Calculating Dissolved Selenium Loads from the Delta to San Francisco Bay Using DSM2

May 1, 2014

Prepared by Tetra Tech

Introduction

Selenium inputs to North San Francisco Bay from the Central Valley via the Delta are expected to be a significant source. Accurately estimating these loads is difficult due to the complex flows within Delta and tidal influences from the bay. Flow in the Delta is a mix of water from the Sacramento River, the San Joaquin River, eastern tributaries (Mokelume, Cosumnes, Calaveras Rivers, as well as other minor sources), agricultural return flows and tidal flows from the Bay (identified operationally as inputs from Martinez). The mix of water varies depending on location and time. The Sacramento River branch of the Delta receives a greater contribution from the Sacramento River. At the confluence of the Sacramento and San Joaquin Rivers at Antioch, the flow may be a more even mixture of water from different sources. A portion of the water in the Delta is also exported out through aqueduct for agricultural and urban uses in other parts of the state. Because of this diversion, a time-varying fraction of San Joaquin River and the Sacramento River waters reach the North Bay. Because the San Joaquin River has much higher selenium concentrations than the other major sources, it is important to estimate the contribution from the San Joaquin River to the North Bay. The Delta Simulation Model II (or DSM2) model provides a tool to estimate contributions from different sources to specific locations within the Delta, and was used to estimate the composition of flow at different locations.

The loads of selenium from the Sacramento and San Joaquin Rivers to the Delta were estimated using different methods in previous work (Tetra Tech, 2008). One of the approaches used selenium concentrations and flow at the Sacramento River at Freeport and San Joaquin River at Vernalis to estimate selenium loads from these two rivers separately and by accounting for loss of loads through the Delta aqueducts (Tetra Tech, 2008). The other approach estimated selenium loads by estimating loads at Sacramento River at Rio Vista and loads at San Joaquin River at the confluence by applying a Delta removal constant for concentrations in the San Joaquin River (Meseck, 2002). In this study, selenium loads from upstream were estimated as selenium loads from the Sacramento River at Rio Vista (representing Sacramento River branch of the Delta) and the San Joaquin River at the confluence (Antioch, representing San Joaquin River branch of the Delta), using the estimated selenium concentrations and flow from DSM2 at Rio Vista and at the confluence. The sum of loads from these two locations represents an estimate of total selenium inputs to the bay. The locations of these stations in the eastern portion of North San Francisco Bay are shown in Figure 1.

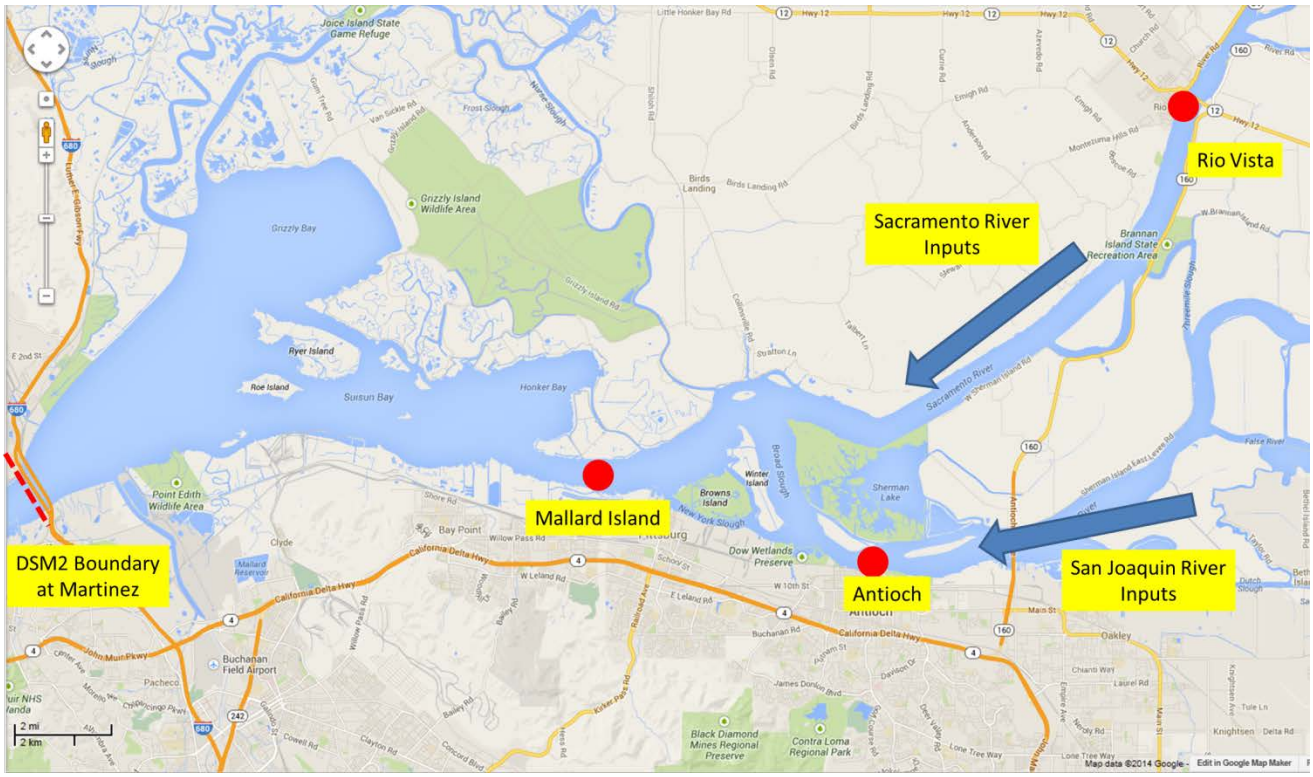


Figure 1 Locations of key stations in the eastern portion of San Francisco Bay (Source: GoogleMaps)

DSM2 Simulations

DSM2 is a one-dimensional mathematical model for simulating the Sacramento – San Joaquin Delta hydrodynamics, water quality, and particle tracking. The DSM2 model calculates stages, flows, velocities, transport of individual particles, and mass transport processes for conservative and non-conservative constituents, including salts, water temperature, dissolved oxygen (DO), and dissolved organic carbon. The DSM2 model can be applied using a "fingerprinting" mode to predict the sources of water at a given location in the Delta.

In this study, the model was used to estimate dissolved selenium loads to the Delta from the Sacramento and San Joaquin River watersheds. The DSM2 model was run using the fingerprinting mode to estimate water composition at three output locations:

- Sacramento River at Rio Vista;
- San Joaquin River at Antioch; and
- Mallard Island.

These locations characterize the Central Valley loads as well as the concentrations in the eastern portion of San Francisco Bay (at Mallard Island). The DSM2 simulation considers contributions from five inputs including:

- Sacramento River at Freeport,
- San Joaquin River at Vernalis,
- Martinez, representing tidal inputs from the Bay to the Delta
- East side tributaries, and
- Agricultural return flows.

The DSM2 model was used to simulate volumetric contributions from these sources to the three output locations. The model was run for the period 1992- 2013.

Simulated Composition of Water

The simulated composition of water at Sacramento River Rio Vista, San Joaquin River at Antioch and Mallard Island is shown in Figure 1 to Figure 3. For Rio Vista, the dominant source of flow is the Sacramento River. Contributions from other sources are generally low (Figure 1).

For the San Joaquin River at Antioch, the major source of flow is also the Sacramento River. However, contributions from the San Joaquin River, Martinez and east side tributaries are considerably larger than for Rio Vista (Figure 1). Contributions from Martinez are generally ~30%. Contributions from the San Joaquin River and east side tributaries are more significant during the wet years.

For Mallard Island, the dominant source of water is the Sacramento River at Freeport (Figure 3). Martinez contributions are also a significant source of water to Mallard Island. The contribution from the San Joaquin River to Mallard Island is generally low with some exceptions during the wet years. During the wet years, contribution from the San Joaquin River to Mallard Island can reach as high as 40% for limited periods. Contribution from the east side tributaries is generally low.

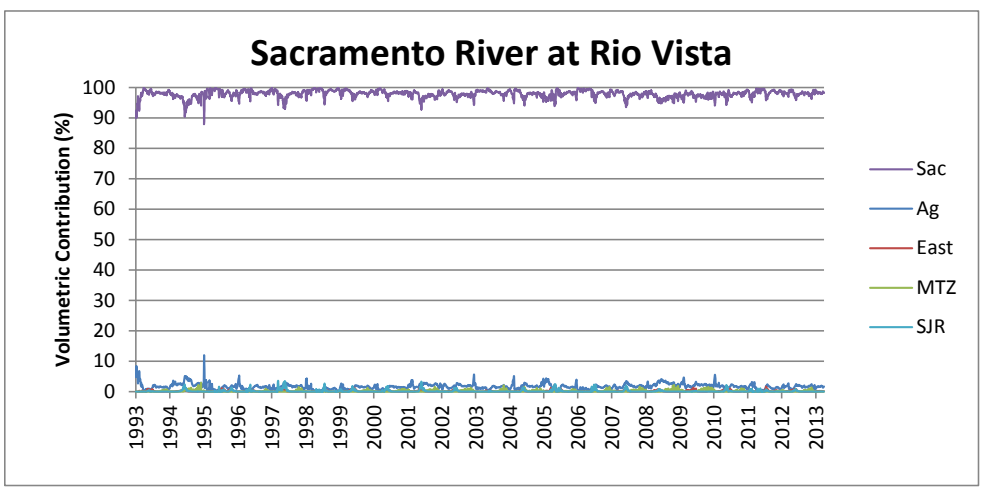


Figure 2 DSM2 simulated volumetric contributions from source waters to Rio Vista

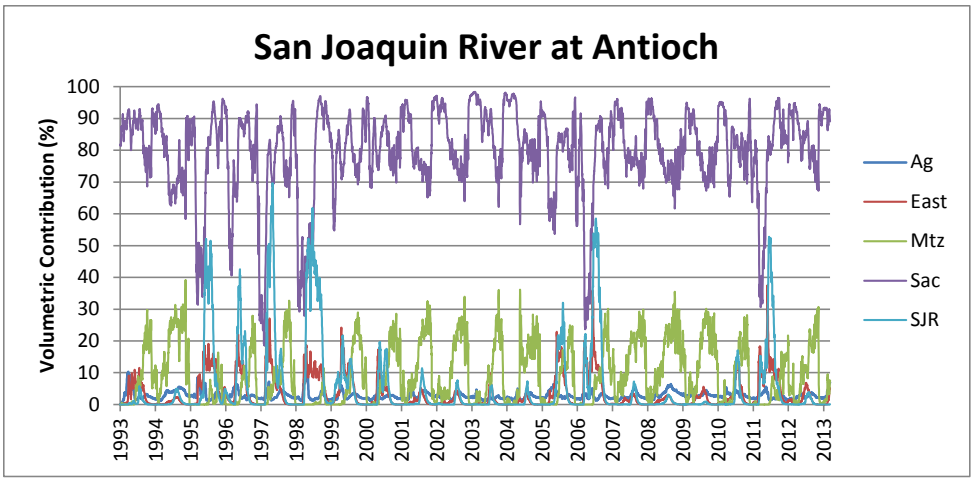


Figure 3 DSM2 simulated volumetric contributions from source waters to Vernalis

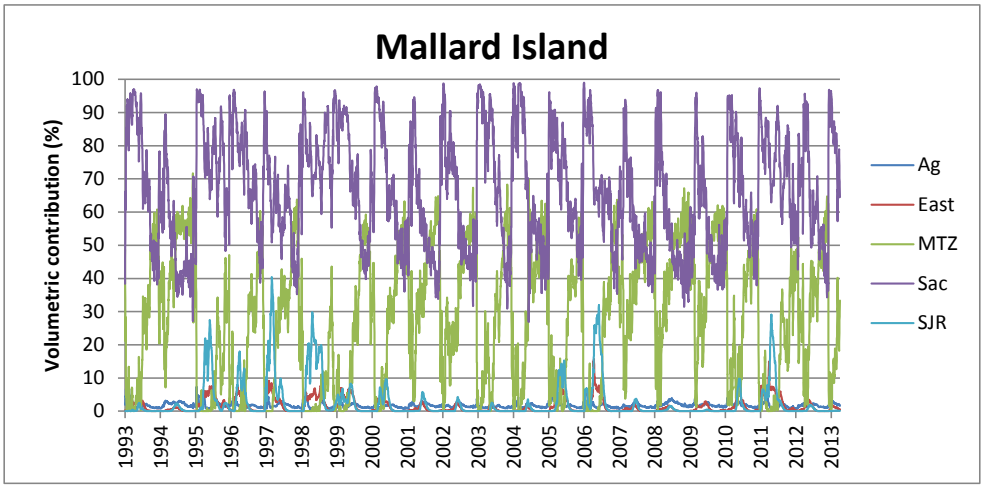


Figure 4 DSM2 simulated volumetric contributions from source waters to Mallard Island

Simulated Selenium Concentrations

Simulated volumetric contributions from source waters in conjunction with selenium concentrations in the source water were used to calculate concentrations at given locations. Dissolved selenium concentrations from USGS for the Sacramento River at Freeport and the San Joaquin River at Vernalis (available for the time period of 2007 -2014) were used to calculate concentrations at Sacramento River at Rio Vista, San Joaquin River at Antioch and Mallard Island. Average dissolved selenium concentrations are 0.095 µg/l for Sacramento River at Freeport and 0.57 µg/l for San Joaquin River at Vernalis. Dissolved selenium concentrations for the Sacramento River at Freeport and the San Joaquin River at Vernalis are shown in Figure 4. The relationship between concentrations and daily flows are shown in Figure 5. There is minimal dependence on flow rate at Freeport, and a strong inverse relationship with flow at Vernalis. For the simulations performed here observed data, linearly interpolated between sampling dates, were used. Dissolved selenium concentrations for Martinez, east tributaries and agricultural

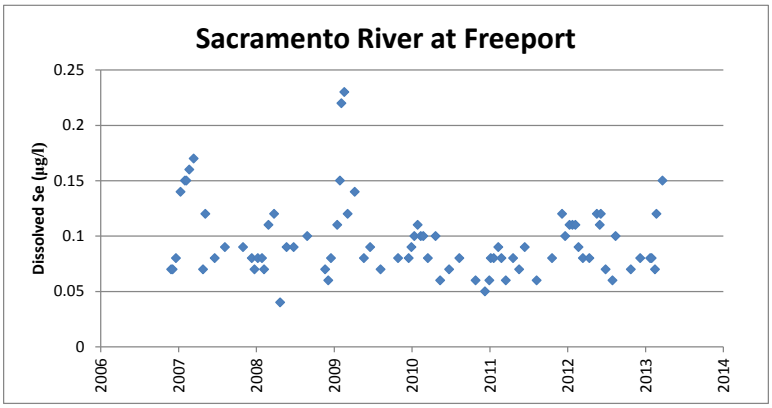
return flows used in the calculation were assumed to be 0.09 μg/L, 0.1 μg/L and 0.11 μg/L and were assumed constant. Concentrations at Yolo Bypass are assigned the same value as the Sacramento River at Freeport.

For the Sacramento River at Rio Vista and the San Joaquin River at Antioch, only the contribution from the Sacramento River, San Joaquin River, east side tributaries and agriculture return flow is used in the calculation. Therefore the calculated concentrations reflect contribution from the rivers only and not from the bay.

For the Sacramento River at Rio Vista, calculated dissolved selenium concentrations are shown in Figure 8. Estimated dissolved selenium concentrations are generally ~0.1 μg/l with occasional peaks greater than 0.1 μg/l.

For the San Joaquin River at Antioch, calculated dissolved selenium concentrations are shown in Figure 8. Estimated dissolved selenium concentrations are generally ~0.1 μg/l with some peak values greater than 0.2 μg/l. The calculated dissolved selenium concentrations at Antioch were compared to concentrations at Vernalis and with a reduction factor of 60% from the Vernalis concentrations as used in Meseck (2002). Calculated dissolved selenium concentrations were lower than values at Vernalis combined with the 0.6 reduction factor. This demonstrates that following the diversion in the South Delta and mixing with the Sacramento River, selenium concentrations at Antioch were significantly lower than Vernalis.

For Mallard Island, the calculated dissolved selenium concentrations are shown in Figure 8. Estimated dissolved selenium concentrations are generally ~0.1 μg/l with occasional peaks greater than 0.2 μg/l. The peaks are strongly associated with higher volumetric contributions from the San Joaquin River.



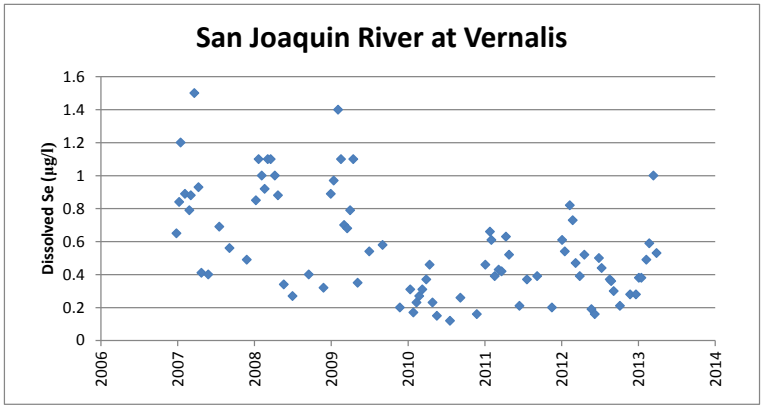


Figure 5 Dissolved selenium concentrations for Sacramento River at Freeport and San Joaquin River at Vernalis used in calculation

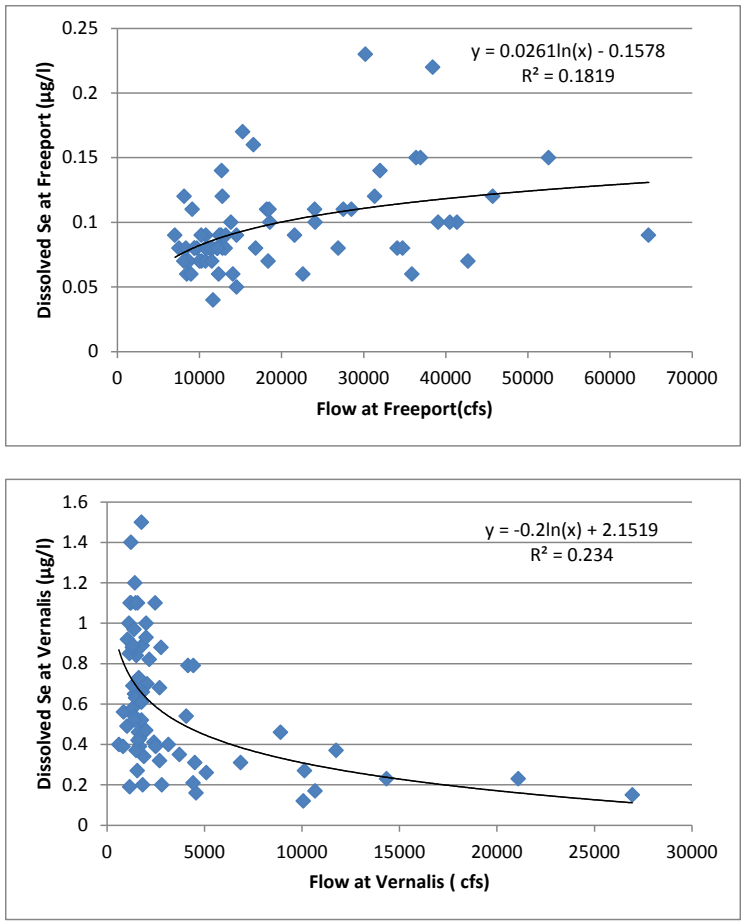


Figure 6 Relationship between dissolved selenium concentrations and daily flow rates on the sampling dates, for Freeport and Vernalis.

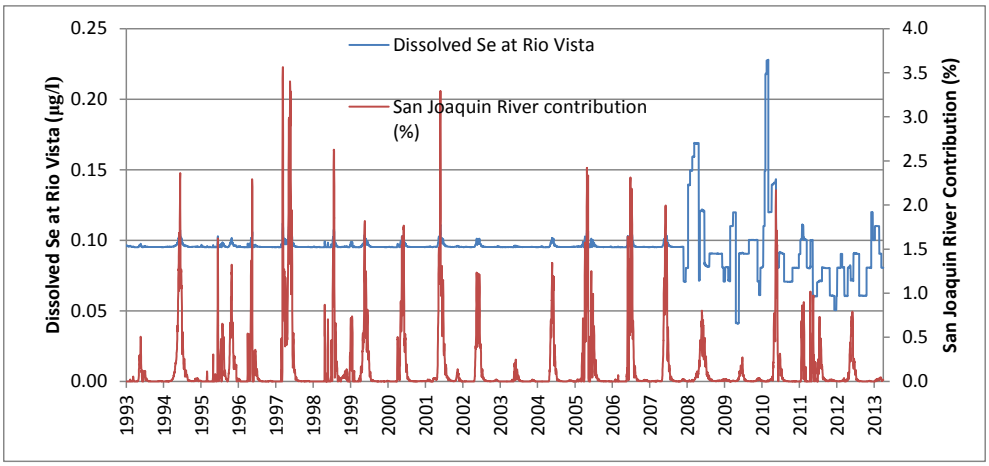
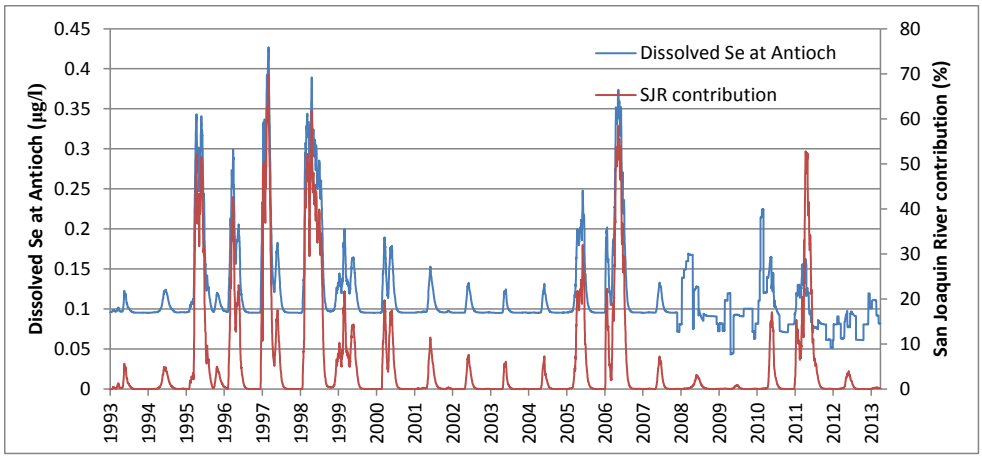


Figure 7 Calculated dissolved selenium concentrations for Sacramento River at Rio Vista



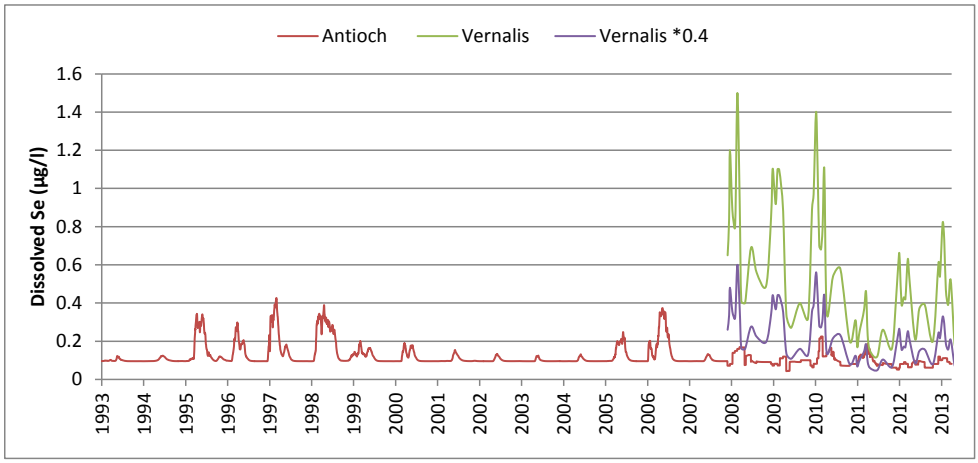


Figure 8 Calculated dissolved selenium concentrations for San Joaquin River at Antioch, compared to concentrations at Vernalis, and concentration multiplied by a constant factor of 0.4 (representing a 60% reduction in concentration).

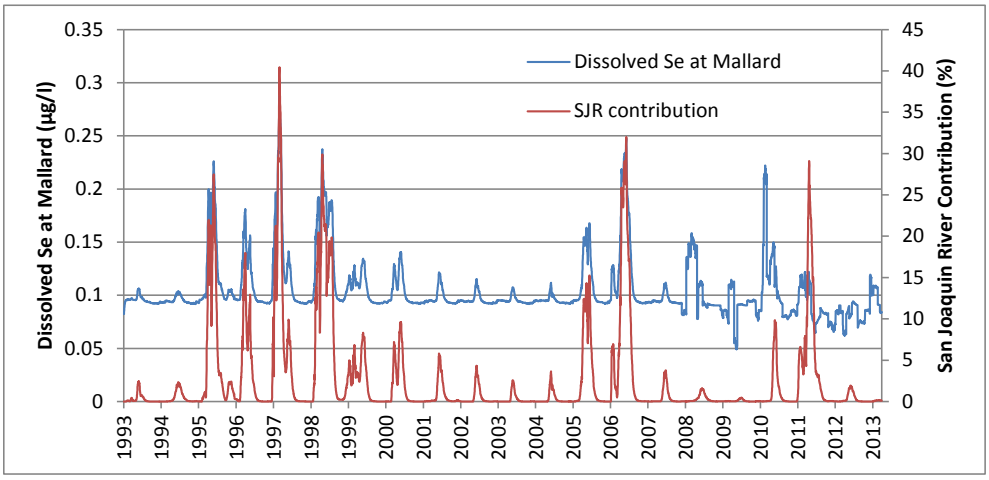


Figure 9 Calculated dissolved selenium concentrations at Mallard Island

Calculated Selenium Loads to the Delta

Model-simulated flow at Rio Vista is very close to the flow at Freeport (Figure 9). Calculated selenium loads at the Sacramento River at Rio Vista are shown on a daily basis (Figure 10) and for the dry and wet seasons of each water year (Figure 11). The wet season was defined as Oct 1st to Apr. 30th and the dry season was defined as May 1st to Sep. 30th, similar to previous approach in Tetra Tech (2008). Estimated dissolved selenium loads averaged 1,881 kg/yr for the entire period of 1993-2012.

Model-simulated flow at Antioch shows large variation across years (Figure 12). Flow at Antioch significantly increases during the wet years. Calculated selenium loads at Antioch are shown on a daily basis (Figure 13) and for the dry and wet seasons (Figure 14). Estimated dissolved selenium loads from Antioch ranged from 7 kg/yr to 3,907 kg/yr. Selenium inputs at this location reflect the variable mixture of inputs from the Sacramento River, the San Joaquin River, the east side tributaries and agricultural return flow.

Estimated total dissolved selenium loads from the Delta to the Bay are shown in Figure 15. The estimated loads compared to previous estimates for the same time period by Tetra Tech (2008) are slightly higher, particularly during the wet years. This is possibly due to the DSM2 model computing a higher contribution from the San Joaquin River during the wet years, plus the higher selenium concentrations from the San Joaquin River, resulting in even higher loads during wet years. A summary of dissolved selenium loads by year and season is listed in Table 1.

Dissolved selenium loads at Mallard Island could also be estimated using the estimated concentrations using the DSM2 finger printing results and DSM2 simulated flow at Mallard Island (tidally average flow and concentrations at daily basis). Estimated dissolved selenium loads at Mallard Island compared well to the estimated load at Rio Vista plus Antioch (Figure 16).

Another approach for estimating selenium loads to the Bay is to subtract selenium loads exported through the aqueducts from the loads *to* the Delta (i.e., sum of Freeport, Yolo, Vernalis and east-side tributary loads). The results from this mass balance approach are compared to the estimated loads at Rio Vista plus Antioch and the estimated loads at Mallard Island (Figure 17 and Figure 18). Although the loads from the different approaches are comparable, the values from the mass balance approach are slightly higher; this is associated with the flow volumes associated with the individual inputs, and a result of losses of water volume in the Delta, likely through consumptive use on the Delta islands.

Discussion

The DSM2 modeling framework can be adapted to estimate the contribution of different watershed sources to the Delta, using upstream boundary stations where the loads can be calculated directly through measurements.

Because of the extensive calibration that DSM2 has been subjected to over the past two decades, there is credibility associated with the mixing and tidal hydrodynamic processes represented by the model. The model is a more robust tool to estimate the contributions of the riverine loads to the bay. Although

the long term annual loads are in the same range as previously estimated (Tetra Tech, 2008), the model illustrates some important seasonal patterns. In particular, the contribution of the San Joaquin River can be elevated during the wet months of wet years, such that high concentrations at Mallard Island may be observed. In contrast the dry year loads from the San Joaquin River to the bay are very small compared to the Sacramento River loads. This finding is consistent with observation of high selenium concentrations in January 2005 and 2006 that were reported by Davis et al. (2012), and likely reflects the greater contribution of San Joaquin flows during this period. However, this is a limited data set and has not been continued since the 2005 and 2006 sampling.

Going forward, additional sampling at a regular frequency at Mallard Island is recommended (in addition to the USGS sampling being performed at Freeport and Vernalis), because this location is a good representation of the relative contribution of Sacramento and San Joaquin Rivers. The relative contributions vary in a complex manner, because higher concentrations occur during wet years, this modeling suggests that worst case conditions for selenium in the bay—at least in the context of Central Valley loads—may not occur during dry or drought years.

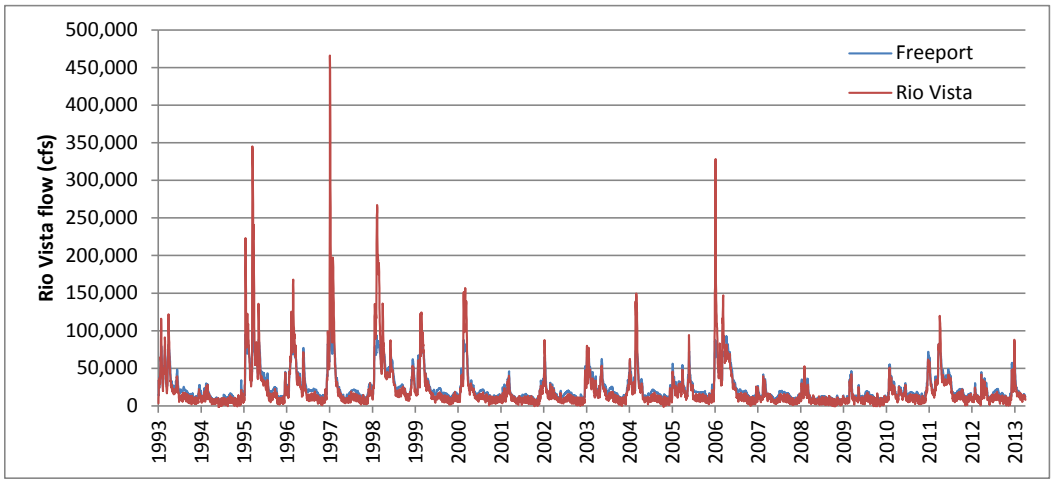


Figure 10 Model simulated flow at Sacramento River at Rio Vista

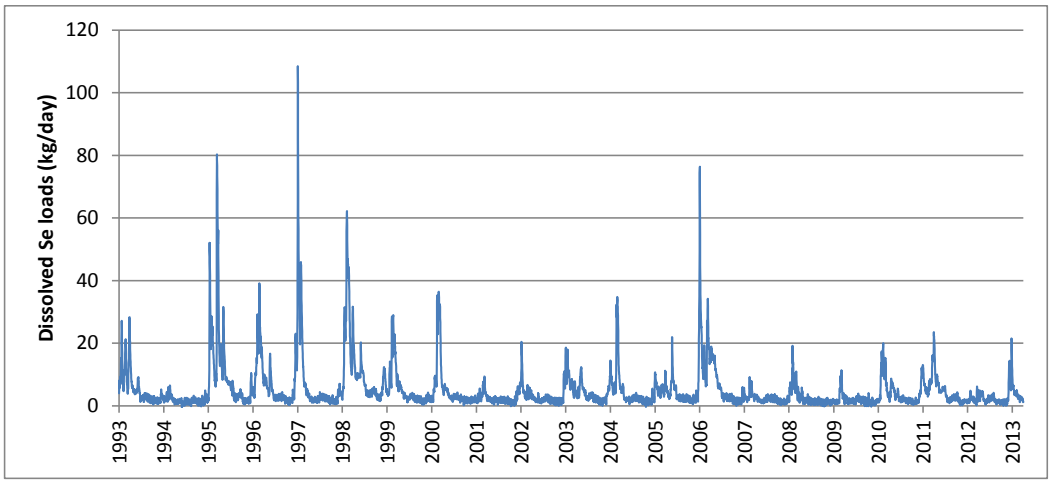


Figure 11 Estimated dissolved selenium loads at Sacramento River at Rio Vista

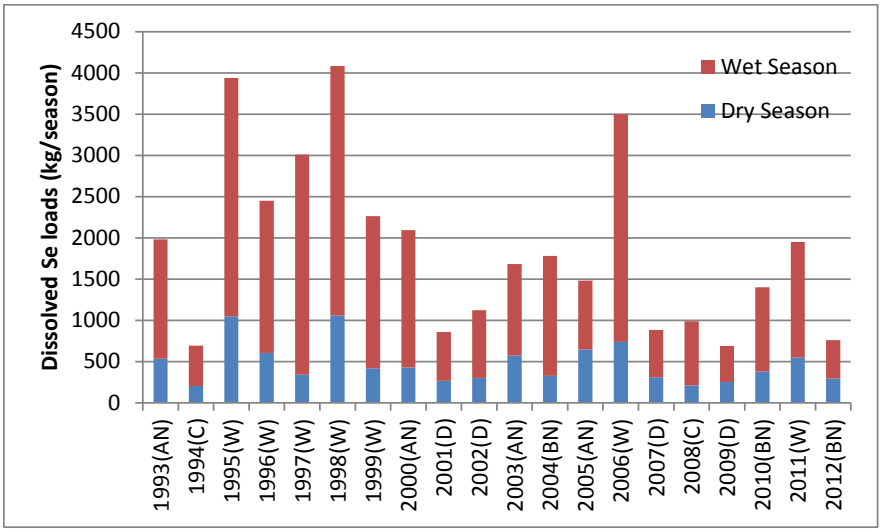


Figure 12 Estimated dissolved selenium loads at Sacramento River at Rio Vista by water year and season. The water year type classification is based on DWR's water year hydrologic classification for the Sacramento Valley (cdec.water.ca.gov/cgi-progs/iodir/WSIHIST). W: Wet, AN: Above normal, BN: Below normal, D: Dry, C: Critical year.

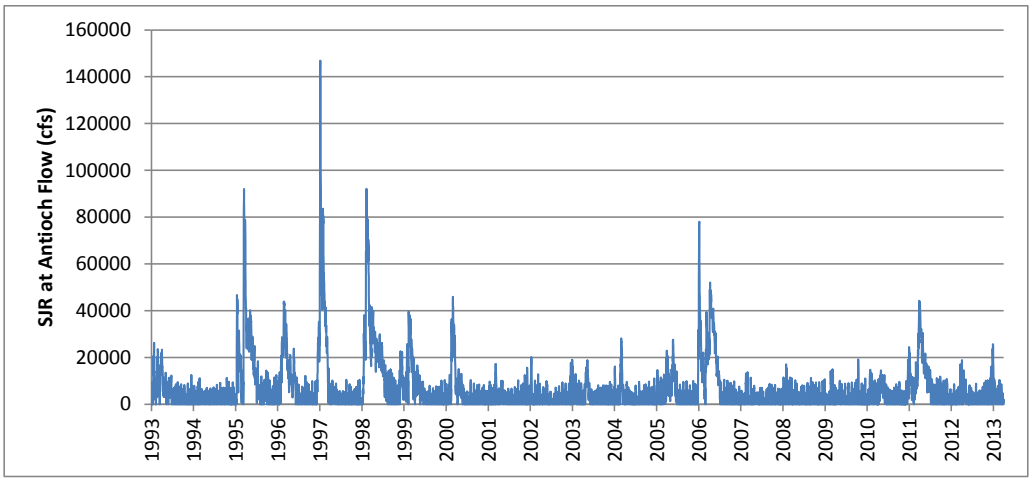


Figure 13 Model simulated flow at San Joaquin River at Antioch

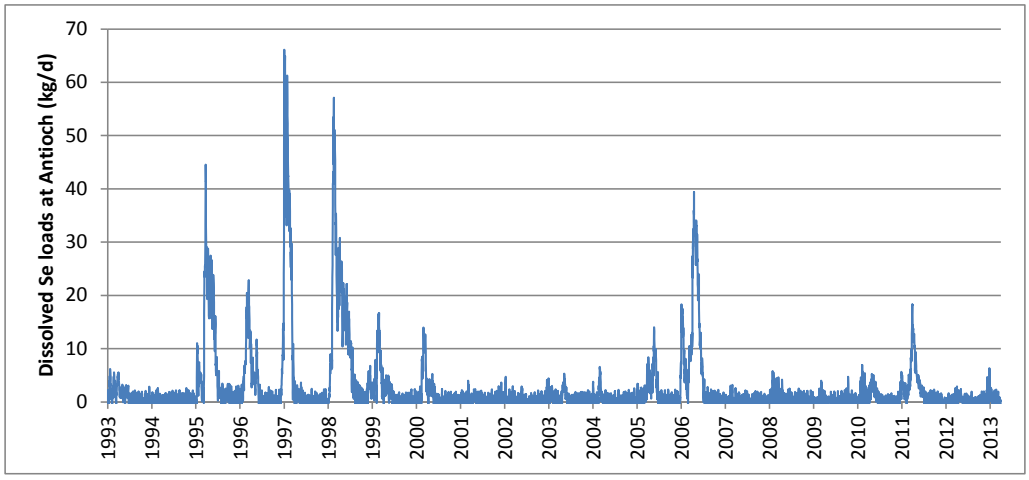


Figure 14 Estimated dissolved selenium loads at San Joaquin River at Antioch

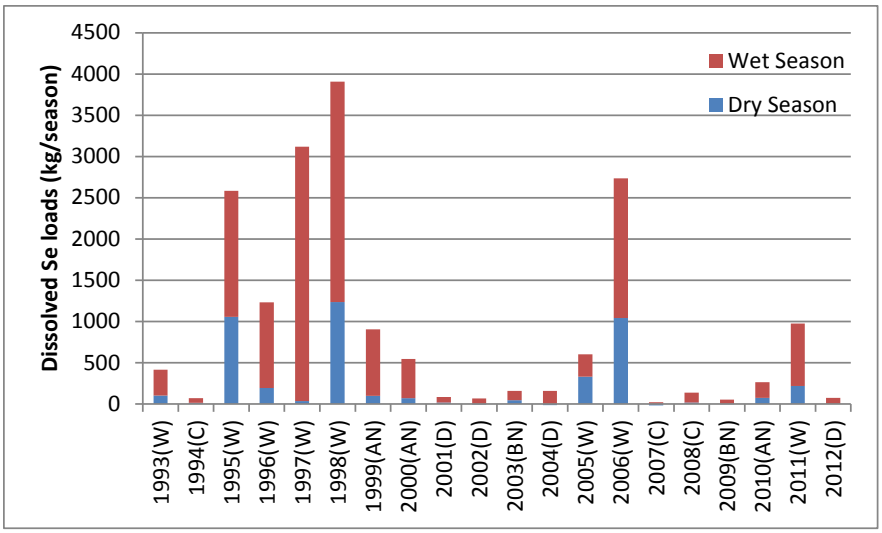


Figure 15 Estimated dissolved selenium loads at Antioch by water year and season. The water year type classification is based on DWR's water year hydrologic classification for the San Joaquin Valley (cdec.water.ca.gov/cgi-progs/iodir/WSIHIST). W: Wet, AN: Above normal, BN: Below normal, D: Dry, C: Critical year.

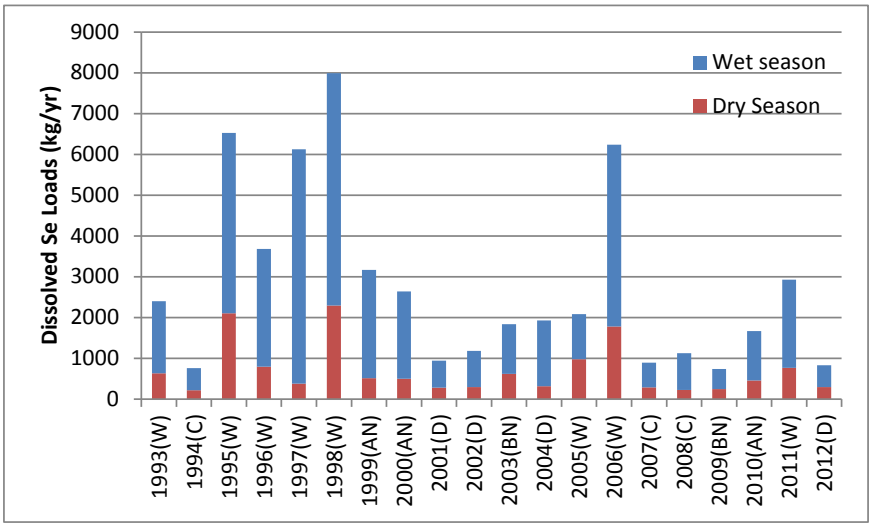


Figure 16 Estimated total dissolved selenium loads to the Bay by water years. The water year type classification is based on DWR's water year hydrologic classification for the San Joaquin Valley (cdec.water.ca.gov/cgi-progs/iodir/WSIHIST). W: Wet, AN: Above normal, BN: Below normal, D: Dry, C: Critical year.

Table 1. Summary of calculated dissolved selenium loads to the Bay.

Water Year (October 1 to September 30)	Type	Dry season (kg/season)	Wet season (kg/season)	Total (kg/yr)
1993	W	639	1761	2400
1994	C	223	543	765
1995	W	2106	4417	6523
1996	W	800	2884	3684
1997	W	381	5747	6128
1998	W	2298	5691	7989
1999	AN	518	2650	3169
2000	AN	502	2138	2641
2001	D	287	659	946
2002	D	299	886	1185
2003	BN	622	1221	1843
2004	D	317	1614	1931
2005	W	981	1104	2086
2006	W	1784	4453	6236
2007	C	294	600	894
2008	C	230	896	1126
2009	BN	252	492	744
2010	AN	457	1212	1669
2011	W	770	2158	2928
2012	D	299	536	835

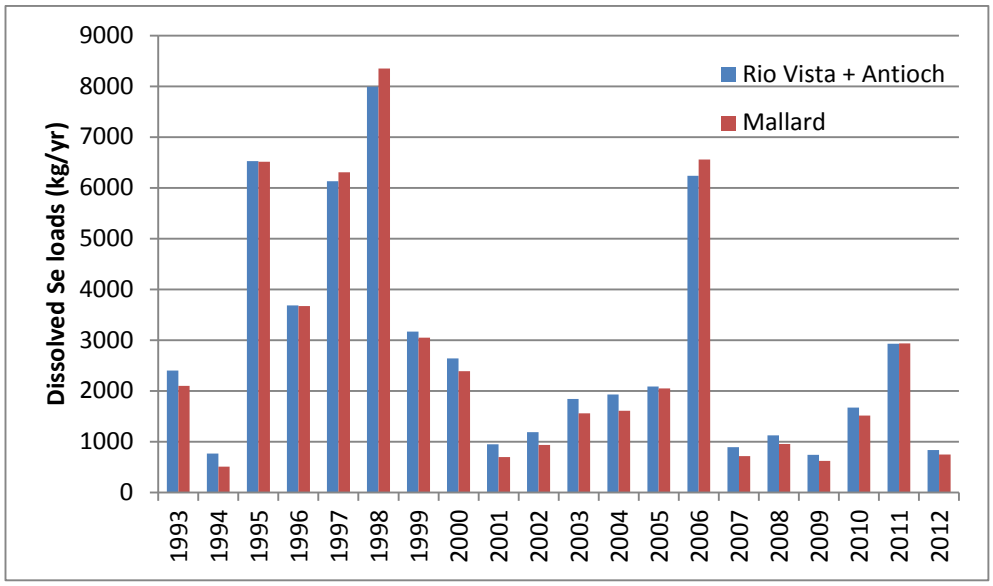


Figure 17 Comparison of estimated dissolved selenium loads as sum of Rio Vista and Antioch and estimated loads at Mallard Island.

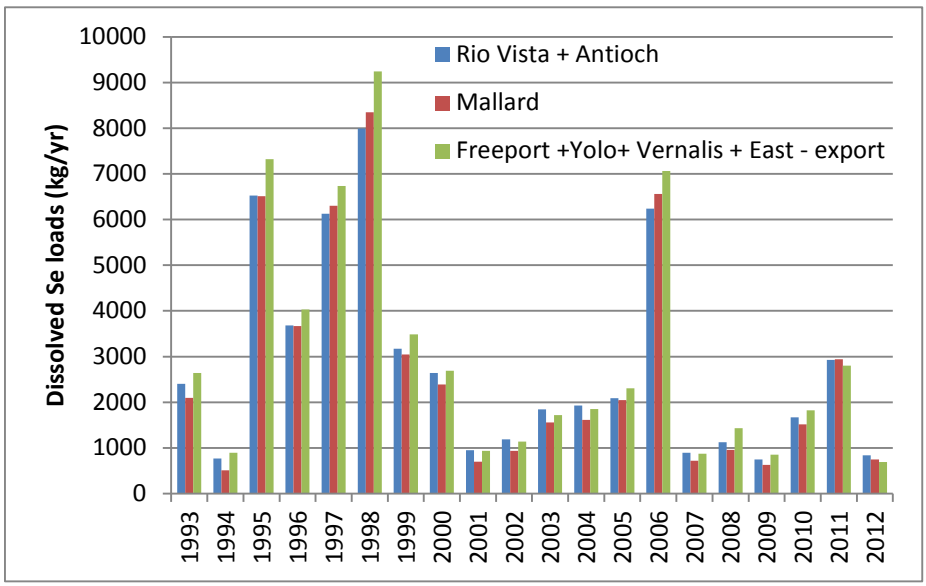


Figure 18 Comparison of estimated dissolved selenium loads as sum of Rio Vista and Antioch, estimated loads at Mallard Island (using tidally average flow calculated by DSM2 and estimated concentrations), and estimated loads as mass balance of Freeport + Vernalis + Yolo + East – export loads.

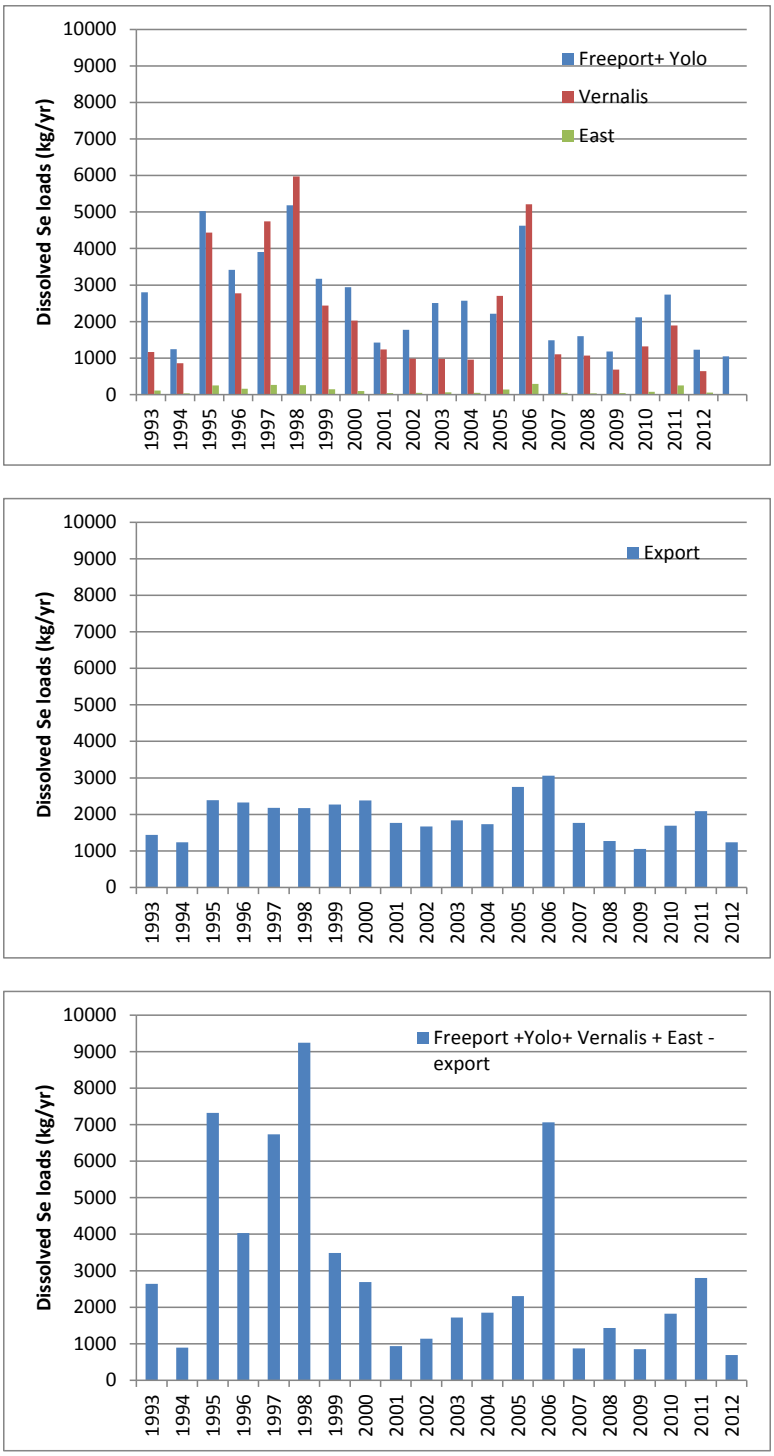


Figure 19 Top. Estimated dissolved Se loads to the Delta from individual sources. Middle. Loads exported through aqueducts. Bottom. Loads entering the Bay (Loads to the Delta – Exports).

References

Meseck, S.L. 2002. Modeling the biogeochemical cycle of selenium in the San Francisco Bay. Ph.D. Dissertation, Old Dominion University.

David, N., Gluchowski, D.C, Leatherbarrow, J.E, Yee, D., and McKee, L.J, 2012. Evaluation of Loads of Mercury, Selenium, PCBs, PAHs, PBDEs, Dioxins, and Organochlorine Pesticides from the Sacramento-San Joaquin River Delta to San Francisco Bay. A Technical Report of the Sources Pathways and Loading Work Group of the Regional Monitoring Program for Water Quality: SFEI Contribution #681. San Francisco Estuary Institute, Oakland, CA. 49 pp.
http://www.sfei.org/sites/default/files/Mallard_Island_Report_120216.pdf

Tetra Tech, 2008. Technical memorandum 2: North San Francisco Bay selenium data summary and source analysis. Prepared for: Regional Water Quality Control Board San Francisco Bay Region.