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Potential Effects Of Selenium Contamination On Federally-Listed Species Resulting From Delivery Of Federal Water To The San Luis Unit

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Potential Effects Of Selenium Contamination On Federally-Listed Species Resulting From Delivery Of Federal Water To The San Luis Unit

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Introduction

Federal water delivered to the San Luis Unit (the Project) is used principally for irrigated agriculture. Due to a nearly-impervious soil layer, irrigated agriculture in this area is unsustainable without subsurface drainage to keep the water table below the root zone of crops and to ameliorate the accumulation of salts in the soil. Therefore, an analysis of the effects of the delivery of federal water must include the effects of subsurface drainwater that may seep, be conveyed, or be carried by floodwaters downstream into sloughs and rivers and thence into the San Francisco Bay/Delta estuary.

Within the direct footprint of the project, consideration must be given to the effects of conveying and storing drainwater, as well as applying drainwater to irrigate salt-tolerant plants in reuse areas, and evaporating drainwater in evaporation ponds or solar evaporators. These are likely to be components of any long-term continuation of irrigated agriculture in the San Luis Unit. In this area, the subsurface drainage of irrigated lands mobilizes selenium that has been historically sequestered in the soil. Selenium concentrations in agricultural drainwater from this area reach levels that, when bioaccumulated through food chains, cause adverse effects on aquatic and aquatic-dependent wildlife. Where such drainwater is applied to uplands, as in reuse areas, strictly terrestrial wildlife may be impacted as well.

Downstream from the San Luis Unit, any drainwater from the Project area is diluted by relatively low-selenium water from rivers that drain the Sierra Nevada Mountains. However, as the San Joaquin River reaches the San Francisco Bay/Delta estuary, flow velocities decrease and salinity increases. In these slow-moving, saline waters, with abundant introduced filter-feeding invertebrates, ecosystems have developed that evidently are much more effective than riverine from the San Joaquin River above the confluence of the Merced River. Planning is underway to restore salmon to this river by increasing flows and restoring habitat. However, seepage and flood flows carrying agricultural drainwater from the San Luis Unit into the San Joaquin River may impact salmon and could impair efforts to restore them to this river.

California Central Valley Chinook salmon evidently are among the most sensitive of fish and wildlife to selenium. They are especially vulnerable during juvenile life stages when they migrate and rear in selenium-contaminated Central Valley rivers and the San Francisco Bay/Delta estuary.

In a laboratory experiment, measurements were made of the selenium bioaccumulation, weight and survival of juvenile (initially swim-up larvae) San Joaquin River fall run Chinook salmon that were exposed for 90 days in fresh water to two parallel graded series of dietary selenium treatments (Hamilton *et al*. 1990). In one series, the food was spiked with seleno-DL-methionine (SeMet); in the other series, the source of selenium was mosquitofish collected from the San Luis Drain (SLD), which carried seleniferous agricultural drainwater from a subsurface tile drainage system in the Westlands Water District in the San Joaquin Valley of California. Although the SLD mosquitofish diets may have included other contaminants, such as pesticides, the results of this experiment indicate that, once selenium is incorporated into fish tissue, there is no difference in the tissue concentration-response relationship due to the different sources of selenium (SLD or SeMet). Therefore, all data from both diet series were combined in the analysis presented here.

The effects of selenium on animals (including fish) are well known to be biphasic (beneficial at low doses; toxic at high doses; see, for example, Beckon *et al*. 2008), and in the Hamilton *et al*. (1990) experiment, the 90-day survival data appear to confirm a biphasic dose-response relationship with respect to the survival endpoint (Figure 8). Therefore, we fitted a biphasic model (Brain and Cousens 1989) to the data by least squares regression. This regression provides a weight-of-evidence estimate of the maximum survival rate (0.7, or 70 percent) of young salmon under these experimental conditions at the estimated optimal selenium concentration in the fish (about 1 μg/g whole body dry weight). It also provides an estimate of the survival rate at any given selenium concentration above the optimum. Any such survival rate estimate can be compared to the maximum survival rate to yield an estimate of the mortality (inverse of survival) specifically attributable to selenium. For example, at a fish tissue concentration of 7.9 μg/g (whole body dry weight) the regression curve predicts a survival of 0.29 (29 percent). As a proportion of the maximum survival this is 0.29/0.7 = 0.41, or 41 percent. Therefore our best weight-of-evidence estimate of the mortality due to selenium toxicity at a tissue concentration of 7.9 μg/g is the inverse of 0.41, which is 0.59, or 59 percent. Similarly, the model predicts that fish with a selenium concentration of 2.45 μg/g (whole body dry weight) after 90 days of exposure would experience 20 percent mortality due to selenium (Figure 8 lower graph).

In the Hamilton *et al*. (1990) experiment, the concentrations of selenium in the food that was provided to the salmon were about the same as the concentrations reached by the salmon themselves. This experiment indicates that, in sloughs that carry agricultural drainwater, concentrations of selenium in invertebrates, small (prey) fish, and larger predatory fish

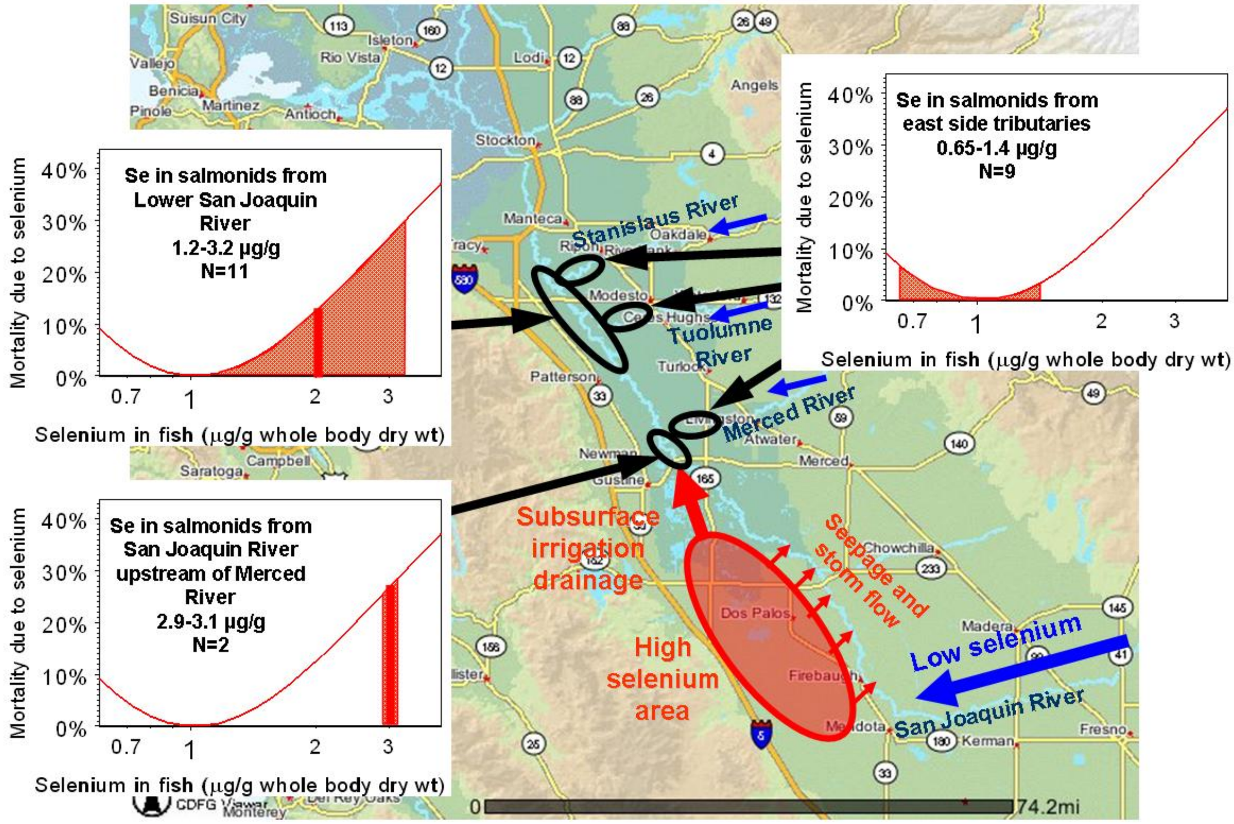

Figure 9. Risk of mortality to juvenile Chinook salmon based on selenium measured in the salmon (Saiki, *et al*. 1991) and the toxicity data shown in Figure 8 (presented here as mortality). Solid red bars represent the geometric mean selenium concentration in sampled fish at each location or cluster of locations. The stippled red areas span the ranges of concentrations in fish at the respective locations.

commonly reach levels (Beckon *et al*. 2003) that could kill a substantial portion of young salmon (Figure 8 upper graph) if the salmon, on their downstream migration, are exposed to those selenium-laden food items for long enough for the salmon themselves to bioaccumulate selenium to toxic levels.

Available data (Saiki *et al*. 1991) confirm that young salmon migrating down the San Joaquin River in 1987 bioaccumulated selenium to levels (about 3 µg/g whole body dry wt.) that were likely to kill more than 25% (**Figure 9**).

Concentrations of selenium in the San Joaquin River have been reduced since juvenile Chinook salmon were sampled in 1987 (Saiki *et al*. 1991). However, the relationship between selenium in water and in young salmon in 1987 (Figure 10) indicates that there remains a substantial ongoing risk to migrating juvenile Chinook salmon in the San Joaquin River (Figure 11).

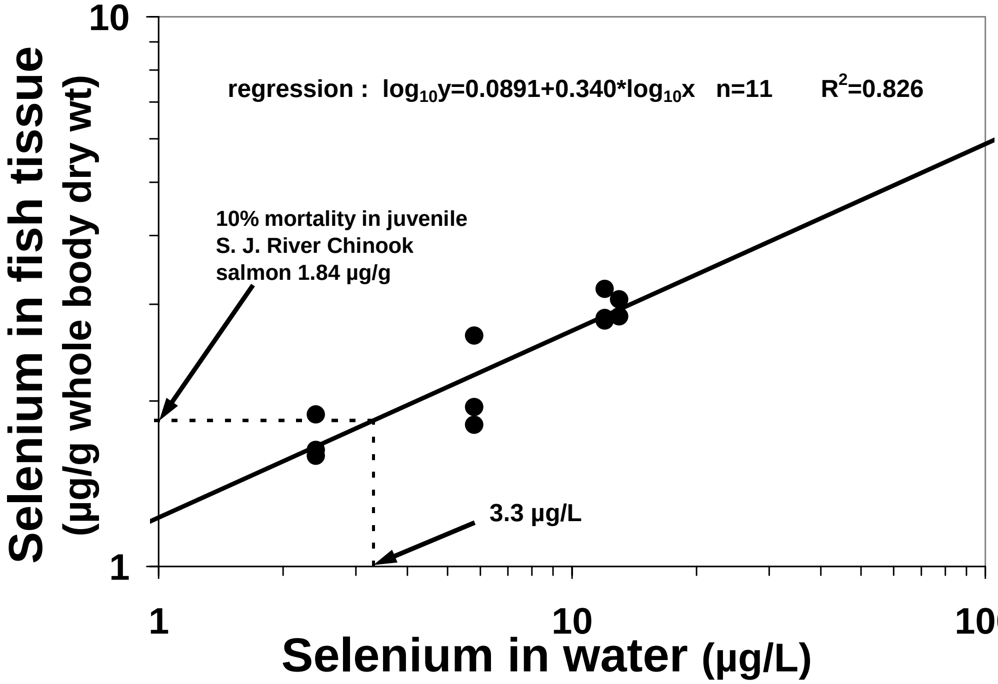

Figure 10. Relationship between selenium in juvenile Chinook salmon (Saiki *et al*. 1991, Saiki pers. com.) and water (Central Valley Regional Water Quality Control Board "Flat File") in the San Joaquin River and its tributaries.

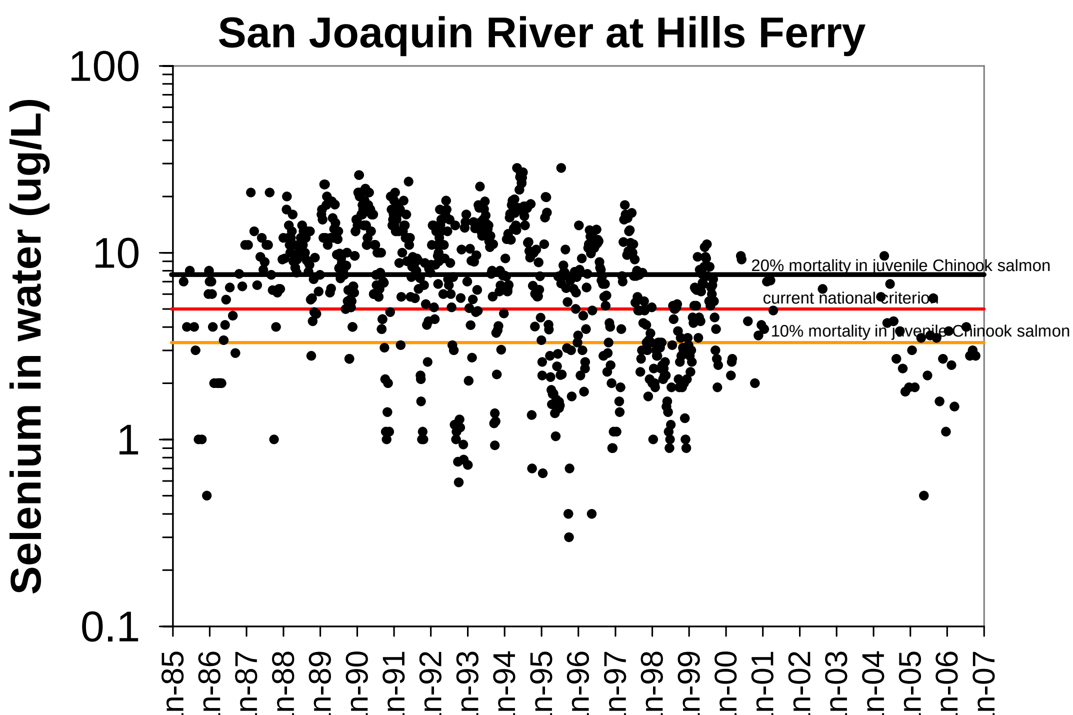

Figure 11. Selenium concentrations measured in the San Joaquin River at Hills Ferry, just upstream of the confluence of the Merced River. The data are from the Central Valley Regional Water Quality Control Board.

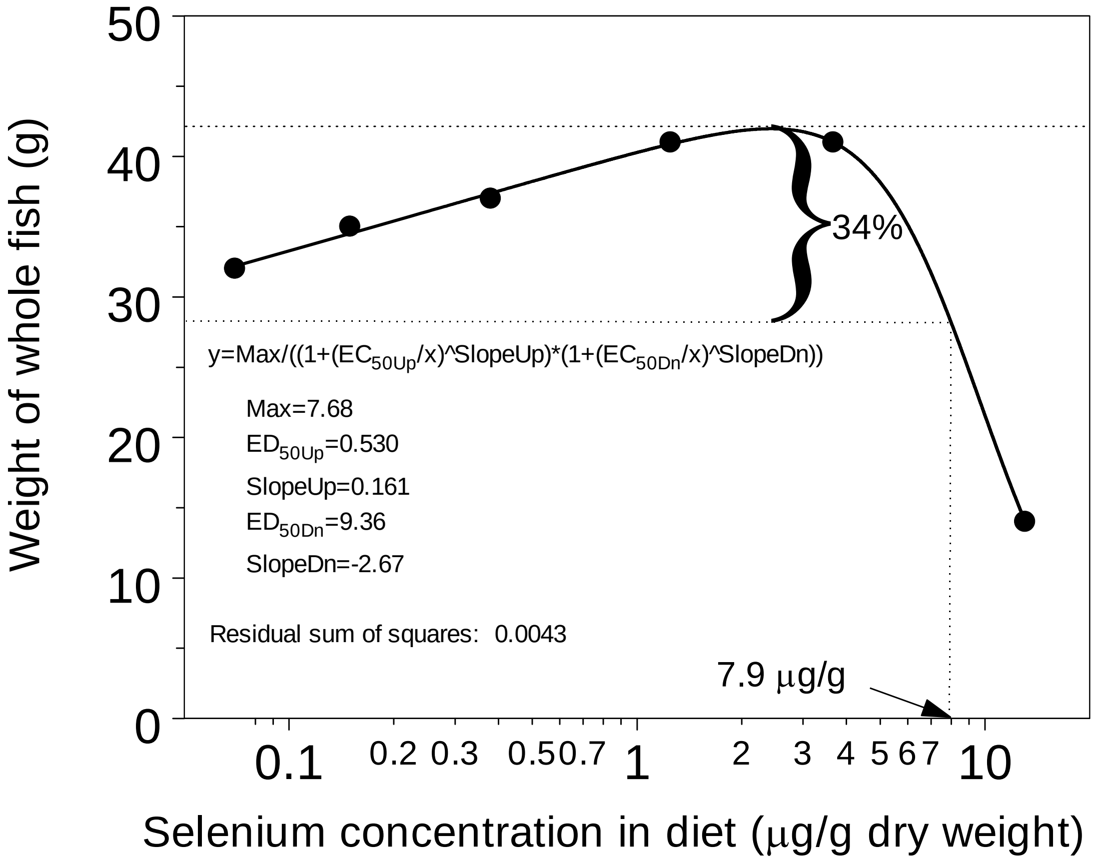

Figure 16. Average weights of juvenile rainbow trout after 20 weeks dietary exposure to sodium selenite (Hilton *et al.* 1980). A biphasic model (Beckon *et al.* 2008) is fitted to the data by least squares non-linear regression.

This experiment also indicates that if young rainbow trout feed on tissue that has a selenium concentration of about 8 µg/g (in the form of sodium selenite) they will suffer a reduction in growth of about 34 percent (Figure 16). Because the form of selenium administered to the fish in this experiment was sodium selenite, this analysis may yield an underestimate of the adverse effects of the more bioavailable organic forms of selenium that fish consume in the wild.

The experiments summarized above indicate that the larval survival and the health and growth of young steelhead trout would be impaired by a concentration of selenium (about 8 µg/g) commonly exceeded in invertebrates, small (prey) fish, and larger predatory fish in waterways that carry agricultural drainwater in the vicinity of the San Luis Unit (Beckon *et al.* 2003).