Part D—Selenium (Se)

Introduction

Selenium (Se) is a natural trace element in the environment that has chemical and physical properties that are intermediate between those of metals and non-metals. It is an essential nutrient for fish, birds, animals, and humans. One of the most important features of selenium is the very narrow margin between nutritionally optimal and potentially toxic dietary exposures for vertebrate animals (Wilber 1980). Excessive amounts of selenium are found to cause toxicity in wildlife. Toxicological effects of selenium on wildlife include lowered reproduction rates, shortened life spans, and stunted growth. Many of these effects are not readily observable and detailed biological studies are required to determine whether or not selenium is negatively impacting biota in a watershed.

This Technical Support Document presents an analysis of the major sources of selenium to San Diego Creek and Upper Newport Bay. Monitoring results and preliminary data on potential sources of selenium in the watershed are reviewed. These studies were not detailed enough to identify all sources, but it is largely recognized that one of the primary sources of selenium in the watershed is from shallow groundwater that enters San Diego Creek through seeps, springs, and weepholes.

Most of the information presented in this Technical Support Document was selected from the DRAFT Selenium TMDL written by Regional Board staff (2001a).

I. Physicochemical description of chemical toxicant

Selenium exists in different environmental compartments that are atmospheric, marine, and terrestrial in nature. Heterogeneity in its distribution results in movement of selenium among those compartments (Nriagu 1989). Parent materials having the highest selenium concentrations are black shales (around 600 mg/kg dry) and phosphate rocks (1-300 mg/kg dry); both of which can potentially give rise to seleniferous soils and food chain selenium toxicity. Selenium can become mobilized and concentrated by weathering and evaporation in the process of soil formation and alluvial fan deposition in arid and semiarid climates (Presser 1994), and through leaching of irrigated agricultural soils and remobilization in irrigation water (Presser and Ohlendorf, 1987; Seiler *et al.* 1999). Selenium contamination of aquatic ecosystems is of special concern in large parts of California, and other semi-arid regions of western North America (Seiler *et al.* 1999).

Chemical Forms/ Speciation

The chemical speciation of selenium is a critical consideration in assessing selenium contamination in that the bioavailability and toxicity of selenium are greatly affected by its chemical forms. Selenium can occur in four different oxidation states: selenide (–2), elemental selenium (0), selenite (+4), and selenate (+6). In general, selenate (Se^{6+}) has a high solubility and is the most mobile in water. Selenite (Se^{4+}) is soluble in water but its strong affinity to be adsorbed to soil particles greatly reduces its mobility. Elemental selenium (Se^{0}) exists in a crystalline form and is usually incorporated in soil particles. In most surface waters, selenate and selenite are the most common chemical forms. Selenite is the most bioavailable of the dissolved phase inorganic species (Maider *et al.* 1993; Skorupa 1998). Though some data suggests that selenite is more toxic than selenate, selenate toxicity data are scant (Nagpal and Howell, 2001). A decrease in cell division and growth rates of some species of algae exposed to selenate have been shown by several studies (Davis et al., 1988; Dobbs et al., 1996; Richter, 1982). Selenate is also readily taken up by plants and thereby enters the food chain (pers. comm., D. Lemly). Organo-selenide was also found to

be very bioavailable and hence potentially toxic to algae, invertebrates, and fish (Maider *et al.* 1993).

Selenium is also found with particulate matter, which may include primary producers (*e.g.*, phytoplankton), bacteria, detritus, suspended inorganic material, and sediments. Interactions and transformation of selenium between dissolved and particulate phases could be biological, chemical, and/or physical in nature. Those reactions play an important role in selenium toxicity (Luoma and Presser 2000). Since all forms of selenium may interconvert however, they should all be considered toxicologically important (T.Fan and G.Cutter, commun. 1998)

Bioaccumulation

Selenium tends to bioaccumulate in bio-tissues and causes toxicological effects. There is strong evidence that the major selenium uptake route into fish is not accumulation from water, but rather via the food chain (Fowler and Benayoun 1976; Wilber 1980; Luoma *et al.* 1992). Bioaccumulation of selenium in lower trophic level invertebrates (*e.g.*, zooplankton and bivalves) is a critical step in determining the effects of selenium since higher trophic level predators such as fish and birds feed on invertebrates. Studies have shown that uptake of dissolved selenium by invertebrates is not as important as uptake from diet (Luoma *et al.* 1992; Lemly 1993). Luoma and Presser (2000) suggested that direct uptake of particulate selenium by invertebrates via filter-feeding or deposit feeding is the primary route for selenium to enter the food web. In laboratory studies of the mussel *Mytilus edulis*, dissolved selenite (+4) is the most bioavailable form of inorganic selenium taken up from solution (Wang *et al.* 1996). However, Luoma *et al.* (1992) showed that the uptake rate of dissolved selenite explained less than 5% of the tissue concentrations of selenium accumulated by the clam *Macoma balthica* at concentrations typical of the San Francisco Bay-Delta. The role of dissolved organic selenides in selenium bioaccumulation is not as well understood as availability of inorganic selenium, but it is unlikely that its uptake rate is greater than uptake rates from food (Luoma and Presser 2000).

II. Monitoring Results

Surface Waters and Groundwater

IRWD monthly monitoring data from 12/1997 to 3/1999 (Figure D-1) indicate consistent violation of the numeric target (5 µg/L) in San Diego Creek at Campus Drive. Figure D-1 shows selenium concentrations in relation to flow rate. No strong correlation is found. However, daily loads estimated from concentrations and flow data seem to exhibit a pattern when plotted as a function of flow rate (Figure D-2). In general, the estimated daily load shows an increasing trend with flow rate at the low end of the flow spectrum. There are too few data points to determine the load pattern at high flow rates.

The monitoring data at Campus Drive provides an estimation of loading to Newport Bay. This estimate uses a statistical method to calculate annual load. The calculation methodology is summarized in Section IV of this document. As discussed in the TMDL summary document, the annual load of selenium is estimated to be 2,443 lbs/year (4/1/98 - 3/31/99) with a dry season load of 1,196 lbs (4/1/98 - 9/30/98) and a wet season load of 1,247 lbs (10/1/98 – 3/31/99). Detailed calculations and data used are shown in Section IV of this TSD (see Table D-3).

III. Source Analysis

Selenium Source Identification Study

Hibbs and Lee (2000) investigated sources of selenium in the Newport Bay/San Diego Creek watershed. The study area is shown in Figure D-3. The study presents convincing evidence that groundwater is a significant source of selenium to San Diego Creek and Newport Bay. At the watershed scale, the study

shows that selenium concentrations exceed the numeric target in most of the surface and groundwater samples collected, and that they exhibit spatial heterogeneity (Figure D-4). Concentrations in groundwater range from below 4 µg/L (method detection limit) to 478 µg/L. A statistical analysis shows that selenium concentrations in groundwater samples were generally found to be higher within the boundaries of a historical marsh ("Swamp of the Frogs" or "La Cienega de las Ranas") than in other areas. Radioisotope analysis on the water samples suggest that high selenium concentrations in groundwater result from oxidation and leaching of subsurface soils in the saturated zone underlying the old marsh area.

Monitoring of nursery discharge shows selenium concentrations in most runoff samples (6 out of 7) were below detection limits (*i.e.*, < 4 µg/L). One sample was detected at 7 µg/L from Bordiers Nursery. Surface water monitoring shows that discharges containing less than 10 µg/L selenium were mostly urban and agricultural runoff. Surface channels and drains with particularly high concentrations coincide with areas where high selenium groundwater samples were collected. Those channels include Como Channel (38 to 42 µg/L), Valencia Drain at Moffett Drive (25 to 40 µg/L), Warner Drain (24 to 33 µg/L), and the circular drains at Irvine Center Drive (141 to 162 µg/L) and at Barranca Parkway (107 µg/L). Channel inspection and chemical composition analysis indicate that those drainage channels collect considerable amounts of groundwater.

Three drainage channels (San Diego Creek above the confluence with Peters Canyon Wash, Como Channel, and Santa Fe Channel) were selected for detailed flow and chemical investigation. In these three channels, stream flows were measured at upstream and downstream gage stations. Results indicated that these channels are gaining streams in the reaches studied. Namely, the increases in flow rates result from seepage of groundwater into the surface channels.

An analysis of the flow and concentration data indicates the significance of groundwater as a source of selenium. The total selenium load from groundwater in these three reaches is approximately 0.36 lbs/day. The surface water loading of selenium at Campus Drive falls in the range of 1.6 to 4 lbs/day at low flow conditions (see Figure D-1). The comparison shows that groundwater inputs to these three reaches alone represent a significant portion (9 to 22%) of the total selenium load to Newport Bay, indicating the significance of groundwater inputs of selenium to surface water. Selenium loads from groundwater may account for up to 70% of the total selenium load in the creek under base flow conditions (pers. comm., B. Hibbs). Detailed calculations are summarized in Table D-6 (Appendix B).

Results of the study suggest that discharges from groundwater cleanup projects and shallow groundwater dewatering activities are potential sources of selenium and could be significant depending on the locations of these activities. However, selenium information is not yet available for these discharges.

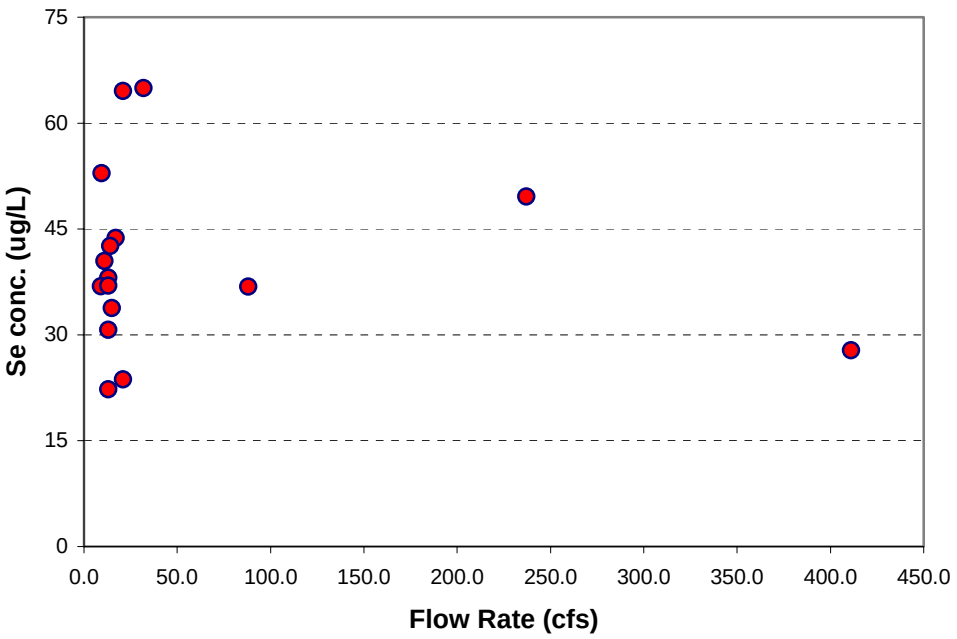


Figure D-1. Relationships between dissolved selenium concentration and flow rate at Campus Drive in San Diego Creek for March 1997 to March 1998 (selenium data: IRWD, flow data: OCPFRD).

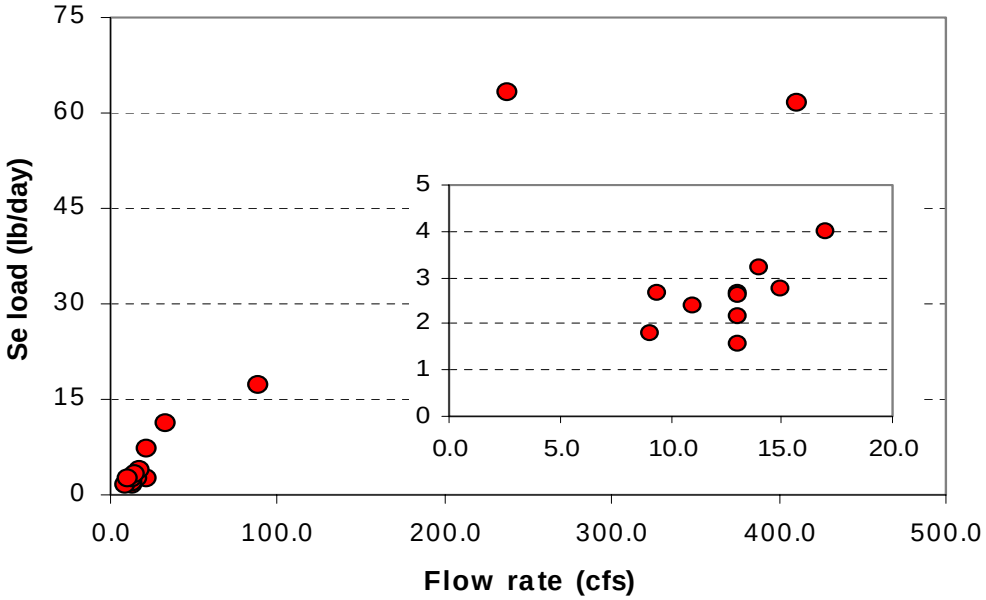


Figure D-2. Estimated selenium daily load (lbs / day) as a function of flow rate (cfs) at Campus Drive in San Diego Creek for March 1997 to March 1998 (selenium data: IRWD, flow data: OCPFRD).

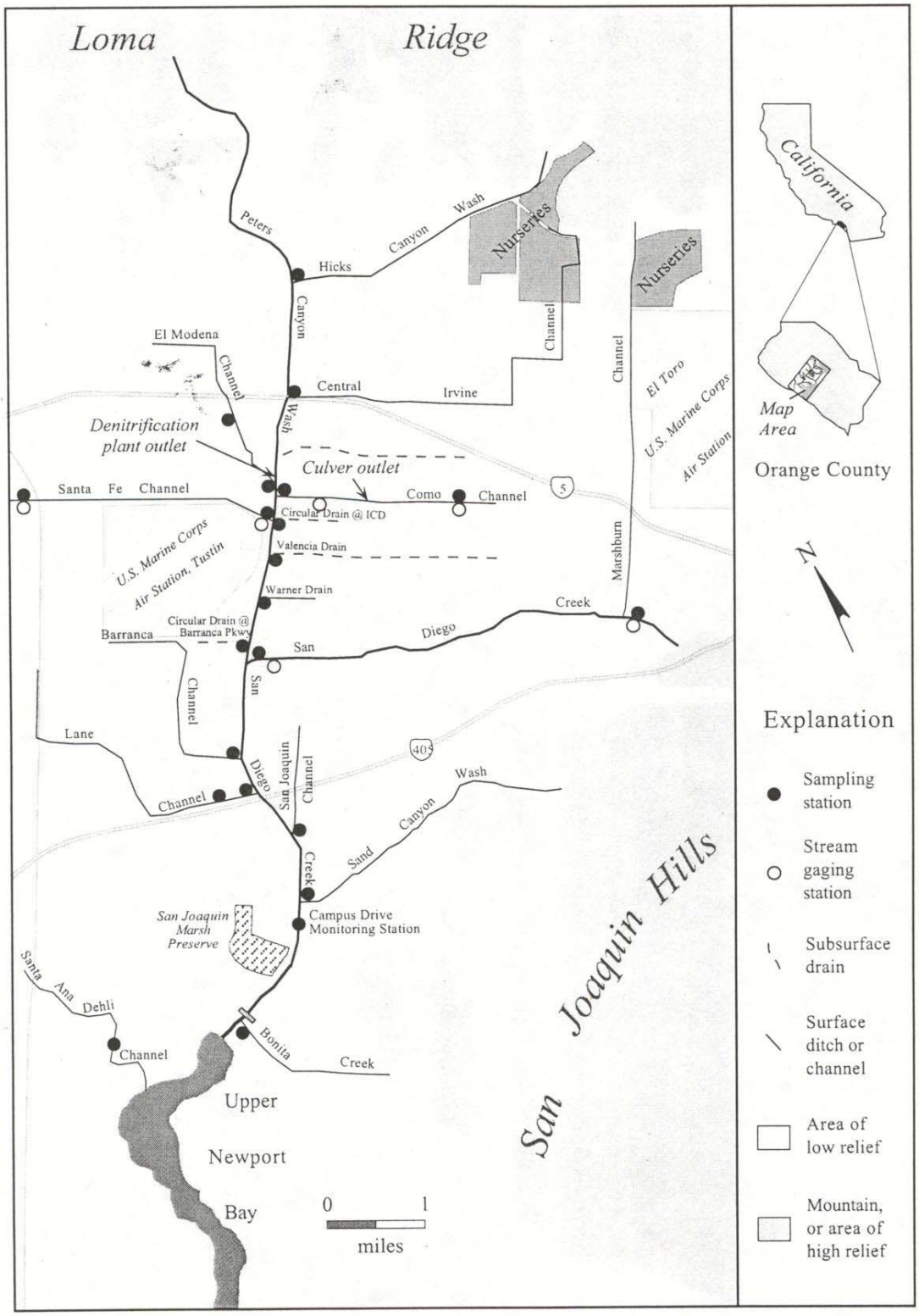


Figure D-3. Map of study area, showing the locations of water sampling stations and stream gage stations on important channels and creeks (source: Hibbs and Lee 2000).

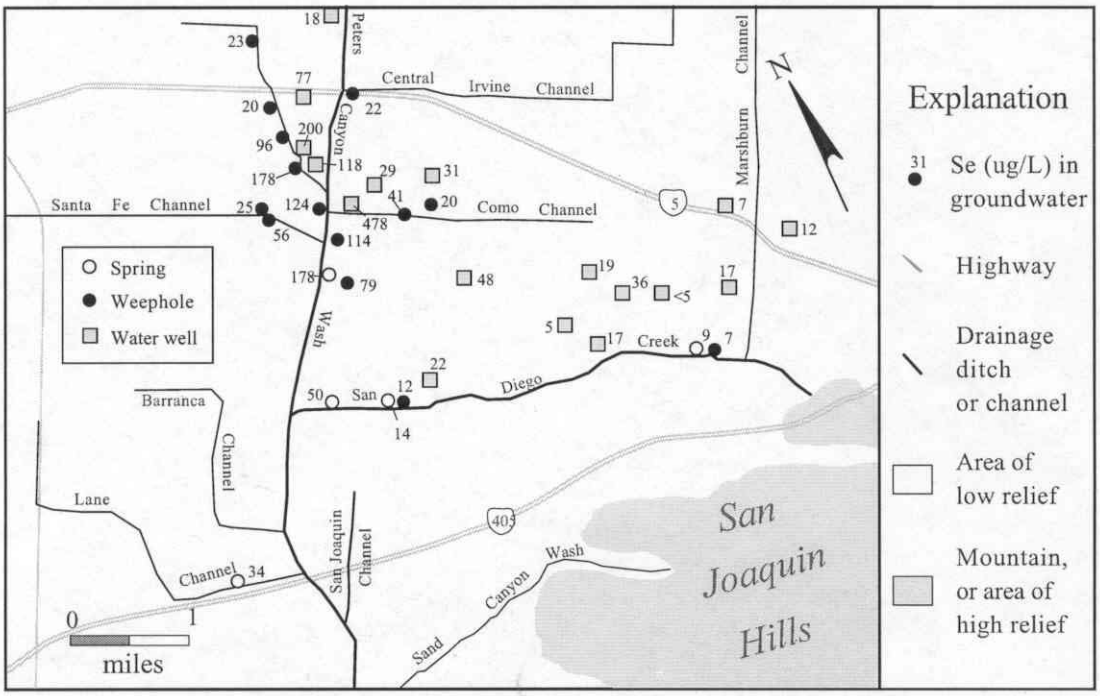
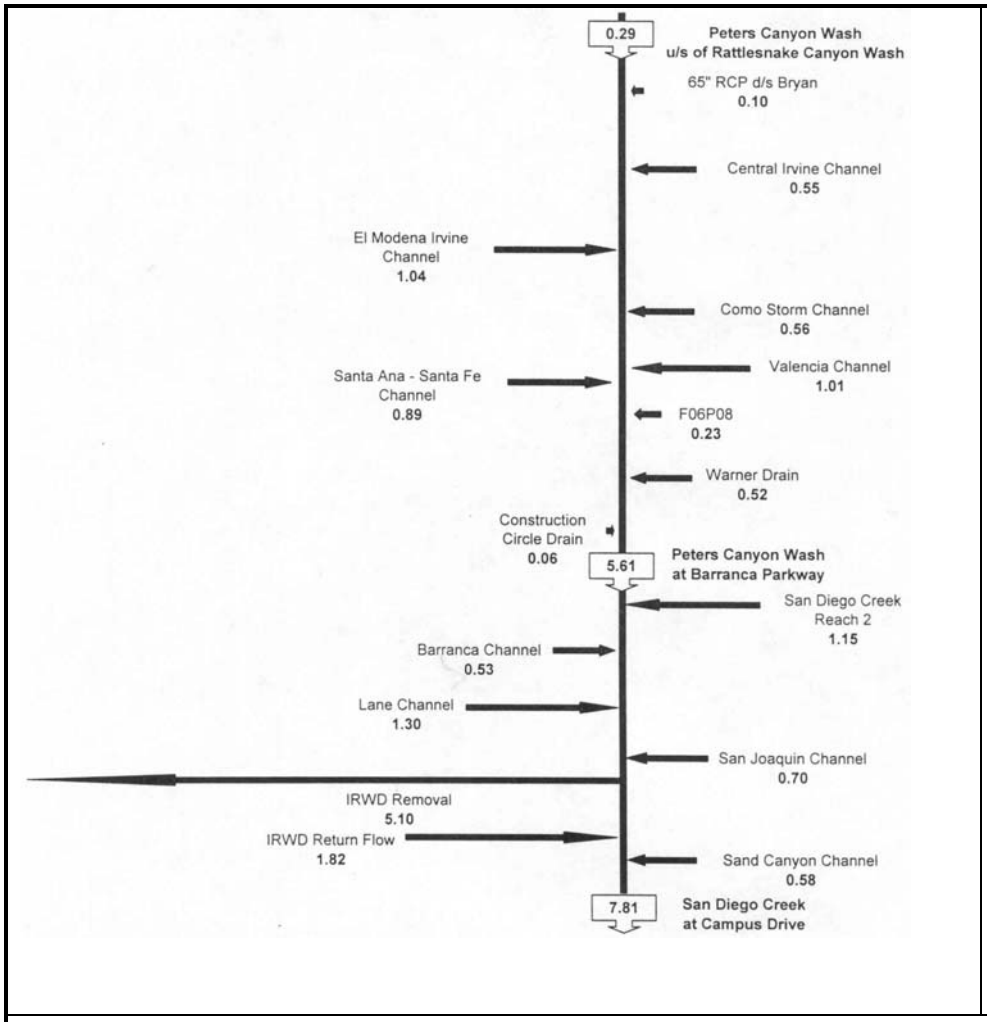


Figure D-4. Selenium concentrations in groundwater (µg/L). Sample points include water wells, weepholes, and springs (data source: Hibbs and Lee 2000).

OCPFRD Sept.1999 Peters Canyon Wash/San Diego Creek Nutrient Study

As part of the investigation of nutrient sources in the San Diego Creek watershed, OCPFRD conducted a one-week program of measurements of flow rate in tributaries of Peters Canyon Wash and reaches 1 and 2 of San Diego Creek in September 1999. The flow information allows estimation of groundwater flow inputs to surface channels at the watershed scale. Results show that the net increase in flow at Barranca Parkway in Peters Canyon Wash was approximately 0.36 cfs in the reach studied. Increases in San Diego Creek were 1.32 and 0.79 cfs for reach 1 and reach 2, respectively. These net flow increases, calculated by subtracting measured creek flow from its tributary flows, are believed to be contributions from groundwater via seepage and weepholes. The net flow increases a total of 2.47 cfs, which represents a significant portion of the Creek at Campus Drive. It should be noted that the overall contribution of groundwater to surface flow is expected to be larger since inputs of groundwater to the tributaries (*e.g.*, Como and Santa Fe Channels, Table D-6, Appendix B) are not included in the calculation.



Q increase
(cfs)

0.36 (PCW)

0.79 (SDC R2)

1.32 (SDC R1)

Figure D-5. Average daily flow rates (cfs) in tributaries to Peters Canyon Wash and Reaches 1 and 2 of San Diego Creek, September 12-20, 1999 (data: OCPFRD 2000).

Aquatic Toxicity Study (Lee & Taylor 2001a)
As part of the 319(h)study, Lee and Taylor (2001a) investigated sources of acute toxicity in the San Diego Creek watershed. Samples were collected on four days in 2000 – 01/25, 02/12, 02/21, and 05/31. The sampling in January and February occurred during storm events and the January sampling represents a "first-flush" event, according to flow records. The May sampling provides information under base flow conditions. Chemical analysis allows differentiation of dissolved and particulate selenium. Sampling stations and selenium concentrations are summarized in Table D-5, Appendix B. The results suggest that water-borne selenium mostly existed in dissolved forms under low flow conditions. Particulate fractions (*i.e.*, total minus dissolved) of selenium during rain events fall in a wider range than those found in dry weather (5/31/00 samples). Consistent with other monitoring data, the measured concentrations exceed the numeric target at most of the locations.

There was only one sample collected on January 25, 2000 and the total selenium concentration was 15.6 µg/L at Campus Drive. Total selenium concentrations for the rest of the sampling days are shown in Figures D-6 – D-8. These figures show spatial distributions of selenium concentrations in the watershed and allow comparisons of loading from different tributaries. Table D-1 lists estimated loads at four locations in the watershed. Several observations concerning selenium sources are summarized below:

- During rain events, high concentrations were found at Hines Channel and Sand Canyon Channel during storms (Figures D-6 and D-7), suggesting that selenium sources exist upstream of the sampling locations when rain events occur. These sources may include runoff from hillside, open fields, agricultural lands, and nurseries. The high concentrations were diluted downstream as flows increased.

- The dry weather sample collected in May (Figure D-8) from Hines Channel shows a low concentration, which is consistent with the findings in Hibbs' study. This suggests that contributions from nursery channels to the watershed are small under base flow conditions.

- The estimated loads indicate that San Diego Creek contributes a substantially higher selenium load to the Bay than Santa Ana-Delhi channel. Of the load at Campus Drive, Peters Canyon Wash is the biggest contributor of selenium in the San Diego Creek watershed in dry weather. As noted in section III of this TSD, the contribution is attributable to inputs of groundwater to Peters Canyon Wash.

- Selenium loads at Barranca Parkway in Peters Canyon Wash did not change considerably between base flow conditions and rain events. The drainage area consists of mostly urban land uses, suggesting that urban selenium loads are not significant.

- Loading at Harvard Avenue in San Diego Creek increases substantially during rain events compared to that in base flow conditions. Estimated loads (Table D-1) are comparable to those from Peters Canyon Wash. The drainage area for Harvard Avenue in SDC covers more open space than that in Peters Canyon Wash drainage area (see Figure A-2, TSD Part A, for land uses). The seasonal variation in loading suggests that open space runoff is a potential source of selenium during rain events.

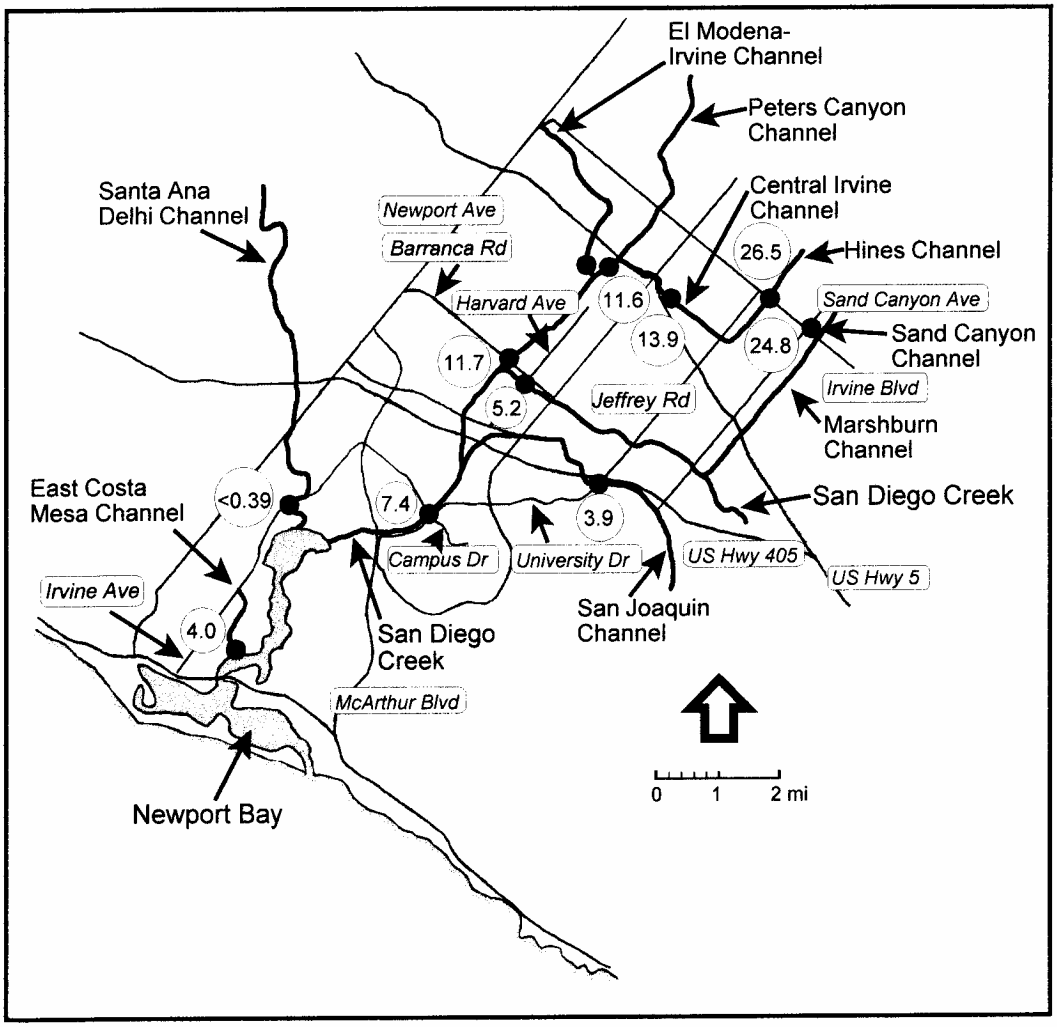
`

Table D-1. Calculated selenium loads from major tributaries in Newport Bay/San Diego Creek watershed

	SDC[a] @ Campus	**SDC @ Harvard**	**PCC[b] @ Barranca**	**Santa Ana-Delhi**
2/12/00				
Conc. (µg / L)	7.4	5.2	11.7	<0.39
Flow[c] (cfs)	96.5	49.9	30.8	23.7
Load (lbs/day)	**3.86**	**1.40**	**1.95**	**<0.05**
2/21/00				
Conc. (µg / L)	5.4	5.4	8.2	3.4
Flow[c] (cfs)	96.5	49.9	30.8	23.7
Load (lbs/day)	**2.81**	**1.45**	**1.36**	**0.44**
5/31/00				
Conc. (µg / L)	22.1	10.1	31	11.9
Flow[c] (cfs)	14.6	3.62	8.21	3.29
Load (lbs/day)	**1.74**	**0.20**	**1.37**	**0.21**

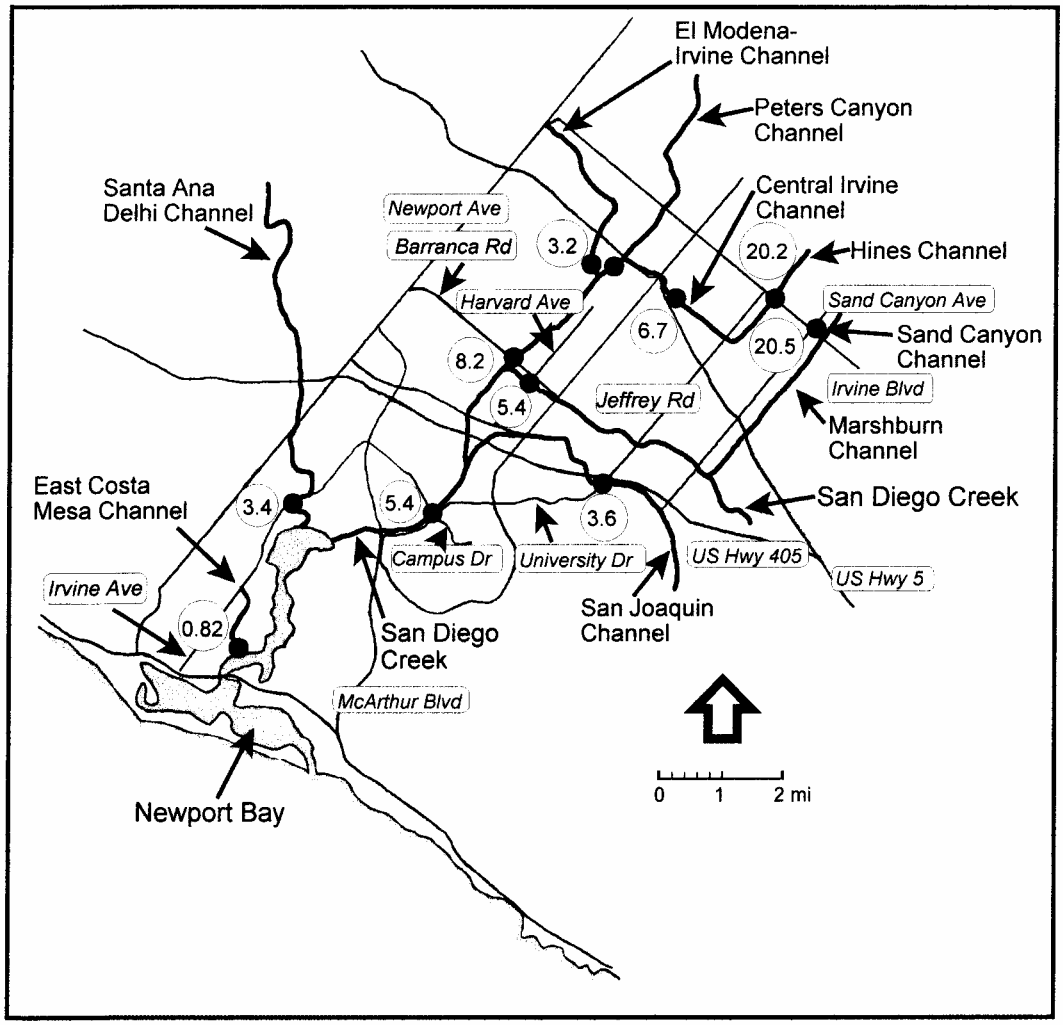
[a]San Diego Creek, [b]Peters Canyon Wash, [c]Monthly average flow rate

(Conc. * Flow * conversion factor = lbs / day or µg / L * ft^3 / sec * 0.0054 = lbs / day)



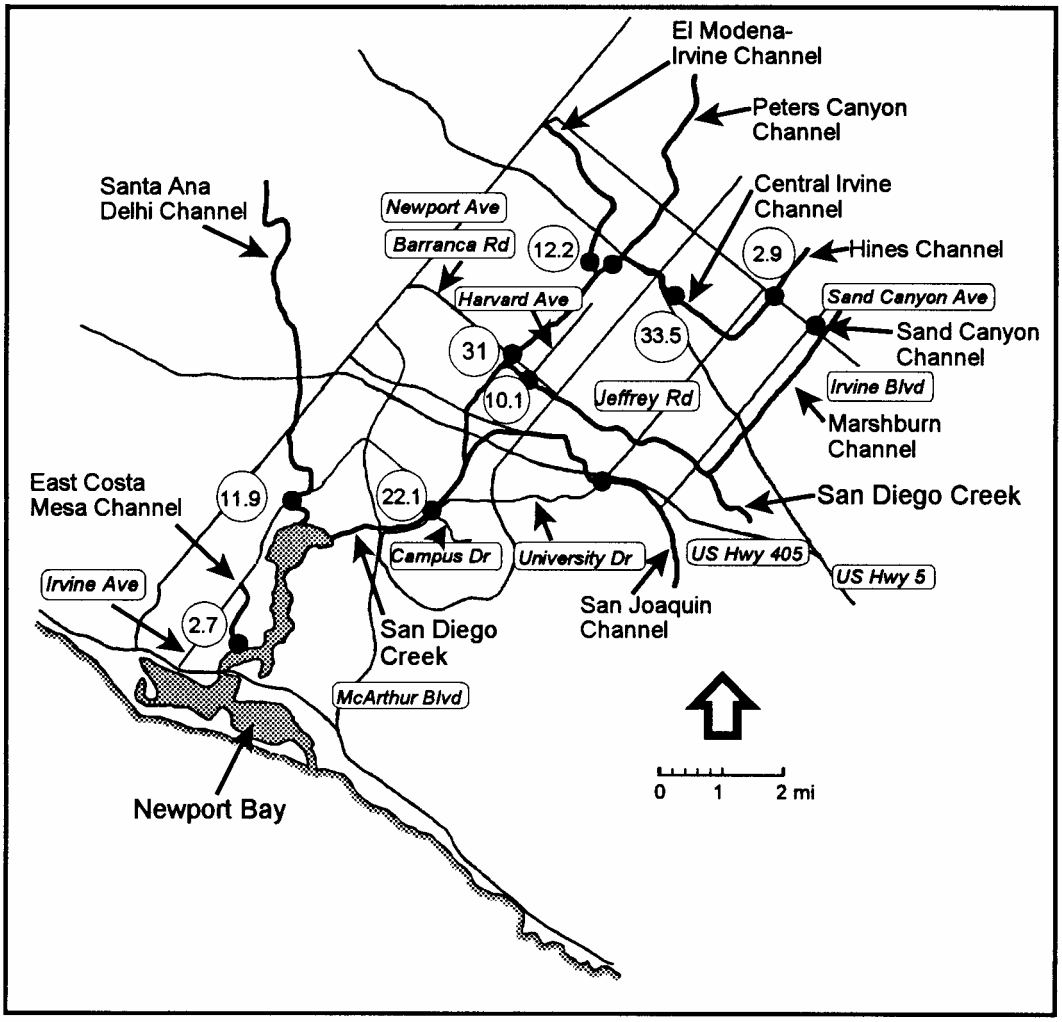
Total Selenium Concentrations (µg/L)
February 12, 2000
(Wet Weather Sampling)

Figure D-6. Spatial distribution of total selenium concentrations during a storm on February 12, 2000 (from Lee and Taylor 2001a).



Total Selenium Concentrations (µg/L)
February 21, 2000
(Wet Weather Sampling)

Figure D-7. Spatial distribution of total selenium concentrations during a storm on February 21, 2000 (from Lee and Taylor 2001a).



Total Selenium Concentrations (µg/L)
May 31, 2000
(Dry Weather Sampling)

Figure D-8. Spatial distribution of total selenium concentrations on May 31, 2000 (from Lee and Taylor 2001a)

Residential Runoff Reduction (R3) Study

The R3 study was initiated in 2000 by a multi-agency workgroup to reduce the impact of urban residential runoff and conserve domestic and reclaimed water resources. The workgroup includes the Southern California Coastal Water Research Project (SCCWRP), the Municipal Water District of Orange County (MWDOC), National Water Research Institute (NWRI), Department of Pesticide Regulations (DPR), the Irvine Ranch Water District (IRWD), and Santa Ana Regional Water Quality Control Board (SARWQCB). The study identified five isolated residential communities to allow investigation of pollutant loading strictly from residential areas. As a part of the baseline monitoring, selenium concentrations in the runoff samples collected from 11/28/00 to 7/3/01 were measured. Results show that all samples were below detection limits of the analytical methods used (1.5 µg/L and 5 µg/L). This suggests that urban runoff is not a significant source for selenium.

Background concentrations

Studies are currently in progress to more accurately assess the extent of selenium levels in various sources in the watershed. No monitoring data are available to determine the extent of selenium sources within the Bay. This might be attributed to very low selenium concentrations in seawater. On the global scale, average seawater dissolved selenium concentrations are 0.03 µg/L and 0.095 µg/L in the surface mixed layer of oceans and in deep oceans, respectively (Nriagu, 1989). In Northern California, dissolved selenium was reported to be 0.1 µg/L at Golden Gate in San Francisco Bay (San Francisco Estuary Institute 1997). These reported levels of selenium fall below the chronic seawater numeric target value (71 µg/L). Therefore, selenium input from seawater is not expected to be significant.

Atmospheric Deposition

Deposition of selenium from the atmosphere is a part of the global cycling of selenium and it represents a source to the watershed. The physical constituents of atmospheric selenium are the particle phases, predominantly less than 1 µm in diameter (Duce *et al.* 1976), and gaseous forms (Mosher and Duce 1983). Gaseous atmospheric selenium can bond to particulate material for long-range transport. Deposition of selenium from the atmosphere to the global surface occurs in both wet and dry forms. Dry deposition accounts for the exchange of particulate and gaseous material between the atmosphere and the global surface. It is usually insignificant compared to wet deposition. Wet deposition refers to rainout and washout of all forms of atmospheric selenium. It is the most important removal mechanism for selenium from the atmosphere to the earth surface. Reported rain concentrations in urban areas are in the range of 0.1 to 0.4 µg/L (Mosher and Duce 1989). Selenium load due to rainfall is then estimated to be 1.43 lbs/year to the Bay (1,363.6 acres, open water area) assuming rainfall concentration of 0.4 µg/L and annual rainfall of 11.6 in (historical average at Newport Beach Harbor Master station, OCPFRD). Therefore, atmospheric deposition is insignificant compared to the load at Campus Drive in San Diego Creek.

Summary of source analysis

In summary, existing data are limited for a thorough study and investigation of the sources and impacts of selenium to Newport Bay/San Diego Creek watershed. The data available allow preliminary assessment of the problem. Conclusions of the analysis in this report are summarized as follows:

- IRWD monitoring data provide analysis of the relationship between concentration, load, and flow rates. The monthly monitoring data at Campus Drive shows no apparent trend between concentration and flow rate. Daily load increases with flow rate and seems to reach a plateau at high flow rates during large storms. However, there were only two data points greater than 100 cfs and they are not sufficient to determine a trend at the high end of the flow spectrum. Statistical analysis of the data estimates that the annual selenium load was 2,443 lbs. from 4/1/98 to 3/31/99.

- Hibbs and Lee's study (2000) provides convincing evidence that shallow groundwater is a significant source of selenium to surface waters in the San Diego Creek watershed. Flow increases in three drainage channels selected were attributable to contributions from groundwater. (See Table D-5 in Appendix B of this TSD.) Measurements of selenium concentrations were found to be substantially higher downstream in these channels than upstream as a result of groundwater inputs. Surface channels associated with high selenium concentrations coincide with areas where high groundwater water concentrations of selenium were found, namely, the general area of Peters Canyon Wash and its tributaries. High selenium concentrations are also found in deeper groundwater in the watershed (IRWD, comment letter, May 2002). This suggests that groundwater cleanup and dewatering operations could be significant sources of selenium to the watershed.

- The OCPFRD investigation of nutrient sources reveals the magnitude of groundwater flow input to surface water. Three major reaches (Peters Canyon Wash, both reaches of San Diego Creek) all contain significant amounts of groundwater in the channel flows.

- The 319(h) study for identifying toxicity source in San Diego Creek watershed (Lee and Taylor 2001a) provides spatial distributions of selenium concentrations in the watershed. San Diego Creek contributes the largest load of selenium to Newport Bay. Of the load from San Diego Creek, Peters Canyon Wash, which collects selenium from selenium-laden shallow groundwater, represents the major source. Nursery channels showed low concentrations during base flow conditions. However, high concentrations were found in the channels during rain events (large flows), suggesting sources existing upstream of the channels. These sources may include runoff from hillsides, open spaces, agricultural lands, and commercial nursery sites. Further studies are needed to identify the sources. During rain events, the selenium load from San Diego Creek-Reach 2 was comparable to that from Peters Canyon Wash, suggesting runoff from open space is a potential source during rain events.

- Atmospheric deposition of selenium is not significant compared to loading from San Diego Creek and other tributaries. Natural selenium concentrations in seawater are unlikely to cause ecological impacts.

Figure D-9 shows sources of selenium in the watershed. The significance of these sources varies, in part depending on the location of discharges and the season of the year (see discussion in Section III, Source Analysis). In general, groundwater seepage/infiltration represents a significant and constant source. Runoff from open space, hillsides, and agricultural lands could be significant sources during rain events. Nursery runoff contains relatively low concentrations of selenium (< 7 µg/L) in dry weather yet are potential sources during storms.

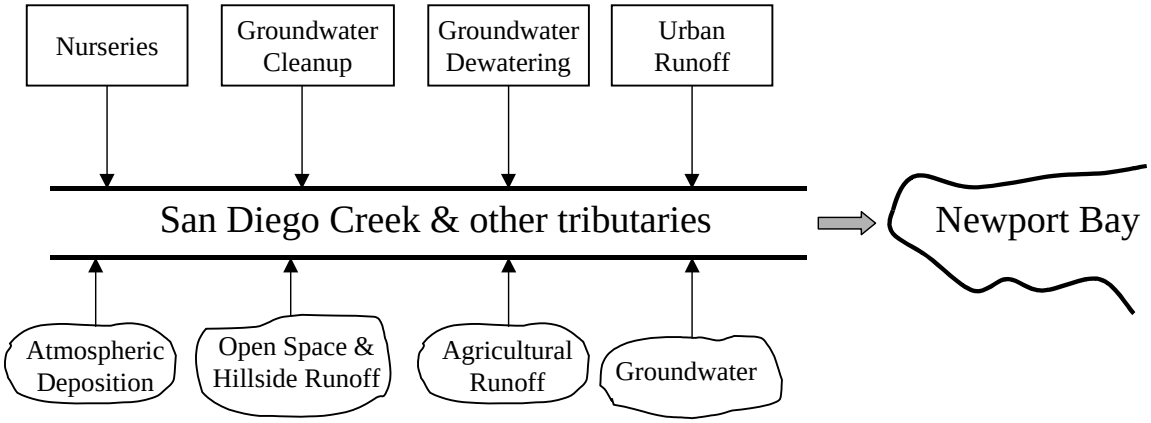


Figure D-9. Sources of selenium in the Newport Bay/San Diego Creek watershed. Sources in boxes are point sources, others are non-point sources.

IV. Approach to Calculating Loads

In southern California, a Mediterranean climate prevails, with dry summer and wet winter seasons. As a result, water bodies typically experience distinctly different seasonal flows and pollutants loads. In the dry season, surface channels in the watershed are mostly at their base flow conditions except those days when rain events take place. In the wet season, rain events occur more frequently than in the dry season. Contributions of selenium from different sources vary under different flow conditions, resulting in variations in water quality (see Section III, Source Analysis). For this reason, flow-based load allocations are developed to achieve the calculated TMDL. Specifically, the annual flow spectrum at Campus Drive in SDC is divided into four flow tiers and loading capacities for each flow tier are allocated to identified pollutant sources. The breakpoints of the flow tiers are based on a statistical analysis of flow records in San Diego Creek at Campus Drive (see TSD—Part B for freshwater flow analysis).

Computation Methodology

The following is the step-by-step procedure used in estimating the current annual and seasonal selenium loads to Newport Bay. Step *a* defines the dry and wet seasons.

a. Use IRWD monthly data for selenium concentrations at Campus Drive in San Diego Creek. The one-year window, 4/1/98 – 3/31/99, is selected for estimating annual load. **Selenium load from 4/1/98 to 9/30/98 is termed dry season load and the remainder (10/1/98 – 3/31/99) is wet season load**. Annual load is then the combination of the dry season and wet season loads.

b. Use OCPFRD daily flow record for the same time period of analysis as in step *a*.

c. Take natural log of the concentration data from step *a*.

d. Calculate means (μ) and variances (s^2) of the natural logs obtained from step *c*.

e. Use the following formula to calculate expected values *ev* (also known as mean of the concentrations) for dry and wet seasons.

$$ev = e^{\left(\mu + \frac{s^2}{2}\right)}$$

Calculate upper and lower confidence limits, x_{hi} and x_{lo} from μ, s, and standardized normal deviate, z.

$$x_{hi} = e^{(\mu + zs)}, \qquad x_{lo} = e^{(\mu - zs)}$$

The value of z corresponds to a given probability of exceedence, which can be converted to a confidence level. For a confidence level of 90%, the z value corresponding to 0.90 is 1.28 (obtained from a standard normal distribution table).

f. Calculate expected selenium loads by multiplying the expected values (mean of concentrations) from step *e* by flow volumes from step *b* for both dry and wet seasons. Expected selenium loads are converted to pounds (lbs) using conversion factor 1 µg/L*cfs = 0.0054 lbs/day.

g. Repeat step *g* to obtain 90% confidence limits for expected selenium loads for dry and wet seasons by substituting the expected values with the confidence limits from step *f*.

Table D-2. IRWD monthly monitoring data and calculated daily load based on OCPFRD flow records from April 1998 to March 1999.

Date	Flow (cfs)	Se Conc. (ug/L)	Daily Load (lbs/day)
04/16/98	20	64.57	6.97
05/21/98	18	23.68	2.30
06/16/98	24	38.12	4.94
07/07/98	9.5	40.49	2.08
08/12/98	16	33.82	2.92
09/01/98	14	30.72	2.32
10/27/98	13	43.74	3.07
11/18/98	7.7	49.61	2.06
12/15/98	3.8	36.87	0.76
01/07/99	15	36.97	2.99
02/23/99	15	42.59	3.45
03/30/99	9.4	52.91	2.69

1 µg/L*cfs = 0.0054 lbs/day.
Complete set of daily flow records for this time period are shown in Appendix A.
Samples for selenium analysis were only collected during base flow and small storm events; therefore, the calculated daily selenium loads do not reflect selenium loading during medium and large storm flows.

Table D-3. Calculations of seasonal and annual loads of selenium using IRWD monitoring data and OCPFRD flow records from April 1998 to March 1999.

Date	Conc. (ug/L)	Nat. log(conc.)		Dry 4/1/98-9/30/98	Wet 10/1/98-3/31/99	Total 4/1/98-3/31/99
04/16/98	64.57	4.17	Mean	3.60	3.77	
05/21/98	23.68	3.16	Variance, s^2	0.11	0.02	
06/16/98	38.12	3.64	s	0.33	0.15	
07/07/98	40.49	3.70	ev	38.84	43.86	
08/12/98	33.82	3.52	Total flow (cfs)	5704.5	5264.1	
09/01/98	30.72	3.42	**Total Load (lbs)**	**1196.40**	**1246.79**	**2443.18**
10/27/98	43.74	3.78				
11/18/98	49.61	3.90	x_{hi} (90%)	56.37	52.44	
12/15/98	36.87	3.61	x_{lo} (90%)	23.92	35.88	
01/07/99	36.97	3.61	Load for x_{hi} (lbs)	1736.46	1490.80	3227.26
02/23/99	42.59	3.75	Load for x_{lo} (lbs)	736.88	1020.05	1756.93
03/30/99	52.91	3.97				

s = Standard Deviation
ev = Expected Value
x_{hi} = Upper Confidence Limit
x_{lo} = Lower Confidence Limit

Table D-4. Waste Load and Load Allocation Calculations for San Diego Creek Watershed.
(This table provides additional information regarding the allocations defined in Table 4.5 of the summary document.)

Source	4/98-3/99 Loading (lbs/year)	Allocations (lbs/year)					% ALLOCATION†† (for individual line items in box to left)			
		Tier 1	Tier 2	Tier 3	Tier 4	Annual Total	Tier 1	Tier 2	Tier 3	Tier 4
Wasteload Allocations (WLA)										
MCAS - Tustin		1.55	1.95	1.76	7.90	**13.16**	2.0%	2.0%	1.8%	1.5%
GW Cleanup		6.19	7.81	7.54	36.88	**58.4**	8.0%	8.0%	7.5%	7.0%
Silverado GTF		3.09	3.91	4.02	21.07	**32.1**	4.0%	4.0%	4.0%	4.0%
GW Dewatering		3.87	4.88	4.52	21.07	**34.3**	5.0%	5.0%	4.5%	4.0%
other GW facilities		0.39	0.49	0.50	2.63	**4.0**	0.5%	0.5%	0.5%	0.5%
Stormwater permit (MS4)		0.39	0.98	1.00	5.27	**7.6**	0.5%	1.0%	1.0%	1.0%
WLA Sub-total		15.47	20.01	19.34	94.83	**149.66**				
Load Allocations (LA)										
Hines Nursery		1.1	1.4	1.5	7.8	**11.9**	4.0%	4.0%	4.0%	4.0%
Bordiers Nursery		0.6	0.7	0.7	3.9	**5.9**	4.0%	4.0%	4.0%	4.0%
El Modeno Gardens		0.2	0.3	0.3	1.6	**2.5**	4.0%	4.0%	4.0%	4.0%
Nakase Nursery		0.4	0.4	0.5	2.4	**3.7**	4.0%	4.0%	4.0%	4.0%
AKI		0.1	0.1	0.1	0.5	**0.8**	4.0%	4.0%	4.0%	4.0%
Unpermitted nurseries		0.7	0.9	0.9	4.9	**7.4**	4.0%	4.0%	4.0%	4.0%
Nursery Sub-total		3.1	3.9	4.0	21.1	**32.1**				
Agriculture Runoff		5.4	7.3	8.0	44.8	**65.6**	7.0%	7.5%	8.0%	8.5%
Undefined Sources[1]		53.4	66.4	69.1	366.2	**555.0**	69.0%	68.0%	68.8%	69.5%
LA Sub-total		61.9	77.6	81.1	432.0	**652.6**				
Total allocations[2]	**2443[3]**	**77.4**	**97.6**	**100.5**	**526.8**	**802.3**				

Cutoff flow	Load %†
0 (cfs)	5 & 20¥ (µg / L)
20	9.6%
181	12.2%
814	12.5%
> 814	65.7%

¥The NTR acute criterion of 20 ug / L is only applied to large flows (>814 cfs) with an average annual duration of 3 days.

[1] Undefined Sources: Open space and hillside runoff, shallow GW, in-bay selenium. Atmospheric deposition has NOT been included as data indicates that this contribution is negligible.
[2] The flow tier total allocations are based on percentages shown in upper right hand corner (see †). Individual allocations per tier are further calculated using values in %allocations columns (see ††).

89.145 MOS

891.45 TMDL

V. References

Davis EA, Maier KJ, and Knight, A. 1988. The biological consequences of selenium in aquatic ecosystems. Calif. Agric. 1: 18-20. (Cited from Masscheleyn and Patrick, Jr. 1993).

Dobbs M.G., Cherry DS, and Cairns Jr., J. 1996. Toxicity and bioaccumulation of selenium to a three-tropic level food chain. Environ. Toxicol. Chem. 15: 340-347.

Duce RA, *et al*. 1976. *Geophys. Res. Lett.*, vol. 3, pp. 339.

Fan, T and Cutter G. 1998. Comments *in* Report on the Peer Consultation Workshop on Selenium Aquatic Toxicity and Bioaccumulation. United States Environmental Protection Agency (USEPA) sponsored workshop held in September 1998 in Washington, DC.

Fowler SW, Benayoun G. 1976. Influence of Environmental Factors on Selenium Flux in Two Marine Invertebrates, *Mar. Biol*., 37:59.

Hibbs BJ, California State University, Los Angeles, June 10, 2002, personal communication.

Hibbs BJ, Lee MM. 2000. Sources of Selenium in the San Diego Creek Watershed, a report submitted to Defend the Bay and California Urban Environmental Research & Education Center.

Irvine Ranch Water District (IRWD) May 28, 2002. Comments on the Draft Toxics TMDL for Newport Bay and Its Watershed. Letter to USEPA Region 9.

Lee FG, Taylor S. 2001. Results of Aquatic Toxicity Testing Conducted During 1999-2000 in the Upper Newport Bay Watershed, EPA CWA 319H grant report.

Lemly AD, U.S. Forest Service, June 10, 2002, personal communication.

Lemly AD 1993. Guidelines for Evaluating Selenium Data from Aquatic Monitoring and Assessment Studies, *Environmental Monitoring and Assessment*, 28:83-100.

Luoma SN, *et al*. 1992. Determination of Selenium Bioavailability to a Benthic Bivalve from Particulate and Solute Pathways, *Environ. Sci. Technol.*, 26:485-491.

Luoma SN, Presser TS. 2000. Forecasting Selenium Discharges to the San Francisco Bay-Delta Estuary: Ecological Effects of a Proposed San Luis Drain Extension, USGS report 00-416.

Maider KJ, *et al.* 1993. Comparative Toxicity of Selenate, Selenite, Seleno-DL-methionine, and Seleno-DL-cysteine to *Daphia Magna*: *Environmental Toxicology and Chemistry*, 12:755-763.

Mosher BW, Duce RA. 1989. The Atmosphere, in *Occurrence and Distribution of Selenium*, Ed. by Milan Ihnat, CRC Press, Inc. Florida, 309 pp.

Mosher BW, Duce RA. 1983. *J. Geophys. Res.*, 88:6761.

Nagpal N K, Howell, K. 2001. Water Quality Guidelines for Selenium – Technical Appendix. National Library of Canada Cataloguing in Publication Data.

Nriagu JO. 1989. Global Cycling of Selenium, in *Occurrence and Distribution of Selenium*, Ed. by Milan Ihnat, CRC Press, Inc. Florida, 327-340 pp.

Orange County Public Facilities and Resources Department (OCPFRD). 2000. September 1999 Peters Canyon Wash / San Diego Creek Nutrient Study.

Presser TS. 1994. Geologic Origin and Pathways of Selenium from the California Coast Ranges to the West-Central San Joaquin Valley, in *Selenium in the Environment*, Ed. by W. T. Frankenberger Jr. and Sally Benson, Marcel Dekker, Inc. New York, 139-155 pp.

Presser TS and Ohlendorf HM. 1987. Biogeochemical cycling of selenium in the San Joaquin Valley, California, USA, in *Environmental Management*, 11, pp. 805-821.

Richter JE. 1982. Center for Lake Superior Environmental Studies, University of Wisconsin-Superior, Superior, WI. (Memorandum to C.E. Stephan, USEPA, Duluth, MN. June 30.) (Cited from USEPA 1987).

San Francisco Estuary Institute. 1997. Annual Report of Regional Monitoring Program for Trace Substances, Richmond, CA.

Seiler RL, *et al.* 1999. Areas Susceptible to Irrigation-Induced Selenium Contamination of Water and Biota in the Western United States: US Geological Survey Circular 1180, 36 pp.

Skorupa JP. 1998. Selenium Poisoning of Fish and Wildlife in Nature: Lessons from Twelve Real-World Examples, in *Environmental Chemistry of Selenium*, Ed. by W. T. Frankenberger Jr. and R. A. Enberg, Marcel Dekker, Inc.

Wang W-X, *et al*. 1996. Kinetic Determinations of Trace Element Bioaccumulation in the Mussel *Mytilus edulis*: *Marine Ecology: Progress Series*, 140:91-113.

Wilber CG. 1980. Toxicology of Selenium: A Review, *Clin. Toxicol*., 17:171.

Appendix A — Daily flow records for San Diego Creek at Campus Dr. (OCPFRD data, March 1998 to April 1999) used for calculating current selenium load estimates in Table D-2

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
03/01/98	88	04/20/98	22	06/09/98	20	07/29/98	18
03/02/98	75	04/21/98	22	06/10/98	19	07/30/98	15
03/03/98	80	04/22/98	22	06/11/98	32	07/31/98	16
03/04/98	65	04/23/98	22	06/12/98	45	08/01/98	15
03/05/98	37	04/24/98	22	06/13/98	21	08/02/98	15
03/06/98	38.5	04/25/98	22	06/14/98	18	08/03/98	14
03/07/98	40	04/26/98	21.5	06/15/98	17	08/04/98	15
03/08/98	34	04/27/98	21	06/16/98	19	08/05/98	14
03/09/98	33	04/28/98	21	06/17/98	21	08/06/98	15
03/10/98	31	04/29/98	22	06/18/98	19	08/07/98	16
03/11/98	31.5	04/30/98	23	06/19/98	18	08/08/98	16
03/12/98	32	05/01/98	20	06/20/98	19	08/09/98	16
03/13/98	114	05/02/98	21	06/21/98	15.5	08/10/98	15
03/14/98	465	05/03/98	21	06/22/98	12	08/11/98	15
03/15/98	42	05/04/98	24	06/23/98	16	08/12/98	16
03/16/98	39.5	05/05/98	484	06/24/98	13	08/13/98	15
03/17/98	37	05/06/98	255	06/25/98	13	08/14/98	16
03/18/98	33	05/07/98	26	06/26/98	13.5	08/15/98	14
03/19/98	31	05/08/98	26	06/27/98	14	08/16/98	13
03/20/98	32	05/09/98	19	06/28/98	13	08/17/98	14
03/21/98	31.5	05/10/98	17	06/29/98	14	08/18/98	13
03/22/98	31	05/11/98	233.5	06/30/98	12	08/19/98	14
03/23/98	26	05/12/98	450	07/01/98	12	08/20/98	12
03/24/98	24	05/13/98	678	07/02/98	9.4	08/21/98	15
03/25/98	1110	05/14/98	46	07/03/98	9.7	08/22/98	15
03/26/98	582.5	05/15/98	30	07/04/98	10	08/23/98	14
03/27/98	55	05/16/98	24.5	07/05/98	9.5	08/24/98	13
03/28/98	322	05/17/98	19	07/06/98	11	08/25/98	13
03/29/98	60	05/18/98	17	07/07/98	9.5	08/26/98	16
03/30/98	41	05/19/98	17	07/08/98	7.8	08/27/98	15
03/31/98	475	05/20/98	18	07/09/98	9.6	08/28/98	16
04/01/98	373	05/21/98	17.5	07/10/98	14	08/29/98	11
04/02/98	75	05/22/98	17	07/11/98	11	08/30/98	11
04/03/98	40	05/23/98	18	07/12/98	10	08/31/98	11
04/04/98	40	05/24/98	18	07/13/98	10	09/01/98	14
04/05/98	35	05/25/98	17	07/14/98	11	09/02/98	16
04/06/98	35.5	05/26/98	18	07/15/98	9.4	09/03/98	18
04/07/98	36	05/27/98	19	07/16/98	9.6	09/04/98	28
04/08/98	55	05/28/98	18	07/17/98	11	09/05/98	17
04/09/98	54	05/29/98	22	07/18/98	11	09/06/98	11
04/10/98	30	05/30/98	20	07/19/98	10	09/07/98	11
04/11/98	57.5	05/31/98	21	07/20/98	11	09/08/98	11
04/12/98	85	06/01/98	22	07/21/98	12	09/09/98	12
04/13/98	31	06/02/98	21	07/22/98	15	09/10/98	12
04/14/98	26	06/03/98	22	07/23/98	13	09/11/98	13
04/15/98	24	06/04/98	20	07/24/98	16	09/12/98	13
04/16/98	31.5	06/05/98	20	07/25/98	17	09/13/98	14
04/17/98	19	06/06/98	20.5	07/26/98	16	09/14/98	14
04/18/98	21	06/07/98	21	07/27/98	14	09/15/98	14
04/19/98	20	06/08/98	20	07/28/98	16	09/16/98	14

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
09/17/98	15	11/06/98	17	12/26/98	4.4	02/14/99	15
09/18/98	18	11/07/98	15	12/27/98	4.3	02/15/99	16
09/19/98	18	11/08/98	452	12/28/98	4.5	02/16/99	16
09/20/98	17	11/09/98	11	12/29/98	4.3	02/17/99	16
09/21/98	17	11/10/98	7.8	12/30/98	9.7	02/18/99	16
09/22/98	19	11/11/98	8.8	12/31/98	12	02/19/99	16
09/23/98	19	11/12/98	7.7	01/01/99	12	02/20/99	16
09/24/98	19	11/13/98	7.2	01/02/99	12	02/21/99	17
09/25/98	19	11/14/98	7.3	01/03/99	15	02/22/99	15
09/26/98	18	11/15/98	7.4	01/04/99	13	02/23/99	15
09/27/98	18	11/16/98	7.7	01/05/99	13	02/24/99	16
09/28/98	18	11/17/98	7.5	01/06/99	13	02/25/99	16
09/29/98	17	11/18/98	7.7	01/07/99	15	02/26/99	16
09/30/98	20	11/19/98	7.9	01/08/99	14	02/27/99	15
10/01/98	16	11/20/98	5.5	01/09/99	13	02/28/99	14
10/02/98	15	11/21/98	3.7	01/10/99	13	03/01/99	88
10/03/98	17	11/22/98	4	01/11/99	14	03/02/99	75
10/04/98	16	11/23/98	4.1	01/12/99	14	03/03/99	80
10/05/98	15	11/24/98	4.1	01/13/99	13	03/04/99	65
10/06/98	14	11/25/98	4.1	01/14/99	14	03/05/99	37
10/07/98	15	11/26/98	4	01/15/99	14	03/06/99	38.5
10/08/98	18	11/27/98	3.9	01/16/99	13	03/07/99	40
10/09/98	16	11/28/98	237	01/17/99	13	03/08/99	34
10/10/98	18	11/29/98	7.9	01/18/99	12	03/09/99	33
10/11/98	17	11/30/98	3.9	01/19/99	11	03/10/99	31
10/12/98	16	12/01/98	348	01/20/99	44	03/11/99	31.5
10/13/98	17	12/02/98	36	01/21/99	21	03/12/99	32
10/14/98	19	12/03/98	7.4	01/22/99	15	03/13/99	114
10/15/98	19	12/04/98	20	01/23/99	13	03/14/99	465
10/16/98	17	12/05/98	71	01/24/99	12	03/15/99	42
10/17/98	17	12/06/98	211	01/25/99	284	03/16/99	39.5
10/18/98	17	12/07/98	6.1	01/26/99	361	03/17/99	37
10/19/98	16	12/08/98	4.8	01/27/99	302	03/18/99	33
10/20/98	16	12/09/98	4	01/28/99	19	03/19/99	31
10/21/98	16	12/10/98	3.7	01/29/99	16	03/20/99	32
10/22/98	15	12/11/98	3.5	01/30/99	14	03/21/99	31.5
10/23/98	16	12/12/98	3.6	01/31/99	243	03/22/99	31
10/24/98	16	12/13/98	3.5	02/01/99	21	03/23/99	26
10/25/98	24	12/14/98	3.6	02/02/99	14	03/24/99	24
10/26/98	14	12/15/98	3.8	02/03/99	13	03/25/99	1110
10/27/98	13	12/16/98	3.9	02/04/99	28	03/26/99	582.5
10/28/98	14	12/17/98	3.9	02/05/99	58	03/27/99	55
10/29/98	13	12/18/98	4.1	02/06/99	16	03/28/99	322
10/30/98	13	12/19/98	14	02/07/99	14	03/29/99	60
10/31/98	12	12/20/98	24	02/08/99	13	03/30/99	41
11/01/98	13	12/21/98	5	02/09/99	38	03/31/99	475
11/02/98	13	12/22/98	5.1	02/10/99	35		
11/03/98	13	12/23/98	6.4	02/11/99	15		
11/04/98	13	12/24/98	8.8	02/12/99	14		
11/05/98	14	12/25/98	9.1	02/13/99	15		

Appendix B—Surface Channel Selenium Data (4/15/99—5/1/00)

Table D-5. Selenium concentrations in tributaries, creeks, and drains of San Diego Creek (Hibbs and Lee 2000)

Sampling Location	Date	Conc. (ug/L)
Hicks Canyon Wash at confluence with Peters Canyon Wash	05/28/99	6
Central Irvine Channel at confluence with Peters Canyon Wash	05/28/99	11
El Modena Channel at Michelle Dr	04/15/99	<4
El Modena Channel at Michelle Dr	05/25/99	5
El Modena Channel at Michelle Dr	05/28/99	9
El Modena Channel at Michelle Dr	06/21/99	7
El Modena Chanel at confluence with Peters Canyon Wash	08/01/99	11
Como Channel at confluence with PCW	05/28/99	42
Como Channel at confluence with PCW	05/01/00	38
Santa Fe Channel at confluence with PCW	06/21/99	16
Santa Fe Channel at confluence with PCW	09/12/99	15
Santa Fe Channel at confluence with PCW	05/01/00	32
Circ. Drain at Irvine Center Dr at confluence with PCW	08/01/99	162
Circ. Drain at Irvine Center Dr at confluence with PCW	10/31/99	141
Valencia (Moffett) Drain at confluence with PCW	08/01/99	25
Valencia (Moffett) Drain at confluence with PCW	10/31/99	40
Warner Drain at confluence with Peters Canyon Wash	06/21/99	33
Warner Drain at confluence with Peters Canyon Wash	08/01/99	28
Warner Drain at confluence with Peters Canyon Wash	10/31/99	24
Circ. Drain at Barranca Pkwy at confluence with PCW	07/05/99	107
San Diego Creek at confluence with PCW	04/15/99	39
San Diego Creek at confluence with PCW	04/15/99	15
San Diego Creek at confluence with PCW	04/15/99	18
Barranca Channel at confluence with SDC	06/21/99	13
Barranca Channel at confluence with SDC	10/02/99	12
Lane Channel at confluence with SDC	07/05/99	25
Lane Channel at McCabe	10/02/99	21
Lane Channel at McCabe	11/08/99	18
San Joaquin Channel at confluence with SDC	07/05/99	11
San Joaquin Channel at confluence with SDC	10/31/99	9
Sand Canyon Wash at confluence with SDC	10/31/99	5
Bonita Canyon at confluence with SDC	07/05/99	14
Santa Ana Delhi Channel at Irvine Ave	07/05/99	18
San Diego Creek at Campus Dr	10/31/99	19

Table D-6. Selenium load from groundwater in three drainage channels based on upstream and downstream flow and selenium concentration measurements. (Hibbs and Lee 2000)

Channel	Date	Upstream		Downstream		Load from groundwater (lb/day)
		Flow (cfs)	Conc. (µg/L)	Flow (cfs)	Conc. (µg/L)	
San Diego Creek Reach 2	08/28/99	1.63	4	2.32	18	0.19
Como Channel	05/01/00	0.0004	<4	0.44	38	0.09
Santa Fe Channel	05/01/00	0.019	<4	0.46	32	0.08

Note: Daily loads of selenium from groundwater are calculated by the differences in loads between downstream and upstream.