FIGURES

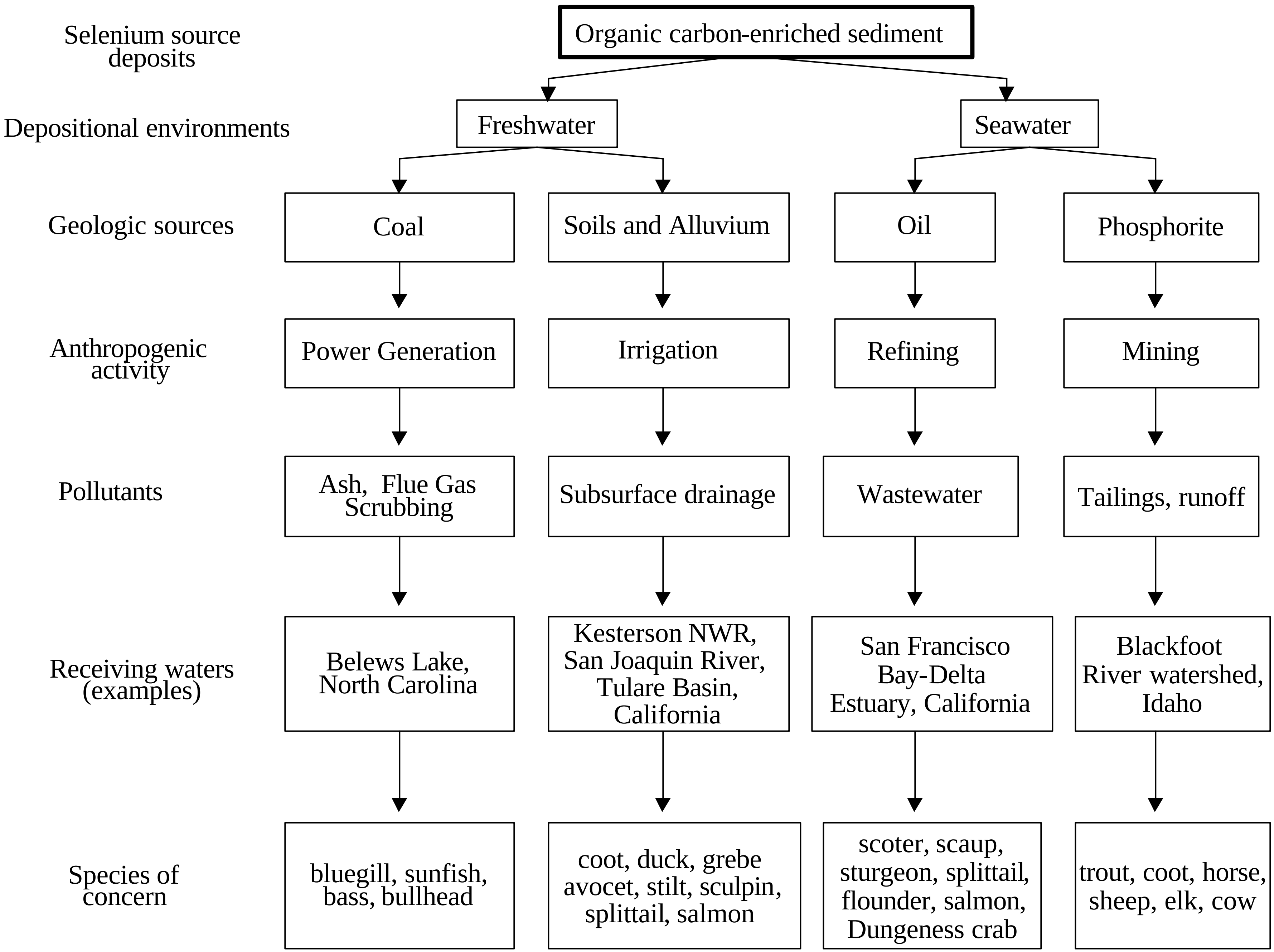


Figure 1. Conceptual model of Se pollution with examples of source deposits, anthropogenic activities, receiving water bodies, and biota at risk.

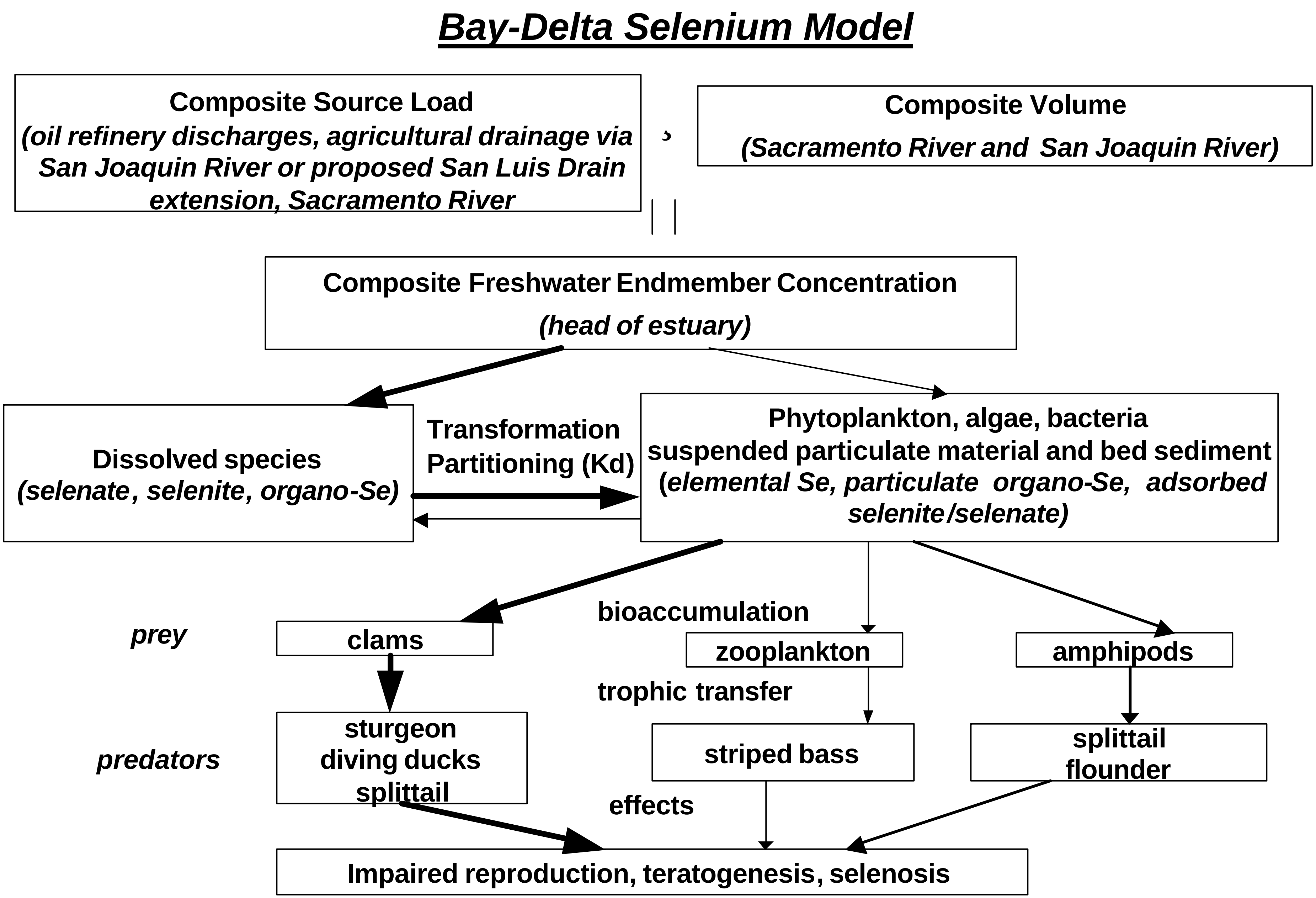


Figure 2. Conceptual model describing linked factors that determine the effects of selenium on ecosystems. The sequence of relations links environmental concentrations to biological effects. The general term "bioaccumulation" can be applied to all of the biological levels of selenium transfer through the food web, but in this report we use the term explicitly in reference to particulate/invertebrate bioaccumulation.

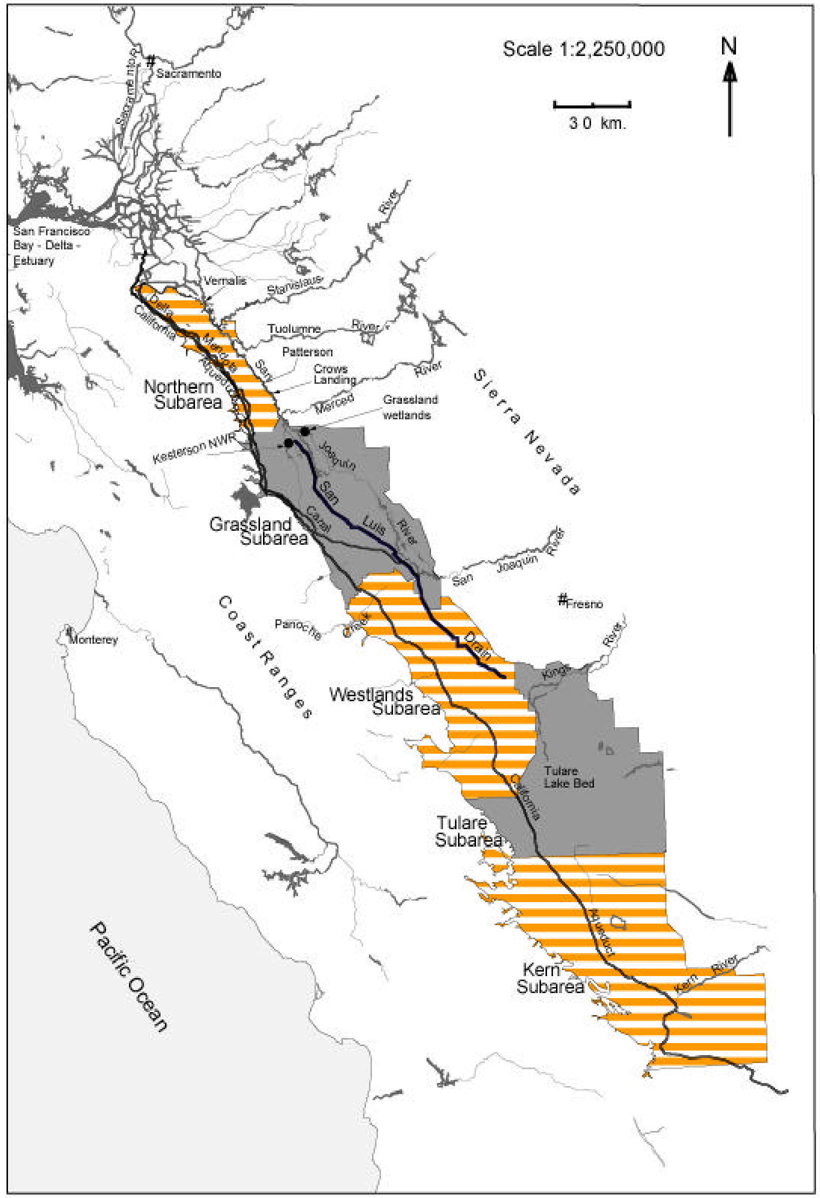


Figure 3, Map of the San Joaquin Valley and the adjacent Coast Ranges and Sierra Nevada. The five designated subareas for management of agricultural drainage are shown along with the major rivers, supply canals, the San Luis Drain, and Kesterson National Wildlife Refuge. The San Joaquin River flows north to the San Francisco Bay-Delta Estuary. Proposed management alternatives to sustain agriculture include draining Se-laden salts into the San Joaquin River or a proposed extension of the San Luis Drain. See Figure 4 for a detailed map of the Bay-Delta and Figure 5 for details of hydrologic connections between the valley and the estuary. Adapted from Presser and Piper (1998).

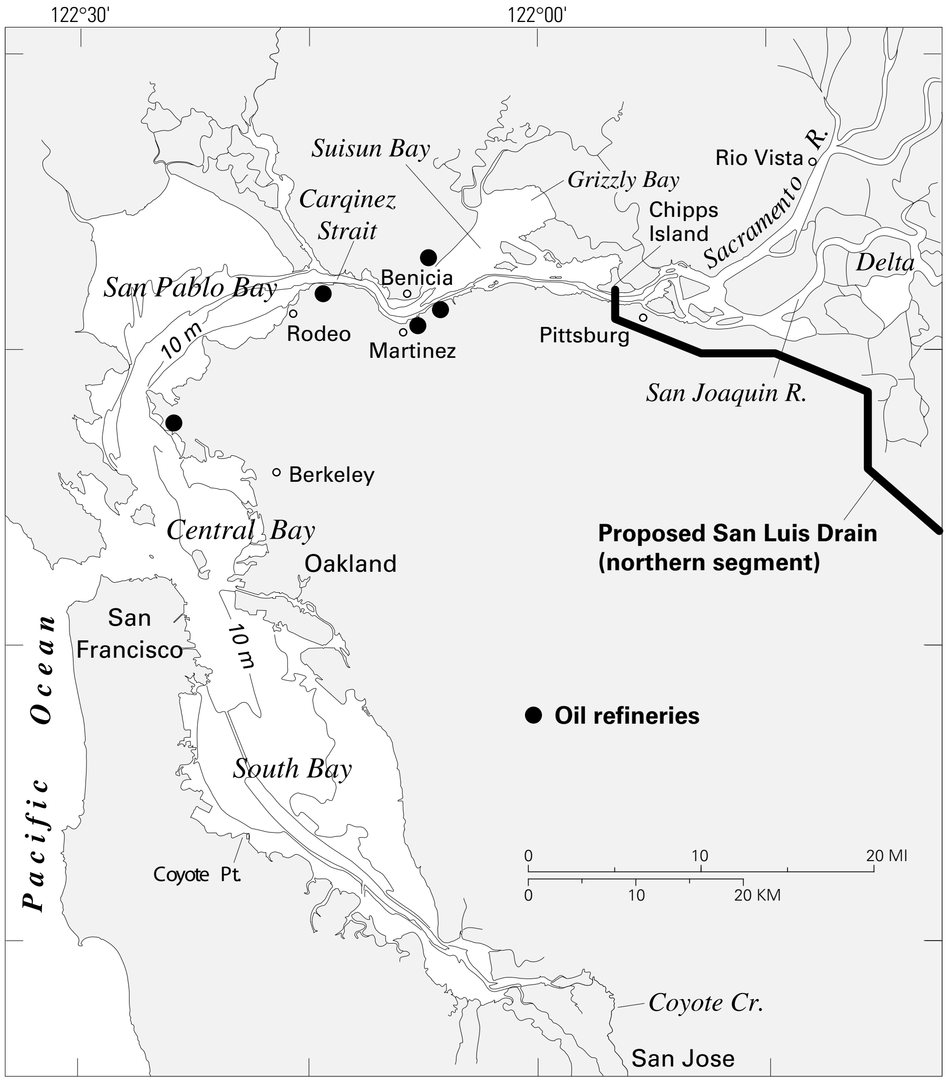
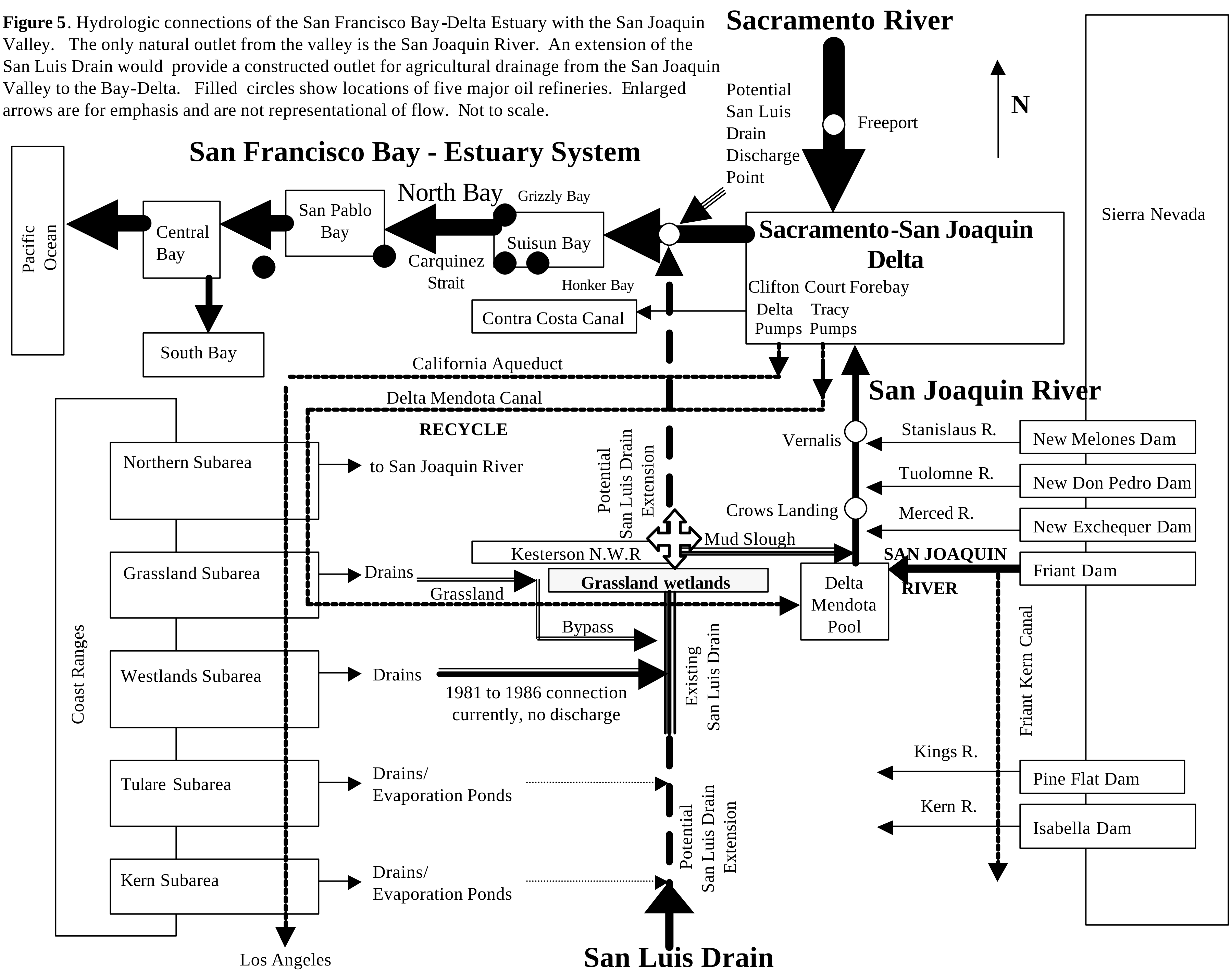


Figure 4. Map of the San Francisco Bay-Delta Estuary including the locations of oil refineries (filled circles) in the North Bay and the location of the proposed northern segment of the San Luis Drain. The North Bay includes Suisun Bay and San Pablo Bay. Adapted from Conomos et al., 1985.

Figure 5. Hydrologic connections of the San Francisco Bay-Delta Estuary with the San Joaquin Valley. The only natural outlet from the valley is the San Joaquin River. An extension of the San Luis Drain would provide a constructed outlet for agricultural drainage from the San Joaquin Valley to the Bay-Delta. Filled circles show locations of five major oil refineries. Enlarged arrows are for emphasis and are not representational of flow. Not to scale.



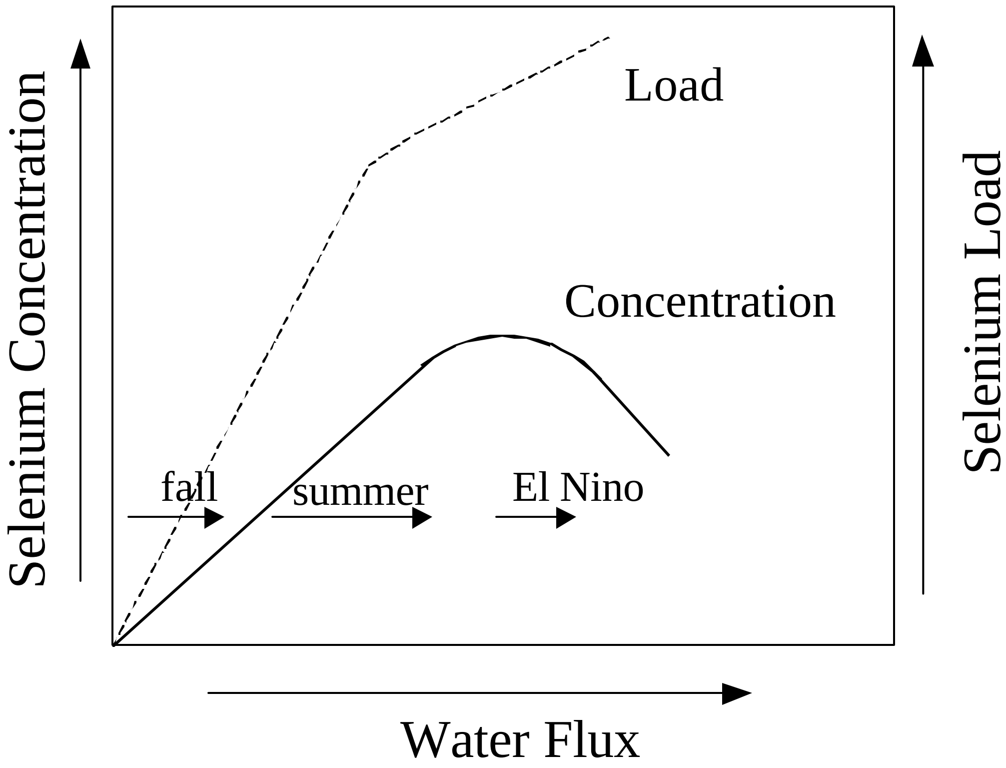


Figure 6. Selenium concentration in drainage (i. e., source waters) as a function of flow (I.e., water flux) and resultant Se load. This schematic representation from current data depicts the effects of a large reservoir of Se on subsurface drainage.

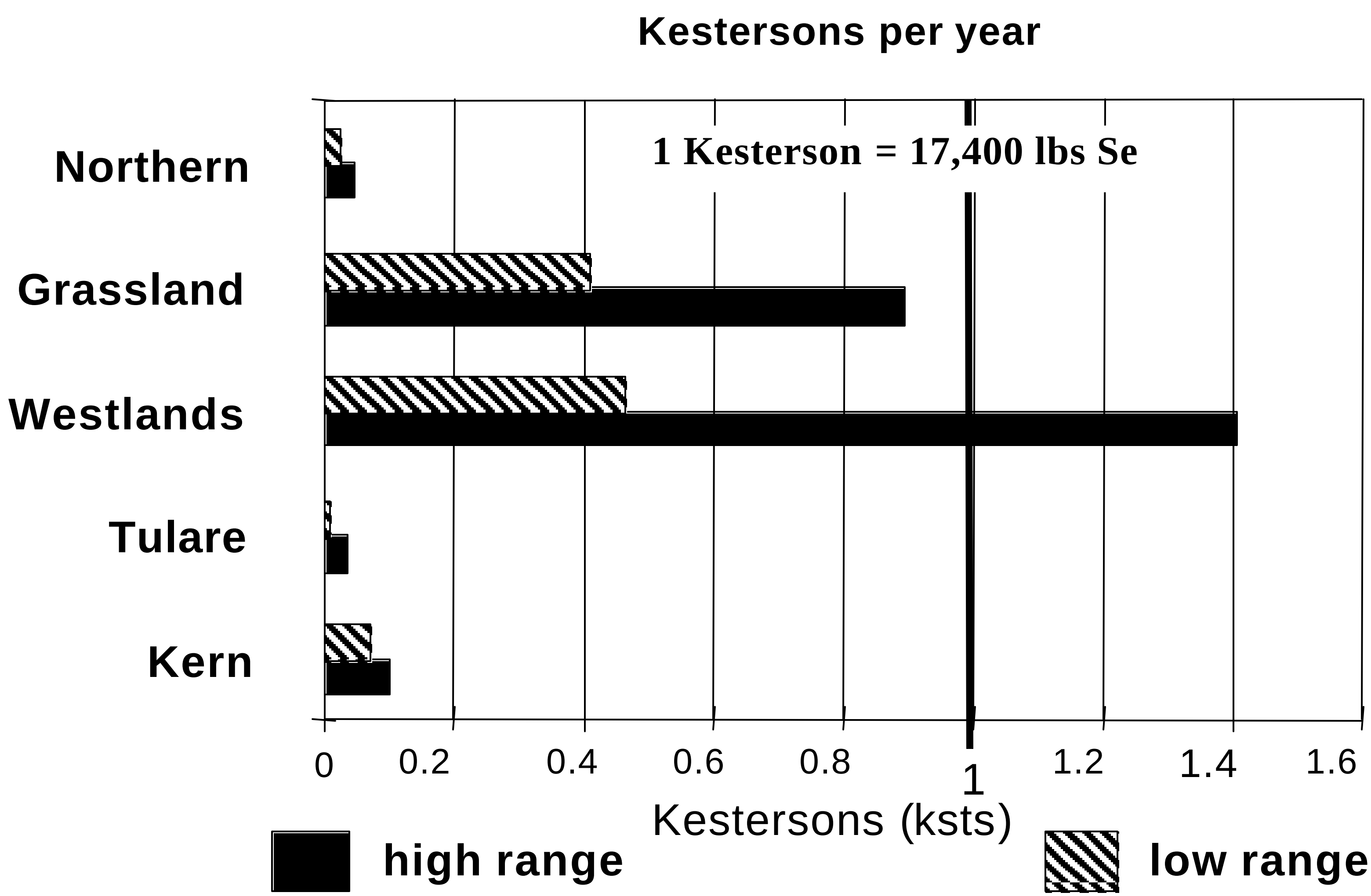


Figure 7. Projected high and low range of annual selenium discharges from the five subareas of the western San Joaquin Valley using current available data. Discharges are given in kestersons (ksts), where 1 kst equals 17,400 lbs. The kst unit is the cumulative total of 17,400 lbs Se, which when released directly into Kesterson Reservoir caused ecotoxicity and visible ecological damage. It is used here as a measure of potential ecological damage based on selenium load.

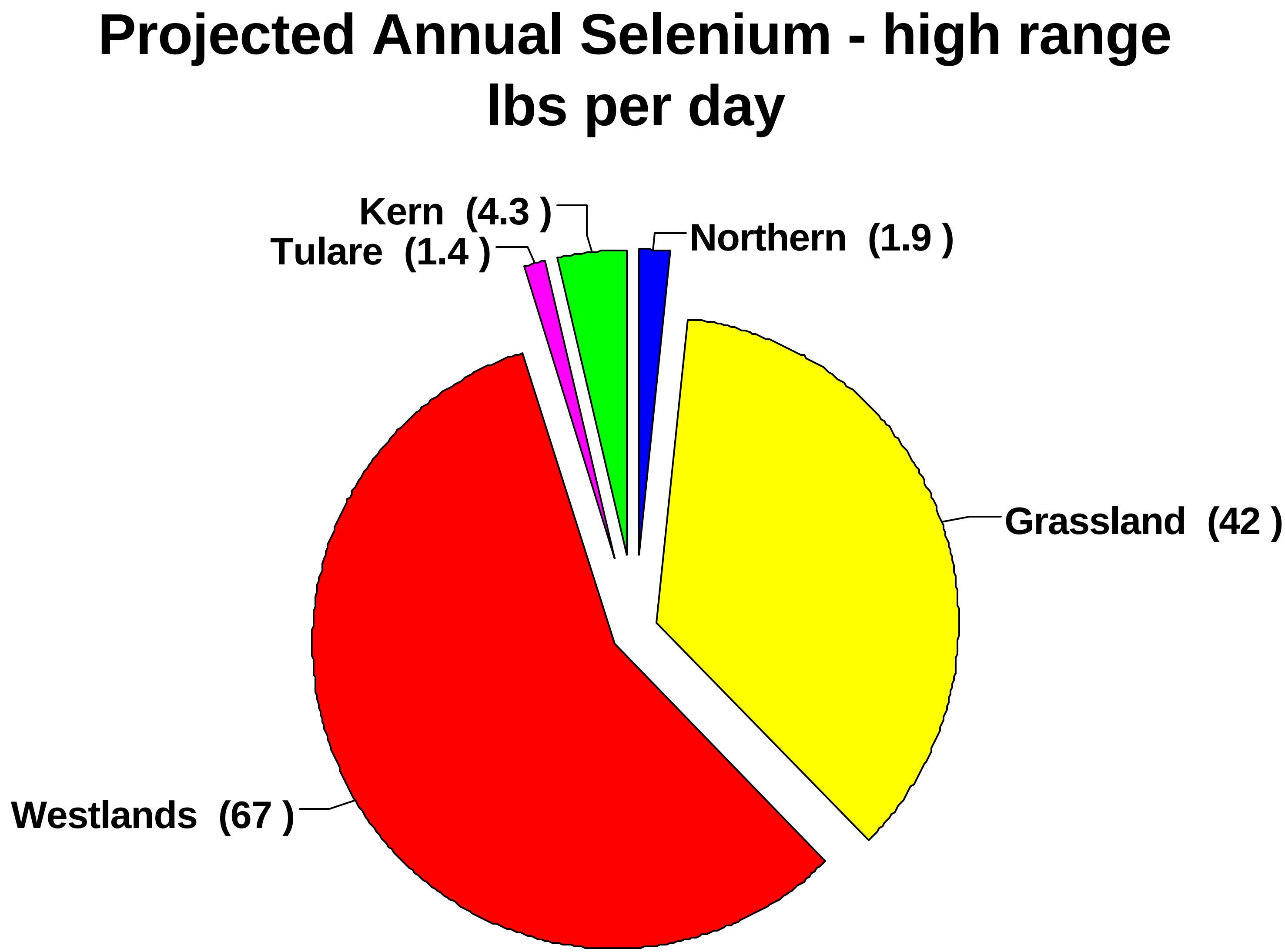


Figure 8. Projected high range of daily selenium discharges from the five subareas shown as proportions of total discharge from the western San Joaquin Valley.

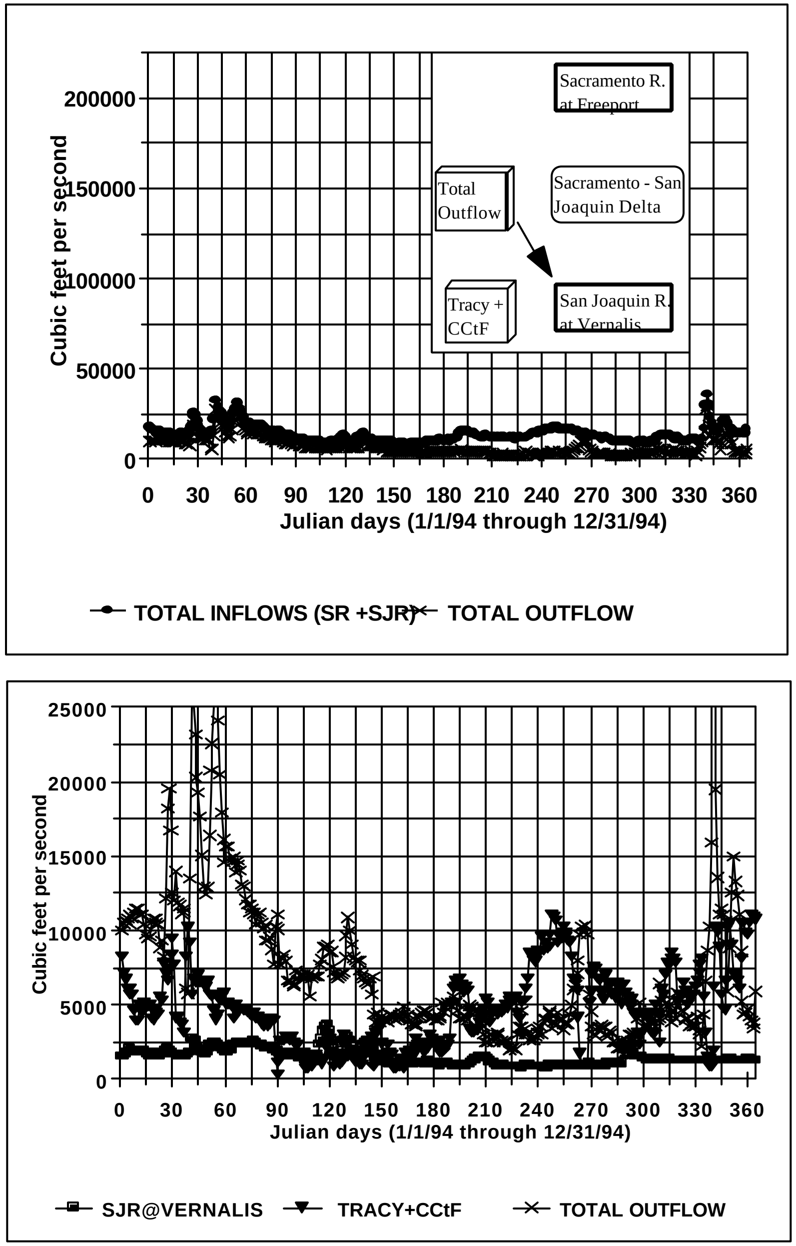


Figure 9. The balance between water diversions (e.g., pumping at Tracy and Clifton Court Forebay), total river inflow to the Bay-Delta, and the discharge of the San Joaquin River in a dry year (1994).

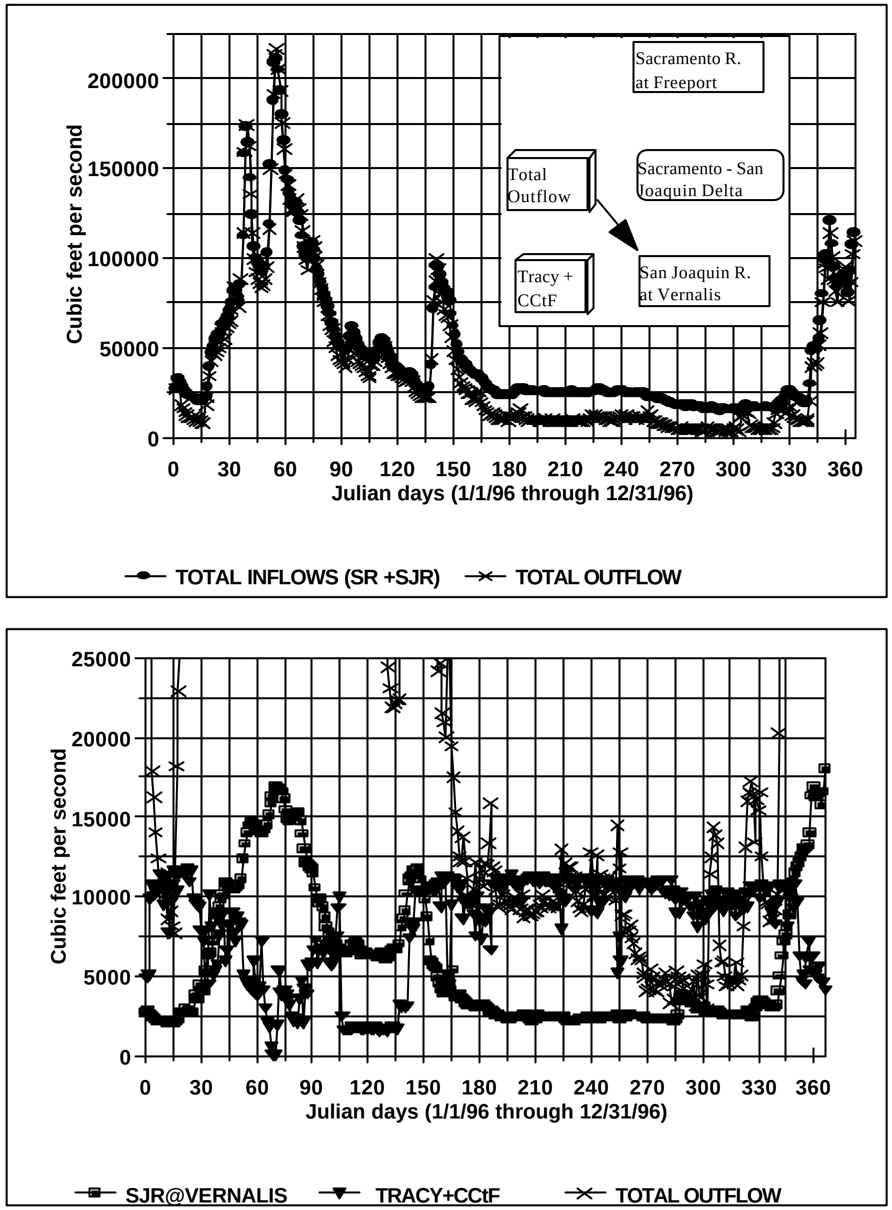


Figure 10. The balance between water diversions (e.g., pumping at Tracy and Clifton Court Forebay), total river inflow to the Bay-Delta, and the discharge of the San Joaquin River in a wet year (1996).

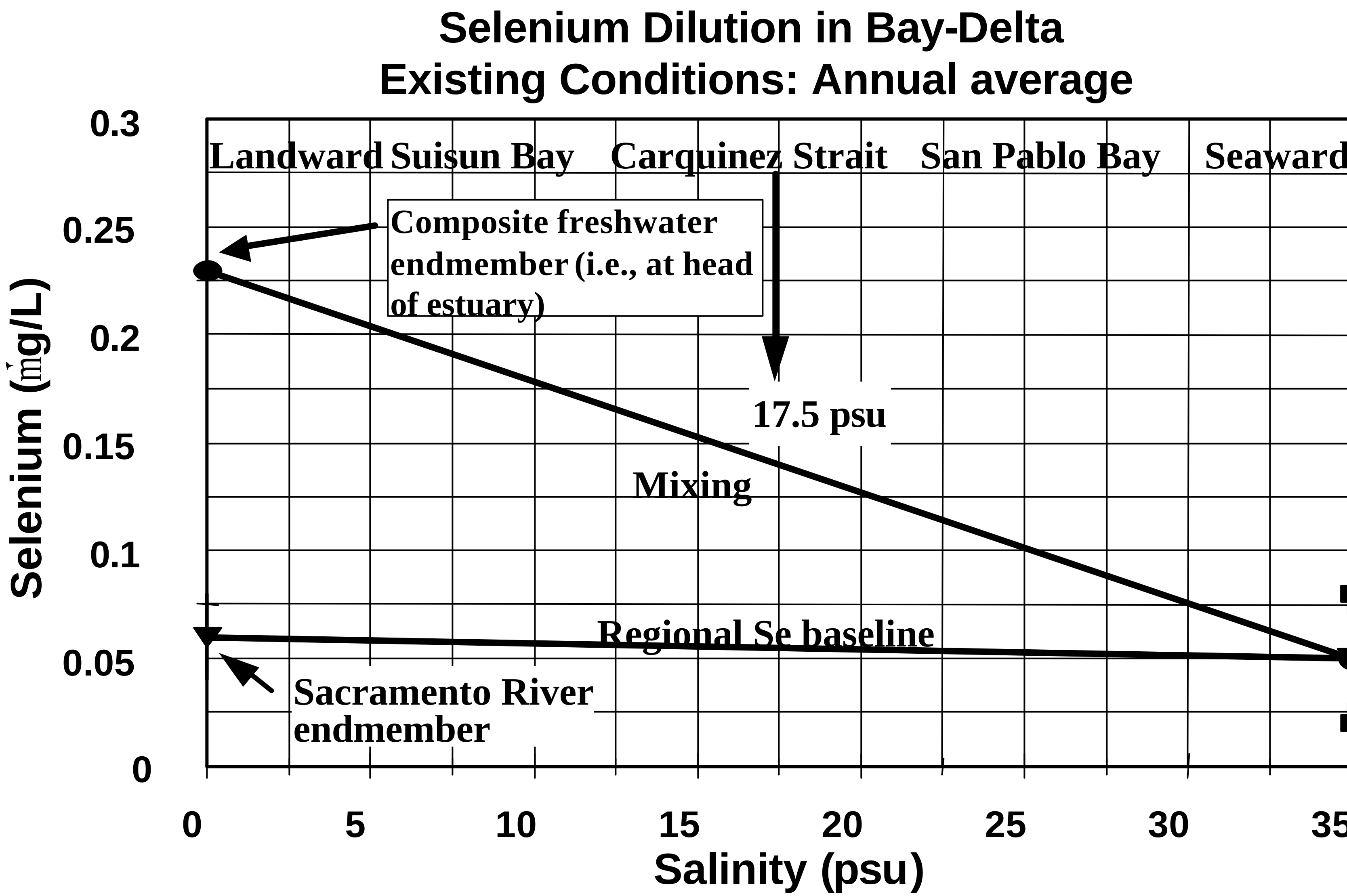


Figure 11. Hypothetical dilution profiles for selenium in the Bay-Delta. The regional baseline profile shows selenium concentrations through the estuary as concentrations in the Sacramento River are diluted by concentrations in the Pacific Ocean as indicated by salinities (practical-salinity units, psu). The example mixing profile shows the selenium concentration in a hypothetical average freshwater endmember as it is diluted by concentrations in the Pacific Ocean. This endmember was calculated from loads and volumes in the Sacramento River at 20 million acre-feet (MAF) per year plus refinery inputs of approximately 4,000 lbs Se per year (typical of a wet year prior to refinery cleanup).

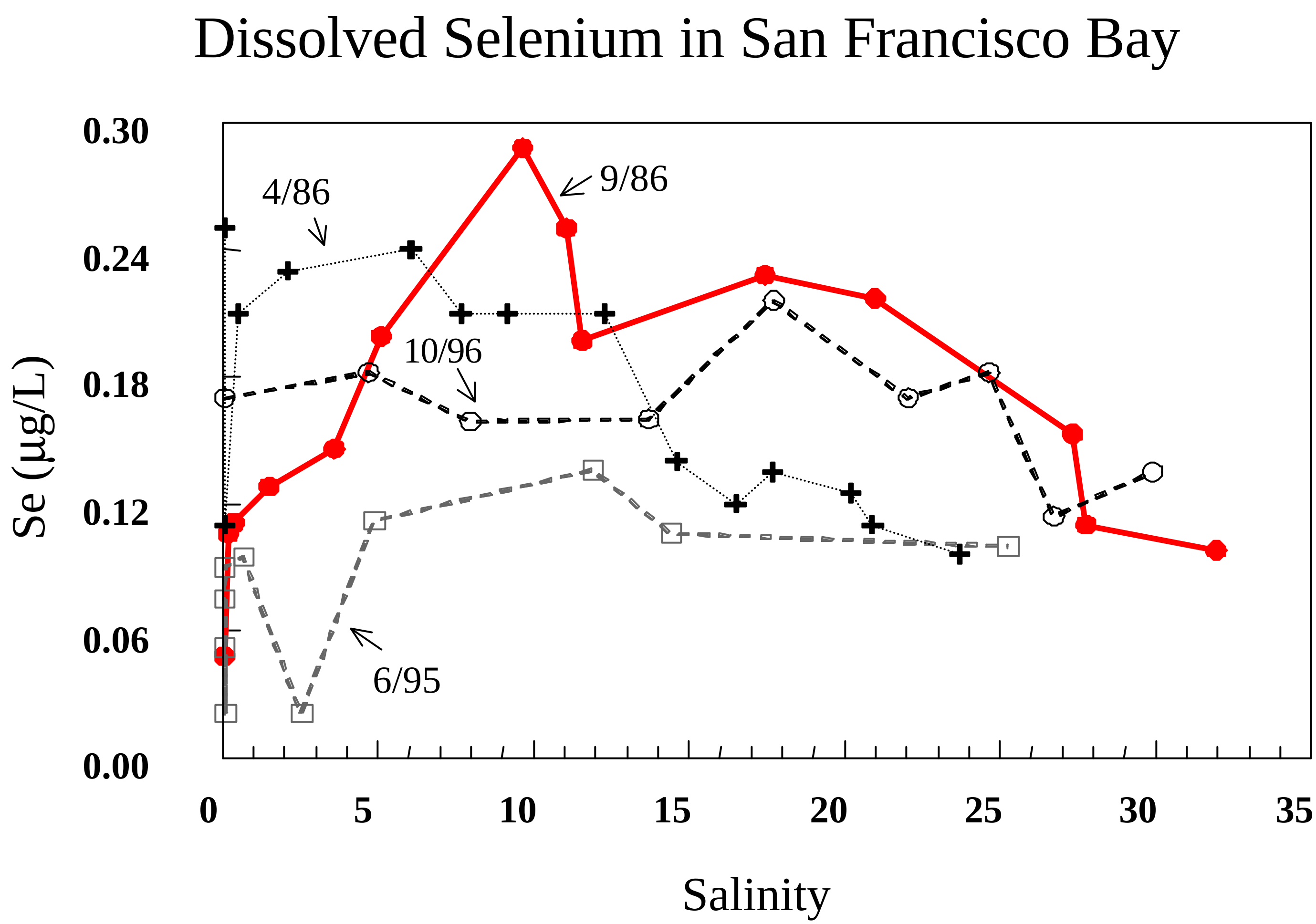


Figure 12. Dissolved selenium profiles as a function of salinity (practical salinity units, psu) in the Bay-Delta, comparing high and low flow seasons in 1986 (4/86 and 9/86) and in 1995-96 (6/95 and 10/96)

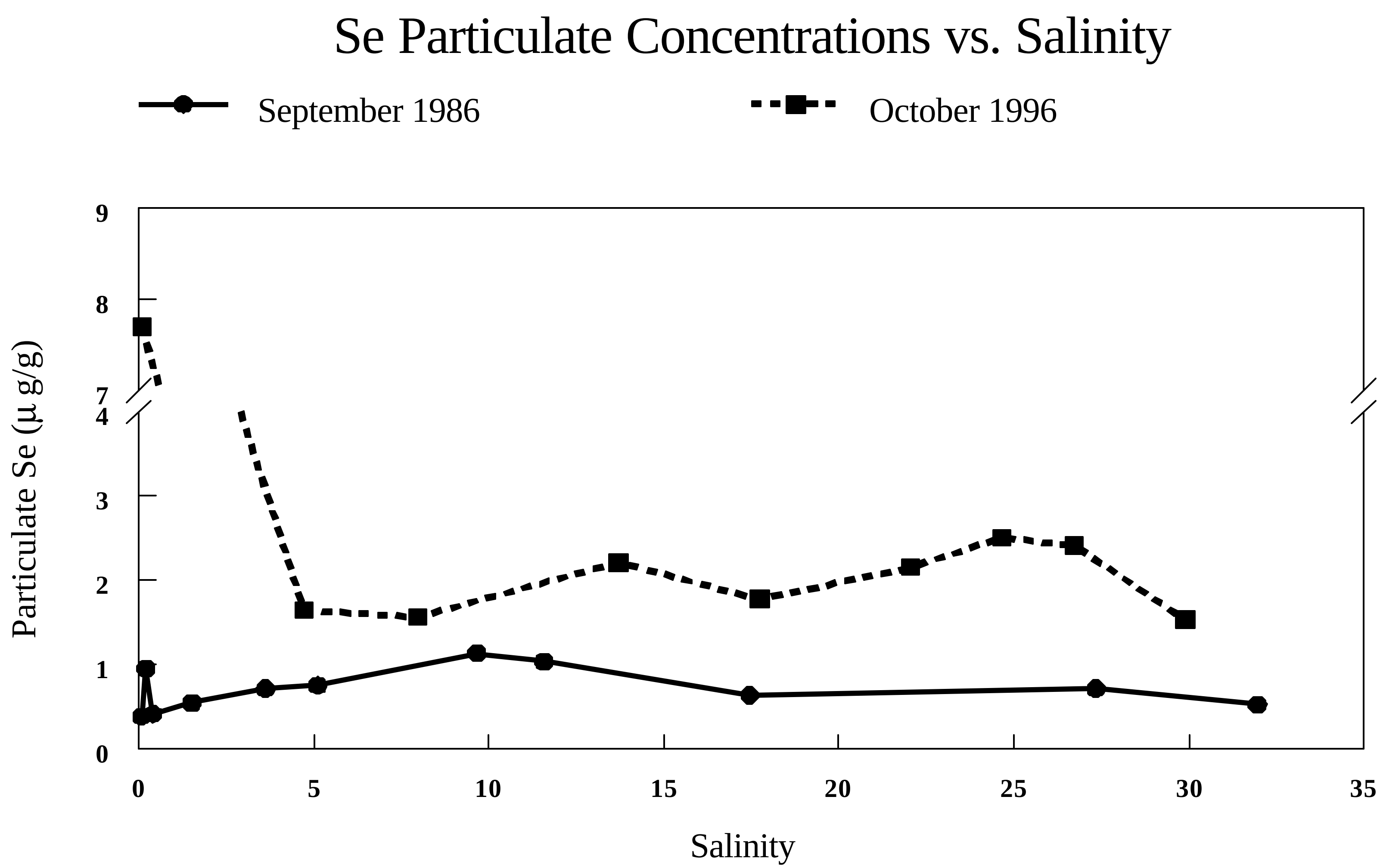


Figure 13. Particulate selenium profiles as a function of salinity (practical salinity units, psu) in the Bay-Delta, comparing high and low flow seasons in 1986 (9/86) and in 1995-96 (10/96).

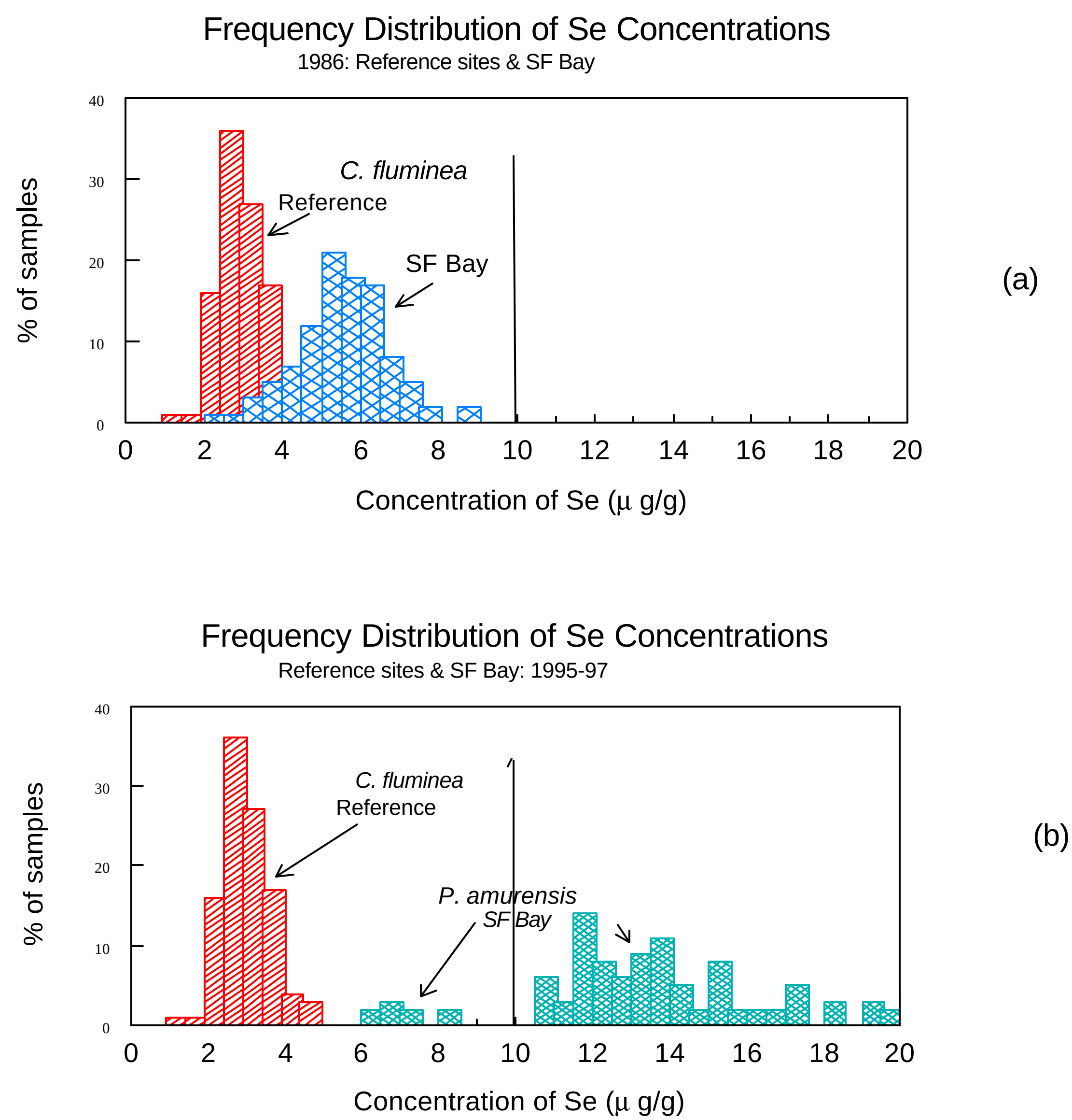


Figure 14. Frequency distributions of selenium concentrations in (a) 129 composite samples of C. fluminea collected betw
January 1985 and October 1986 and (b) 62 composite samples of P. amurensis collected between May 1995 and June 1
from the Bay-Delta. Concentrations in bivalves from reference sites also are given.

Se Concentrations in Potamocorbula

compared to river inflows

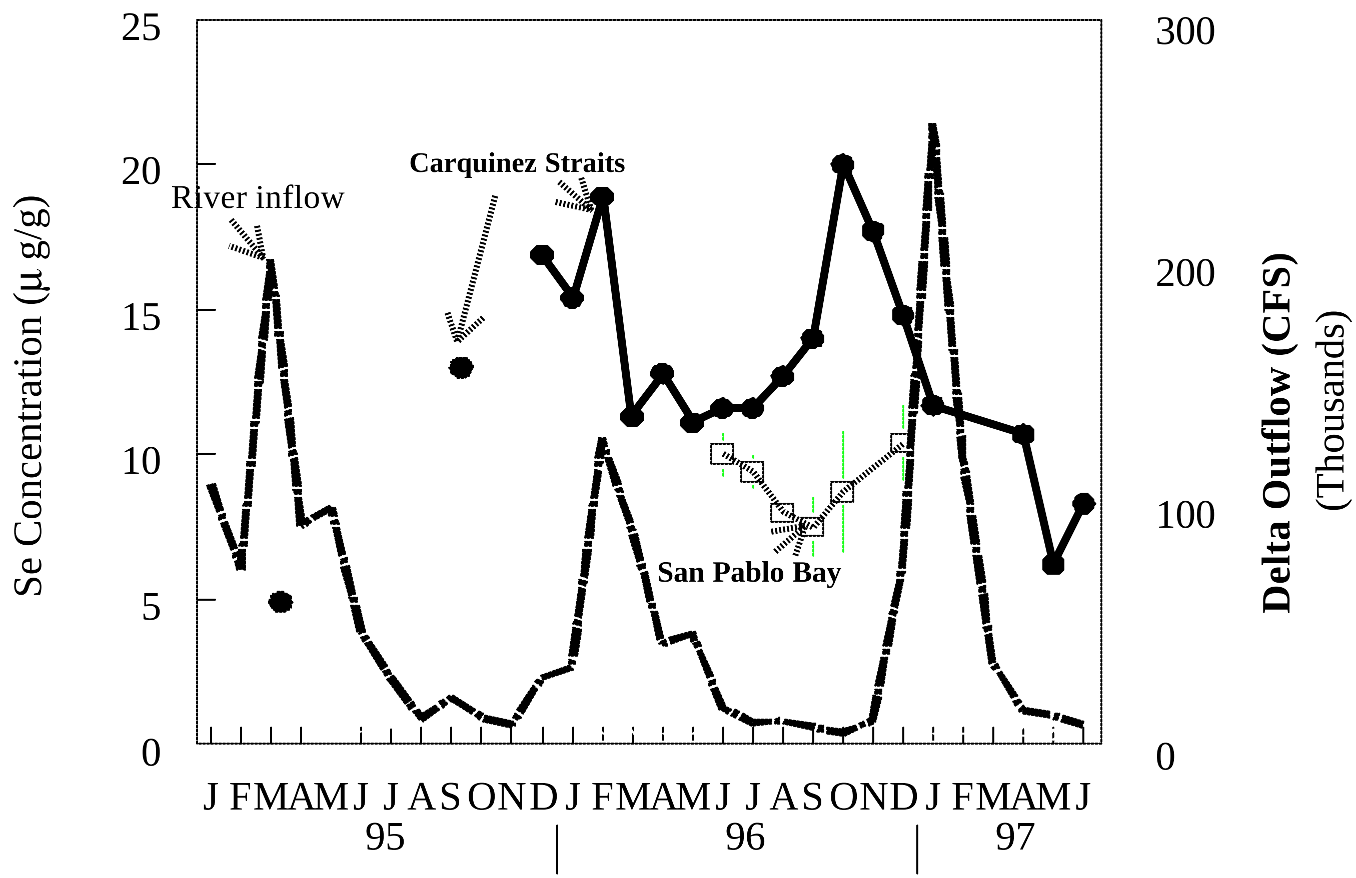


Figure 15. Selenium concentrations in replicate composite samples of P. amurensis from 1995 through 1997 as a function of Delta outflow. Flows are averaged on a monthly basis.

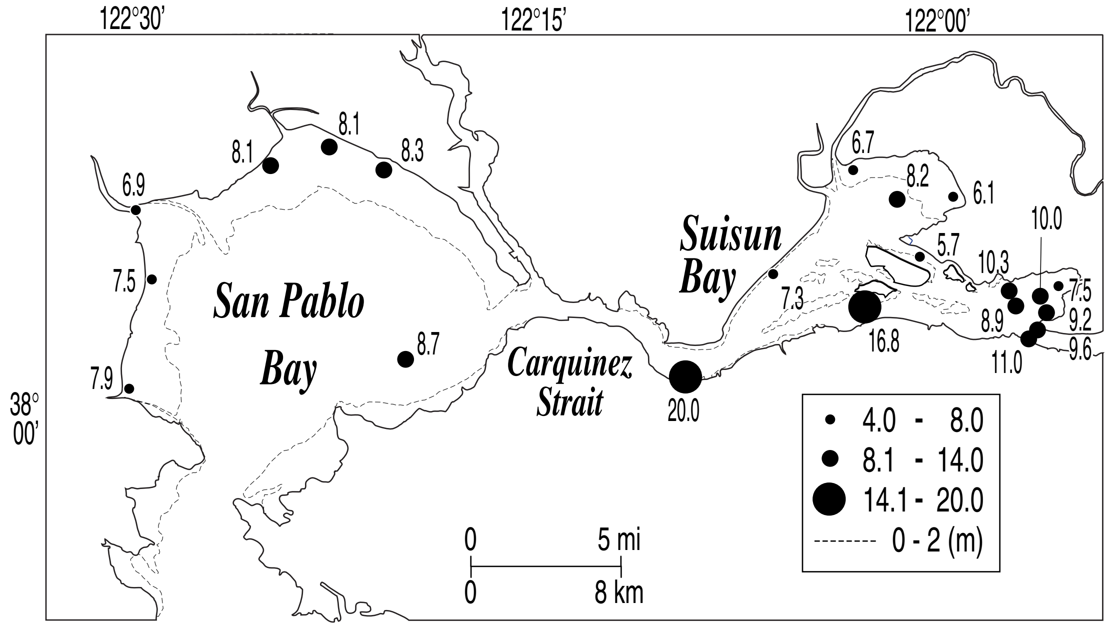


Figure 16. Selenium concentrations in replicate composite samples of *Potamocorbula amurensis* at 22 locations in the Bay-Delta during October 1996. Bivalve selenium concentrations are given in µg Se/g, dry weight.

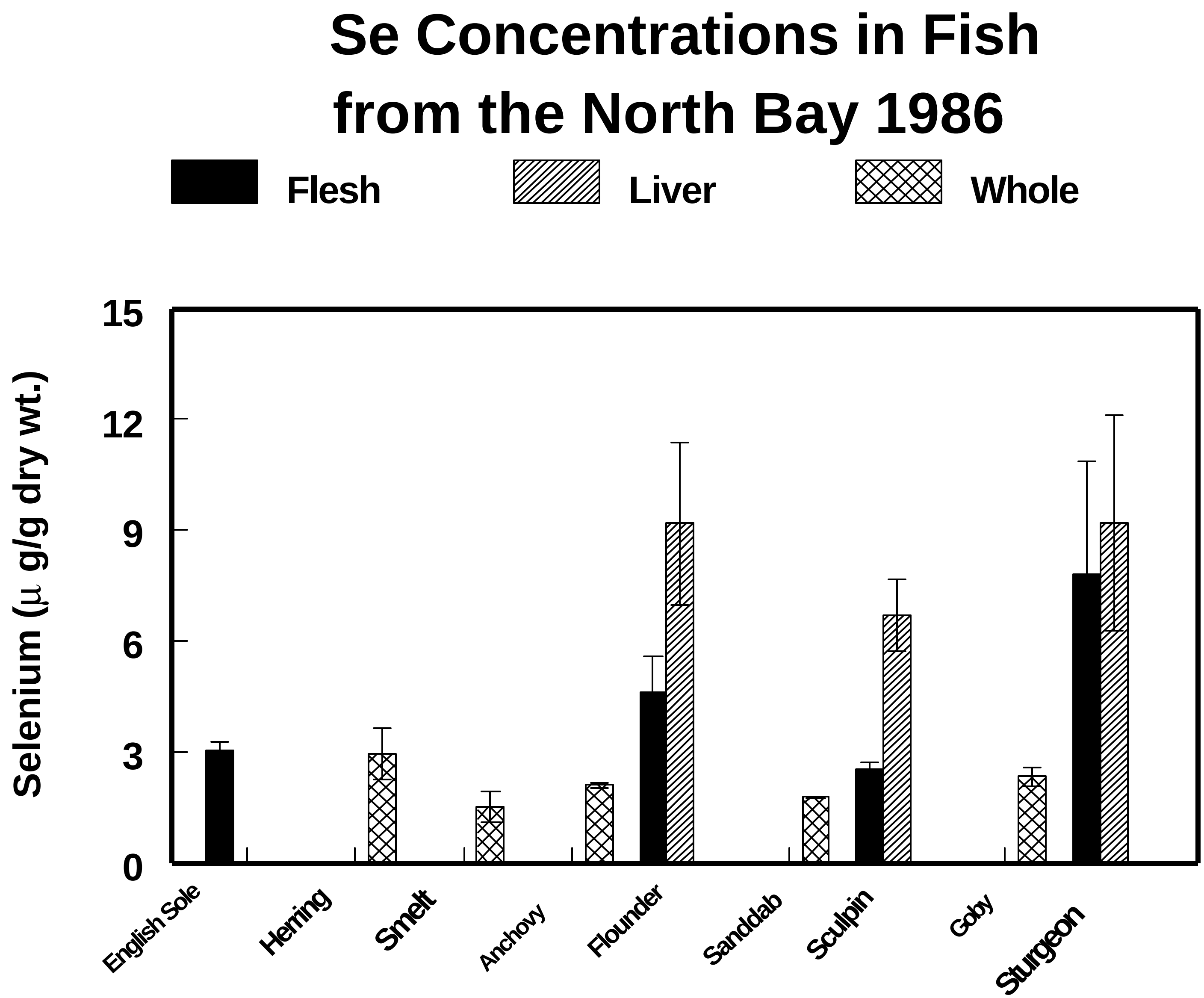


Figure 17. Selenium concentrations in fish samples collected from the North Bay during 1986. Data from California Department of Fish and Game *Selenium Verification Study* (White et al., 1987; 1988; 1989; Urquhart and Regalado, 1991)

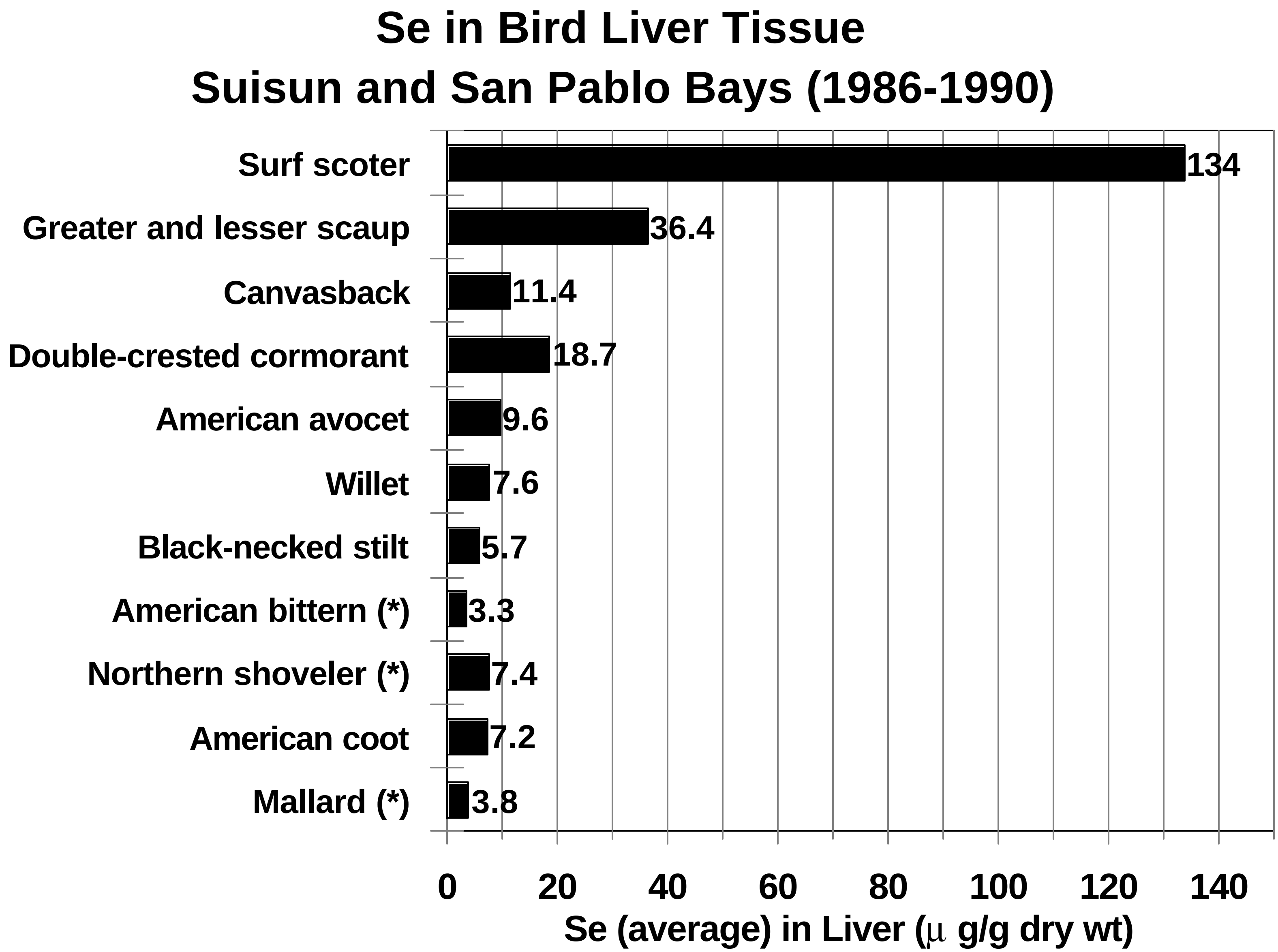


Figure 18. Average selenium concentrations in bird liver samples collected from Suisun Bay and San Pablo Bay from 1986 to 1990. Data from California Department of Fish and Game *Selenium Verification Study* (White et al., 1987; 1988; 1989; Urquhart and Regalado, 1991). Species marked with an asterisk were collected in Suisun Marsh.

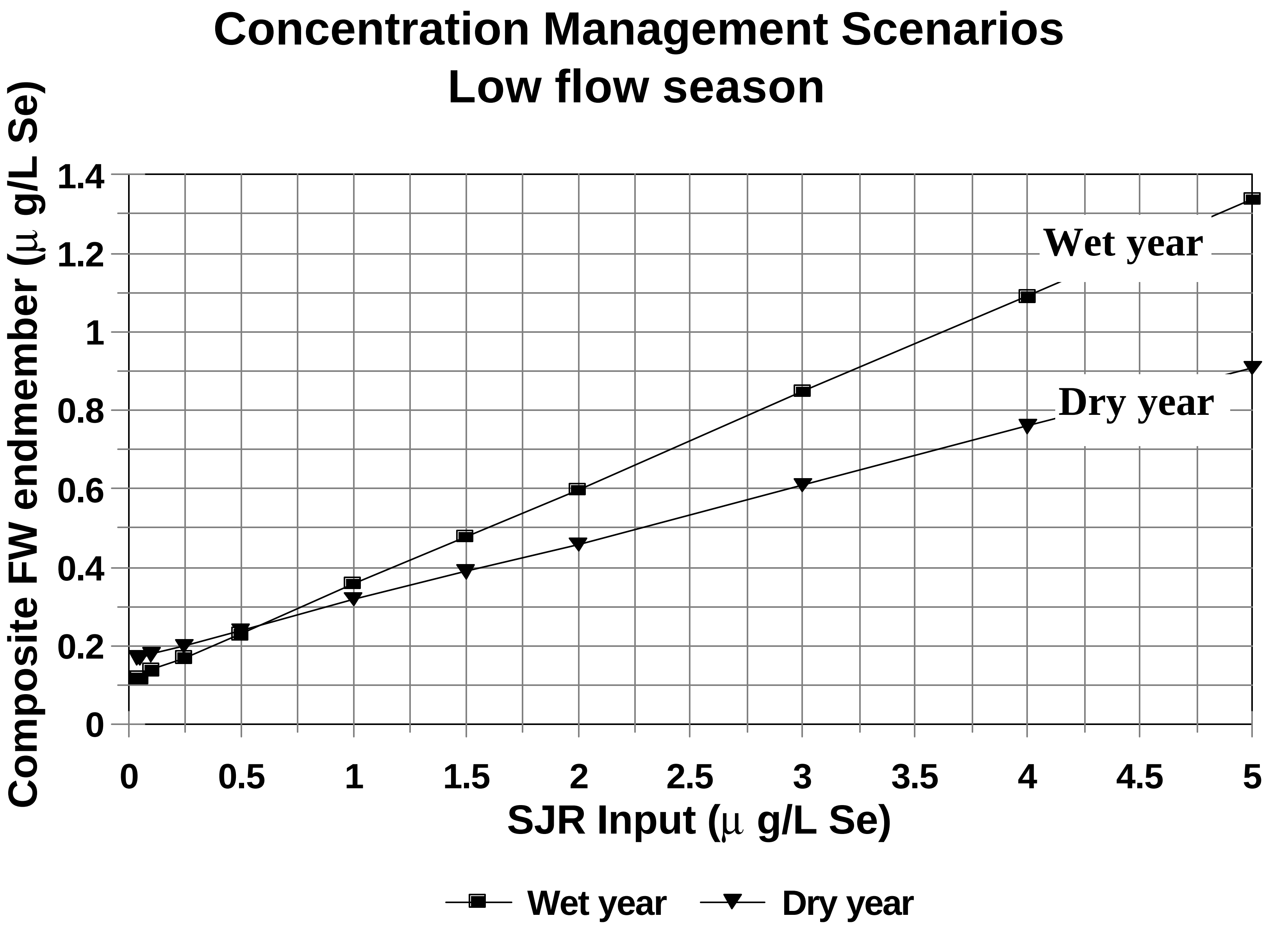


Figure 19. Forecasts of composite freshwater endmember selenium concentrations for a series of concentration management scenarios for the SJR in low flow seasons of both wet and dry years.

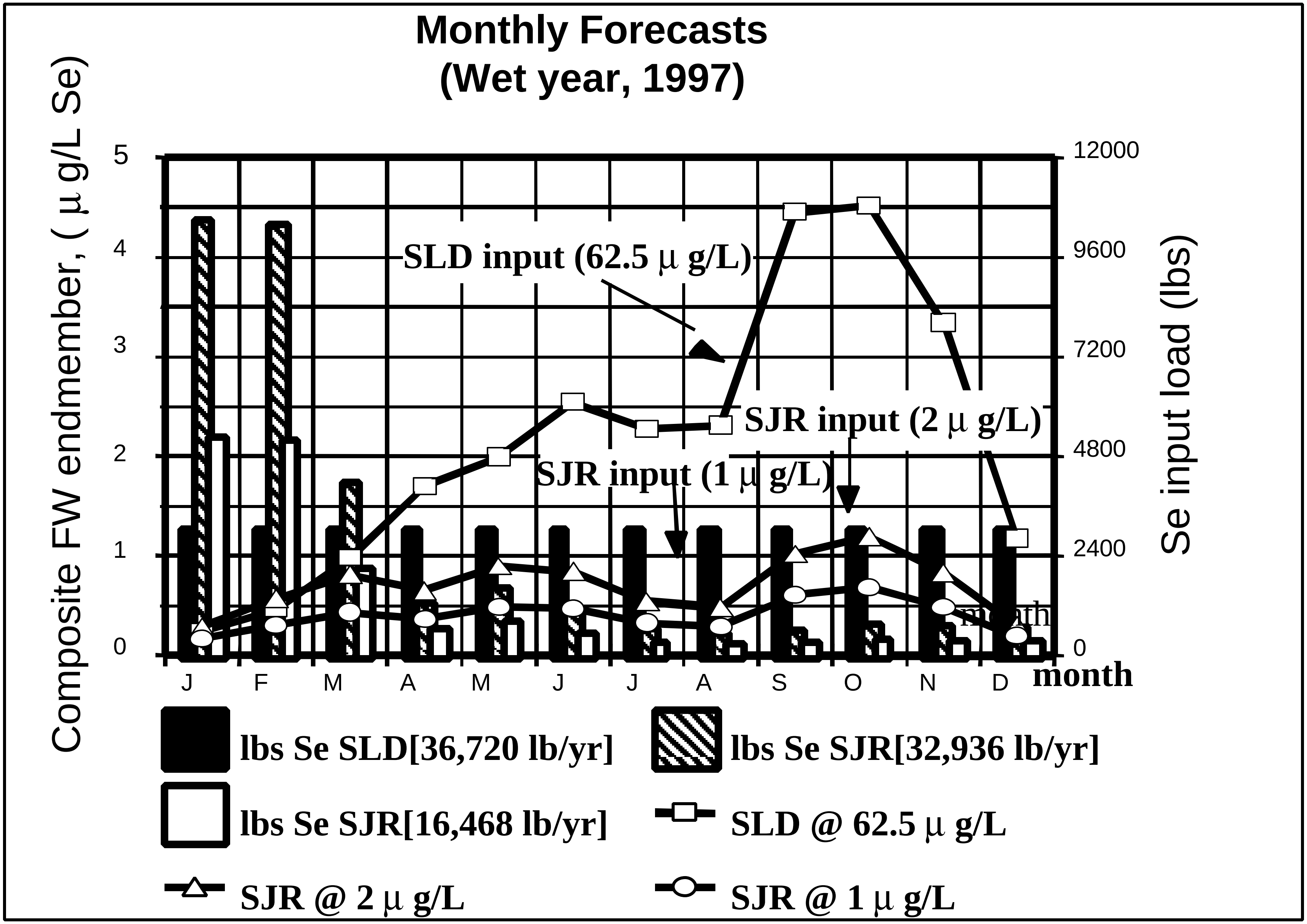


Figure 20. Forecasts of monthly composite freshwater endmember selenium concentrations under three discharge scenarios (San Joaquin River at 1 and 2 μg Se/L; San Luis Drain at 62.5 μg Se/L) contrasted to input concentrations and loads of selenium.

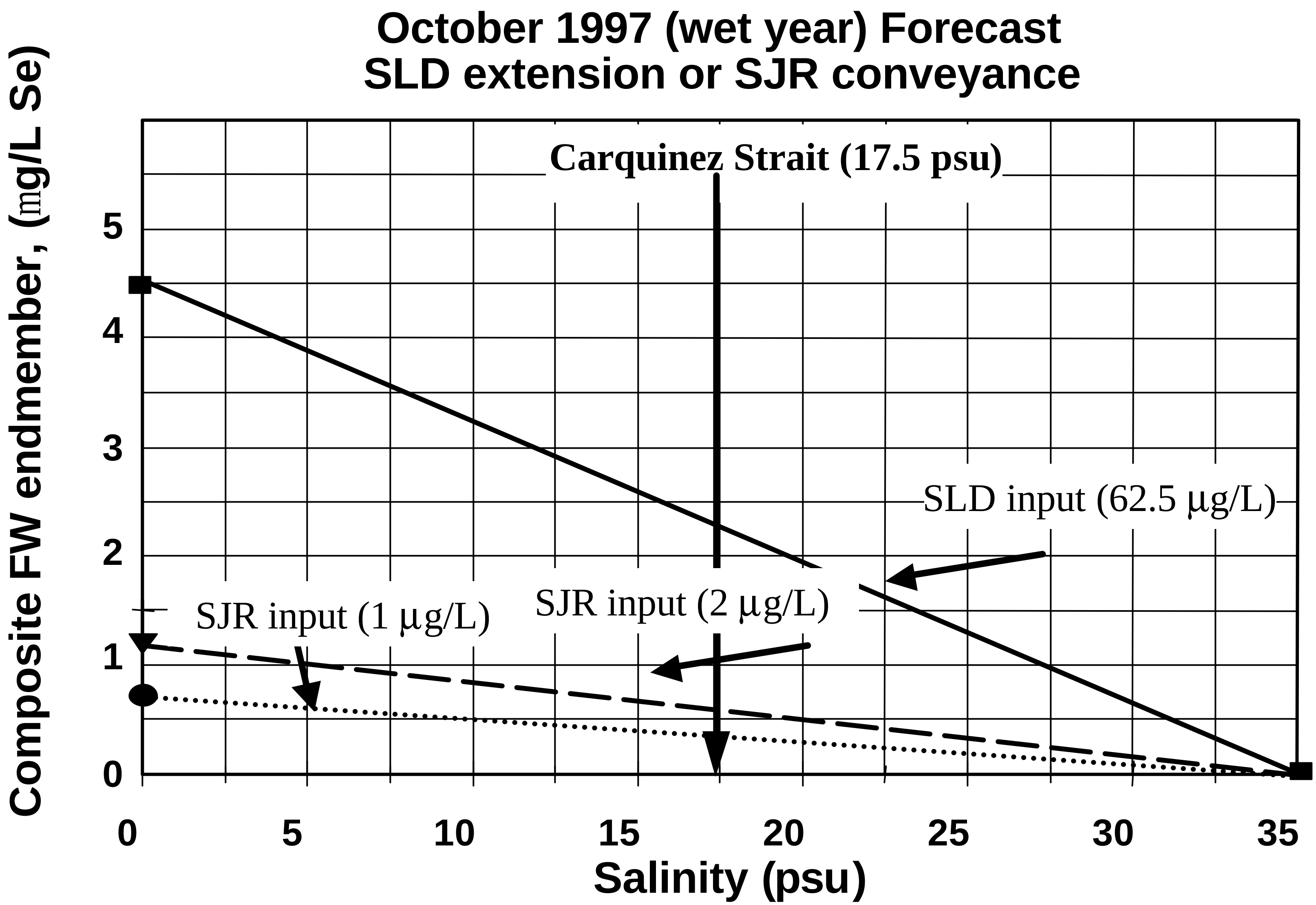


Figure 21. Dilution of selenium through the estuary as a function of salinity (practical-salinity units, psu) in October 1997 (wet year). Carquinez Strait is assumed to be about half seawater salinity (17.5 practical-salinity units). The composite freshwater endmember selenium concentrations are forecast for the SJR at 1 and 2 µg Se/L and for a SLD extension at 62.5 µg Se/L.

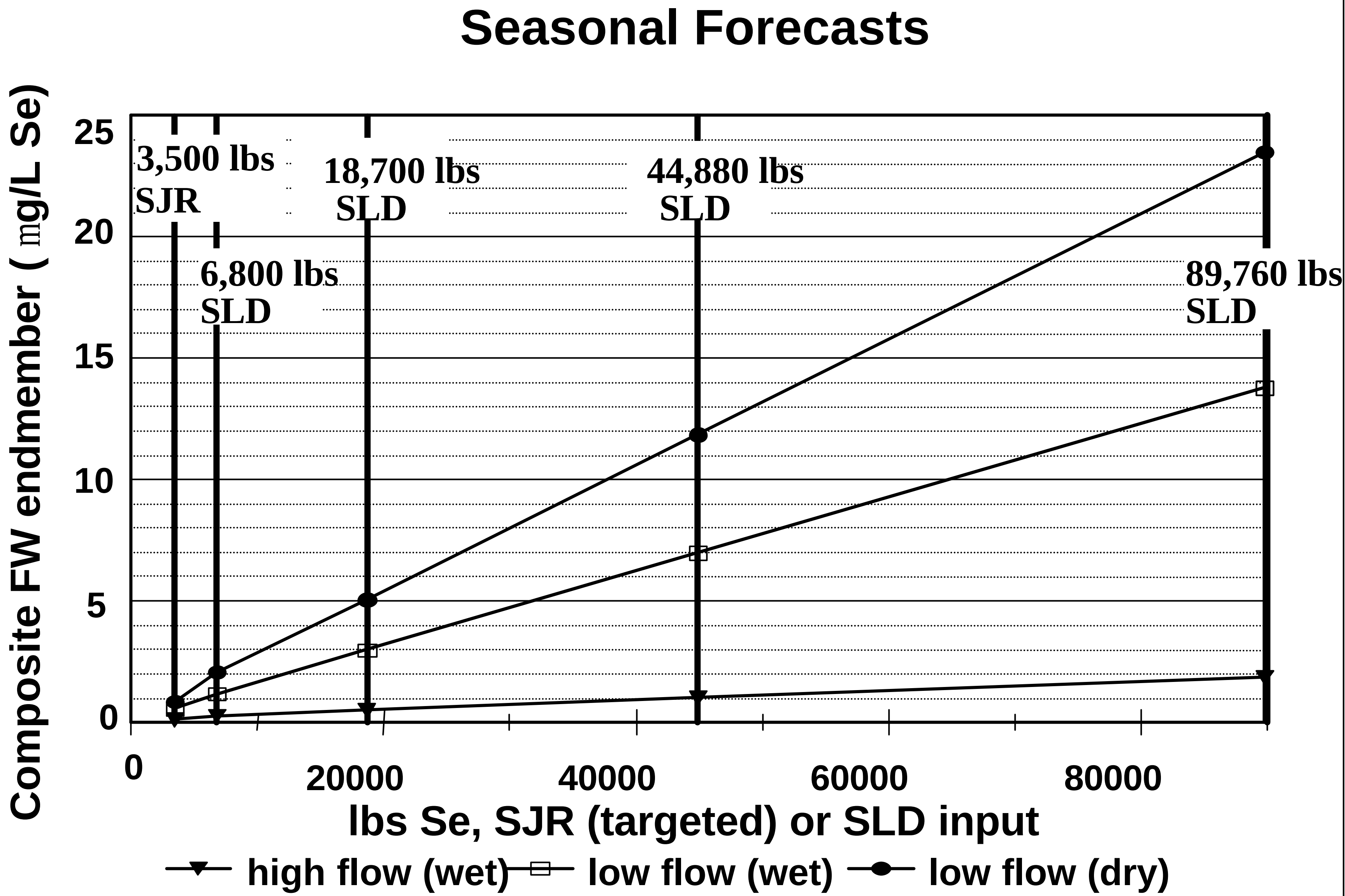


Figure 22. Forecasts of seasonal composite freshwater endmember concentrations under five discharge scenarios for the high flow season of a wet year and the low flow seasons of wet and dry years. Input agricultural selenium loads released through a SLD conveyance are from 6,800 to 89,760 lbs per six months. The SJR forecast releases 3,500 lbs Se per six months.

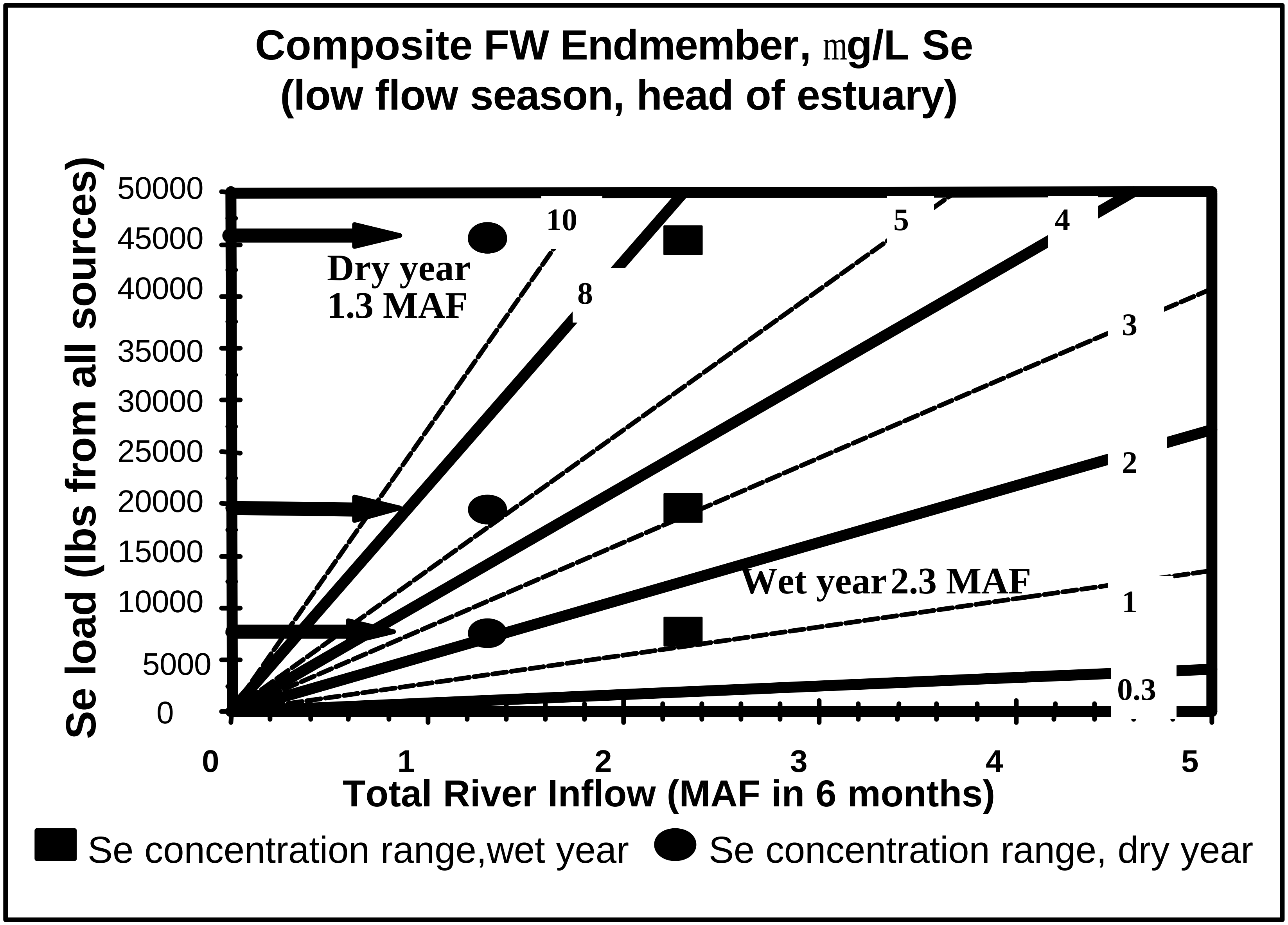


Figure 23. Calculation of eight composite freshwater endmember selenium concentrations as derived from different combinations of total input load and total river inflow. River inflows are the composited mass of water that reaches the estuary in a six-month period. The range of inflows and input loads are typical of different climate regimes (wet year or dry year) during the six-month dry season.

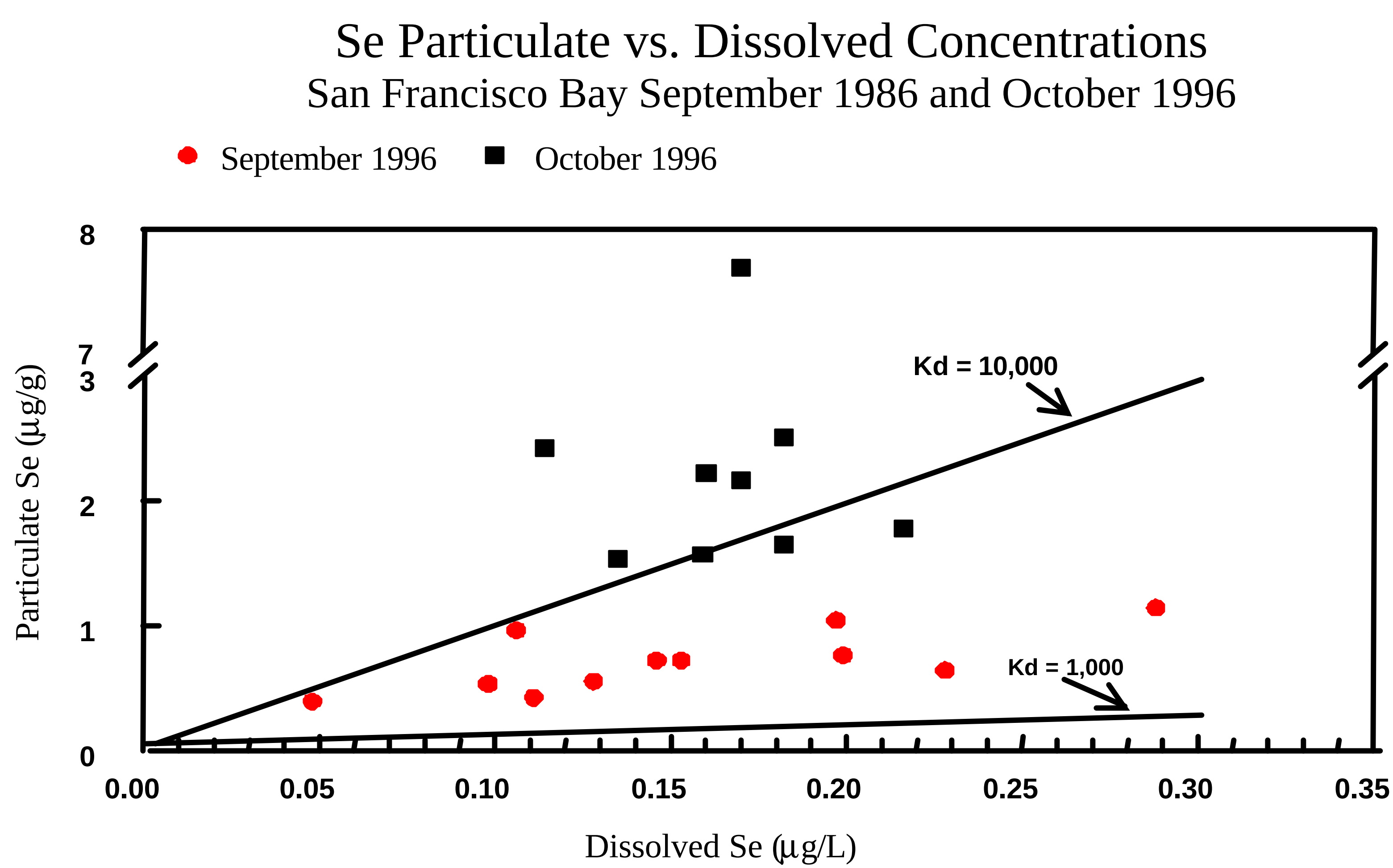


Figure 24. Suspended particulate selenium concentrations as a function of total dissolved selenium concentrations. Lines describing predicted particulate concentrations using Kd's of 1 X 10^3 and 1 X 10^4 are superimposed on the plots.

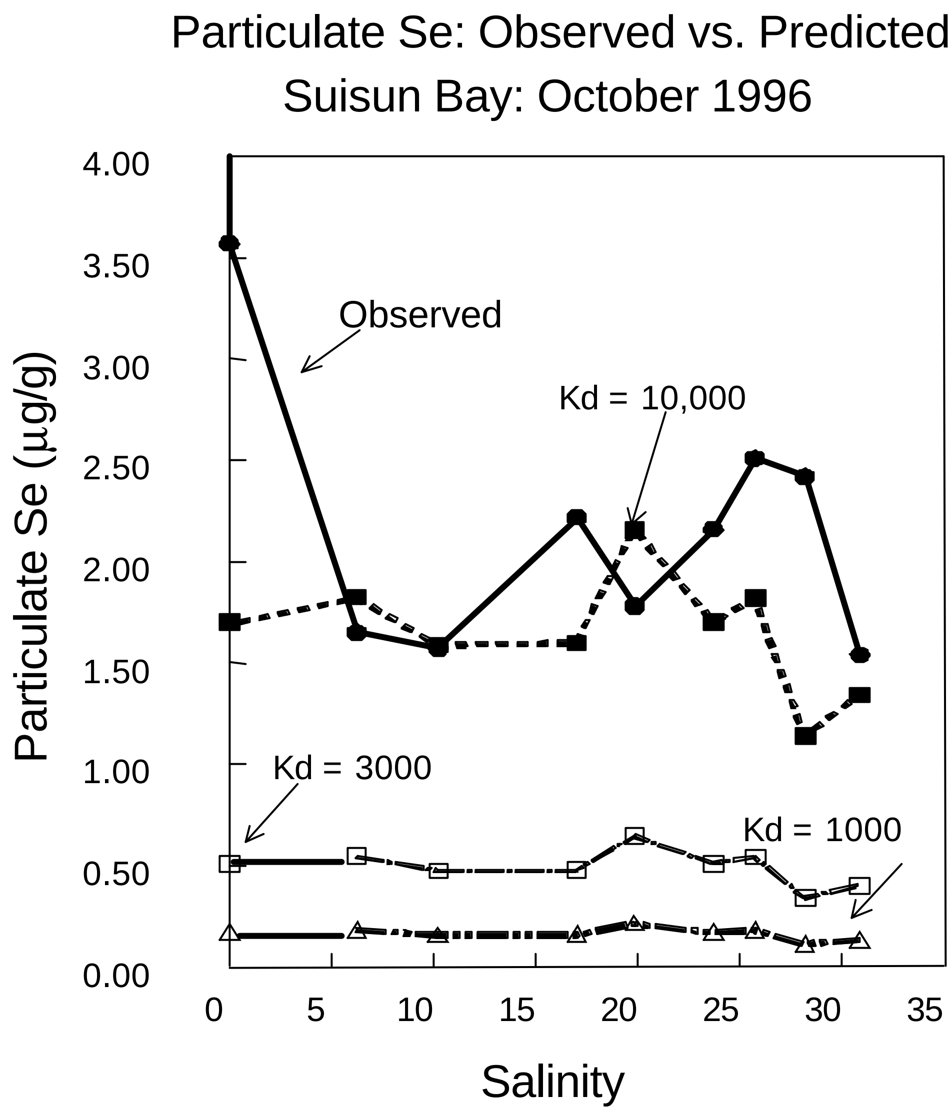


Figure 25. Particulate selenium concentrations as occurring landward (salinity, psu = 0) to seaward (salinity, psu = 35) in the Bay-Delta. Three different Kd's forecast three different trend lines for particulate concentrations using dissolved Se concentrations (**Figure 24**). The observed October 1996 particulate data is superimposed on the projections.

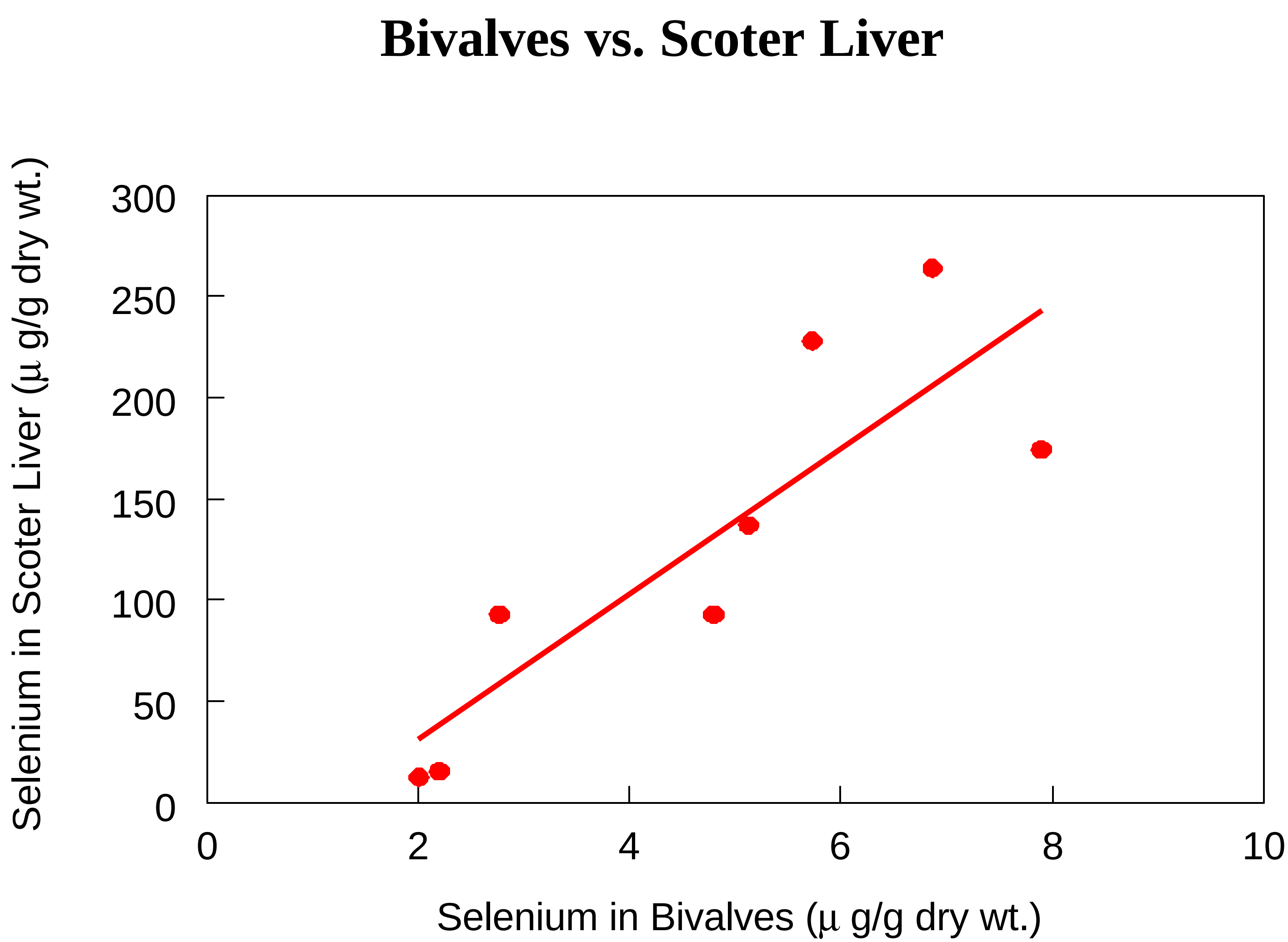


Figure 26. Relation between bivalve selenium concentrations and selenium in surf scoter liver. Data from California Department of Fish and Game *Selenium Verification Study* (White et al., 1987; 1988; 1989; Urquhart and Regalado, 1991).

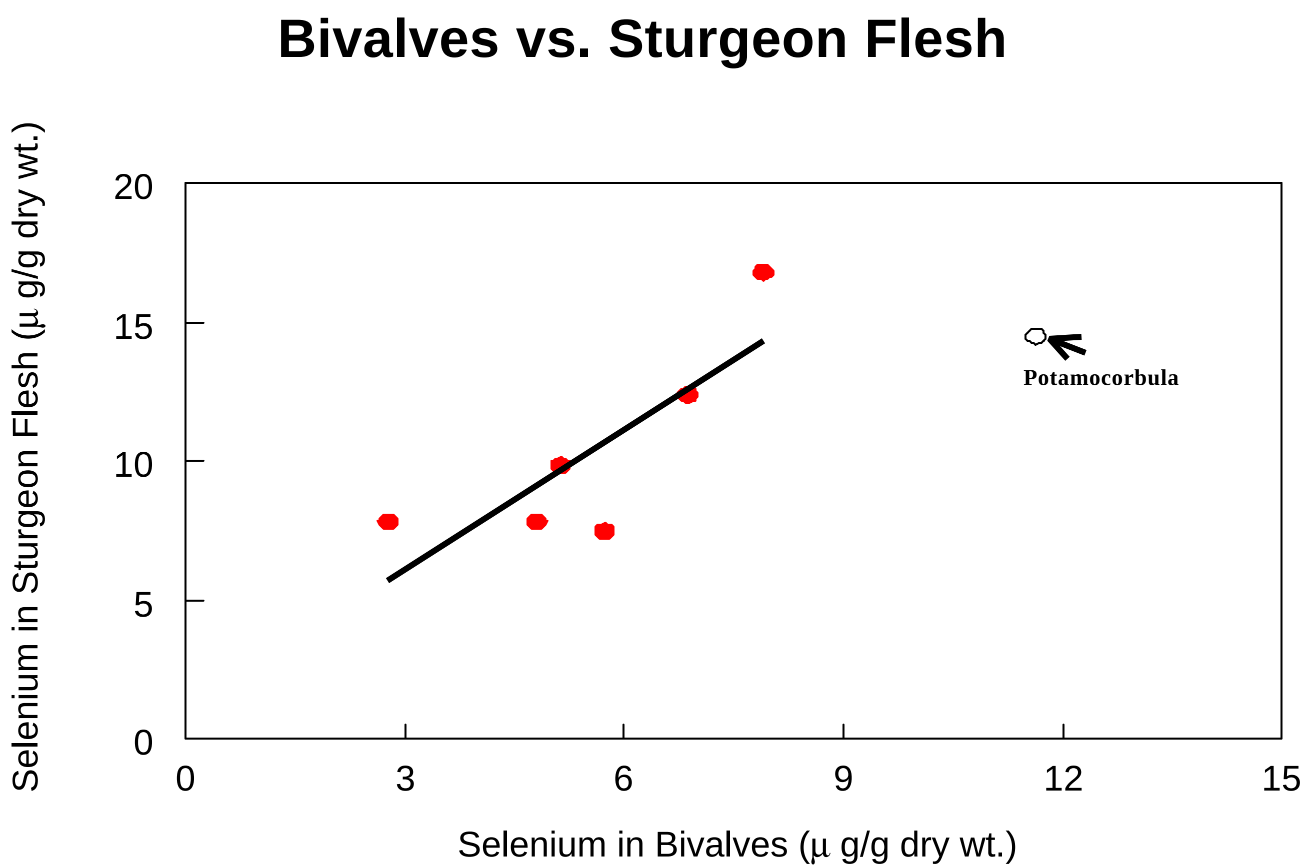


Figure 27. Relation between bivalve selenium concentrations and selenium in sturgeon flesh. Data from California Department of Fish and Game *Selenium Verification Study* (White et al., 1987; 1988; 1989; Urquhart and Regalado, 1991).

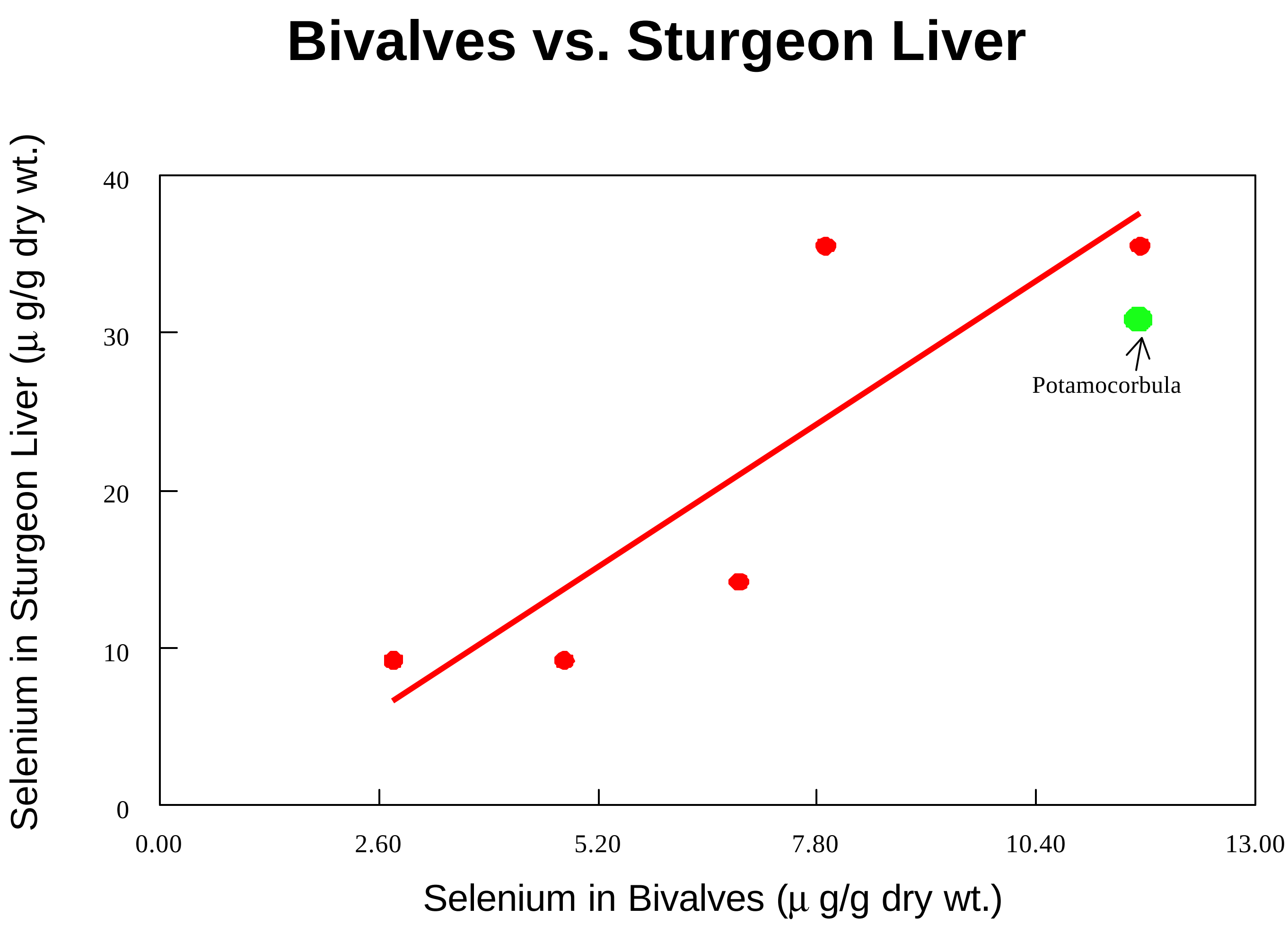


Figure 28. Relation between bivalve selenium concentrations and selenium concentrations in sturgeon liver. Data from California Department of Fish and Game *Selenium Verification Study* (White et al., 1987; 1988; 1989; Urquhart and Regalado, 1991).

TABLES

Table 1. Chronology of authorizing, planning, regulatory, and evidentiary events for construction of a valley-wide drain or a San Luis Drain.

Date	Agency or Industry	Event
1950	U.S. Bureau of Reclamation (USBR)	Begins Central Valley Project (CVP) Delta-Mendota Service Area water deliveries
1955	USBR	Feasibility report for drainage canal (300 cubic feet per second capacity; 197 miles length) from the San Joaquin Valley (SJV)
1960	Federal Law (Public Law 86-488) ‡	Authorizes San Luis Unit (SLU) of Central Valley Project (CVP) and makes provision for constructing interceptor drain to the S.F. Bay-Delta
1962	USBR	Definite Plan Report for SLU (includes capacity for other areas)
1965	State of California ‡	Proposes expansion of drainage plans to install valley-wide master drain
1965 to present	U.S. Congress *	Includes a rider to CVP appropriations act specifying development of a plan which conforms with state water quality standards as approved by USEPA to minimize any detrimental effects of the SLU drainage waters
1967	State of California	Declines to participate in valley-wide master drain
1968	USBR	Begin (1) CVP water deliveries to the San Luis Service Area and (2) construction of San Luis Drain (SLD) for use by Westlands Water District
1969	Drainage Advisory Group	Issues final report recommending drain to the Delta
1970	USBR and U.S. Fish and Wildlife Service (USFWS)	Designate Kesterson Reservoir, a regulating reservoir for the San Luis Drain, as a new USFWS National Wildlife Refuge
1972	USBR	EIS on SLU filed with Council on Environmental Quality
1975	USBR	Completes 85-mile SLD to Kesterson, 120 miles of collector drains, and 1200-acre reservoir; agrees to supplemental EIS on impacts of SLD from SLU
1975	USBR *	Halts construction of remainder of SLD due to Federal budget restrictions and increasing environmental concerns regarding discharge to the Delta
1975	USBR and state water agencies ‡	Recommend completion of the SLD to the SF Bay/Delta
1977	Federal Law (Public Law 95-46) *	Authorizes study of problems related to completion of SLD
1977	USBR *	Asks USEPA about requirements for a waste discharge permit for SLD
1979	USBR and California water agencies * ‡	Issues study of alternatives and final report recommending construction of drain; issues First Stage EIR for discharge at Suisun Bay (Chipps Island)
1981	USBR * ‡	Begins drainwater flow into Kesterson Reservoir; begins San Luis Special Study to fulfill state requirements for obtaining a permit for discharge of SJV drainage to the SF Bay/Delta at Chipps Island in Suisun Bay
1983	USFWS	Advises USBR of bird deformities/deaths at Kesterson Resv.
1984	USFWS and USGS *	Studies show environmental damage from selenium at Kesterson Reservoir
1985	Secretary of U.S. Department of Interior (USDOI) and California Governor *	Establishes Federal-State San Joaquin Valley Drainage Program to conduct comprehensive studies to identify magnitude and sources of problem, the toxic effects of selenium on wildlife, and actions needed to resolve these issues
1985	Secretary of the USDOI	Orders cessation of discharge to Kesterson Reservoir and closure of SLD; initiates National Irrigation Water Quality Program to study effects of agricultural drainage on refuges across the western U.S.

Table 1. continued

1986	USBR	Closes SLD; issues EIS for cleanup alternatives for Kesterson Reservoir
1986	Barcellos Judgment, U.S. District Court ‡	Calls for a Drainage Plan, Service Facilities, and a Drainage Trust Fund
1987	Federal and State Interagency Committee, San Joaquin Valley Drainage Program (SJVDP) *	Issues report of potential out-of-valley areas for disposal; due environmental groups and coastal communities opposition, future studies limited to in-valley options
1988	USBR as ordered by State of California	Fills and grades Kesterson Reservoir as part of Kesterson Cleanup Program
1990	Federal and State Interagency Committee	Completes SJVDP Management Plan for in-valley solutions to drainage problem
1991	Federal and State Interagency Committee	Forms San Joaquin Valley Drainage Implementation Program and signs MOU to help implement in-valley recommendations; state CDWR is lead agency
1992	USBR ‡	As part of Barcellos Judgment, submits Draft EIS for San Luis Unit Drainage Program; EIS suggests in-valley approaches and stated "the social and environmental unacceptability" of completing a drain "precludes further consideration"; court rejects EIS as not complying with judgment
1992	Federal Law 102-575 (CVPIA)	Calls for water for protection of fish and wildlife and land retirement in the SJV
1993	U.S. House of Representatives (Subcommittee on Natural Resources)	Oversight Hearing on agricultural drainage issues in the Central Valley including re-use of a portion of SLD by Grassland subarea
1993	Porgans, Carter, U.S. Fish and Wildlife Service, and environmental groups	Petition state over adequacy of EIS's for operation of privately owned drainage evaporation ponds where unavoidable bird loss was occurring
1994	Wanger Decision, U.S. District Court * ‡	Decides to send the salty water north; calls for initiation of process to obtain a discharge permit for the SLD to the SF Bay/Delta
1995	USBR; Contra Costa County et al.	Appeals Wanger decision; environmental groups intervene; decision pending
1995 - 1996	USBR and San Luis Delta-Mendota Water Authority	Issues Environmental Assessment (FONSI) for re-use of SLD by Grassland subareas; 28-miles of SLD reopens to convey drainage to the San Joaquin River
1996	State Water Resources Control Board ‡	State re-emphasizes that valley-wide drain is best technical and feasible solution for water-quality and salt balance in the SJV, but calls for NPDES permit
1997	State Department of Water Resources	Starts preparing update of SJVDP Management Plan due to non-implementation
1999	State Department of Water Resources	Declares SJVDP to have been unsuccessful
1999	USBR, State Department of Water Resources and State Water Resources Control Board Water Right Decision 1641 * ‡	Recommend completion of the SLD to S.F. Bay/Delta or other out-of-valley alternative; call for MOU to initiate environmental review for consideration of discharge application for the SLD
1999	U.S. House of Representatives	Field hearing to examine agricultural drainage issues including completing SLD
2000	Hug, et al., 2000, U.S. Court of Appeals	Reverses previous decision to compel USBR to build a drain to Bay-Delta, but rules USBR has duty to provide drainage service; drainage plan pending

‡ recommendation for completion of drainage facility (i.e., San Luis Drain); ***** call for environmental review or notice of environmental concerns; CVP includes the San Luis and Delta-Mendota Service Areas.

Table 2. Chronology of investigative and regulatory events for the San Francisco Bay/Delta concerning selenium.

Date	Agency or Industry	Event
1975	Report to Association of Bay Area Governments (regional monitoring program, Risebrough et al., 1977)	Samples of transplanted *Mytilus edulis* show some of highest concentrations in Carquinez Strait
1982 and 1985	U.S. Fish and Wildlife Service	Elevated Se concentrations found in scoter and scaup from South and North Bay
1985	California State Water Resources Control Board	Initiates 5-year *Selenium Verification Study* for intensive sampling of biota in areas of concern including Bay-Delta and San Joaquin River
1985-1986	U.S Geological Survey and U.S Bureau of Reclamation	Samples of *Corbicula fluminea* and *Macoma balthica* show enrichment in North Bay
1986	California Department of Water Resources and Cutter (1989)	Sampling shows internal sources of Se from refineries in the mid-estuary
1986	California Department of Water Resources and U.S. Geological Survey	Invasion of the Asian clam (*Potamocorbula amurensis*) in Suisun Bay changes benthic macroinvertebrate community
1986-1991	California Department of Fish and Game and U.S. Fish and Wildlife Service	As part of SVS, sampling shows elevated levels of Se in scoter, scaup, white sturgeon, starry flounder, Dungeness crab and Bay shrimp
1986	California Department of Health Services/Office of Environmental Health Hazard Assessment	Issues human health advisory for consumption of waterfowl (scaup and scoter) for Bay
1987-1988	California Department of Water Resources and Cutter and San Diego-McGlone (1990)	Sampling shows anthropogenic Se source is 52% to 92% of total Se
1988	California San Francisco Bay Regional Water Quality Control Board (CSFBRWQCB)	Directs oil refineries to investigate selenium; crude oils from the San Joaquin Valley are targeted as source; call for Se control technologies rather than best management practices of waste streams
1988	California Department of Health Services/Office of Environmental Health Hazard Assessment	Reaffirms human health advisory for consumption of waterfowl (scaup and scoter) and extends it to entire estuary
1988	U.S. Environmental Protection Agency	Establishes San Francisco Estuary Project as part of National Estuary Program
1988-1989	California San Francisco Bay Regional Water Quality Control Board	Determines water-quality standards not met in the North Bay to develop comprehensive conservation and management plan by 1992
1989	U.S. Environmental Protection Agency	Because of bioaccumlation in predators, overrules regional board and places North Bay on 304(l) list as substantially impaired by point sources of Se; mandates control strategies to be implemented to reduce loads resulting in standards being met within 3 yrs.
1991	California San Francisco Bay Regional Water Quality Control Board	Issues Se mass limits in NPDES permits including 50 μg/L daily concentration maximum limit

Table 2. continued

1991-1992	USEPA's National Estuary Program and San Francisco Estuary Project	Issues series of reports on status of pollutants, wildlife, wetlands, and aquatic resources of Bay-Delta
1992	U.S. Environmental Protection Agency	Promulgates 5 μg Se/L standard for Bay-Delta because salt water objective of 71 μg/L is underprotective
1992	U.S Geological Survey	Modeling studies show importance of phytoplankton-particulate-bivalve foodweb to predator tissues Se concentrations
1992	Oil Refiners	Appeal permits and sue regional board
1992	USEPA	Promulgates 5 ppb Se standard in National Toxics Rule
1992	California San Francisco Bay Regional Water Quality Control Board	Proposes Basin Plan Amendment that takes iterative mass reduction approach
1993	California San Francisco Bay Regional Water Quality Control Board	Settlement agreement and issuance of cease and desist order for non-compliance of mass reductions
1993	USEPA's National Estuary Program and San Francisco Estuary Project	Workbook on Comprehensive Conservation and Management Plan for the Bay-Delta
1993 to present	Oil Refiners	Research and implement Se reduction technologies on mandated time schedule
1993 and 1994	San Francisco Estuary Institute	Issues annual report regional monitoring program for trace substances
1994	California San Francisco Bay Regional Water Quality Control Board and Oil Refiners	Mandated avian risk study showed elevated concentrations in avian eggs and embryo deformities in Chevron marsh, a constructed wetland receiving oil refinery effluent
1995-1996	U.S. Geological Survey (and Interagency Ecological Program for the Sacramento-San Joaquin Estuary)	Sampling in North Bay shows elevated Se concentrations in Potamocorbula amurensis
1996	U.S. Fish and Wildlife Service	Issues recovery plan for Sacramento/San Joaquin Delta native fishes
1998-2000	CALFED	Ecosystem Restoration Plan for Bay-Delta
1998, amended in 2000	U.S. Environmental Protection Agency in consultation with U.S. Fish and Wildlife Service	Issues California Toxics Rule withholding rule on Se
1998	California San Francisco Bay Regional Water Quality Control Board and Oil Refiners	Scheduled to meet load reductions
1999	USEPA's National Estuary Program and San Francisco Estuary Project	Report on Comprehensive Conservation and Management Plan for the Bay-Delta
2000	California State Water Resources Control Board	Lists Bay-Delta as toxic hot spot

Compiled with assistance of Khalil Abu-Saba, San Francisco Bay Regional Water Quality Control Board, and Kim Taylor, formerly with San Francisco Bay Regional Water Quality Control Board and now with the U.S. Geological Survey, Sacramento CA.

TABLE 3. Measured and estimated selenium concentrations in shallow ground water and subsurface drainage in Westlands Water District, Grassland Drainage Problem Area, Tulare subarea, and Kern subarea.

Source and Sampling	**ppb Se**	
San Luis Drain and agricultural sumps		
SWRCB, 1985 (WQ No. 85-1)		
San Luis Drain, discharge (measurement average, 1983-1984)	330-430	
USGS, 1985 (Presser and Barnes, 1985)		
San Luis Drain discharge, 1984	340	
Westlands subarea drainage sumps	140-1,400	
Grassland subarea drainage sumps	8-4,200	
Testimony (Stevens and Bensing, 1994; Wanger, 1994; WWD, 1996) **Westlands subarea**		
San Luis Drain discharge (1981-1984 range)	230-350	
Westlands Water District compilation of USGS data (depending on grid size)	208-277 (range of means)	
Westlands Water District estimate	300	
Westlands Water District 1993 survey of 63 locations within 42,000 drained acres	163 (mean)	
Westlands Water District estimate of drainage with treatment	50	
U.S. Bureau of Reclamation (conservative estimate)	at least 150 ppb	
CCVRWQCB (1996a,b) **Grassland Drainage Problem Area**		
Subsurface tile drainage estimate	150	
Subsurface tile drainage modeling estimate	120	
Subsurface drainage sumps (annual survey of measurements	211 (mean); 134 (median)	
1994 drainage leaving problem area (surface plus subsurface) modeled estimate	80 (average)	
SJVDP (1990) **Grassland subarea**		
Year 1990 Estimated subsurface discharge to San Joaquin River	150	
Year 2040 Estimated subsurface discharge to San Joaquin River	75	
USGS observation wells, 10-50 feet (Gilliom et. al., 1989) **Panoche Creek alluvial fan (Grassland and Westlands subareas)**		
Murietta field well	320-7,300	
Murietta field subsurface drains	800-1,000	
15-year field wells	96-1,000	
15-year field subsurface drains	400	
CCVRWQCB (1990 a, b) **Tulare and Kern Basins Evaporation Ponds (1988 and 1989)**		
Inflows to evaporation ponds	<1 – 760	
Evaporation ponds	<1 – 6,300	
USGS Observation wells, 12-25 feet (Fujii and Swain, 1995) **Tulare and Kern subareas**		
Alluvial fan zone	(median)	(maximum)
West-side alluvium	8	520
East-side alluvium	< 1	25
Basin zone		
West-side basin	3	240
East-side basin	<1	320
Tulare Lake Zone		
Northeastern margin	<1	4
Southern/western margin	34	1,000
Lake bed	< 1	2

Table 4. Conversion factors for selenium and salt or Total Dissolved Solids (TDS).

Selenium (Se)	**Salt or Total Dissolved Solids (TDS)**
1 ppb Se =1 µg Se/L	1 ppm TDS = 1 mg salt/L
1 gallon = 3.785 Liters	1 gallon = 3.785 Liters
1 acre-foot = 325,900 gallons = 1,233,532 Liters	1 acre-foot = 325,900 gallons = 1,233,532 Liters
1,233,532 µgrams Se/acre-foot at 1 ppb Se	
1.23 grams Se/ acre-foot at 1 ppb Se	1,234 grams salt/acre-foot at 1 ppm salt
454 grams = 1 lb	454 grams = 1 lb
0.00272 lbs Se/acre-foot at 1 ppb Se	2.72 lbs salt/acre-foot at 1 ppm salt
[1 ppb Se = 0.00272 lbs Se/acre-foot]	[1 ppm salt= 2.72 lbs salt/acre-foot]
	2000 lbs = 1 ton
	1 ppm salt = 0.00136 tons salt/acre-foot
Volume	
1 cubic foot per second (cfs) = 1.98 acre-feet/day	

TABLE 5. Annual acre-feet or million acre-feet (MAF) and selenium loads from the upstream drainage source (Drainage Problem Area or Grassland Bypass Channel Project site B) and downstream sites for Mud and Salt Sloughs, and the San Joaquin River at Crows Landing (state compliance point for SJR) and at Vernalis.

Water-year	Upstream Drainage Source (problem acres 65,200 to 103,390) (drained acres 47,500 to 51,000) (historic drainage quality average* 1986-1994 64 ppb)			Mud and Salt Sloughs			San Joaquin River at Crows Landing (USEPA 5 ppb Se standard exceeded > 50% of the year in 1987, 1988, 1989, 1990, 1991 and 1994; drainage prohibition of 8,000 lbs/year enacted in 1996)			San Joaquin River at Vernalis		
	acre-feet	ppb Se	lbs Se	acre-feet	ppb Se	lbs Se	MAF	ppb Se	lbs Se	MAF	ppb	lbs Se
1986	67,006	52	9,524	284,316	8.6	6,643	2.67	1.6	11,305	5.22	1.0	14,601
1987	74,902	54	10,959	233,843	12.0	7,641	0.66	4.9	8,857	1.81	1.8	8,502
1988	65,327	57	10,097	230,454	13.0	8,132	0.55	6.2	9,330	1.17	2.7	8,427
1989	54,186	59	8,718	211,393	14.1	8,099	0.44	6.3	7,473	1.06	3.0	8,741
1990	41,662	65	7,393	194,656	14.6	7,719	0.40	5.6	6,125	0.92	3.0	7,472
1991	29,290	74	5,858	102,162	14.0	3,899	0.29	4.5	3,548	0.66	2.0	3,611
1992	24,533	76	5,083	85,428	12.6	2,919	0.30	3.7	3,064	0.70	1.9	3,558
1993	41,197	79	8,856	167,955	15.0	6,871	0.89	3.5	8,379	1.70	1.9	8,905
1994	38,670	80	8,468	183,546	16.0	7,980	0.56	4.8	7,270	1.22	2.3	7,760
1995	57,574	76	11,875	263,769	14.9	10,694	3.50	1.6	14,291	6.30	1.0	17,238
1996	52,978	70	10,034	267,344	13	9,697	1.44	3.0	10,686	3.95	1.1	11,431
1997	37,483	62.5	7,097	not available	30 Mud only	not available	4.18	2.9	8,667-9,054	6.77	0.6	11,190
1998	45,858	66.9*	9,118	not available	27 Mud only	not available	5.13	1.6	13,445-15,501	8.5	--	15,810
Daily range		0.4 to 286 (1986-1995) 15 to 134 (1997 and 1998)			0.5 to 59 (1986-1995) 3 to 104 (1997 and 1998)		956 to 73,458 acre-feet (1997-1998)	0.4 to 17 (1986 – 1995) 0.1-8.2 (1997 and 1998)			0.4 to 9.6 (1986 – 1995) 0.1-8.2 (1997 and 1998)	

DATA SOURCES: 1-Drainage Problem Area) California Central Valley Regional Water Quality Control Board, 1996b; c; 1998d; e; f; g; h; 2000b; c (note: The regional board in 1996 recompiled data from 1985 through 1995; therefore earlier versions of the regional board's data may be quoted in some examples); 2-Grassland Bypass Channel Project monthly reports (see website, http://www.mp.usbr.gov/; select projects, then select GBP) and annual reports (USBR et al., 1997, 1998, 1999).

Table 6. Load scenarios using data from the SJV Drainage Program (1990a) and 50 ppb, 150 ppb, and 300 ppb assigned selenium concentrations. *Problem acres* are assumed to generate a generic *problem water* as an expression of affected acres. Tile-drained or subsurface drained acres would be expected to generate concentrated drainage as opposed to *problem water*. In our analysis, the distinction between *problem water* and subsurface drainage helps in assigning water-quality. The SJVDP defined scenarios of *without future* (i.e., no implementation of recommended plan) and *with future* (i.e., implementation of recommended plan). A third condition defined for use in our projections is called *with targeted future* which applies a factor of 0.20 acre-feet/acre/year of generated drainage, estimating the lowest, although probably not realistic, irrigation water return. The year 2000 projection for *problem water* is calculated here applying a factor of 0.4 acre-feet per acre per year; this projection was not part of the SJVDP consideration.

Loading Scenario (five subareas Northern, Grassland, Westland, Tulare, and Kern)	**Total problem acres or tile drained acres**	**Factor acre-feet/acre/year**	**Total problem or drainage acre-feet**	**lbs Se (assigned 50 ppb)**	**lbs Se (assigned 150 ppb)**	**lbs Se (assigned 300 ppb)**
1990 Without Future *Subsurface drainage*	133,000	0.60-0.75	100,000	13,600	40,800	81,600
1990 With Future *Subsurface drainage*	133,000	0.40	53,200	7,235	21,706	43,411
2000 Without Future *Subsurface drainage*	269,000	Northern 0.75 Tulare 0.65-0.70 Others 0.50-0.55	163,000	22,168	66,504	133,008
2000 With Future *Subsurface drainage*	360,000	0.40	144,000	19,584	58,752	117,504
2000 With Targeted Future *Subsurface drainage*	360,000 (hypothesized from above case)	0.20 (hypothesized for minimum drainage)	72,000	9,793	29,376	58,753
2000 ***Without Future*** *Problem Water*	**444,000**	**0.70 (range 0.60-0.75)**	**314,000**	**42,704**	**128,112**	**256,224**
2000 *Apply 0.4 acre-feet/acre/year future factor* *Problem Water*	**444,000**	**0.40**	**177,600**	**24,154**	**72,460**	**144,922**
2040 Without Future *Subsurface drainage*	386,000	Northern 0.75 All others 0.55 (i.e., minimum improvement)	223,000 (243,000)	30,328	90,984	181,968
2040 With Future *Subsurface drainage*	759,000	0.40 (hypothesized)	303,600	41,290	123,869	247,738
2040 *Without Future* *Problem Water*	**951,000**	**0.75 (steady increase)**	**666,000**	**90,576**	**271,728**	**543,456**

TABLE 7. Our calculations of selenium concentrations in discharge from SJV Drainage Program subareas based on evidence presented by Westlands Water District or currently available ranges of measurements for drainage volume (acre-feet) and selenium load (i.e., measured values after the SJV Drainage Program database measurements in 1986-1989; see footnotes for source), except for Northern subarea where there was no recommended management plan by the SJV Drainage Program (1990a) (see footnote). Only one set of values for the Westlands Water District drainage volume and selenium load was presented in evidence (see minimum). Since no updated measurements are available for Westlands Water District, the condition for the maximum load was calculated using an assigned* concentration of 150 ppb to the volume of drainage presented in evidence.

Subarea or area	Drainage volume (acre-feet/ year)	Minimum (lbs Se/ year)	**Calculated minimum ppb Se**	Maximum (lbs Se/ year)	**Calculated maximum ppb Se**	Calculated maximum and minimum (lbs Se/acre-foot)	problem acres
Northern	26,000	350	**5**	700	**10**	0.014- 0.027	
Grassland Farmers	37,483	6,960	**68**	15,500	**152**	0.186- 0.414	97,000
Westlands	60,000	8,000	**49**	24,480	**150***	0.133- 0.408	200,000
Tulare	19,493 (avg)	91	**1.7**	519	**9.8**	0.005- 0.027	
Kern	2,292 (avg)	1,089	**175**	1,586	**254**	0.475- 0.692	
Total	**145,268**	**16,490**		**42,785**			

Data Sources for subareas (also see Appendices A and B)
Northern: a nominal 5 ppb and 10 ppb selenium concentrations; drainage volume is from SJVDP, 1990, Table 3 for year 2000.
Grassland: minimum is value measured for WY 1997 as part of the Grassland Bypass Channel Project and maximum is 17,250 lbs Se measured for the San Joaquin River at Vernalis for WY 1995 (CCVRWQCB, 1998).
Westlands: minimum is for condition presented as evidence for Westlands Water District and maximum condition is the same volume of drainage, but with an assigned concentration of 150 ppb.
Tulare and Kern: personal communication (Anthony Toto, CCVRWQCB, 1/98) of measurements for volume and selenium concentration for 1993 to1997 from which an average volume (1993-1997) was calculated and the minimum and maximum lbs Se were selected as the range.

Table 8. Projections of selenium loads from the western San Joaquin Valley under different drainage scenarios. A *kesterson* (kst) is 17,400 lbs of Se, the cumulative load that caused visible ecological damage when released to a wetland (Kesterson National Wildlife Refuge, California).

Scenario: Subarea or subareas discharging to a proposed San Luis Drain extension	**annual selenium load (lbs Se/year)**	**kestersons/year (kst/year)**	**cumulative kestersons (ksts in 5 years)**
Grassland (based upon current data)	6,960 – 15,500	0.4 – 0.89	2.0 – 4.45
Westlands (based upon 50 to 150 µg Se/L in drainage and 60,000 acre-feet)	8,000 – 24,500	0.46 – 1.41	2.3 – 7.05
Grassland + Westlands (from above)	14,960 – 40,000	0.86 – 2.30	4.3 – 11.5
Valleywide Drain (current conditions and Westlands projection)	16,490 – 42,785	0.95 – 2.46	4.75 – 12.3
Vallywide Drain (all potential problem lands with management of drainage quantity and quality)	19,584 – 42,704	1.12 – 2.45	5.6 – 12.2
Valleywide Drain (all potential problem lands with minimum management of quality and quantity)	42,704 – 128,112	2.45 – 7.36	12.2 – 36.8
TMDL or TMML management (Load targeted for environment, Grassland subarea)	1,394 – 6,547	0.08 – 0.38	0.4 – 1.9

Table 9. Load of Se discharged if a constant concentration is maintained in the SJR and conveyed to the Bay-Delta under high (3 MAF per year) and low (1.1 MAF per year) flow regimes. Approximately 220,000 acre-feet/year represents the annual volume of flow from a proposed extension of the SLD at maximum capacity or a small SJR input to the Bay-Delta in a dry year.

Selenium Concentration in the SJR or a SLD extension	**@ 3.0 (million acre-feet/ year)** **Load (lbs Se/year)**	**@ 1.1 million acre-feet/ year)** **Load (lbs Se/year)**	**@ 216,810 acre-feet/year (300cfs)** **Load (lbs Se/year)**
0.1 µg Se/L	816	299	60
1.0 µg Se/L	8,160	2,990	598
2.0 µg Se/L	16,320	5,980	1,197
5.0 µg Se/L	40,800	14,960	2,992
50 µg Se/L	--------	--------	29,920
150 µg Se/L	--------	--------	89,760
300 µg Se/L	--------	--------	179,520

Table 10. Annual and daily oil refinery Se loads for the Bay-Delta for the period 1986 to 1992 and 1999. Cleanup of discharges and further permitting was required by 1998.

Oil refinery	**1986-1992 lbs Se/year (range)**	**1986-1992 lbs Se/day (range)**	**1999 lbs Se/year**	**1999 lbs Se/day**
Equilon Enterprises LLC at Martinez (formerly Shell Oil)	1,203-2,595	3.3-7.1	440	1.2
Tosco Corporation at Avon	180-482	0.49-1.3	118	0.32
Tosco Corporation at Rodeo (formerly Unocal)	1,045-1,938	2.9-5.3	98	0.27
Valero Refining Company (formerly Exxon Corporation)	321-755	0.88-2.1	132	0.36
Chevron Corporation	354-1,687	0.97-4.6	327	0.90
TOTAL	**3,103-7,457**	**8.5-20.4**	**1,115**	**3.05**

1986-1992 data: CSFRWQCB, 1992 and 1993
1999 data: CSFRWQCB, personal communication, Johnson Lam, 9/19/00

Table 11. Partitioning between dissolved Se and particulate or sediment Se in ecosystems for which reliable analytical data is available.

Ecosystem	***TSe_{diss} μg/L***	***TSe_{Sed} μg/g***	***TSe_{Sed}/ Tse_{diss} (Kd)***	***Reference***
Kesterson Reservoir (terminal pond)	14	55	$4 X 10^3$	Presser and Piper, 1998
Belews Lake	~11	~15	$1.3 X 10^3$	Lemly, 1985
Benton Lake Pool 1 Channel	4	10	$2.5 X 10^3$	Zhang and Moore, 1996
Benton Lake Pool 2	10.4	3.5	$0.34 X 10^3$	Zhang and Moore, 1996
Benton Lake Pool 5	0.74	0.35	$0.5 X 10^3$	Zhang and Moore, 1996
Constructed Wetland	<5 - 30	2.1 - 6.7	$0.3 X 10^3$	Hansen et al., 1998
SLD (means)	62.5	55	$0.9 X 10^3$	This report
Delaware: Tidal Freshwater	0.17 - 0.35	0.6 - 1.5	$4 X 10^3$	Reidel and Sanders, 1998
Diatoms			$1.1X10^5$	Reinfelder and Fisher, 1991
Dinoflagellate			$4.0 X 10^3$	Reinfelder and Fisher, 1991
Great Marsh, Delaware	0.01 - 0.06	0.3 - 0.7	$3 X 10^3$ – $1 X 10^4$	Velinsky & Cutter, 1991
Bay-Delta SPM (suspended particulate matter) 1986/1995/1996	0.1 - 0.4	1 - 8	$1 – 4 X 10^4$	Cutter et al., in preparation
Bay-Delta sediment	0.1 - 0.3	0.2 - 0.5	$1 - 5 X 10^3$	Johns et al., 1988

Table 12. Selenium concentrations in fish (µg/g dry weight) from the Bay-Delta (North Bay including Suisun, San Pablo, Grizzly and Honker Bays) and Humboldt Bay (Selenium Verification Study, White et al., 1987; 1988; 1989; Urquhart and Regalado, 1991).

Location/Date	**flesh (µg Se/g, dry weight)**			**liver (µg Se/g, dry weight)**			**whole-body (µg Se/g, dw)**		
	average	**std dev.**	**n**	**average**	**std dev.**	**n**	**average**	**std dev.**	**n**
North Bay (January-June, 1986)									
white sturgeon	7.8	3.1	10	9.2	2.9	10			
English sole	3.0	0.2	4						
starry flounder	4.6	1.0	7	9.2	2.2	7			
longfin smelt							1.5	0.4	8
Pacific staghorn sculpin	2.5	0.2	8	6.7	1.0	8			
Pacific herring							3.0	0.7	4
speckled sanddab							1.8	0.03	2
northern anchovy							2.1	0.08	4
yellowfin goby							2.4	0.2	7
North Bay (March-May, 1987)									
white sturgeon	10	3.7	13						
North Bay (December, 1987 and January, 1988)									
white sturgeon	7.2	4.4	14						
North Bay (February, 1989 to March, 1990)									
white sturgeon	15	11	62	30	21	42			
yellowfin goby	2.0	NA	1	4.3	NA	1	3.1	NA	1
Humboldt Bay (February and June, 1986)									
English sole	1.8	0.22	3	7.8	NA	1			
starry flounder	0.9		1	3.6		1			
longfin smelt							1.2	0.08	2
Pacific staghorn sculpin	1.6	0.13	4	3.9	0.46	3			
Pacific herring	1.6	0.08	2				4.5		1
speckled sanddab							1.6	0.3	4

n = number of samples; NA = not applicable

TABLE 13. Examples of thresholds for Se effects (health, reproductive, teratogenesis, or survival) in fish based on concentrations of Se in food; the example of massive poisoning at Kesterson Reservoir, California also applies to aquatic birds. Selenium concentrations in the most abundant benthic prey (food) organism in the Bay-Delta are given for comparison.

Concentration in food (µg Se/g, dry weight)	***Approach***	**Response Observed**	**Reference(s)**
0.1 - 0.5 µg/g	Lab	Nutritionally sufficient range. Additional nutritional benefits often observed up to 1 µg/g. Diets containing < 0.1 µg/g often associated with deficiency syndrome.	cited in Lemly, 1998a (Hodson and Hilton, 1983)
3 - 8 µg/g	Lab, field, and synthesis	Reproductive impairment (similar threshold for birds, Skorupa and Ohlendorf, 1992; Skorupa, 1998b; see also Table 15).	e.g., Engberg et al., 1998; Skorupa, 1998a; b; Lemly, 1998a; b; Hamilton et al., 1996; 2000b
2 - 5 µg/g	Belews Lake, North Carolina (1996)	Teratogenesis in fry of four recovering fish species	Lemly, 1993b; 1997b
5 µg/g	Lab	Winter stress syndrome (includes mortality) in juvenile bluegill	Lemly, 1993b
9 - 13 µg/g	Lab, field, and synthesis	Reduced growth and/or mortality in rainbow trout and bluegill	Cited in Hamilton et al., 2000a (Goettl and Davies, 1978; Hilton et al., 1980; Cleveland et al., 1993); Skorupa, 1998b
5 - 10 µg/g in prey (fish) 18 µg/g in prey (fish)	Lab Freshwater Brackish water	Growth and survival affected in chinook salmon (swim-up) larvae (SLD diet) Growth reduced of chinook salmon fingerlings (SLD diet)	Hamilton et al., 1990
30 - 35 µg/g	Synthesis	Complete reproductive failure in adult sensitive species (e.g., bluegill)	Cited in Skorupa, 1998b (Coyle et al., 1993; Woock et al., 1987)
20 - 80 µg/g	Belews Lake, North Carolina (1973-1984)	Massive poisoning of fish community: 16 of 20 species disappear; two species rendered sterile, but persisted as aging adults; one occasionally re-colonized as adults; and one unaffected. Deformities in survivors. Some recovery after Se removal.	Cumbie and VanHorn, 1978; Lemly, 1985; 1997b; 1998a
>100 µg/g	Kesterson Reservoir, California	Massive poisoning of fish and birds, including deformities in coots, grebes, ducks, and stilts.	Saiki and Lowe, 1987; Ohlendorf, 1989; Presser and Ohlendorf, 1987.
Se concentrations in the most abundant benthic prey organism in the Bay-Delta			
4 - 20 µg/g	***Bay-Delta 1985-1986 1995-1996 (Suisun Bay/San Pablo Bay)***	***Range of Se concentrations in the predominant bivalve in the North Bay are sufficient to load eggs beyond teratogenic thresholds and approach the lower thresholds for systems where fish were eliminated by Se poisoning.***	***Selenium Verification Study; Johns et al, 1988; Linville and Luoma, in press***

TABLE 14. Examples of thresholds for Se effects (health, reproductive, teratogenesis, or survival) in fish based on Se concentrations in tissues of fish. Selenium concentrations in tissue of white sturgeon from the Bay-Delta are given for comparison.

Effect/Threshold	**Location**	**Concentration in Tissue (µg Se/g, dry weight)**	**Reference(s)**
Deformities/tissue	Field	• 10 - 20 µg/g in whole homogenate; • 6 - 12 µg/g in muscle (fillets) • 20 - 40 µg/g in viscera.	Lemly, 1998a
Percent deformed larvae, fry, juveniles, or adults (e.g., centrarchids)/ whole-body	Field	• 5 - 10 µg/g whole-body = onset of deformities (<6%) in *larvae, fry, juveniles, and adults.* • 11 - 20 µg/g whole-body = <11% deformities in *juveniles and adults* • 25 - 35 µg/g whole body = rapid rise in rate of deformities in *larvae* of some species (35-65%) • 40 - 50 µg/g - rapid rise in rate of deformities = 20 - 30% in *juveniles and adults.* • 30 - 40 µg/g whole body = 80% deformities in *larval fish* • 70 - 90 µg/g whole body = 70% deformities in *juveniles and adults*	Lemly, 1997a
Growth and survival of salmon (larval; fingerling)/whole-body	Lab (SLD diet) and synthesis	• 4 - 6 µg/g whole-body	Hamilton et al., 1990; also cited in 2000a
Survival of razorback sucker larval fish/whole-body	Field	• 4 - 14 µg/g whole body	Hamilton, et al., 1996
<u>Thresholds</u> • whole body (sensitive species)	Synthesis	• 4 - 6 µg/g	Skorupa, 1998b
<u>Thresholds</u> • whole body, • skeletal muscle, • liver • ovary and egg • larvae and fry	Synthesis	• 5 - 7 µg/g • 6 - 8 µg/g • 15 - 20 µg/g • 5 - 10 µg/g (6 - 17 µg/g, terata) • 8 - 12 µg/g (5 - 12 µg/g, terata)	Lemly, 1998b
<u>Thresholds</u> • whole body • ovary	Synthesis	• 6 (coldwater) - 9 (warmwater) µg Se/g • 17 µg Se/g	Deforest et al., 1999
<u>Thresholds</u> • whole body	Synthesis	• 4 - 12	Engberg et al., 1998
Selenium concentrations in white sturgeon tissue (µg Se/g, dry weight) from the Bay-Delta			
White sturgeon 1989-1990 (Suisun, San Pablo, Grizzly, and Honker Bays)	***Field***	• ***30 µg Se/g in liver (average, n=42) (range 6 – 80 µg/g)*** • ***15 µg Se/g in flesh (average, n=62) (range 2 - 50 µg/g)***	***Selenium Verification Study (Urquhart and Regalado, 1991)***
White sturgeon San Pablo Bay	***Field***	• ***ovaries 3 - 29 µg Se/g*** • ***plasma 5 - 9 µg Se/g*** • ***egg yolk components 3 - 90 µg Se/g***	***Kroll and Doroshov, 1991***

Table 15. Examples of thresholds for Se effects (health, reproductive, teratogenesis, or survival) in birds based upon Se concentrations in different tissues of birds. Thresholds based on diet are also included. Selenium concentrations in tissues of bird species from Kesterson Reservoir and the Bay-Delta are given for comparison.

Selenium in tissue (µg/g, dry weight)	***Embryo Deformity* Threshold**	***Hatchability* Threshold**	***Reference(s)***
Egg	13 – 24 (mean egg) (field, western and northern plains, U.S.)		Skorupa and Ohlendorf, 1991
Egg	12 – 15 (lab, mallard and chicken)		Heinz, 1996
Egg		10 (Kesterson Reservoir, California)	Skorupa and Ohlendorf, 1991; Skorupa, 1998a; b
Egg		6 (mean) (Salton Sea, California)	Skorupa, 1998a; b
Egg		4 – 10 (Tulare Basin, California)	Skorupa, 1998a; b
Egg (taxa specific)	duck, 15-20 stilt, 18-25 avocet, 38-60	- 6 – 7 -	Skorupa, 1998a; c; pers. comm.., 2000
Egg (impaired reproduction*)		>6 to > 9*	Engberg et al., 1998; Skorupa, 1998a; b; Lemly, 1998b
Liver	14 – 19		Heinz et al., 1989; Heinz, 1996
Liver	23 – 32 (terata)		Lemly, 1998b
Liver**	>30**		Skorupa, 1998b
Diet	4 - 8		Heinz et al., 1989; Heinz, 1996
Diet	6 - 9		Ohlendorf, 1989
Diet	3 - 8		Lemly, 1998b
Se concentration range in bird (ducks, coots, grebes, stilts) tissue (µg Se/g, dry weight) From Kesterson Reservoir, California (1983-1984)			
Egg	***2-180***		**Ohlendorf et al., 1986a; b; Skorupa, 1998a**
Liver	***3-360***		**Presser and Ohlendorf, 1987**
Se concentration (average/range) in bird tissue (µg Se/g, dry weight) from the Bay-Delta (1986-1990)			
Liver surf scoter (Suisun Bay) n = 71 average = 145	***(1986) 80/37-113 (1987) 84/13-167 (1988) 193/134-244 (1989) 240/137-368 (1990) 127/78-190***		**(White et al., 1987; 1988; 1989; Urquhart and Regalado, 1991)**
Liver surf scoter (San Pablo Bay) n = 62 average = 123	***(1986) 74/ 41-148 (1987) 113/65-196 (1988) 135/62-176 (1989) 162/81-217 (1990) 130/84-192***		**Selenium Verification Study (1986 – 1990) (White et al., 1987; 1988; 1989; Urquhart and Regalado, 1991)**
Liver (greater and lesser scaup, Suisun Bay) n = 39 average =41	***(1986) 14-86 (1987) 8-48*** *(range only)* ***(1988) 85/35-114***		**(White et al., 1987; 1988; 1989)**
Liver (scaup, San Pablo Bay) n = 31 average = 32	***(1986) 12-23 (1987) 11-47*** *(range only)* *(1988)* ***46/26-87***		**(White et al., 1987; 1988; 1989)**

**Presented as reproductive impairment and juvenile and adult toxicity. Also at Ouray National Wildlife Refuge, Utah, a range of 40 to 50 µg Se/g in bird liver was associated with adult mortality (Skorupa, 1998b). Review of experimentally induced selenosis in mallards proposed a diagnostic Se liver criterion of 66 µg Se/g (Albers et al., 1996).

Table 16. Selenium loads employed in forecasts of Se impacts. Loads were calculated for a six-month season. Annual loads would be two times higher if Se discharge is continuous (i.e., at a constant rate). Agricultural inputs fall into three groups depending on management strategy: *supply-driven management* (3,000 to 8,000 lbs Se/year); *demand-driven load with management of land and/or drainage quality* (15,000 to 45,000 lbs Se/year); and *demand-driven load with minimum management* (45,000 to 128,000 lbs Se/year).

INPUTS TO BAY/DELTA (**µg Se/L** or parts per billion) (**cfs** cubic feet per second) (**MAF** million acre-feet)	FLOW: Year/season **WET YEAR/HIGH FLOW** (lbs Se discharged in six months)	FLOW: Year/season **WET YEAR/LOW FLOW** (lbs Se discharged in six months)	FLOW: Year/season **CRITICALLY DRY/LOW FLOW** (lbs Se discharged in six months)
Agricultural Drainage ***via San Joaquin River*** (targeted load)	3,400-3,600 lbs/season	3,400-3,600 lbs/season	3,400-3,600 lbs/season
via SLD 50 µg/L, 150 cfs (0.05 MAF/season)	6,800	6,800	6,800
via SLD 62.5 µg/L, 300 cfs (0.11 MAF/season)	18,700	18,700	18,700
via SLD 150 µg/L, 300 cfs (0.11 MAF/season)	44,880	44,880	44,880
via SLD 300 µg/L, 300 cfs (0.11 MAF/season)	89,760	89,760	89,760
SAN JOAQUIN RIVER (maximum recycling)	3-5 lbs/season	3-5 lbs/season	3-5 lbs/season
Oil Refineries	680 lbs/season	680 lbs/season	680 lbs/season
Sacramento River	141 lbs/season	250 lbs/season	1,850 lbs/season

Table 17. Comparison of Se hazard in the Bay-Delta and other environments. Values are Se concentrations in µg Se/g dry wt. Hazard ratings for each set of concentrations are stated within each cell (as defined by Lemly, 1995 and 1996b). The individual scores and total score are compared to listed evaluation criteria to determine a hazard rating (high, moderate, low, minimal, or none identified) (Lemly, 1995). For the Bay-Delta, bird egg concentrations are converted from bird liver. Data sources are Lemly, 1995; 1996a; b; 1997a; b; c for western U.S. sites and this report and *Kroll and Doroshov, 1991 for the Bay-Delta.

Site	**Water; Hazard**	**Sediment; Hazard**	**Invertebrates; Hazard**	**Fish Eggs; Hazard**	**Bird Eggs; Hazard**	**Score; Hazard**
Ouray Refuge (Leota), Utah	<1 - 3 Low	0.7 - 1.0 None	1 - 3 Minimal	2 - 4 Minimal	2 - 7 Low	11 Low
Ouray Refuge (Ponds), Utah	9 - 93 High	7 - 41 High	12 - 72 High	75 - 120 High	12 - 120 High	25 High
Ouray Refuge (Sheppard), Utah	3 - 4 Moderate	0.6 - 3.0 Low	3 - 33 High	8 - 27 High	1 - 17 Moderate	21 High
Belews Lake, pre-1986, North Carolina	5 - 20 High	4 - 12 High	15 - 57 High	40 - 159 High		20 High
Belews Lake, 1996 North Carolina	<1 None	1 - 4 Moderate	2 - 5 Moderate	5 - 20 Moderate	2 - 5 Minimal	15 Moderate
Animas River, Colorado and New Mexico	1 - 20 High	0.1 - 2.3 Low	1.8 - 2.9 Minimal	3.0 - 15.8 Moderate		14 Moderate
La Plata River, Colorado and New Mexico	1 - 12 High	0.1 - 0.95 None	1.1 - 2.2 Minimal	2.6 - 39.6 High		13 Moderate
Mancos River, Colorado and New Mexico	2 - 29 High	0.2 - 0.8 None	1.8 - 11.2 High	5.6 - 46.2 High		16 High
Ridges Basin Reservoir, Colorado and New Mexico	1 - 10 High	1 - 8 High	5 - 75 High	5 -100 High	5 - 100 High	25 High
Southern Ute Reservoir, Colorado and New Mexico	1 - 6 High	1 - 5 High	5 - 50 High	5 - 80 High	5 - 80 High	25 High
Bay-Delta Suisun Bay, 1990-1996	***<1 None***	***0.5 - 2 (8) Low - Mod***	***4 - 20 High***	***3 – 29* High***	***Moderate - High***	***17 High***
Rating protocol	***Water***	***Sediment***	***Invertebrate***	***Fish eggs***	***Bird eggs***	***Total***
None	***<1***	***<1***	***<2***	***<3***	***<3***	***5***
Minimal	***1-2***	***1-2***	***2-3***	***3-5***	***3-5***	***6-8***
Low	***2-3***	***2-3***	***3-4***	***5-10***	***5-12***	***9-11***
Moderate	***3-5***	***3-4***	***4-5***	***10-20***	***12-20***	***12-15***
High	***>5***	***>4***	***>5***	***>20***	***>20***	***16-25***

Table 18. Calculation of a composite freshwater endmember concentration of Se (ug Se/L) from inputs of the Sacramento River (Sac R), the San Joaquin River (SJR), and oil refineries under conditions simulating those prior to refinery cleanup. Forecasts contrast wet and dry years; and high and low flow seasons. Load is expressed in lbs Se per six months.

	Volume MAF	*Volume billion L*	*Concentration ug Se/L*	*Load billion ug*	*Load lbs Se*	*Contribution Sum billion ug*	*Volumes Sum billion liters*	*Concentration FW Endmember ug Se/L*	*Concentration at Carquinez Strait at 17.5 psu ug Se/L*
Prior to Refinery Cleanup Scenarios (No SLD extension)									
Wet Year (1997 data), High Flow Season (six months, December through May)									
Sac R.	17	20961	0.04	838	1,850				
SJR	3	3699	1	3699	8,160				
SLD		0		0	0				
Refineries	0.005	6.165	150	925	2,040				
						5,462	*24,666*	***0.22***	***0.11***
Wet Year (1997 data), Low Flow Season (six months, June-November)									
Sac R.	2.3	2835.9	0.04	113	250				
SJR	0.1	123.3	1	123	272				
SLD	0	0		0	0				
Refineries	0.005	6.165	150	925	2,040				
						1,161	*2,965*	***0.39***	***0.20***
Critically Dry Year (1994 data), Low Flow Season (six months, June-November)									
Sac R.	1.62	1997.46	0.04	80	176				
SJR	0.1	123.3	1	123	272				
SLD		0		0	0				
Refineries	0.005	6.165	150	925	2,040				
						1,128	*2,127*	***0.53***	***0.27***

Table 19. Calculation of a composite freshwater (FW) endmember concentration of Se (ug Se/L) from inputs of the Sacramento River (Sac R.), the San Joaquin River (SJR), a proposed San Luis Drain (SLD) extension, and oil refineries under different load scenarios. Forecasts are for a wet year (1997) during the high flow season. Load is expressed in lbs Se per six months. Forecasts 1a through 1d use a SLD extension and assume a 2 MAF SJR inflow reaches the Bay-Delta. The final forecast assumes no SLD extension and a SJR inflow of 1.1 MAF.

	Volume MAF	*Volume billion L*	*Concentration ug Se/L*	*Load billion ug*	*Load lbs Se*	*Contribution Sum billion ug*	*Volumes Sum billion liters*	*Concentration FW Endmember ug Se/L*	*Concentration at Carquinez Strait at 17.5 psu*
1. Scenarios: Wet Year (1997 data), High Flow Season (six months, December - May), Refinery cleanup									
a) SLD at 150 cfs, 50 ppb Se (6,800 lbs SLD load in six months).									
Sac R.	17	20961	0.04	838	1,850				
SJR	2	2466	1	2466	5,440				
SLD	0.05	61.65	50	3083	6,800				
Refineries	0.005	6.165	50	308	680				
						6,695	*23,495*	***0.28***	***0.14***
b) SLD at 300 cfs and 62.5 ppb Se (18,700 lbs SLD load in six months).									
Sac R.	17	20961	0.04	838	1,850				
SJR	2	2466	1	2466	5,440				
SLD	0.11	135.63	62.5	8477	18,700				
Refineries	0.005	6.165	50	308	680				
						12,090	*23,569*	***0.51***	***0.26***
c) SLD at 300 cfs and 150 ppb Se (44,880 lbs SLD load in six months).									
Sac R.	17	20961	0.04	838	1,850				
SJR	2	2466	1	2466	5,440				
SLD	0.11	135.63	150	20345	44,880				
Refineries	0.005	6.165	50	308	680				
						23,957	*23,569*	***1.02***	***0.51***
d) SLD at 300 cfs and 300 ppb Se (89,760 lbs SLD load in six months).									
Sac R.	17	20961	0.04	838	1,850				
SJR	2	2466	1	2466	5,440				
SLD	0.11	135.63	300	40689	89,760				
Refineries	0.005	6.165	50	308	680				
						44,302	*23,569*	***1.88***	***0.94***
Targeted SJR load of 7,180 lbs Se annually; 3,590 lbs Se in six months									
Sac R.	17	20961	0.04	838	1,850				
SJR	1.1	1356.3	1.2	1628	3,590				
SLD	0	0	0	0	0				
Refineries	0.005	6.165	50	308	680				
						2,774	*22,323*	***0.12***	***0.06***

Table 20. Calculation of a composite freshwater (FW) endmember concentration of Se (ug Se/L) from inputs of the Sacramento River (Sac R), the San Joaquin River (SJR), a proposed San Luis Drain (SLD) extension, and oil refineries under different load scenarios. Forecasts are for a wet year (1997) during the low flow season. Se load is lbs Se per six months. Forecasts 2a through 2d use a SLD extension and assume little SJR inflow reaches the Bay-Delta. The final forecast assumes no SLD extension and a 0.5 MAF SJR inflow.

	Volume MAF	*Volume billion L*	*Concentration ug Se/L*	*Load billion ug*	*Load lbs Se*	*Contribution Sum billion ug*	*Volumes Sum billion liters*	*Concentration FW Endmember ug Se/L*	*Concentration at Carquinez Strait at 17.5 psu*
a) SLD at 150 cfs and 50 ppb Se (6,800 lbs SLD load in six months).									
Sac R.	2.3	2835.9	0.04	113	250				
SJR	0.001	1.233	1	1	3				
SLD	0.05	61.65	50	3083	6,800				
Refineries	0.005	6.165	50	308	680				
						3,505	*2,905*	***1.21***	***0.60***
b) SLD at 300 cfs and 62.5 ppb Se (18,700 lbs SLD load in six months).									
Sac R.	2.3	2835.9	0.04	113	250				
SJR	0.001	1.233	2	2	5				
SLD	0.11	135.63	62.5	8477	18,700				
Refineries	0.005	6.165	50	308	680				
						8,901	*2,979*	***2.99***	***1.49***
c) SLD at 300 cfs and 150 ppb Se (44,880 lbs SLD load in six months).									
Sac R.	2.3	2835.9	0.04	113	250				
SJR	0.001	1.233	2	2	5				
SLD	0.11	135.63	150	20345	44,880				
Refineries	0.005	6.165	50	308	680				
						20,769	*2,979*	***6.97***	***3.49***
d) SLD at 300 cfs and 300 ppb Se (89,760 lbs SLD load in six months).									
Sac R.	2.3	2835.9	0.04	113	250				
SJR	0.001	1.233	2	2	5				
SLD	0.11	135.63	300	40689	89,760				
Refineries	0.005	6.165	50	308	680				
						41,113	*2,979*	***13.80***	***6.90***
Targeted SJR load at 6,800 lbs Se annually; 3,400 lbs Se in six months; no SLD.									
Sac R.	2.3	2835.9	0.04	113	250				
SJR	0.5	616.5	2.5	1541	3,400				
SLD	0	0	0	0	0				
Refineries	0.005	6.165	50	308	680				
						1,963	*3,459*	***0.57***	***0.28***

Table 21. Calculation of a composite freshwater (FW) endmember concentration of Se (ug Se/L) from inputs of the Sacramento River (Sac R.), San Joaquin River (SJR), a proposed San Luis Drain (SLD) extension, and oil refineries under different load scenarios. Forecasts are for a critically dry year (1994) during the low flow season. Se load is lbs Se per six months. Forecasts 3a through 3d use a SLD extension and assume little SJR inflow reaches the Bay-Delta. The final forecast assumes no SLD extension and a 0.5 MAF SJR inflow.

	Volume MAF	*Volume billion L*	*Concentration ug Se/L*	*Load billion ug*	*Load lbs Se*	*Contribution Sum billion ug*	*Volumes Sum billion liters*	*Concentration FW Endmember ug Se/L*	*Concentration at Carquinez Strait at 17.5 psu*
3. Scenarios: Critically Dry Year (1994 data), Low Flow Season (June - November), Refinery cleanup									
a) SLD at 150 cfs and 50 ppb Se (6,800 lbs SLD load in six months).									
Sac R.	1.3	1602.9	0.04	64	141				
SJR	0.0005	0.6165	2	1	3				
SLD	0.05	61.65	50	3083	6,800				
Refineries	0.005	6.165	50	308	680				
						3,456	*1,671*	***2.07***	***1.03***
b) SLD at 300 cfs and 62.5 ppb Se (18,700 lbs SLD load in six months).									
Sac R.	1.3	1602.9	0.04	64	141				
SJR	0.0005	0.6165	2	1	3				
SLD	0.11	135.63	62.5	8477	18,700				
Refineries	0.005	6.165	50	308	680				
						8,850	*1,745*	***5.07***	***2.54***
c) SLD at 300 cfs and 150 ppb Se (44,880 lbs SLD load in six months).									
Sac R.	1.3	1602.9	0.04	64	141				
SJR	0.001	1.233	2	2	5				
SLD	0.11	135.63	150	20345	44,880				
Refineries	0.005	6.165	50	308	680				
						20,719	*1,746*	***11.87***	***5.93***
d) SLD at 300 cfs and 300 ppb Se (89,760 lbs SLD load in six months).									
Sac R.	1.3	1602.9	0.04	64	141				
SJR	0.0005	0.6165	2	1	3				
SLD	0.11	135.63	300	40689	89,760				
Refineries	0.005	6.165	50	308	680				
						41,063	*1,745*	***23.53***	***11.76***
Targeted SJR load of 6,800 lbs Se annually; 3,400 lbs Se in six months.									
Sac R.	1.3	1602.9	0.04	64	141				
SJR	0.5	616.5	2.5	1541	3,400				
SLD	0	0	0	0	0				
Refineries	0.005	6.165	50	308	680				
						1,914	*2,226*	***0.86***	***0.43***

Table 22. Calculation of a composite freshwater endmember concentration of Se (ug Se/L) from inputs of the Sacramento River (Sac R), the San Joaquin River (SJR), and oil refineries, under a restoration scenario. Se load is lbs Se per six months. Assume greater SJR inflows enter the Bay-Delta to aid fish migration and the SJR input is held constant at 0.5 ppb Se. High flow season conveys 75% of SJR annual flow; low flow season, 25%.

	Volume MAF	*Volume billion L*	*Concentration ug Se/L*	*Load billion ug*	*Load lbs Se*	*Contribution Sum billion ug*	*Volumes Sum billion liters*	*Concentration FW Endmember ug Se/L*	*Concentration at Carquinez Strait at 20 psu ug Se/L*
Restoration Scenarios (No SLD extension, refinery cleanup)									
Wet Year (1997 data), High Flow Season, conveys 75% of SJR inflow (six months, December-May)									
Sac R.	17	20961	0.04	838	1,850				
SJR	2.25	2774.25	0.5	1387	3,060				
SLD		0		0	0				
Refineries	0.005	6.165	50	308	680				
Total	**19.255**	**23741.42**	**50.54**	**2534**	**5,590**	*2,534*	*23,741*	***0.11***	***0.05***
Wet Year (1997 data), Low Flow Season, conveys 25% of SJR inflow (six months, June-November)									
Sac R.	2.3	2835.9	0.04	113	250				
SJR	0.75	924.75	0.5	462	1,020				
SLD	0	0		0	0				
Refineries	0.005	6.165	50	308	680				
Total	**3.055**	**3766.815**	**50.54**	**884**	**1,950**	*884*	*3,767*	***0.23***	***0.12***
Dry Year (1994 data), High Flow Season, conveys 75% of SJR inflow (six months, December-May)									
Sac R.	5	6165	0.04	247	544				
SJR	0.82	1011.06	0.5	506	1,115				
SLD		0		0	0				
Refineries	0.005	6.165	50	308	680				
Total	**5.825**	**7182.225**	**50.54**	**1060**	**2,339**	*1,060*	*7,182*	***0.15***	***0.07***
Dry Year (1994 data), Low Flow Season, conveys 25% of SJR inflow (six months, June-November)									
Sac R.	1.6	1972.8	0.04	79	174				
SJR	0.28	345.24	0.5	173	381				
SLD		0		0	0				
Refineries	0.005	6.165	50	308	680				
Total	**1.885**	**2324.205**	**50.54**	**560**	**1235**	*560*	*2,324*	***0.24***	***0.12***

Table 23. Summary of forecasts of Se concentrations in a composite freshwater endmember entering the Bay-Delta under different conditions. Load is expressed in lbs per six months. SLD loads are for the SLD only; targeted load and "restoration" scenario is for the SJR only. C_F is a composite concentration in all sources of freshwater at the head of the estuary (i.e. near the discharge point of a proposed SLD extension); C_E is a composite concentration at 17.5 practical-salinity units (psu), usually near Carquinez Strait during the low flow season.

Forecast **Year/Season**	**Prior to refinery cleanup**	**SLD: Half capacity, 50 µg/L**	**SLD: Full capacity, 62.5 µg/L**	**SLD: Full capacity, 150 µg/L**	**SLD: Full capacity, 300 µg/L**	**Targeted Load SJR**	**"Restoration" in SJR 0.5 µg Se/L**
Wet/High							
Load (lbs/6 mo)		**6,800**	**18,700**	**44,880**	**89,760**	**3,590**	**3,060**
Conc.$_F$ (µg/L)	0.22	0.28	0.51	1.02	1.88	0.12	0.11
Conc.$_E$ (µg/L)	0.11	0.14	0.26	0.51	0.94	0.06	0.05
Wet/Low							
Load (lbs/6 mo)		**6,800**	**18,700**	**44,880**	**89,760**	**3,400**	**1,020**
Conc.$_F$ (µg/L)	0.39	1.21	2.99	6.97	13.8	0.57	0.23
Conc.$_E$ (µg/L)	0.20	0.60	1.49	3.49	6.9	0.28	0.12
Dry/Low							
Load (lbs/6 mo)		**6,800**	**18,700**	**44,880**	**89,760**	**3,400**	**381**
Conc.$_F$ (µg/L)	0.53	2.07	5.07	11.9	23.5	0.86	0.24
Conc.$_E$ (µg/L)	0.27	1.03	2.54	5.93	11.8	0.43	0.12
Criteria	2 to 5 µg Se/L						

Table 24. Summary of forecasts of Se concentrations in particulate material under different conditions. Load is expressed in lbs Se/six months. SLD scenario loads are for the SLD only; the targeted load and "restoration" scenario are for the SJR only. C1 is the concentration forecast at a Kd of 10^4, typical of suspended sediment; C2 is the concentration forecast at a Kd of $3X10^3$, typical of shallow-water bed sediment; C3 is the low reactivity concentration forecast at a Kd of 10^3. All concentrations are those at the head of the estuary (near the release point of a proposed SLD extension).

Forecast **Year/Season**	**Prior to refinery cleanup**	**SLD: Half capacity, 50 μg Se/L**	**SLD: Full capacity, 62.5 μg Se/L**	**SLD: Full capacity, 150 μg Se/L**	**SLD: Full capacity, 300 μg Se/L**	**Targeted Load SJR**	**"Restoration" in SJR 0.5 μg Se/L**
Wet/High							
Load (lbs/6 months)		**6,800**	**18,700**	**44,880**	**89,760**	**3,500**	**3,060**
C1 (μg Se/g)	2.2	2.8	5.1	10.2	18.8	1.2	1.1
C2 (μg Se/g)	0.66	0.84	1.53	3.06	5.6	0.36	0.33
C3 (μg Se/g)	0.22	0.28	0.51	1.02	1.88	0.12	0.11
Wet/Low							
Load (lbs/6 months)		**6,800**	**18,700**	**44,880**	**89,760**	**3,400**	**1,020**
C1 (μg Se/g)	3.9	12.1	29.9	69.7	138	5.7	2.3
C2 (μg Se/g)	1.2	3.63	8.97	20.9	41.4	1.71	0.69
C3 (μg Se/g)	0.39	1.21	2.99	6.97	13.8	0.57	0.23
Dry/Low							
Load (lbs/6 months)		**6,800**	**18,700**	**44,880**	**89,760**	**3,400**	**381**
C1 (μg Se/g)	5.3	20.7	50.7	118.7	235	8.6	2.4
C2 (μg Se/g)	1.6	6.21	15.2	35.6	70.6	2.58	0.72
C3 (μg Se/g)	0.53	2.07	5.07	11.9	23.5	0.86	0.24
Guidelines	1.5 to 4 μg Se/g						

Table 25. Forecast of particulate Se concentrations at the head of the Bay-Delta estuary:

- in years with different climate regimes;
- in different seasons; and
- for alternative speciation and biogeochemical behavior patterns.

The scenarios considered are:

- a SLD extension discharge of 18,700 lbs per six months (full capacity, 62.5 µg Se/L); and
- a SJR discharge of a targeted load of 3,590 lbs per six months for a wet year (1.2 µg Se/L) and 3,400 lbs per six months for a dry year (2.5 µg Se/L).

Forecasts are compared to conditions prior to refinery cleanup.

Forecast	Composite Freshwater Endmember Se (µg/L)	Particulate Se (µg/g) low reactivity Kd: 10^3 (**C3**)	Particulate Se (µg/g) shallow sediment Kd: 3 X 10^3 (**C2**)	Particulate Se (µg/g) biotransformed suspended matter Kd: 10^4 (**C1**)
SLD				
Wet Year **High Flow Season**	**0.46**	***0.5***	***1.5***	***5.1***
Wet Year **Low Flow Season**	**3.0**	***3.0***	***9.0***	***30.0***
<u>Critically Dry Year</u> Low Flow Season	**5.1**	***5.1***	***15.2***	***50.7***
SJR (targeted load)				
<u>Wet Year</u> **High Flow Season**	**0.12**	***0.12***	***0.36***	***1.2***
Wet Year **Low Flow Season**	**0.57**	***0.57***	***1.71***	***5.7***
<u>Critically Dry Year</u> Low Flow Season	**0.86**	***0.86***	***2.58***	***8.6***
Prior to refinery cleanup				
Wet Year **High Flow Season**	**0.22**	***0.22***	***0.66***	***2.2***
Wet Year **Low Flow Season**	**0.39**	***0.39***	***1.2***	***3.9***
<u>Critically Dry Year</u> Low Flow Season	**0.53**	***0.53***	***1.6***	***5.3***
Criteria	**2 – 5**	**1.5 – 4.0**	**1.5 – 4.0**	**1.5 – 4.0**

Table 26. Laboratory-derived physiological constants for Se bioaccumulation by several species of bivalve and composite values for a generic bivalve (data from Luoma et al., 1992; Reinfelder et al., 1997).

Species	**Feeding rate (grams food/grams tissue/day)**	**Assimilation Efficiency (AE %)**	**Rate Constant of Loss k_e (d^{-1})**	**AE/ k_e**
Oyster		***70 ± 6***		
Clam (Macoma balthica)		***80 ±7***	***0.03 ± 0.001***	***24.6***
Clam (Mercenaria mercenaria)		***92 ± 2***	***0.01 ± 0.004***	***92.0***
Mussel (Mytilus edulis)		***74 ± 8***	***0.02 ± 0.007***	***37.0***
Generic bivalve (from diatom)	**0.2**	***79***	***0.02***	***39***
Sorbed Se	**0.2**	***40***	***0.02***	**20**
Elemental Se	**0.2**	***23***	***0.02***	**10**

Table 27. Selenium concentrations in a generic bivalve when exposed to different concentrations of particulate organo-Se or particulate elemental Se (constants from Luoma et al., 1992 and Reinfelder et al., 1997).

Exposure to different concentrations of:	**Particulate Concentration (µg Se/g)**	**Absorption Efficiency (speciation)**	**Rate Constant of Loss (d^{-1})**	**Tissue Concentration at Steady State (µg Se/g)**	**Reference**
particulate organo-Se					Luoma et al., 1992; Reinfelder et al., 1997
	0.5	***0.8***	***0.02***	**4.0**	
	1.0	***0.8***	***0.02***	**8.0**	
	1.5	***0.8***	***0.02***	**12.0**	
	2.0	***0.8***	***0.02***	**16.0**	
	3.0	**0.8**	***0.02***	**24.0**	
particulate elemental Se					Luoma et al., 1992; Reinfelder et al., 1997
	0.5	***0.2***	***0.02***	**1.0**	
	1.0	***0.2***	***0.02***	**2.0**	
	2.0	***0.2***	***0.02***	**4.0**	
	3.0	***0.2***	***0.02***	**6.0**	
	4.0	***0.2***	***0.02***	**8.0**	
	5.0	***0.2***	***0.02***	**10.0**	
	8.0	***0.2***	***0.02***	**16.0**	

Particulate concentrations of Se range from 0.3 to 3 µg Se/g dw in brackish Bay-Delta and 0.3 to 8 µg Se/g dw at the head of the estuary (Cutter, 1989 and Cutter et al., in preparation).

Table 28. Summary of forecasts of Se concentrations in a generic bivalve under different conditions. Load is expressed in lbs per six months. SLD scenario loads are for the SLD only. The targeted load and "restoration" scenario are for the SJR only. C1 is the concentration forecast at a Kd of 10^4, typical of suspended sediment; C2 is the concentration forecast at a Kd of 3×10^3, typical of shallow-water bed sediment; **C3** is the low reactivity concentration forecast at a Kd of 10^3. Four assimilation efficiencies have been assumed for each Kd: AE4 = 0.8; AE3 = 0.63; AE2 = 0.55; and AE1 = 0.35. All concentrations are those at the head of the estuary (near the release point of a proposed SLD extension)

Forecast **Year/Season**	**Prior to refinery cleanup**	**SLD: Half capacity, 50 µg/L**	**SLD: Full capacity, 62.5 µg/L**	**SLD: Full capacity, 150 µg/L**	**Targeted Load in SJR**
	Particulate **bivalve**	Particulate **bivalve**	Particulate **bivalve**	Particulate **bivalve**	Particulate **bivalve**
Wet/High					
Load (lbs/6months)		**6,800**	**18,700**	**44,880**	**3,500**
C1-AE4 (µg/g)	*2.2* **22**	*2.8* ***19***	*5.1* ***34***	*10* ***68***	*1.2* **8.0**
C1-AE3 (µg/g)	*2.2* ***17***	*2.8* ***15***	*5.1* ***27***	*10* ***54***	*1.2* ***6.3***
C2-AE2 (µg/g)	*0.66* ***4.5***	*0.84* ***3.9***	*1.5* ***7.0***	*3.1* ***14***	*0.36* ***1.7***
C3-AE1 (µg/g)	*0.22* ***0.96***	*0.28* ***0.8***	*0.5* ***1.5***	*1.0* ***3.0***	*0.12* ***0.4***
Wet/Low					
Load (lbs/6 months)		**6,800**	**18,700**	**44,880**	**3,500**
C1-AE4 (µg/g)	*3.9* ***39***	*12* ***81***	*30* ***199***	*70* ***465***	*5.7* ***38***
C1-AE3 (µg/g)	*3.9* ***31***	*12* ***64***	*30* ***157***	*70* ***366***	*5.7* ***30***
C2-AE2 (µg/g)	*1.2* ***8.0***	*3.6* ***17***	*9.0* ***41***	*21* ***96***	*1.7* ***7.8***
C3-AE1 (µg/g)	*0.39* ***1.7***	*1.2* ***3.5***	*3.0* ***8.7***	*7.0* ***20***	*0.57* ***1.7***
Dry/Low					
Load (lbs/6 months)		**6,800**	**18,700**	**44,880**	**3,500**
C1-AE4 (µg/g)	*5.3* **53**	*21* ***138***	*51* ***338***	*119* ***793***	*8.6* ***57***
C1-AE3 (µg/g)	*5.3* ***42***	*21* ***109***	*51* ***266***	*119* ***625***	*8.6* ***45***
C2-AE2 (µg/g)	*1.6* ***11***	*6.2* ***28***	*15* ***70***	*36* ***163***	*2.6* ***12***
C3-AE1 (µg/g)	*0.53* ***2.3***	*2.1* ***6.1***	*5.1* ***15***	*12* ***35***	*0.9* ***2.5***
Guidelines		**1.5 - 4.0/ 10 - 40 µg Se/g**			

Table 29. Forecast of Se concentrations bioaccumulated by a generic bivalve at the head of the Bay-Delta estuary:

- in years with different climate regimes;
- in different seasons; and
- for alternative speciation and biogeochemical behavior patterns.

The scenarios considered are:

- a SLD extension discharge of 18,700 lbs per six months (full capacity, 62.5 µg Se/L); and
- a SJR discharge of a targeted load of 3,590 lbs per six months for a wet year (1.2 µg Se/L) and 3,400 lbs per six months for a dry year (2.5 µg Se/L).

Forecasts are compared to conditions prior to refinery cleanup.

Forecast	Composite Freshwater Endmember Se (µg/L)	**Low reactivity: Kd: 10^3 (C3/AE1) Particulate Se [Bioaccum. Se] (µg/g)**	**Shallow sediment: Kd: 3 X 10^3 (C2/AE2) Particulate Se [Bioaccum. Se] (µg/g)**	**Suspended matter: Kd: 10^4 (C1/AE3) Particulate Se [Bioaccum. Se] (µg/g)**
SLD				
Wet Year High Flow Season	**0.5**	***0.5*** / ***1.5***	***1.5*** / ***7***	***5.1*** / ***27***
Wet year Low Flow Season	**3.0**	***3.0*** / ***9***	***9.0*** / ***41***	***30*** / ***157***
Critically Dry Year Low Flow Season	**5.1**	***5.1*** / ***15***	***15.2*** / ***70***	***51*** / ***266***
SJR (targeted load)				
Wet Year High Flow Season	**0.12**	***0.12*** / ***0.4***	***0.36*** / ***1.7***	***1.2*** / ***6.3***
Wet year Low Flow Season	**0.57**	***0.57*** / ***1.7***	***1.7*** / ***7.8***	***5.7*** / ***30***
Critically Dry Year Low Flow Season	**0.86**	***0.86*** / ***2.5***	***2.6*** / ***12***	***8.6*** / ***45***
Prior to refinery cleanup				
Wet Year High Flow Season	**0.22**	***0.22*** / ***0.96***	***0.66*** / ***4.5***	***2.2*** / ***17***
Wet year Low Flow Season	**0.39**	***0.39*** / ***1.7***	***1.2*** / ***8.0***	***3.9*** / ***31***
Critically Dry Year Low Flow Season	**0.53**	***0.53*** / ***2.3***	***1.6*** / ***11***	***5.3*** / ***42***
Criteria (water and particulate food)	**2 – 5**	**1.5-4.0** / **10-40**	**1.5-4.0** / **10 - 40**	**1.5-4.0** / **10 – 40**

Table 30. Regression equations for bivalves vs. bivalve predators. Data from Selenium Verification Studies (White, et al., 1987; 1988;1989; Urquart and Regalado, 1991).

Bivalves avg. ppm Se	Scoter North Bay Avg. ppm Se Flesh
4.8	12.5
2.77	12.5
2.2	4.0
5.13	21.3
2.01	3.0
5.73	37.8
6.87	51.8
7.90	35.8

Regression Output:	
Constant	-10.98
Std Err of Y Est	9.07
R Squared	**0.77**
No. of Observations	8
Degrees of Freedom	6
X Coefficient(s)	7.12
Std Err of Coef.	1.57

Bivalves vg. ppm S	Scoter North Bay Avg. ppm Se Liver
4.8	92.8
2.77	92.8
2.2	15.5
5.13	137.0
2.01	12.5
5.73	228.0
6.87	263.8
7.90	174.3

Regression Output:	
Constant	-41.57
Std Err of Y Est	51.07
R Squared	**0.74**
No. of Observations	8
Degrees of Freedom	6
X Coefficient(s)	36.06
Std Err of Coef.	8.83

Bivalves avg. ppm Se	Scaup North Bay Avg. ppm Se Flesh
4.8	7.1
2.77	7.1
2.2	3.9
5.13	12.0
2.01	6.57
5.73	23.93

Regression Output:	
Constant	-2.80
Std Err of Y Est	5.19
R Squared	**0.59**
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	3.42
Std Err of Coef.	1.42

Bivalves vg. ppm S	Scaup North Bay Avg. ppm Se Liver
4.8	25.8
2.77	25.8
2.2	9.7
5.13	29.1
2.01	13.57
5.73	65.12

Regression Output:	
Constant	-8.14
Std Err of Y Est	13.19
R Squared	**0.64**
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	9.63
Std Err of Coef.	3.61

Bivalves avg. ppm Se	WHITE STURGEON North Bay Avg. ppm Se Flesh
4.8	7.81
2.77	7.81
5.13	9.84
5.73	7.47
6.87	12.38
7.90	16.81

Regression Output:	
Constant	1.04
Std Err of Y Est	2.38
R Squared	**0.66**
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	1.68
Std Err of Coef.	0.60

Bivalves vg. ppm S	WHITE STURGEON North Bay Avg. ppm Se Liver
4.8	9.20
2.77	9.20
6.87	14.19
7.90	35.50

Regression Output:	
Constant	-7.15
Std Err of Y Est	9.49
R Squared	**0.62**
No. of Observations	4
Degrees of Freedom	2
X Coefficient(s)	4.33
Std Err of Coef.	2.41

'88, '89 & '90 scoter data matched to Potamocorbula, (replace Corbicula)

Bivalves avg. ppm Se	Scoter Avg. ppm Se Liver
4.80	92.8
2.77	92.8
2.20	15.5
5.13	137.0
2.01	12.5
11.63	228.0
11.63	263.8
11.63	174.3
R Squared	**0.86**

Regression Output:	
Constant	
Std Err of Y Est	
R Squared	
No. of Observations	
Degrees of Freedom	
X Coefficient(s)	19.28
Std Err of Coef.	3.21

Replaced Corbicula from 1990 with Potamocorbula

Bivalves avg. ppm	WHITE STURGEON Avg. ppm Se Liver
4.80	9.20
2.77	9.20
6.87	14.19
11.63	35.5
R Square	**0.91**

Regression Output:	
Constant	-3.50
Std Err of Y Est	4.63
R Squared	**0.91**
No. of Observations	4.00
Degrees of Freedom	2.00
X Coefficient(s)	3.15
Std Err of Coef.	0.70

Table 31. Data employed in regression of Se concentrations in bivalves vs. Se concentrations in bivalve predators. Means from diiferent years are aggregated; North Bay is Suisun Bay and San Pablo Bay. Both flesh and liver are shown for predators. Bivalves are from different species (*Corbicula fluminea**; *Mya arenaria***; *Macoma balthica****; and *Potamocorbula amurensis*****) and different studies (White et al., 1987*; 1988*; 1989*; Urquhart and Regalado, 1991*, Johns et al., 1988*; Luoma and Linville, 1997****; Linville and Luoma, in press****). Selenium as ppm is equivalent to micrograms Se per gram. All values are for dry weight.

Date	Bivalves avg. ppm Se	Scoter North Bay Avg. ppm Se Flesh	Scoter Liver	Scaup North Bay Avg. ppm Se Flesh	Scaup Liver	WHITE STURGEON North Bay Avg. ppm Se Flesh	WHITE STURGEON Liver
1986	**4.8***	**12.5**	**92.8**	**7.1**	**25.8**	**7.81**	**9.20**
1986-Humboldt	**2.2****	4.0	15.5	3.9	9.7		
1987	**5.13***	**21.3**	**137.0**	**12.0**	**29.1**	**9.84**	
1988-Humboldt	**2.0*****	3.0	12.5	6.57	13.57		
1988	**5.73***	**37.8**	**228.0**	**23.93**	**65.12**	**7.47**	
1989	**6.9***	**51.8**	**263.8**			**12.38**	**14.19**
1990	**7.9***	**35.8**	**174.3**			**16.81**	**35.50**
1995-1996	**11.6******	35.8	174.3			16.81	35.50

Table 32. Forecasts of Se concentrations in bivalves and resulting Se concentrations in livers of surf scoter, greater and lesser scaup, and white sturgeon under two Se discharge conditions: 1) the SLD scenario is for 18,700 lbs per six months (37,400 lbs per year) and 2) the SJR scenario is for a targeted load of 3,500 lbs per six months (7,000 lbs per year) (SJR conditions defined earlier). All forecasts are for six months of discharge during the low flow season of a critically dry year. Forecast concentrations are compared to average Se concentrations in these organisms (*Corbicula fluminea*, 1988-1990; *Potamocorbula amurensis,* 1995-1996; surf scoter, greater and lesser scaup, and white sturgeon, 1989-1990) in the Bay-Delta and to thresholds for adverse effects described earlier. Forecasts for predators were predicted by extrapolation from regressions between bivalve and predator concentrations using data from 1986 to 1990 (Tables 30 and 31).

Load Scenario	**Load in six months (lbs Se)**	**Bioaccumulation by bivalves (μg Se/g dry wt)**	**Selenium Concentration in Liver (μg Se/g dw)**		
			Scoter	**Scaup**	**Sturgeon**
SLD					
1. Low Reactivity (C3/AE1)	***18,700***	***15***	***248***	***136***	***45***
2. Shallow Sediment (C2/AE2)	***18,700***	***70***	***1293***	***664***	***221***
3. Suspended Sediment (C1/AE3)	***18,700***	***266***	***5017***	***2546***	***848***
SJR Target Load					
1. Low Reactivity (C3/AE1)	***3,500***	***2.5***	***10***	***16***	***5***
2. Shallow Sediment (C2/AE2)	***3,500***	***11.8***	***187***	***105***	***35***
3. Suspended Sediment (C1/AE3)	***3,500***	***45***	***818***	***424***	***141***
Average Concentration 1988-1990 1995-1996 (μg Se/g dw)		***Corbicula fluminea = 8*** ***Potamocorbula amurensis =12***	***164***	***64***	***30***
Threshold for Effects (μg Se/g dw)		***10 - 40***	***20 - 50***	***20 - 50***	***20 - 50***

Table 33. Relation of Se loads, composite freshwater endmember Se concentrations, particulate Se concentrations, Se bioaccumulation by bivalves, Se bioaccumulation by two predators (sturgeon and scaup) and Se guidelines or concentrations at which effects are expected. Forecasts are for:

- discharges from a SLD extension or the SJR;
- concentrations in the North Bay near the site of input (i.e., head of estuary) with instantaneous mixing; and
- the low flow season of a dry year.

Conditions prior to refinery cleanup are given for comparison.

Forecast Dry year/ low flow season (lbs Se/six months)	**Composite freshwater endmember (μg Se/L)**	**Particulate (μg Se/g dw) Kd = 3 X 10^3 (C2)**	**Bioaccumlation, generic bivalve (μg Se/g dw) AE2 (0.55)**	**White Sturgeon Liver (μg Se/g dw)**	**Greater and Lesser Scaup Liver (μg Se/g dw)**
SLD					
6,800	2.1	6.2	28	87	261
18,700	5.1	15	70	221	664
44,880	12	36	163	519	1557
SJR (targeted load)					
3,500	0.86	2.6	11.8	35	105
Prior to refinery cleanup					
	0.53	1.6	11	30	65
Guidelines	1-5	1.5 – 4.0	10 - 40	20 – 50	20 – 50

APPENDIX A

San Joaquin Valley Historic Planning and Geologic Inventory