for marine spawners*	**fall run Chinook salmon** spring run Chinook salmon white sturgeon steelhead *Diversity of riverine hydrographs and habitats in the Central Valley*	fall run Chinook salmon spring run Chinook salmon winter run Chinook salmon late fall run Chinook salmon *increased availability of floodplain habitats*	**Delta smelt**
Productivity/ Stability	**longfin smelt** **bay shrimp**	**fall run Chinook salmon**	**fall run Chinook salmon** **Sacramento splittail** spring run Chinook salmon winter run Chinook salmon late-fall run Chinook salmon white sturgeon green sturgeon American Shad striped bass *increased production and transport of materials off of floodplains to river and tidal habitats*	**longfin smelt** **Delta smelt** **SJR Chinook salmon**

Figure 8: Public trust resources (species and ecosystem attributes) protected by flow recommendations in this submission. Bold text indicates that analysis of a species' catch, distribution, and life history data contributed directly to formulation of the flow recommendation. Research studies and or life history similarities indicate that other species (plain text) and ecosystem attributes (italics) will benefit from the recommended flows. The list is not exhaustive; absence of species names indicates absence of research that we are aware of, not absence of a mechanistic relationship (e.g., all species native to the lower Sacramento River are expected to benefit from a restoration of higher magnitude flows during the appropriate season).

While Delta outflow is a critical driver of ecological conditions in the estuary, restricting the Board's consideration of flow criteria to Delta outflow is unlikely to sufficiently address all the viability needs of the Delta's public trust resources. For this reason and to help meet statutory requirements, in addition to Delta outflow criteria, this testimony also proposes flow criteria for Sacramento and San Joaquin River inflows and Delta hydrodynamics. We further recommend that the geographic source of Delta inflow from the watershed be taken into account in the Board's decisionmaking.

In general, species are affected by flows in their immediate proximity (i.e., riverine species/life stages may be more strongly affected by Delta inflows or Delta hydrodynamics whereas estuarine pelagic species/life stages may be more strongly impacted by Delta outflows). Because species move seasonally and different life stages occur in different locations, the *magnitude* and *location* of their flow requirements change *seasonally*. At a minimum, therefore, it is worth considering the extent to which public trust resources have viability needs strongly associated with Delta inflows and hydrodynamics, in addition to Delta outflows.

Furthermore, actual Delta outflows may be composed entirely or largely of Sacramento River inflows for most of the year. Viability needs of the Delta's public trust resources, including those directly related to higher San Joaquin River inflows, are almost certain not to be met if they are reliant on Delta outflows that do not include a San Joaquin inflow requirement.

Improving Delta outflows will to a large extent track improving inflow patterns to achieve more desirable Sacramento River inflow amounts and timing. In addition to testing this assumption, developing Sacramento River inflow criteria also provides guidance to planning processes (as required by the legislation mandating these proceedings) such as the Bay Delta Conservation Plan that are evaluating the effects of constructing and operating North Delta diversion facilities to capture these inflows.

Delta hydrodynamic conditions where net flows are negative in the south Delta due to low inflows and outflows combined with high rates of export pumping can have devastating impacts on viability of public trust resources, particularly when population levels are as low as they are today. Flow criteria to address these within-Delta hydrodynamic conditions are necessary to complement outflow and inflow criteria.

Current Delta flow requirements are met by releases from selected federal and state storage facilities in the Delta's watershed. We recognize that the legislation requires the Board to address upstream public trust needs at a later date. However, in order to reasonably address the viability requirements of the Delta's public trust resources, the Board should adopt the principle that each tributary should contribute proportionally to Delta inflows as they relate to the migratory life cycles of trust resources. A disproportionate allocation between source streams of releases to meet downstream criteria disrupts the flow-related connectivity between the upstream and Delta life history stages of migratory species, and contributes (along with water project operations to meet unsustainable delivery commitments, arguably an even bigger cause of adverse impacts) to adverse flow and temperature conditions below facilities that are disproportionately responsible for meeting the criteria. We recommend that the Board include the principle that responsibility for meeting Delta flow criteria should be proportionately shared among source streams and watersheds, subject to the ecological conditions and disturbances particular to each source stream and watershed and other considerations.

Finally, we recommend that the flow criteria be expressed, to the maximum extent practicable, as continuous hydrographs that relate a measure of unimpaired runoff or other antecedent hydrological conditions to the specific flow criterion. These hydrographs may reflect the straightforward continuous relationships between flow and viability that exist for many public trust resources, or may reflect ecological thresholds that create step changes in the hydrograph. In either case, such an approach allows flow criteria to be highly sensitive to the actual hydrological conditions of each season and year, rather than the much cruder approach to flow criteria using water year types.

Uncertainty and Adaptive Management

Summary points:

- *Adaptive management requires clear goals, quantitative objectives, and appropriate indicators.*
- *Flow criteria should be based on the best available information, informed by conceptual models and hypothesis formulation, on what flow manipulations are most likely to meet the goals and objectives.*
- *Performance monitoring and assessment should be used over time to evaluate success and revise flow criteria to more effectively meet goals and objectives.*

The challenges of managing a highly complex, variable and dynamic estuarine ecosystem like the Delta are made far more difficult by the unprecedented degree of land conversion and hydrologic alteration that has transformed the Delta's landscape and hydroscape over the last 150 years. Emerging threats such as climate change and seismic risk increase the uncertainties exponentially.

Managing adaptively in such a challenging environment requires first and foremost the adoption of clear and measurable goals aimed at protecting the viability of public trust resources; quantitative, relevant, achievable, and time-bound objectives that describe the specific outcomes associated with achieving the goals; and ecological indicators for which data can feasibly be generated that measure progress toward meeting the objectives. These goals, objectives and indicators should directly address the viability attributes for specific public trust species, habitats, and ecosystems that flow criteria and flow manipulations are intended to affect. The CALFED Ecosystem Restoration Program Plan and the CVPIA Anadromous Fish Restoration Plan represent important foundational efforts for establishing goals and objectives for public trust resources.

Flow criteria should then be based, as we discussed earlier, on knowledge concerning causal mechanisms, significant correlations, historical conditions, and unimpaired runoff. Conceptual models such as those developed by the ERP Delta Regional Ecosystem Restoration Implementation Plan process can be extremely useful in clarifying the relationship between desired outcomes for public trust resources and proposed management actions, assessing the level of certainty associated with information used to develop flow criteria, and help clarify hypotheses concerning the response of public trust resources to flow manipulations.

Adaptive management cannot succeed without an active feedback mechanism between the managed environment and the decision making process. This requires that a well-designed, fully resourced program be implemented to monitor the response of public trust resources to flow manipulations and evaluate the effectiveness of flow criteria, in conjunction with other management actions and non-management factors, in achieving goals and objectives. Such a program must be a standardized process utilizing independent review and oversight whose results are reviewed on a regular basis by the Board, in order to ensure a credible and transparent decision making process and timely assessment of progress toward public trust protection goals and objectives.

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