February 12, 2010

SWRCB Proceeding on Delta Flow Criteria

The Nature Conservancy Exhibit 3 – Importance of Freshwater Flows to Estuaries: A Synopsis

Prepared by Jeanette Howard, Associate Director of Science, TNC
Submitted by Leo Winternitz, TNC

ABSTRACT:

Freshwater flows into tidal estuaries are an essential element of the natural assemblage of processes that make tidal estuaries some of the most ecologically diverse places on earth. The questions of how much freshwater flow is enough to sustain estuarine systems has plagued scientists and resource managers worldwide, and even in the most studied estuaries of the world, questions of required quantity and timing of flows remain. However, this lack of specific information is no excuse for lack of action. There is considerable knowledge about the general behavior and mechanisms of the effects of freshwater flow on estuarine ecological health. This synopsis provides a quick view of the breadth of recent scientific work relating freshwater flows to estuarine health and of the generally accepted important estuarine processes that are driven in large part by freshwater flows. A large body of scientific work, both specific to the Sacramento-San Joaquin Delta and in other estuarine systems around the world, exposes the following conclusions:

- **Adequate freshwater flows are critically important to the health of estuarine ecosystems.**
- **We must accept that our understanding of the causal mechanisms relating flows to ecological health are not often adequate to allow precise a priori prescription of adequate flows.**
- **Initial estimates of adequate flow must be made with the best available knowledge.**
- **An effective adaptive management approach must be employed to adjust flow prescriptions as new knowledge of ecosystem processes and response is obtained.**

Introduction

In a review of literature concerning fresh water flow management in riverine estuaries, Peirson et al. (2002) cite a study by Estevez (2000) that concluded:

"Freshwater is an integral part of the definition of an estuary and so deserves primacy in all aspects of estuarine ecology, as a matter of first principles. Changes to inflows have harmed many estuaries in the world, and have the potential to harm more."

And as the largest estuary on the West Coast into which nearly half of the state's runoff from five major rivers converge, and from which over two-thirds (~25 million) of the state's population get a portion of their drinking water and whose water irrigates ~45 percent of the nation's fruits and vegetables, the importance of freshwater flows to San Francisco Bay and

Sacramento-San Joaquin Delta cannot be overstated. The mingling of fresh and salt water in the Sacramento-San Joaquin Delta estuary creates an ecosystem unique for its size and diversity of species; roughly 738,000 acres support more than 750 species of plants and animals, some, such as the Delta smelt, are unique to the Delta. Over 50 different species of fish and 380 animals, mostly birds, call the Delta estuary home. Endangered and threatened fishes that use the Delta and associated rivers include the spring-run and winter-run Chinook salmon, Central Valley steelhead, longfin smelt, and green sturgeon (Moyle and Bennett 2008). In addition to being the gateway for hundreds of thousands of salmon and steelhead that spawn in the streams of the Central Valley, the Delta is a critical link in the Pacific Flyway for migratory birds (Herbold and Moyle 1989).

At the broad scale, estuaries are the recipients of almost all of the runoff and groundwater flow yielded by a catchment (Peirson et al. 2002). Rivers act as the primary drainage system of a catchment, and, as the rivers enter the coastal zone, they become estuaries. Water that is not returned to the atmosphere by evaporation or evapotranspiration by plants or diverted for human needs flows downstream to the estuary.

Estuaries are by their nature transitions zones between catchments and the coastal ocean. Estuaries by definition are dependent on freshwater inputs, and cannot be thought of as an independent ecosystem (Schlacher and Woolridge 1996).

What we refer to as Delta outflow is the amount of inflow from the Sacramento-San Joaquin system that has not been consumptively used upstream or in the Delta and has not been diverted as part of the state and federal export system.

To that effect, the following provides a brief review of the importance of freshwater flows to estuaries in general – referred to as “inflow” in most studies. This synopsis of the collective global understanding of the significance of freshwater flow in sustaining estuarine ecologic health is provided to underscore the relevance of the Delta-specific flow information provided by The Nature Conservancy and our other California conservation partners.

Estuarine processes and associated ecological systems impacted by freshwater inflows

The linkages between freshwater flow and estuarine conditions can be represented by a simple conceptual model of the effects of freshwater inflows on estuaries as shown in Figure 1 below – (modified from Alber 2002).

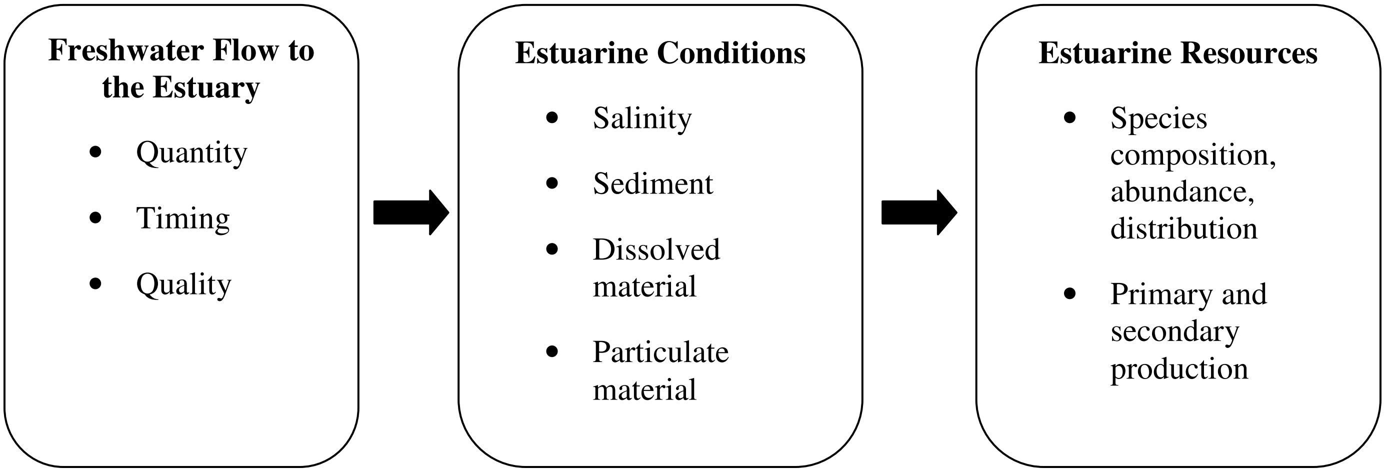

Figure 1. Diagram of the impact of freshwater flow into an estuary.

In short, the quantity, timing and quality of freshwater flows are linked directly to four physical estuarine conditions – salinity, sediment, dissolved and particulate material (Alber 2002, Peirson et al. 2002). In turn, these four processes are linked to biological conditions such as species composition, abundance and distribution and primary and secondary production (Alber 2002, Peirson et al. 2002) and are summarized in Appendix 1. These linkages have been documented in numerous studies around the world and are expertly reviewed and summarized in Peirson et al. 2002. A checklist of major ecological processes by which freshwater flow reductions may impact estuaries was developed by Bishop (1999) and cited by Peirson et al. 2002 as follows:

1. *Salinity-mediated processes*

Freshwater inflows directly impact the salinity structure of estuaries. Salinity is indirectly relevant to two other processes – temperature and dissolved oxygen. The link between salinity and DO aggravates issues of hostile water quality at depth and the anoxia-driven release of pollutants from estuary-bed sediments. Many complex follow-on impacts may occur as a result of altering salinity included impacts on the instream and riparian flora, loss of shelter and foraging areas for fauna, bank instability and multi-linked water quality reduction, the distribution of estuarine organisms (Deeling and Paling, 1999).

2. *Reductions in inflow-induced currents and vertical mixing*

Processes involving changes in inflow-induced currents and vertical mixing are the second most common process impacted by reduced flows. Impacts include water quality changes induced by diminished vertical mixing (i.e. reduced water turbulence), direct physical impacts on eggs and larvae, specifically, reductions in their suspension in the water column and their transport along the estuary.

3. *Reductions in connectivity*

The longitudinal connectivity between the estuary and the upstream river system is impacted by reduced inflows.

4. *Reductions in flushing and channel-maintenance flow*

Reduction of flushing and channel-maintenance flows may result in a decrease of habitat quality. Substrates are coated by sediments or organic material for prolonged periods, and water-quality deteriorates due to the accumulation of organic material and subsequent high biochemical oxygen demand. In addition, reducing channel-maintenance freshwater inflows results in habitat contraction.

5. *Reduced input of sediment, river-borne nutrients and organic material*

This process drives estuarine foodwebs and is responsible for the high productivity of estuaries (Grange *et al.*, 2000, Loneragan and Bunn, 1999; Binnie, Black and Veatch, 1998). Organic matter and nutrients (bound to sediments) primarily enter estuaries from catchments during high flow events.

6. *Reduced dilution of pollutants.*

Concentration of pollutants also results from reduced inflows.

Longley (1994) as cited by Peirson et al. 2002 examined the functions of freshwater inflows to Texas bays and estuaries and developed the following list of significant impacts as a result of reduced flows:

- increased salinities and vertical stratification of the water column;
- penetration of the salt-wedge farther upstream allowing intrusion of predators and parasites of estuarine species, and increased intrusion into groundwater and surface water resources;
- increased frequency of benthic anaerobic conditions and decreased inputs of nutrient and organic matter used by estuarine species;
- loss of characteristic species and economically important seafood harvests; and
- increases in erosion of delta areas resulting from the reduction of sediment flux.

In terms of freshwater flow impacts to the biotic components of estuaries, in the Delta, Jassby et al. in 1995, Kimmerer (2002, 2009) and Rosenfield and Baxter (2007) provided evidence that freshwater inflow was significantly and positively correlated with nine ecosystem attributes: organic carbon, phytoplankton supply, abundance of one invertebrate taxon, biomass of benthic macroinvertebrates and the survival/abundance of five fish taxa. Similar results, involving nutrients, phytoplankton, zooplankton, ichthyoplankton and ichthyonekton, have been found in a number of South African estuaries in relation to freshwater flows (Grange *et al.*, 2000).
Peirson et al. (2002) cites studies by:

- Drinkwater and Frank (1994) where reductions in freshwater inflows resulted in declines in coastal fisheries explained by impacts to migration, spawning success, advection of eggs and larvae, species competition and distribution, general productivity, food supply, and water quality; and

- Glaister (1978) and Ruello (1973) where commercial crustacean catches decreased in Australian estuaries due to decreases in freshwater inflows.
- Powell and Matsumoto (1994) where freshwater inflow is an essential factor influencing biological productivity of estuarine areas as diverse as the Black Sea, the Caspian Sea, the Nile Delta, the Gulf of St. Lawrence, Chesapeake Bay, and the bays and estuaries of the Gulf of Mexico (particularly those within the U.S. states of Texas and Florida).

Protecting and maintaining estuarine ecosystems in a knowledge-poor environment

The Delta is highly valued for its water supply, recreational opportunities and dependent commercial and recreational fishers. The Delta is also an important in terms of conservation value as it provides viable habitat for threatened or endangered flora and fauna. In managing the environmental impact of freshwater inflows to the Delta system it is of course important to have some understanding of the way in which biological risks change in relation to, and are linked with, the impacts arising from reduction in flows. Currently there is little information on the causal links between biological-risk and freshwater inflow in the Delta.

However, there is a substantial literature addressing the impacts of freshwater impacts to estuarine processes and ecosystems that should not be ignored.

Peirson et al. 2002 cite a study by Binnie, Black and Veatch (1998) that acknowledges a generally “knowledge-poor environment” in terms of freshwater reductions on estuarine systems. These authors caution both estuary managers and nature-conservation groups alike to “accept that precise quantitative answers cannot be provided regarding the impact of inflow reductions on the ecology of estuaries, and that initial predictions of ecological effects will contain a degree of uncertainty.”

As stated above, estuarine systems are highly complex systems composed of a variety of biotic and abiotic components and linkages (Peirson *et al. 2002, Perillo 2009*). Acknowledging these complexities Peirson et al. 2002 urge groups to employ an adaptive management approach to the management of ecological impacts in estuaries:

"Given the complexities of estuarine ecosystems and inaccuracies which may occur in the methodologies, particularly in relation to the range of working thresholds utilized, it is imperative that any implemented extraction regime be viewed as an interim condition, to be revised once substantial knowledge is gained through ensuing scientific research and monitoring."

<u>**References**</u>

Alber, M. 2002. A conceptual model of estuarine freshwater inflow management. Estuaries 25:1246-1261.

Binnie, Black and Veatch (1998b), "Quality control manual for computational estuarine modelling", TR W168, September, ISBN BCXH Peirson *et al.* (1999).

Deeley, D. M. and Paling, E. I. (1999), "Assessing the Ecological Health of Estuaries in Australia", Marine and Fresh water Research Laboratory, Institute for Environmental Science, Murdoch University, LWRRDC Occasional Paper 17/99 (Urban Sub-Program, Report No. 10).

Drinkwater, K.F. and Frank, K.T. (1994). Effects of river regulation and diversion on marine fish and invertebrates. *Aquatic Conservation: fresh water and marine ecosystems*, **4**, 135-151.

Estevez, E.D. (2000). *A review and application of literature concerning freshwater flow management in riverine estuaries.* Report to the South Florida Water Management District, West Palm Beach, Florida. Mote Marine Laboratory Technical Report Number 680. 68pp.

Glaister, J.P. (1978). The impact of river discharge on distribution and production of the school prawn *Metapenaeus macleayi* (Haswell) (Crustacea: Penaeidae) in the Clarence River region, northern New South Wales. *Aust. J. Mar. Freshwat. Res.*, **29**, 311-323.

Grange, N., Whitfield, A.K., de Villiers, C.J. and Allanson, B.R. (2000). The response of two South African east coast estuaries to altered river flow regimes. *Aquatic Conservation and Fresh water Ecosystems*, **10**, 155-177.

Herbold, B. and P.B. Moyle. 1989. The Ecology of the Sacramento-San Joaquin Delta: A Community Profile. U.S. Fish and Wildlife Service Biological Report 85.106 pp.

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

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

Kimmerer, W.J., E.S. Gross, M.L. Williams. 2009. Is the response of estuarine nekton to freshwater flow in the San Francisco Estuary explained by variation in habitat volume? Estuaries and Coasts

Loneragan, N.R. and Bunn, S.E. (1999). River flows and estuarine ecosystems: implications for coastal fisheries from a review and a case study of the Logan River, southeast Queensland. *Aust. J. Ecol.*, **24**, 431-440.

Longley, W.L. (Ed.) (1994). *Freshwater inflows to Texas Bays and estuaries: ecological relationships and methods for determination of needs*. Water Development Board and Texas Parks and Wildlife Department, Austin, Texas, 386pp.

Moyle and Bennett (2008).The Future of the Delta Ecosystem and its fish. Technical Appendix D. This document is an appendix to the Public Policy Institute of California report, *Comparing Futures for the Sacramento-San Joaquin Delta*, prepared by a team of researchers from the Center for Watershed Sciences (University of California, Davis) and the Public Policy Institute of California.

Peirson, WL., Bishop, K., Van Senden, D., Horton, PR. and Adamantidis, CA., *Environmental Water Requirements to Maintain Estuarine Processes* (2002), Environmental Flows Initiative Technical Report Number 3, Commonwealth of Australia, Canberra.

Perillo, G.M.E., 1995. Definition and geomorphologic classifications of estuaries. In: Perillo, G.M.E. (Ed.), Geomorphology and Sedimentology of Estuaries. Elsevier, Amsterdam, pp. 17–47.

Powell, G.L. and Matsumoto, J. (1994). Texas estuarine mathematical programming model: a tool for freshwater inflow management. In: Dyer, K.R. and Orth, R.J. (Eds.), *Changes in fluxes in estuaries: implications from science to management.* Olsen & Olsen.

Rainer, S. (1981). Temporal patterns in the structure of macrobenthic communities of an Australian estuary. *Estuarine, Coastal and Shelf Science*, **13**, 597-620.

Rosenfield, J.A. and R.D. Baxter. 2007. Population dynamics and distribution patterns of longfin smelt in the San Francisco Estuary. Transactions of the American Fisheries Society 136:1577–1592.

Ruello, N.V. (1973). The influence of rainfall on the distribution and abundance of the school prawn *Metapenaeus macleayi* in the Hunter region. *Marine Biology*, **23**, 221-228.

Schlacher, T.A. and T.H. Wooldridge. 1996. Ecological responses to reductions in freshwater supply and quality in South Africa's estuaries: lessons for management and conservation. Journal of Coastal Conservation 2:1115-130.

Appendix 1. Key estuarine processes and impacts of reduced flows.

<table>
<tr><th>Key Attributes of freshwater flow to estuaries</th><th>Importance to Estuarine processes</th><th>Impacts of reduced flows to ecological systems</th></tr>
<tr><td>Quantity

Quality

Timing</td><td>Influences:
Amount of river-supplied nutrients and organic material
Advection – transport in water column
Concentration of pollutants/toxicity
Connectivity to upstream water bodies (important for migrating organisms)
Currents and vertical mixing -
Distribution of flora and fauna and trophic interactions
Duration of elevated salinity
Evaporation
Flushing and channel maintenance flows
Nutrient fluxes
Inundation
Input of river-borne nutrients and organic material (food supply)
Larval and egg suspension in water column
Lateral connectivity
Position of the estuarine turbidity maxima (which in turn influences particle settling).
Primary productivity
Residence time which has implications for the settling, nutrient uptake and organic decay of planktonic organisms and detrital particles
Salinity mediated processes (DO, temperature)
Salt-wedge position
Sediment regime
Stratification
Transport and dilution of pollutants
Water quality
Woody debris inputs</td><td>Loss of:
Freshwater habitat
Migratory pathways – both to ocean and upstream
Primary productivity
Impacts:
Distribution of flora and fauna and trophic interactions
Food web dynamics
Larval and egg suspension in water column
Water quality conditions (low DO at depths)
Increases:
Competition and predation from organisms normally found in lower estuary habitats
Physiological stress to low-salinity tolerant fauna and flora</td></tr>
</table>

	Maintains : • Tidal channel openings **Transports:** • Nutrients (DOM/POM) and pollutants – nutrient fluxes • Woody debris	

References used to create table:

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

Longley, W.L. (Ed.) (1994). *Freshwater inflows to Texas Bays and estuaries: ecological relationships and methods for determination of needs*. Water Development Board and Texas Parks and Wildlife Department, Austin, Texas, 386pp.

Peirson, WL., Bishop, K., Van Senden, D., Horton, PR. and Adamantidis, CA., *Environmental Water Requirements to Maintain Estuarine Processes* (2002), Environmental Flows Initiative Technical Report Number 3, Commonwealth of Australia, Canberra.

Ruesink, J.L., G.C. Roegner, B.R. Dumbauld, J.A. Newton and D. Armstrong. 2003. Contributions of oceanic and watershed energy sources to secondary production in a northeastern Pacific estuary. Estuaries 26:1079-1093.

Ruiz, G, J.T. Carlton, E.D. Grosholz, and A.H. Hines. 1997. Global invasions of marine and estuarine habitats by non-indigenous species: mechanisms, extent and consequences. American Zoologist 37:621–32.