WRITTEN SUMMARY OF THE DEPARTMENT OF WATER RESOURCES FOR THE PUBLIC INFORMATION PROCEEDING TO DEVELOP FLOW CRITERIA FOR THE DELTA ECOSYSTEM NECESSARY TO PROTECT PUBLIC TRUST RESOURCES FEBRUARY 16, 2010

INTRODUCTION

Through the recently enacted Water Code section 85086, the California Legislature directed, as part of the early actions, the State Water Resources Control Board (State Water Board) to "develop new flow criteria for the Delta ecosystem necessary to protect public trust resources", including "the volume, quality, and timing of water necessary for the Delta ecosystem under different conditions." The purpose of this task is not predecisional to any Board permit action, but instead to inform the "planning decisions for the Delta Plan and the Bay Delta Conservation Plan[.]" Additionally, this task must be completed within nine months.

In compliance with section 85086, the State Water Board has initiated the process by which it will develop the new flow criteria and issued a Notice of Public Informational Proceeding and Pre-Proceeding, dated December 16, 2009 (Notice). In the Notice, the State Water Board stated that the key issue for the informational proceeding is "what volume, quality, and timing of Delta outflows are necessary for the Delta ecosystem under different hydrologic conditions to protect public trust resources pursuant to the State Water Board's public trust obligations and the requirements of SB1."

The Department of Water Resources (Department) submits the following summary in response to the key issue and associated questions raised by the State Water Board in its Notice. Before focusing on the science, however, the Department would like to address a fundamental issue raised by the proceeding's key issue. While the following discussion is more policy than science, the Department believes that a brief discussion is warranted here because it provides the context and, in part, explains the Department's positions on how the key issue should be addressed.

In developing flow criteria necessary to protect public trust resources pursuant to the State Water Board's public trust obligations, the Board must, at some point, identify the level of protection that is required under State law. The standard which governs Board determinations generally, as well as those in the Bay-Delta estuary in particular, is the Constitutional standard of reasonable use and the Water Code injunction to serve the public interest. It should follow that the State standard for "level of protection" is that level which secures the reasonable use of water.

Applying the “reasonable use” principle to this proceeding has, in turn, two major implications. First, the reasonable level of protection for a given use can only be defined in reference to the costs it imposes upon other uses. When a particular level of protection is advocated for a given use, the first question that should be asked is, what are the costs of that level of protection on other uses. Parties and interests will come in and recommend various levels of protection for the public trust resources. However, it is only after the Board has considered all of those interests and uses, and after it has balanced them and made a reasonable allocation of water among them, that we can discover the level of protection to which any given use, or resource, is entitled.

Just as we cannot say that export users are entitled to a level of protection insuring a certain level of export per year without asking what the environmental consequences of that level of protection are, we cannot say that the public trust uses of the estuary ought to receive a certain level of protection without also inquiring what the water costs and economic consequences of that level of protection are.

The Department recognizes that given the short time frame in which the Board must complete its task and the fact that the developed criteria will not be considered predecisional, the State Water Board may take the position that balancing is not required for this proceeding. If that is the case, however, any specific criteria or advocated levels of protection that result from this proceeding must be clearly represented as unbalanced proposals or positions.

The second implication of applying the reasonable use principle is that it requires water to be used efficiently. A fundamental principle of California water policy is that water should not be taken from one beneficial use to serve another where non-water (physical) solutions or water-efficient physical solutions are available. While no water will be “changing hands”, so to speak, as a result of this proceeding, the principle that favors non-water solutions is very much applicable to this proceeding.

An example that can illustrate the above principle can be taken from the Board’s 1995 and 2006 Water Quality Control Plans. Both Plans recognized that a non-water solution through the operation of the Delta Cross Channel Gates could be used to help protect salmon and protect public trust resources. An important point of the above example is that when “flow” was postulated as the problem for salmon, only flow measures could be considered to solve that problem. However, when cross-channel diversion is understood to be the true difficulty (and actually not even that, but longer exposure to higher water temperatures or to agricultural diversions in the interior Delta), then two other additional measures become available: closures of the Delta Cross Channel or screening or modification of Delta agricultural diversions. Notably, both of these measures offer solutions that do not require additional flow [or as much additional flow].

These would be measures that the Board would be compelled to entertain by the California constitutional mandate to seek physical, non-water solutions.

This question of how to best balance water solutions such as outflow with other reasonable uses also arises in situations where flows or reverse flows are associated with abundances of other species, such as delta smelt. If what is actually happening is that "flow" is moving delta smelt beyond the potentially adverse influence of diversions or that reverse flow causes the smelt to be more susceptible to loss at the State Water Project facilities, then neither outflow nor positive flow are truly habitat requirements. They are simply secondary or intermediate mechanisms to remove delta smelt from the influence of the perceived primary concern: entrainment loss. And, as in the example of Chinook salmon, measures to correct this concern need not necessarily be either Delta outflow or positive flow in the San Joaquin River. Every time abundance is said to be correlated with flow, or with outflow, or with any other flow-type phenomenon, we must ask if there is not a further or ultimate issue that flow may be masking. This is especially true when we see certain fishery responses related to flow when issues like pollutant discharges (e.g. nitrogen effects on the base of the food web) may be actual cause of the relationship. Wise water use and reasonable public policy would be to address the discharge issue before requiring water to dilute these pollutants. Knowing the mechanism driving relationships are key to ensuring reasonable use of water consistent with the constitutional requirement to prevent waste and unreasonable use of water.

It is only through this careful analysis of flow and its intended benefits, and a full understanding of the Delta's ecological needs that we may begin to understand how the Delta's ecosystem is "broken" and how in the short-term or in the long-term we may adequately and efficiently protect it. It is also key to understanding how near-term criteria may relate to the long-term solution to be developed in the Delta Plan and Bay-Delta Conservation Plan (BDCP). It is important for the Board to distinguish between those issues in which outflow is necessarily involved from those issues in which outflow is proposed to correct a problem fundamentally with diversion, flow regimen, or other stressors within the Delta.

With the State water policy of finding the reasonable and efficient use of water in mind, the following discussion addresses the key issue and related questions raised in the Board's Notice.

1. **What key information, in particular scientific information or portions of scientific information, should the State Water Board rely upon when determining the volume, quantity, and timing of water needed for the Delta ecosystem pursuant to the board's public trust obligations? What does this scientific information indicate regarding the minimum and maximum volume, quality, and timing of flows needed under the existing physical conditions, various hydrologic conditions, and biological conditions? With respect to biological conditions, what does**

the scientific information indicate regarding appropriateness of flow to control non-native species?

The below summary includes key points and information regarding Delta outflow. Importantly, the information does not indicate what the minimum and maximum volume of flows should be under various conditions. Given the poor state of primary drivers such as food supply and habitat (productive tidal water habitat, not “habitat” as measured by X2), changing the current Delta outflow regime would likely have limited effect in increasing Delta ecosystem protection.

Nonetheless, changing aspects of the Delta flow regime could have positive effects on primary drivers such as food supply. For example, increasing flows down the Yolo Bypass has been demonstrated to have positive effects on food supply and rearing. However, this type of change in Delta flow regime does not necessarily require a change in the existing Delta outflow objectives. Perhaps the best method to address this specific issue is to find ways to flood the Yolo Bypass with more frequency by lowering the Fremont Weir with an operable gate and keeping the Delta outflow unchanged. This is being actively explored in the BDCP process.

There are multiple factors affecting the upper estuary ecosystem. Delta outflow is just one of many.

Given the large population of California and the extensive urban and agricultural economy built around the region, it is no surprise that San Francisco estuary has been heavily modified (Atwater et al. 1979; Nichols et al. 1986; CALFED 2008). Indeed, this is the case for the all of the other major estuaries on the Pacific Coast of the United States. The high degree of alteration at multiple levels has caused major adverse changes in each of these systems.

The different factors affecting the estuary have been studied at varying levels of detail for several decades, leading to a large body of literature on the multiple factors affecting fishes in the upper estuary. Most recently, the major factors have been reviewed in detail by CALFED (2008) and the Interagency Ecological Program (Baxter et al. 2008), the latter of which focused on pelagic fishes. To summarize briefly, the current basic conceptual model is four major components: (1) prior fish abundance, which recognizes that continued low abundance of adults fishes leads to low juvenile production (i.e., stock-recruit effects); (2) habitat, which recognizes that estuarine water quality variables (e.g. ammonia, pesticides), disease, and toxic algal blooms (e.g. Microcystis) in the estuary affect survival and reproduction; (3) top-down effects, which recognizes that invasive predators (e.g. largemouth bass) and water project entrainment affect mortality rates of fishes; and (4) bottom-up effects, which recognizes that food web interactions (e.g. changes in zooplankton abundance and species, low phytoplankton production) affect survival and reproduction of estuarine organisms.

There are several examples that help illustrate the importance of some of the above effects. First, there has been an apparent increase in the number of toxic *Microcystis* blooms coincident with the Pelagic Organism Decline (Baxter et al. 2008). While these blooms may not affect all of the POD species, they reflect an overall degradation of habitat conditions in the ecosystem. Ammonia loading has been increasing substantially (Figure 1; Jassby 2008), potentially an issue for the downstream food web (Wilkerson et al. 2006; Dugdale et al. 2007). Specifically, primary production is relatively low in the San Francisco estuary, which in turn is thought to reduce fisheries yields (Figure 2). Moreover, there has been a recent major decline in chlorophyll *a* coincident with the invasion of the clam *Corbula*. These changes are thought to be much more than academic as zooplankton growth in the estuary has been directly linked to chlorophyll a (Mueller-Solger et al. 2002); hence, changes at lower trophic levels can affect the food supply of species such as delta smelt. This is illustrated in a recent analysis by Kimmerer (2009), who showed a statistical relationship between delta smelt survival and copepod biomass (Figure 3).

In addition to these factors, flow is known to be an important issue for the ecosystem. A recent conceptual model prepared by the U.S. Fish and Wildlife Service's Habitat Study Group (formed as requirement of the 2008 Delta Smelt Biological Opinion) proposes conceptually how flow might pelagic fishes including delta smelt (Figure 4). Specifically, delta fishes are strongly affected by a series of "drivers" (also referred to as "stressors") that can either improve or impede their populations. As illustrated in Figure 4, flow could act as a follow-up "filter" that modulates the response. In other words, while things such as food supply and habitat are the primary drivers, flow might influence the magnitude of impact from a given change. For example, contaminants represent a primary driver, but flow changes can influence its effect by diluting or concentrating toxins. In this way, flow itself is not a primary driver, although it can affect outcomes. From a State Water Board point of view, the pollutant issues need to be addressed first in these cases before it considers changes in flows to address what are actually pollutant issues.

There are still relationships between Delta outflow and the abundance of some species, but these relationships have deteriorated in recent years.

As reported by Jassby (1995), the San Francisco estuary is fairly unique because it has flow-abundance relationships for a suite of fishes and invertebrates. As noted below, the causes of these relationships are not known; however, they seem to be present across a suite of trophic levels. Examples included relationships for bay shrimp, starry flounder, Pacific herring, American shad, longfin smelt, splittail, and striped bass. The existence of these relationships was a major rationale for the current State Water Board flow criteria found in the 1995 and 2006 Water Quality Control Plans for the estuary, which focuses on flow targets during the key winter-spring spawning and rearing period for many organisms (SWRCB 1995).

One of the most significant developments in recent years is the deterioration of the flow-abundance relationships. There seem to have been at least two major step changes in the relationships. First, Kimmerer (2002a; 2009) showed that many of the relationships weakened following the invasion of the clam Corbula around 1987. After that point there were still significant relationships between species abundance and outflow, but fewer fish were produced for a given amount of net Delta outflow. Perhaps even more dramatically, there was another major step change around 2000 coinciding with the Pelagic Organism Decline (Sommer et al. 2007; Thomson et al. 2009). As described in Sommer et al (2007) and Kimmerer et al. (2009), moderate to wet years after 2000 no longer resulted in the expected production of several pelagic fishes. For example, this was apparent for longfin smelt and juvenile striped bass, whose recent abundance levels fall below the expected post-1987 X2-abundance relationships (Figure 5). Simply put, the ecosystem is getting much less “bang for buck” for a given amount of flow than just two or three decades ago.

The causes of the relationships between Delta outflow and species abundance are still relatively poorly understood

As noted above, it is remarkable that a broad suite of species respond to outflow. Hence, one of the major research topics for the past 15+ years has been to evaluate the mechanisms behind the apparent flow-abundance relationships. Examples include the “entrapment zone” studies in the mid-90s (Kimmerer et al. 1999; Bennett et al. 2002) to recent evaluations of habitat (Kimmerer et al. 2009). The mechanisms have been examined in particular detail by Kimmerer (2002a) as well as Kimmerer and Bennett (2008), the latter of which is a work plan to specifically address the major questions.

Despite the high level of research into the flow-abundance relationships, the specific mechanisms remain fairly elusive. As noted by Kimmerer (2002a) and Kimmerer and Bennett (2008), there are multiple mechanisms by which flow might influence species, some of which likely interact. It is therefore not a trivial task to describe the specific pathways by which flow may influence and affect species abundance. In addition, if the conceptual model of the USFWS habitat study group’s is correct, flow may act as filter that modulates the effects of the suite major drivers (Figure 4). The consequence of this is that it may be difficult to separate the marginal effect of flow from the broader effect of the main drivers (e.g. food web alteration and toxins).

While there are still major uncertainties about the potential effects of flow, this does not mean that no progress has been made towards addressing this issue. First, the work of Kimmerer (2002b) and Kimmerer and Bennett (2008) have done an excellent job of cataloguing the likely suite of mechanisms. The latter study has taken things a step further by developing a list of suggested targeted research to resolve these issues. Secondly, there has been good progress in studying some of the individual mechanisms. As described in Kimmerer (2002b) and Kimmerer and Bennett (2008), the general categories of mechanisms include increased food supply, improved water quality, better transport, and increased habitat availability.

The effect of flow on food supply could result from a variety of was at higher flow such as increased nutrient and organic material loading, increased stratification, and dilution of contaminants (e.g. ammonia). At its most basic level, this pathway follows the “agricultural model”, where the base of the food web drives abundance at higher trophic levels (Nixon et al. 1986; 1988; Figure 2). Potential linkages between food and abundance have been noted for several pelagic fishes including delta smelt (Baxter et al. 2008; Kimmerer 2008). However, this mechanism is difficult to evaluate because the relative contribution of organic carbon (e.g. bacterial pathways) versus phytoplankton are not clear. This issue is therefore the target of intensive CALFED-funded research by San Francisco State University.

Transport effects are especially complicated, potentially resulting from the following changes at higher flow: reduced diversion losses of organisms or their food supply, increased food transport, better migration cues, faster downstream migration, and increased gravitational circulation. The latter was central to the reigning conceptual model during in the early 90’s. Gravitational circulation is a physical process that can enhance concentrations of food and young organisms (Kimmerer et al. 1999; Bennett et al. 2002). The research confirmed that there are indeed regions of the estuary with enhanced concentrations of different constituents and that organisms in these regions exhibit complex behaviors. However, Schoelhammer and Burau (1998) report that gravitational circulation is more strongly dependent on geography than simple flow patterns, so this mechanism does not function linearly like the flow-abundance relationships. Note that this revelation led to a much broader range of research studies on the potential mechanisms.

Water quality changes associated with flow include dilution of contaminants, lower salinities, reduced benthic grazing of food, and increased sediment and turbidity leading to lower predation rates. Although some contaminants are diluted by flow, Kimmerer and Bennett (2008) questioned the former mechanism because pesticide concentrations are often highest during rainfall events, when flow is also higher. This doesn’t mean that contaminants are not affected by flow; rather, the relationships may be complex and involve mixtures of toxins. With respect to benthic grazing, high flow events have been observed to reduce abundance of Corbula in the upper estuary (Baxter et al. 2008), but some of the benefits may be offset by range expansion by freshwater Corbicula from upstream (Kimmerer and Bennett 2009). Based on research in other systems (e.g. Gregory and Levings 1998), Nobriga et al. (2005) hypothesized that higher water clarity increased predation risk for delta smelt, young striped bass, and other fishes typically associated with turbid water. As a consequence, increased turbidity at higher flows may be beneficial.

Finally, habitat area or volume may increase, providing refuge from predators, spawning and rearing habitat, and improved food supply. This is perhaps the best-studied mechanism by which flow might influence abundance. The best example is inundation of the upstream Yolo Bypass at high flows, which provides spawning and rearing habitat for splittail, the most floodplain dependent species in the estuary (Sommer et al. 1997; Moyle et al. 2004). Hence, the positive relationship between flow and splittail abundance appears to be a result of Delta inflow, not outflow (Kimmerer 2002b; Kimmerer and Bennett 2008). The most recent work in this topic has been focused on how flow may affect habitat area for estuarine fishes. Kimmerer et al. (2009) found that flow was positively associated with both habitat area and volume for several delta fishes. However, the linkage between habitat changes and abundance was shown for only two fish species, both introduced species. Feyrer et al. (2007), who found evidence of increased delta smelt habitat (based on salinity) at higher flow. However, Kimmerer et al. (2009) concluded that habitat area did not seem to be a reasonable single mechanism for most of the flow-abundance relationships. Hence, the potential linkages between habitat area and abundance remain unclear for most of the estuarine fishes, particularly delta smelt (PBSJ 2008).

Flow is not a very effective tool unless the mechanisms for benefits are understood.

As noted above, the current conceptual model of flow effects (Figure 4) considers flow as a filter that moderates ecological effects. However, management of flow by itself may be relatively inefficient if the basic mechanisms underlying the linkages between flow and abundance are not understood. As an example, the pathway for flow may be as important as (or more important than) the quantity of flow in the system. Such is the case in Yolo Bypass, where inflow from the Sacramento River can either flow down the main stem river or inundate the seasonal floodplain of the bypass. Research over the past decade has clearly demonstrated that flow through the Yolo Bypass enhances rearing for juvenile Chinook salmon (e.g. enhanced food and growth) and provides spawning habitat for splittail. The latter is probably the most floodplain dependent fish in the estuary (Moyle et al. 2004).

The bottom line is that a major effort is needed to evaluate the mechanisms for flow effects. Some of these studies are planned as part of the new IEP work plan (IEP, in preparation).

Flow variability targets need to consider and integrate ecosystem and individual species requirements, as well as future changes to the estuary.

It is now accepted that flow variability in estuaries is a good thing (Moyle et al. 2009). It is therefore important to have both period high flow and low flow events. In the San Francisco estuary, allowing salinity to intrude during dry years may benefit the ecosystem by controlling invasive species such as the clam Corbula and the aquatic weed Egeria. However, there is also evidence that delta smelt often do poorly in dry years. As a consequence, we have a *Flow Variability Paradox*—periodic major salinity intrusion may be a good thing for the ecosystem, but a bad thing for delta smelt (Moyle et al. 1992; Feyrer et al. 2007). One possible way to resolve this paradox is through habitat restoration. At present, higher salinities "push" delta smelt into narrow Delta channels where habitat conditions are thought to be poor. Major restoration of the Delta through processes like BDCP could make upstream areas much more beneficial for delta smelt, and allow more salinity variability (which would benefit the ecosystem as whole). Examples of key locations for restoration include Sherman Island and Cache Slough Complex.

Note that catastrophic changes to the delta such as levee breaks from earthquakes, floods or sea level rise could also totally alter the quality and of habitat for delta fishes (Lund et al. 2007, 2008; Moyle et al. 2008). Indeed, the consensus at a 2008 Interagency Ecological Program Estuarine Ecology Team meeting was that projecting flow targets for dramatically different future Delta conditions currently may not be feasible. The bottom line is that flow variability targets need to be considered in relation to the landscape, both present day and future (e.g. following BDCP, sea level rise).

2. What methodology should the State Water Board use to develop flow criteria for the Delta? What does that methodology indicate them needed minimum and maximum volume, quality, and timing of flows are for different hydrologic conditions under the current physical conditions of the Delta?

In light of the Legislature's direction, and possibly the perception as well, and the fact that the Board has only nine months to develop the criteria, it is understandable why Delta outflow, X2 in particular, is the initial focus of this proceeding.

The X2 objective was developed by lumping together an assortment of biological factors and considerations: avoiding entrainment of organisms at agricultural diversions and project export facilities in the Delta; transport flows; location of the entrapment zone; reverse flows; cross-Delta flow; low-salinity habitat; food supply; organic loading; etc. The proponents of X2 believed that the most beneficial feature of using a single estuarine variable as a management device is that policy makers could simply "dial" the amount of estuarine protection they wanted. Under this approach, even problems which do not necessarily need water could be cured or their effects mitigated by "dialing" for more water.

This formulation may be wonderful in its simplicity, but it does not help or support the idea that we are supposed to be looking for solutions that don't waste water and use water reasonably especially when there are other more effective way to protect aquatic resources. To explore physical or other non- water-costing solutions, we must begin to separate out biological and hydrologic mechanisms to be able to respond individually to those needs that do not necessarily place a demand upon scarce water supplies, such as food supply, flow regimen, etc.

Thus, the Department recommends a systematic approach to determining what is necessary to protect the Delta ecosystem. This approach involves several steps. First, we must identify and focus on the basic needs or primary drivers of aquatic communities. Once the basic needs are identified, the next step is to examine what factors significantly contribute to or detract from providing the basic needs. Then, where flow has been identified as a contributor to providing a basic need, it must be determined what the volume, quality, and/or timing of flow is needed. Lastly, all the areas where flow has been identified as a proper mechanism should be reviewed in consideration of other reasonable uses.

Under this approach, flow becomes one of the factors affecting the basic needs of the estuarine communities – as opposed to being represented as a primary driver of the Delta ecosystem. By doing this, we will be better able to determine where flow is the proper/necessary mechanism to provide a basic need and where other factors either sufficiently provide the basic need or reduce the reliance on flow.

While this approach is certain to lead to a better understanding of the relationship between flow and aquatic communities, the Department is uncertain as to what the ultimate indications for Delta flows will be. The Department realizes that the Board is being directed to develop "new" criteria, but we do not believe that new numerical criteria are necessary for Delta outflow. There are few studies where causal mechanisms between outflow and a particular need or driver have been identified. Also, the statistical relationships between X2 and abundances (the main rationale for X2) are deteriorating. This, of course, does not mean outflow or X2 is not important to ecosystem health, but it does suggest that there are other factors causing problems or, at least, severely limiting the current flow regime's effectiveness. As such, there seems to be no reason for the resulting criteria to differ from the current outflow objectives included in D-1641.

3. **When Determining Delta outflows necessary to protect public trust resources, how important is the source of those flows? How should the State Water Board address this issue when developing Delta outflow criteria?**

Delta outflow, whether indexed by X2 or not, is water that originates from sources largely upstream of the delta. In determining how much outflow is needed, the impacts on where that water must come from (the source of those flows) must be determined and considered. This consideration will help determine whether the flows are reasonable and will be helpful to the BDCP process as it weights the impact of the flows on the other beneficial uses of the water.

4. How should the State Water Board address scientific uncertainty when developing the Delta outflow criteria? Specifically, what kind of adaptive management, monitoring, and special studies programs should the State Water Board consider as part of the Delta outflow criteria, if any?

It is wholly appropriate for the Board to take an action based upon facts and circumstances that are less than certain, especially as the potential benefit of that action increases. But it is imperative that the factual or scientific basis for such decisions be fully and accurately represented so that society and future decision makers will not be misled by the character of the determinations and actions taken in this proceeding.

Where there is uncertainty with a particular criterion, that uncertainty should not only be highlighted and discussed, an approach to address or reduce the uncertainty should be developed as well. In fact, the Department is hopeful that some beneficial results of this proceeding will be 1) a clear statement/summary of the current status of understanding of the relationship between flow and the Delta ecological health including the need to resolve pollutant related effects Delta productivity before addressing changes in the outflow criteria and 2) an identification of critical gaps in scientific knowledge that can be used to guide future research and monitoring activities.

5. What can the State Water Board reasonably be expected to accomplish with respect to flow criteria within the nine months following enactment of SB 1? What issues should the State Water Board focus on in order to develop meaningful criteria during this short period of time?

The Department cannot provide detailed guidance on what the State Water Board can be reasonably expected to accomplish since much of that depends on the resources the Board has and is willing and able to devote to this process. However,, the Department believes that nine months is too short of a time period to adequately develop and assess a new flow regime for all criteria in the Delta. As such, the State Water Board should focus on developing the narrative criteria needed to establish new outflow objectives. Chief among these is the need to address the growing linkage between increased nitrogen discharges and the effects this is likely having of the primary productivity of the Delta and those effects on both zooplankton production and the abundance of key pelagic fish species. As discussed above, the Department does not consider the current Delta outflow objectives set forth in the 2006 Water Quality Control Plan are ripe for change because of the current state of the science.

References

Atwater, B. F., S.G. Conard, J. N. Dowden, C.W. Hedel, R.L. MacDonald, and W. Savage. 1979. History, landforms and vegetation of the estuary's tidal marshes. Pages 347-385 in T.J. Conomos, ed. San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science, San Francisco, CA.

Baxter, R., R. Breuer, L. Brown, M. Chotkowski, F. Feyrer, M. Gingras, B. Herbold, A. Mueller-Solger, M. Nobriga, T. Sommer, and K. Souza. 2008. Pelagic organism decline progress report: 2007 synthesis of results. Interagency Ecological Program for the San Francisco Estuary, Technical Report 227.

Bennett, W. A., W.J. Kimmerer, and J.R. Burau. 2002. Plasticity in vertical migration by native and exotic fishes in a dynamic estuarine low-salinity zone. Limnol. Oceanogr 47:1496-1507.

CALFED. 2008. The State of Bay-Delta Science 2008. Available at: http://www.science.calwater.ca.gov/publications/sbds.html

Dugdale, R.C., F.P. Wilkerson, V.E. Hogue, and A. Marchi. 2007. The role of ammonium and nitrate in spring bloom development in San Francisco Bay. Estuarine, Coastal and Shelf Science 73:17-29.

Feyrer, F., M. Nobriga, and T. Sommer. 2007. Multi-decadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences 64:723-734

Gregory, RS, Levings, CD. 1998. Turbidity reduces predation on migrating juvenile Pacific salmon. Transactions of the American Fisheries Society 127:275-285.

Jassby, A. D., W. J. Kimmerer, S. G. Monismith, C. Armor, J. E. Cloern, T. M. Powell, J. R. Schubel, and T. J. Vendlinski. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological Applications 5: 272-289.

Jassby, A.D. 2008. Phytoplankton in the upper San Francisco Estuary: recent biomass trends, their causes and their trophic significance. San Francisco Estuary and Watershed Science. Vol. 6, Issue 1 (February), Article 2.

Kimmerer, W.J, J. R. Burau, and W.A. Bennett. 1998. Tidally-oriented vertical migration and position maintenance of zooplankton in a temperate estuary. Limnology and Oceanography 43:1697-1709.

Kimmerer, W.J. 2002a. Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages. Marine Ecology Progress Series 243:39-55.

Kimmerer, W. J. 2002b. Physical, biological, and management responses to variable freshwater flow into the San Francisco Estuary. Estuaries 25: 1275-1290.

Kimmerer, W. J., E. S. Gross, and M. L. MacWilliams. 2009. Is the response of estuarine nekton to freshwater flow in the San Francisco Estuary explained by variation in habitat volume? Estuaries and Coasts DOI 10.1007/s12237-008-9124-x.

Kimmerer, W. and W.A. Bennett. 2008. Research plan to determine the mechanisms underlying the "Fish-X2" relationships. Report to the CALFED Ecosystem Restoration Program. Contract ERP-01-P19.

Lund, J., E. Hanak, W. Fleenor, W. Bennett, R. Howitt, J. Mount, and P. Moyle. 2008. Comparing Futures for the Sacramento-San Joaquin Delta. San Francisco: Public Policy Institute of California. 184 pp.

Lund, J., E. Hanak., W. Fleenor, W., R. Howitt, J. Mount, and P. Moyle. 2007. Envisioning futures for the Sacramento-San Joaquin Delta. San Francisco: Public Policy Institute of California. 284 pp.

Moyle, P.B. 2008. The future of fish in response to large-scale change in the San Francisco Estuary, California. Pages 357-374 In K.D. McLaughlin, editor. Mitigating Impacts of Natural Hazards on Fishery Ecosystems. American Fishery Society, Symposium 64, Bethesda, Maryland.

Moyle, P. B., B. Herbold, D.E. Stevens, and L.W. Miller. 1992. Life history and status of delta smelt in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society 121:67-77.

Moyle, P.B., R.D. Baxter, T.R. Sommer, T.C. Foin, and S.A. Matern. 2004. Biology and population dynamics of Sacramento splittail (Pogonichthys macrolepidotus) in the San Francisco Estuary: a review. San Francisco Estuary and Watershed Science 2:2(May 2004), Article 3.

Moyle, Peter, William A. Bennett, William E. Fleenor, and Jay R. Lund. 2009. Habitat Variability and Complexity in the San Francisco Estuary. Unpublished report. Center for Watershed Sciences, University of California, Davis.

Nichols, F. H., J. E. Cloern, S. N. Luoma, and D. H. Peterson. 1986. The modification of an estuary. Science 231:567-573.

Nixon et al. 1986. Nutrients and productivity of estuarine and coastal marine systems. Journal of the Limnological Sodciety of South Africa 12: 43-71.

Nixon, S.W., 1988. Physical energy inputs and the comparative ecology of lake and marine ecosystems. Limnology and. Oceanography, Part II 33 (4), 1005–1025.

Nobriga, M. L., F. Feyrer, R. D. Baxter, and M. Chotkowski. 2005. Fish community ecology in an altered river Delta: spatial patterns in species composition, life history strategies and biomass. Estuaries. 776-785.

PBSJ. 2008. Independent peer review of two sets of proposed actions for the OCAP. November 18, 2008. Prepared for USFWS.

Schoelhammer, D.H. and J.R. Burau. 1998. Summary of findings about circulation and the estuarine turbidity maximum in Suisun Bay, CA.USGS Fact Sheet FS-047-98.

Sommer, T., R. Baxter, and B. Herbold. 1997. Resilience of splittail the the Sacramento-San Joaquin Estuary. Transactions of the American Fisheries Society 126:961-976.

Sommer, T., C. Armor, R. Baxter, R. Breuer, L. Brown, M. Chotkowski, S. Culberson, F. Feyrer, M. Gingras, B. Herbold, W. Kimmerer, A. Mueller-Solger, M. Nobriga, and K. Souza. 2007. The collapse of pelagic fishes in the upper San Francisco Estuary. Fisheries 32:270-277.

State Water Resources Control Board. 1995. Environmental Report: Appendix 1 to Water Quality Control Plan for the San-Francisco Bay/Sacramento-San Joaquin Delta Estuary. V 10-15; VIII 25-27. (By reference.)

Thomson, J.R., W. J. Kimmerer, L. R. Brown, K. B. Newman, R. Mac Nally, W. A. Bennett, F. Feyrer, E. Fleishman. 2009. Bayesian change-point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary. In press, Ecological Applications

Wilkerson F. P., Dugdale R. C., Hogue V. E., Marchi, A. 2006. Phytoplankton blooms and nitrogen productivity in San Francisco Bay. Estuaries and Coasts 29: 401-416.

Figure 1: Increases in ammonium loading to the San Francisco estuary. Source: Dave Fullerton, Metropolitan Water District. Jassby (2008) found similar trends.

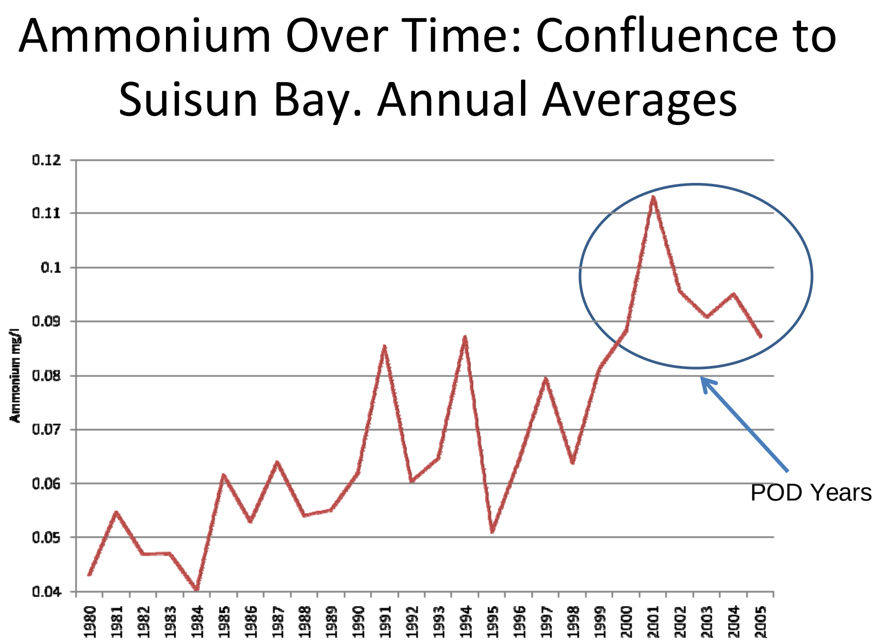

Figure 2. Mean value and range in primary production in Suisun Bay and the Delta in the 1970s and 1990s plotted on the relationship of fishery yield to primary production from other estuaries around the world (modified from Nixon 1988, using data provided by Alan Jassby, U.C. Davis and James Cloern, U.S. Geological Survey).

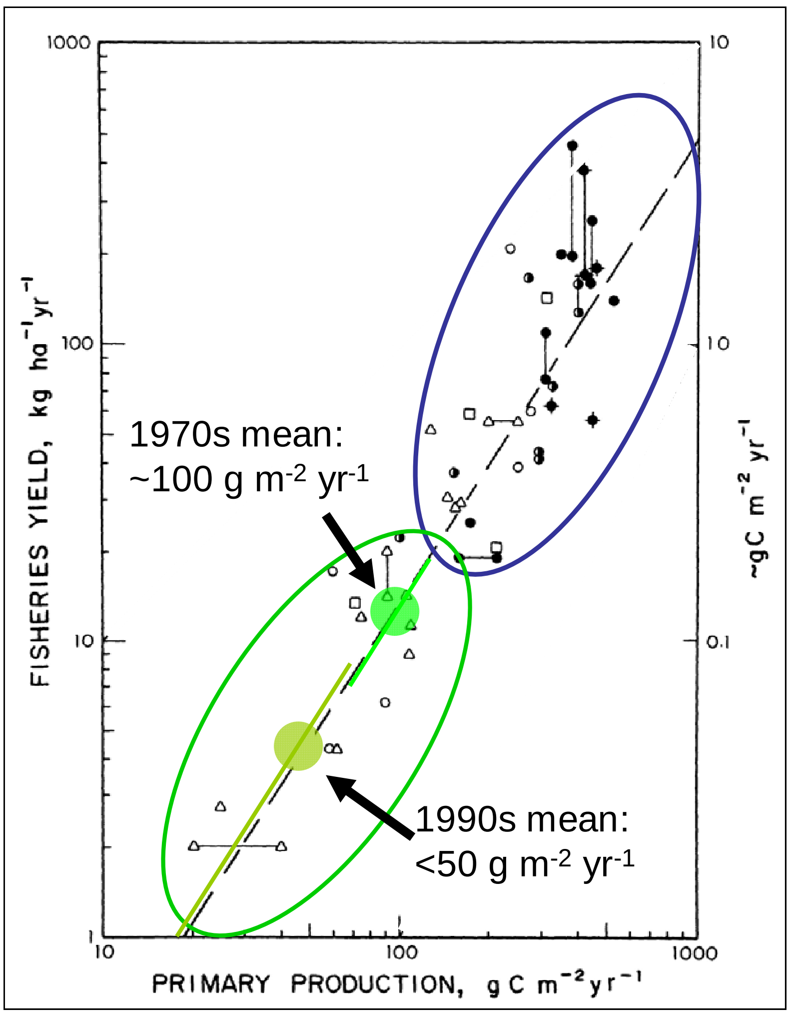

Figure 3. Relationship between delta smelt survival index and copepod biomass (Kimmerer 2009). Specifically the data show the summer to fall survival index of delta smelt in relation to zooplankton biomass in the low salinity zone (0.15 – 2.09 psu) of the estuary. The survival index is the log ratio of the Fall Midwater Trawl index to the Summer Townet Survey index.

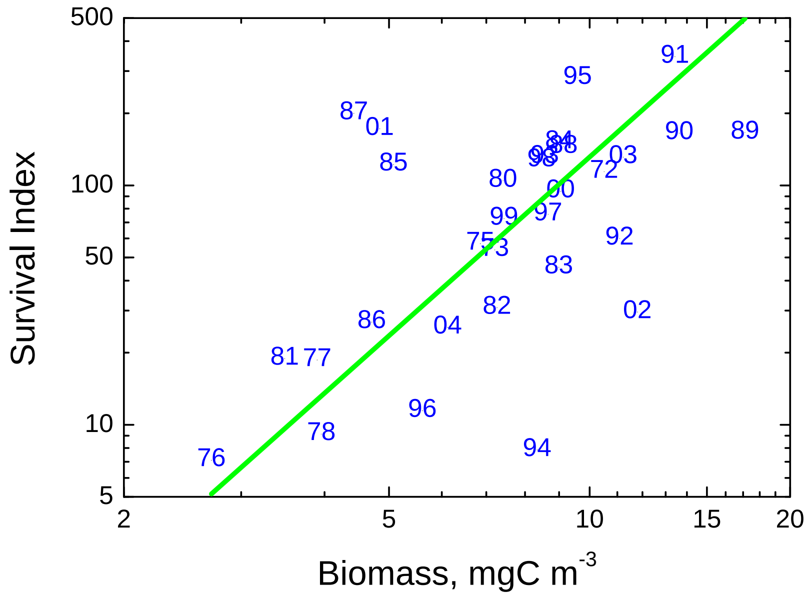

Figure 4: Conceptual Model showing how flow acts as a “filter” for major drivers such as food web changes, water quality, and mortality. Source: Interagency Ecology Program Pelagic Organism Decline Habitat Study Group Draft 2009 Conceptual Work Plan, Evaluation of the Effects of Fall X2 on Delta Smelt. Distributed at FWS workshop 2009. The main point is that young delta smelt are affected by are suite of different drivers. The exact response of the fish to these drivers is subsequently affected by flow. Finally, the ultimate effects on adult fishes can be variable depending on the response of the drivers.

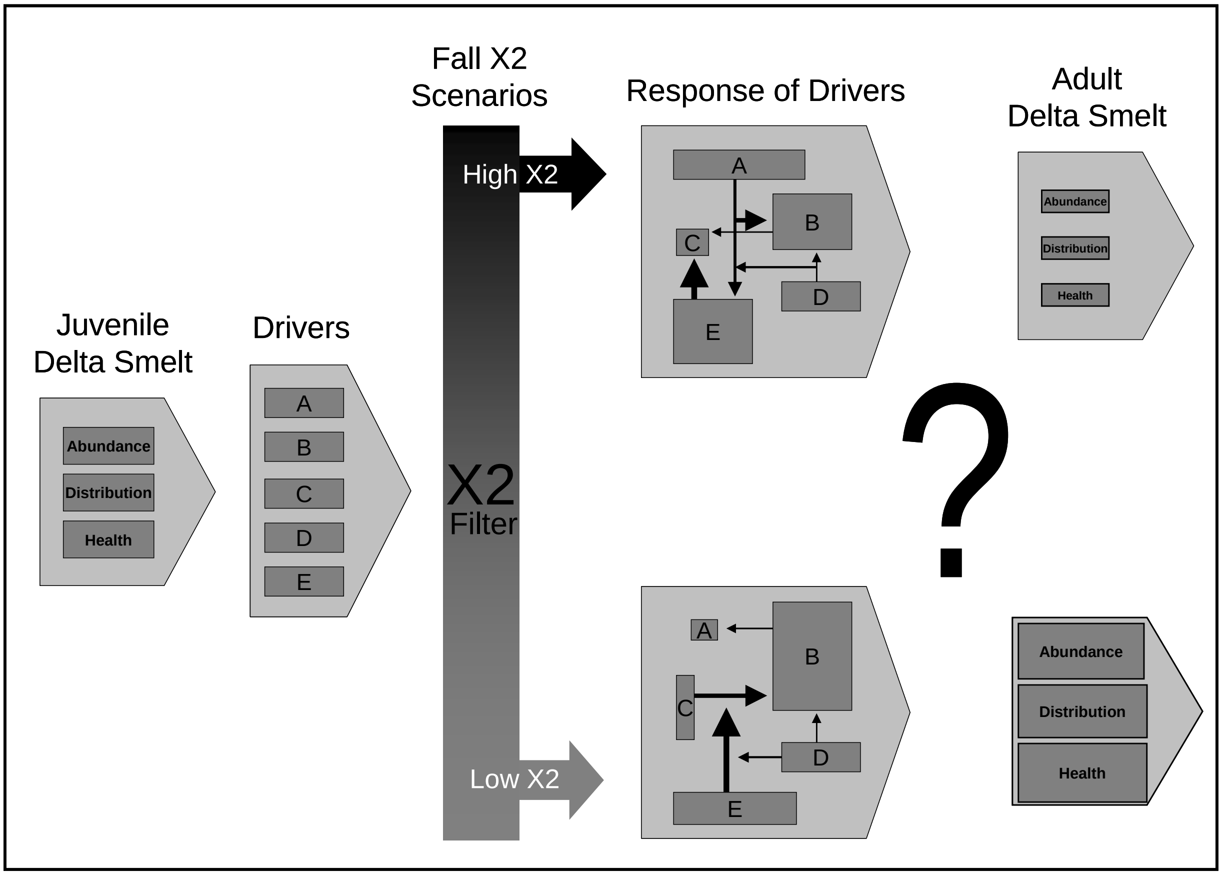

Figure 5. . Log-log relationships between Fall Midwater Trawl abundance indices and delta outflow for longfin smelt and young-of-the-year striped bass. Delta outflow (m3/s) values represent the mean levels during January–June for longfin smelt, and during April–July for striped bass. The data are compared for pre-Corbula invasion years (1967–1987; white circles), post-Corbula invasion (1988–2000; filled circles), and during the POD years (2001–2006; triangles). Fitted lines indicate linear regression relationships that are statistically significant at the P < 0.05 level (from Sommer at al. 2007).