Results of Heavy Metal Water Quality analysis Conducted During 2000 in the Upper Newport Bay Orange County, CA Watershed[1]

Including Recommended Regulatory Approaches

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Stormwater runoff water quality monitoring that the Orange County Public Facilities Resources Department (PFRD) has been conducting in the Upper Newport Bay Orange County, CA as part of its NPDES permit for managing stormwater runoff water quality impacts has reported some heavy metals present in total and dissolved forms above US EPA water quality criteria. This finding has led to the listing of Upper Newport Bay tributaries (San Diego Creek) and the Bay as Clean Water Act 303(d) "impaired," which has led to the need to develop a TMDL to control heavy metal inputs to the tributaries and the Bay.

As part of a US EPA sponsored 319(h) study of the water quality characteristics of the Upper Newport Bay tributaries samples were collected (flow permitting) for heavy metal analysis at the ten 319(h) sampling stations on January 25, 2000, February 12 and 21, 2000, and May 31, 2000. These samples were sent to Battelle Laboratories in Sequim, Washington, for low-level heavy metal analysis. This summary report presents a summary of the heavy metal water analysis conducted in the Upper Newport Bay Watershed tributaries conducted in 2000. Samples at each of the 10 locations were analyzed for total and dissolved arsenic, cadmium, chromium (total), chromium VI, copper, lead, mercury, nickel, selenium, silver and zinc. Also measurements were made in the field at the time of sampling for pH, temperature, and electrical conductivity. Further information on these studies is provided in Lee *et al*. (2001) in the 319(h) project final report.

Characteristics of Upper Newport Bay and its Watershed.

Upper Newport Bay is one of the major estuaries/inland bays in southern California. The primary tributary of Upper Newport Bay is San Diego Creek. The San Diego Creek watershed is bounded on the north by the Santiago Hills (Loma Ridge) and to the south by the San Joaquin Hills. The major portion of the basin is comprised of the Tustin Plain, a broad alluvial valley occupying the central portion of the watershed. Figure 1 presents the general features of the watershed with respect to San Diego Creek and Upper Newport Bay. The watershed has been greatly altered due to development. The Newport Bay watershed includes an area of about 154

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1 Reference as, :Lee, G. F., and Taylor, S. "Results of Heavy Metal Analysis Conducted During 2000 in the Upper Newport Bay Orange County, CA Watershed" Report of G. Fred Lee & Associates, El Macero, CA (2001). http://www.gfredlee.com/Watersheds/Heavy-metals-319h.pdf

square miles. The San Diego Creek watershed contains about 119 square miles with a mix of residential, commercial, industrial, recreational, and open space land uses. Other major tributaries of Upper Newport Bay include the Santa Ana Delhi Channel with a watershed of about 17 square miles, Big Canyon Wash with a watershed of about 2 square miles, and 16 square miles from other smaller tributaries. Table 1 summarizes the general land uses within the watershed. The central portion of the Upper Newport Bay watershed retains the most agriculture, although this area is undergoing urbanization at a rapid pace. Currently, it is estimated that less than 40 percent of the developed Upper Newport Bay watershed is impervious

Table 1
Land Use—San Diego Creek - (1990 Data)[1]

Land Use	Percent of Watershed	Area (mi^2)
Residential	15.0	17.9
Commercial	8.0	9.5
Industrial	6.3	7.5
Open space/vacant	23.1	27.5
Agriculture/ranching	10.0	11.9
Public	0.3	0.4
Recreation	0.3	0.4
Transportation and communication/utility	1.2	1.4
Roads	35.8	42.6
Sum	100	119.1

[1] Data are based on projections for ultimate buildout.
Source: OCEMA, (1990), and SRWQCB, (2000)

surface. The developed area represents about 50 percent of the total watershed area. Table 2 provides tributary drainage areas and flow rates at locations coincident or near the primary stormwater runoff sampling point (Campus Drive) described in this paper.

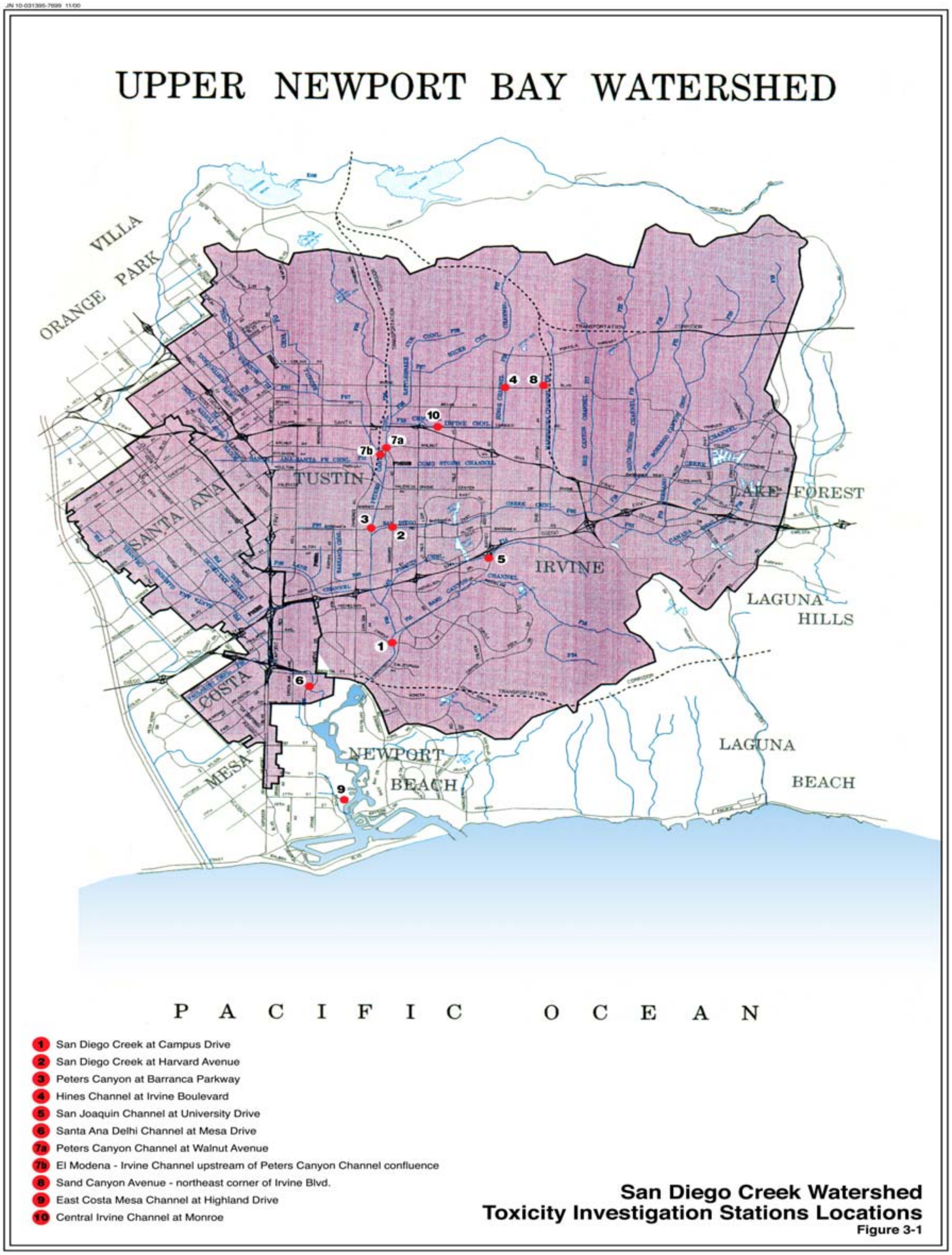
Table 2
Discharges for San Diego Creek

Location	Area (sq. mi.)	Q_{100} (cfs)	Q_2 (cfs)
Near Culver Dr.	42.9	18,050	3,700
At Jamboree Rd.	119.2	34,300	7,000

Source: Simons, Li and Asoociates (1987)

Two discharge frequency values are provided in Table 2, Q_{100} and Q_2. The value for Q_{100} represents the discharge at the point indicated for a storm with a hypothetical return period of once every 100 years. A storm of this magnitude has a 1 percent chance of occurring in any

Figure 1


UPPER NEWPORT BAY WATERSHED
VILLA
PARK
ORANGE
TUSTIN
SANTA ANA
IRVINE
LAKE FOREST
LAGUNA
HILLS
COSTA
MESA
NEWPORT
BEACH
LAGUNA
BEACH
PACIFIC OCEAN
1 San Diego Creek at Campus Drive
2 San Diego Creek at Harvard Avenue
3 Peters Canyon at Barranca Parkway
4 Hines Channel at Irvine Boulevard
5 San Joaquin Channel at University Drive
6 Santa Ana Delhi Channel at Mesa Drive
7a Peters Canyon Channel at Walnut Avenue
7b El Modena - Irvine Channel upstream of Peters Canyon Channel confluence
8 Sand Canyon Avenue - northeast corner of Irvine Blvd.
9 East Costa Mesa Channel at Highland Drive
10 Central Irvine Channel at Monroe
San Diego Creek Watershed
Toxicity Investigation Stations Locations
Figure 3-1

given year. A 100-year return frequency represents the design return period used for San Diego Creek flood control improvements.

Heavy Metal Analysis and Discussion

The results of the heavy metal analyses are presented in Table 3. The data reported in Table 3 present the concentrations of heavy metals analyzed by Battelle and allows a comparison to be made between the concentrations found in the 319(h) study samples and the US EPA (1999a) National Recommended Water Quality Criteria-Correction. These are the California Toxics Rule (CTR) criteria/objectives promulgated by the US EPA in May 2000 (US EPA, 2000a). Table 3 presents the Criterion Maximum Concentration (CMC) and the Criterion Continuous Concentration (CCC) for freshwater and salt water. In accord with US EPA current regulatory approaches, the CMC is the acute criterion that is implemented as a one-hour average. The CCC is the chronic criterion that is implemented as a four-day average. These criteria are not to be exceeded by any amount more than once every three years. An exceedance frequency greater than this would represent a violation of an ambient water quality criteria/standard/objective. For many of the constituents, the US EPA regulates the aquatic life toxicity of the heavy metal based on a dissolved form. Further, the freshwater criterion value is adjusted to reflect the impact of hardness on the toxicity of the dissolved forms of the metal to aquatic life.

Generally, stormwater runoff events in the Upper Newport Bay Watershed last for a day or two. Under these conditions, the appropriate criterion to judge excessive concentrations is the CMC rather than the CCC. The CCC should only be used to evaluate a water quality objective violation in the Upper Newport Bay Watershed and in the Bay where the four-day average concentration in the waters being sampled exceeds the CCC value.

The US EPA provides an exponential equation that can be used to determine the hardness-adjusted water quality criterion for a dissolved metal. Table 3 presents the freshwater hardness-adjusted criteria for the hardness found in the toxicity tests conducted on the same samples by University of California Davis Aquatic Toxicology Laboratory or *Aqua*Science of Davis, CA.

The US EPA (1999a) also presents criterion values for dissolved forms of heavy metals in marine waters and for some constituents that tend to bioaccumulate in aquatic life tissue or are a threat through domestic water supplies. The criterion values are designed to be protective of those who eat fish taken from the water (Human Health - Organisms Only) as well as those who consume fish taken and drink the water as a water supply (Human Health - Water + Organism).

Battelle reported total chromium and total dissolved chromium and for some samples, total chromium VI. The US EPA does not provide a water quality criterion for chromium, but does provide criteria for chromium III and chromium VI. The aqueous environmental chemistry of chromium is such that with few exceptions, the total chromium VI is dissolved chromium. Lee and Jones-Lee (1997a, 1998a,b) have reviewed the aqueous environmental chemistry of chromium. The chemistry of chromium is such that ordinarily, most of the chromium III is in a particulate form. The data reported in Table 3 assumes that the concentrations of total chromium VI and dissolved chromium VI are the same. Using this approach it is possible to compare the total chromium results to the US EPA criterion for chromium VI.

Table -3
Concentrations of Heavy Metals and Associated Water Quality Criteria
Site 1 – San Diego Creek @ Campus Drive on January 25, 2000

Parameter	Concentration (μg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (μg/L)		Saltwater (μg/L)		Human Health (μg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	8.9						
Dissolved	6.1	340	150	69	36		
Cadmium, Total	1.0						
Dissolved	0.2	23.6	7.2	42	9.3		
Chromium, Total	10.3						
Dissolved	1.8						
Chromium III, Total	N/A						
Dissolved	N/A	2080	271				
Chromium VI, Total	N/A						
Dissolved	N/A	16	11	1100	50		
Copper, Total	28.5						
Dissolved	5.5	60	34.6	4.8	3.1	1300	
Lead, Total	10.7						
Dissolved	0.35	343	13.3	210	8.1		
Mercury, Total	0.051						
Dissolved	0.006	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	16.2						
Dissolved	7.3	1784	198	74	8.2	610	4600
Selenium, Total	15.6		5.0				
Dissolved	13.4			290	71	170	11000
Silver, Total	0.023						
Dissolved	<0.004	52.3		1.9			
Zinc, Total	119						
Dissolved	23.1	447	451	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	486						

N/A means not analyzed.

Table 1 (continued)
Site 1 – San Diego Creek @ Campus Drive on February 12, 2000

Parameter	Concentration (µg/L)*	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	13.1						
Dissolved	4.1	340	150	69	36		
Cadmium, Total	2.6						
Dissolved	0.26	7.5	3.3	42	9.3		
Chromium, Total	37.5						
Dissolved	1.1						
Chromium III, Total	36.7						
Dissolved	0.29	871	113				
Chromium VI, Total	0.81						
Dissolved	0.81	16	11	1100	50		
Copper, Total	39.7						
Dissolved	2.9	22	14.0	4.8	3.1	1300	
Lead, Total	20.3						
Dissolved	0.11	113	4.4	210	8.1		
Mercury, Total	0.056						
Dissolved	0.002	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	32.1						
Dissolved	6.6	726	81	74	8.2	610	4600
Selenium, Total	7.4		5.0				
Dissolved	4.0			290	71	170	11000
Silver, Total	0.14						
Dissolved	0.2	8.4		1.9			
Zinc, Total	202						
Dissolved	6.6	182	183	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	168						

N/A means not analyzed.

Table 1 (continued)
Site 2 – San Diego Creek @ Harvard Avenue on February 12, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	17.8						
Dissolved	3.6	340	150	69	36		
Cadmium, Total	5.6						
Dissolved	0.11	5.9	2.8	42	9.3		
Chromium, Total	54						
Dissolved	0.56						
Chromium III, Total	52.7						
Dissolved	0	733	95				
Chromium VI, Total	1.3						
Dissolved	1.3	16	11	1100	50		
Copper, Total	65.8						
Dissolved	2.3	18	11.6	4.8	3.1	1300	
Lead, Total	33.8						
Dissolved	0.14	90	3.5	210	8.1		
Mercury, Total	0.11						
Dissolved	0.002	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	55.3						
Dissolved	4.6	607	67	74	8.2	610	4600
Selenium, Total	5.2		5.0				
Dissolved	1.9			290	71	170	11000
Silver, Total	0.39						
Dissolved	0.058	5.9		1.9			
Zinc, Total	350						
Dissolved	11.9	152	153	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	136						

N/A means not analyzed.

Table 1 (continued)
Site 3 – Peters Canyon Channel @ Barranca Parkway on February 12, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	12.9						
Dissolved	4.9	340	150	69	36		
Cadmium, Total	3.18						
Dissolved	0.85	9.6	3.9	42	9.3		
Chromium, Total	25.9						
Dissolved	0.18						
Chromium III, Total	25.7						
Dissolved	0	1054	137				
Chromium VI, Total	0.67						
Dissolved	0.67	16	11	1100	50		
Copper, Total	35.9						
Dissolved	3.2	27	17	4.8	3.1	1300	
Lead, Total	15.5						
Dissolved	0.16	145	5.6	210	8.1		
Mercury, Total	0.035						
Dissolved	0.002	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	26.4						
Dissolved	9.2	884	98	74	8.2	610	4600
Selenium, Total	11.7		5.0				
Dissolved	9.3			290	71	170	11000
Silver, Total	0.11						
Dissolved	<0.004	12.6		1.9			
Zinc, Total	178						
Dissolved	10.5	221	223	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	212						

N/A means not analyzed.

Table 1 (continued)
Site 4 – Hines Channel @ Irvine Boulevard on February 12, 2000

Parameter	Concentration (μg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (μg/L)		Saltwater (μg/L)		Human Health (μg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	17.9						
Dissolved	12.4	340	150	69	36		
Cadmium, Total	4.6						
Dissolved	3.2	19.9	6.4	42	9.3		
Chromium, Total	16.8						
Dissolved	1.8						
Chromium III, Total	15.9						
Dissolved	0.87	1831	238				
Chromium VI, Total	0.93						
Dissolved	0.93	16	11	1100	50		
Copper, Total	26.6						
Dissolved	7.5	51	30.3	4.8	3.1	1300	
Lead, Total	9.1						
Dissolved	0.46	292	11.4	210	8.1		
Mercury, Total	0.022						
Dissolved	0.003	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	24.4						
Dissolved	15.2	1564	174	74	8.2	610	4600
Selenium, Total	26.5		5.0				
Dissolved	20.2			290	71	170	11000
Silver, Total	0.019						
Dissolved	0.005	40.1		1.9			
Zinc, Total	105						
Dissolved	17.1	392	395	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	416						

N/A means not analyzed.

Table 1 (continued)
Site 5 – San Joaquin Channel @ Sand Canyon on February 12, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	13.2						
Dissolved	10.7	340	150	69	36		
Cadmium, Total	<0.015						
Dissolved	0.22	30.3	8.5	42	9.3		
Chromium, Total	10.6						
Dissolved	1.3						
Chromium III, Total	9.5						
Dissolved	0.2	2512	327				
Chromium VI, Total	1.1						
Dissolved	1.1	16	11	1100	50		
Copper, Total	12.8						
Dissolved	8.0	74	42.1	4.8	3.1	1300	
Lead, Total	2.2						
Dissolved	0.097	432	16.8	210	8.1		
Mercury, Total	0.014						
Dissolved	0.005	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	18.8						
Dissolved	16.8	2168	241	74	8.2	610	4600
Selenium, Total	3.94		5.0				
Dissolved	4.6			290	71	170	11000
Silver, Total	<0.004						
Dissolved	0.012	77.8		1.9			
Zinc, Total	25.4						
Dissolved	16.4	544	548	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	612						

N/A means not analyzed.

Table 1 (continued)
Site 6 – Santa Ana Delhi Channel @ Mesa Drive on February 12, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	2.6						
Dissolved	1.6	340	150	69	36		
Cadmium, Total	<0.015						
Dissolved	0.14	6.3	2.9	42	9.3		
Chromium, Total	6.53						
Dissolved	1.0						
Chromium III, Total	5.34						
Dissolved	0	768	100				
Chromium VI, Total	1.19						
Dissolved	1.19	16	11	1100	50		
Copper, Total	14.9						
Dissolved	6.6	19	12.2	4.8	3.1	1300	
Lead, Total	4.98						
Dissolved	0.90	96	3.7	210	8.1		
Mercury, Total	0.012						
Dissolved	0.0043	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	5.4						
Dissolved	5.1	637	71	74	8.2	610	4600
Selenium, Total	<0.39		5.0				
Dissolved	2.9			290	71	170	11000
Silver, Total	<0.004						
Dissolved	0.035	6.5		1.9			
Zinc, Total	60.9						
Dissolved	27.7	160	161	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	144						

N/A means not analyzed.

Table 1 (continued)
Site 7a – Peters Canyon Channel at Walnut Avenue on February 12, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	19.3						
Dissolved	7.9	340	150	69	36		
Cadmium, Total	4.6						
Dissolved	1.0	15.4	5.4	42	9.3		
Chromium, Total	36.5						
Dissolved	0.76						
Chromium III, Total	35.6						
Dissolved	0	1507	196				
Chromium VI, Total	0.94						
Dissolved	0.94	16	11	1100	50		
Copper, Total	55.0						
Dissolved	4.1	41	24.7	4.8	3.1	1300	
Lead, Total	22.7						
Dissolved	0.24	229	8.9	210	8.1		
Mercury, Total	0.053						
Dissolved	0.002	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	37.0						
Dissolved	12.6	1279	142	74	8.2	610	4600
Selenium, Total	11.6		5.0				
Dissolved	9.7			290	71	170	11000
Silver, Total	0.10						
Dissolved	0.018	26.6		1.9			
Zinc, Total	250						
Dissolved	10.8	321	323	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	328						

N/A means not analyzed.

Table 1 (continued)
Site 8 – Sand Canyon Channel @ NE Corner Irvine Boulevard on February 12, 2000

Parameter	Concentration (μg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (μg/L)		Saltwater (μg/L)		Human Health (μg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	9.3						
Dissolved	7.6	340	150	69	36		
Cadmium, Total	0.36						
Dissolved	0.51	15	5.3	42	9.3		
Chromium, Total	8.42						
Dissolved	4.2						
Chromium III, Total	7.42						
Dissolved	3.2	1477	192				
Chromium VI, Total	1.0						
Dissolved	1.0	16	11	1100	50		
Copper, Total	10.4						
Dissolved	5.2	40	24.2	4.8	3.1	1300	
Lead, Total	1.8						
Dissolved	0.96	223	8.7	210	8.1		
Mercury, Total	0.007						
Dissolved	0.003	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	15.9						
Dissolved	14.9	1253	139	74	8.2	610	4600
Selenium, Total	24.8		5.0				
Dissolved	26.9			290	71	170	11000
Silver, Total	<0.004						
Dissolved	<0.004	25.5		1.9			
Zinc, Total	40.0						
Dissolved	18.7	314	317	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	320						

N/A means not analyzed.

Table 1 (continued)
Site 9 – East Costa Mesa Channel @ Highland Avenue on February 12, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	2.9						
Dissolved	2.1	340	150	69	36		
Cadmium, Total	<0.02						
Dissolved	0.09	3.7	2.0	42	9.3		
Chromium, Total	7.8						
Dissolved	1.6						
Chromium III, Total	6.3						
Dissolved	0.1	513	67				
Chromium VI, Total	1.5						
Dissolved	1.5	16	11	1100	50		
Copper, Total	18.6						
Dissolved	14.2	12	8.0	4.8	3.1	1300	
Lead, Total	2.35						
Dissolved	0.93	56	2.2	210	8.1		
Mercury, Total	0.01						
Dissolved	0.006	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	5.1						
Dissolved	4.9	420	47	74	8.2	610	4600
Selenium, Total	4.0		5.0				
Dissolved	1.0			290	71	170	11000
Silver, Total	<0.004						
Dissolved	0.008	2.8		1.9			
Zinc, Total	91.1						
Dissolved	30.7	105	106	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	88						

N/A means not analyzed.

Table 1 (continued)
Site 10 – Irvine Central Channel at Monroe on February 12, 2000

Parameter	Concentration (μg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (μg/L)		Saltwater (μg/L)		Human Health (μg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	17.7						
Dissolved	8.2	340	150	69	36		
Cadmium, Total	4.2						
Dissolved	1.7	18.1	6.0	42	9.3		
Chromium, Total	27.2						
Dissolved	1.1						
Chromium III, Total	<26.1						
Dissolved	<0.45	1700	221				
Chromium VI, Total	<0.65						
Dissolved	<0.65	16	11	1100	50		
Copper, Total	41.2						
Dissolved	5.8	47	28	4.8	3.1	1300	
Lead, Total	16.4						
Dissolved	0.21	266	10.4	210	8.1		
Mercury, Total	0.04						
Dissolved	0.003	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	29.2						
Dissolved	13.7	1449	161	74	8.2	610	4600
Selenium, Total	13.9		5.0				
Dissolved	11.8			290	71	170	11000
Silver, Total	0.096						
Dissolved	<0.004	34.3		1.9			
Zinc, Total	189						
Dissolved	15.4	363	366	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	380						

N/A means not analyzed.

Table 1 (continued)
Site 1 – San Diego Creek @ Campus Drive on February 21, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	9.4						
Dissolved	4.2	340	150	69	36		
Cadmium, Total	2.1						
Dissolved	0.20	9.8	3.9	42	9.3		
Chromium, Total	19.2						
Dissolved	1.54						
Chromium III, Total	18.0						
Dissolved	0.34	1067	139				
Chromium VI, Total	1.2						
Dissolved	1.2	16	11	1100	50		
Copper, Total	23.1						
Dissolved	2.4	28	17.2	4.8	3.1	1300	
Lead, Total	16.9						
Dissolved	0.11	147	5.7	210	8.1		
Mercury, Total	0.028						
Dissolved	0.002	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	25.1						
Dissolved	2.8	895	99	74	8.2	610	4600
Selenium, Total	5.4		5.0				
Dissolved	3.3			290	71	170	11000
Silver, Total	0.19						
Dissolved	<0.004	12.9		1.9			
Zinc, Total	181						
Dissolved	9.6	224	226	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	215						

N/A means not analyzed.

Table 1 (continued)
Site 2 – San Diego Creek @ Harvard Avenue on February 21, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	11.9						
Dissolved	4.7	340	150	69	36		
Cadmium, Total	3.6						
Dissolved	0.14	10.4	4.1	42	9.3		
Chromium, Total	33.9						
Dissolved	1.8						
Chromium III, Total	31.0						
Dissolved	0	1115	145				
Chromium VI, Total	2.9						
Dissolved	2.9	16	11	1100	50		
Copper, Total	42.3						
Dissolved	2.4	29	18	4.8	3.1	1300	
Lead, Total	22.4						
Dissolved	0.096	156	6.1	210	8.1		
Mercury, Total	0.048						
Dissolved	0.002	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	39.7						
Dissolved	2.9	937	104	74	8.2	610	4600
Selenium, Total	5.4		5.0				
Dissolved	2.0			290	71	170	11000
Silver, Total	0.19						
Dissolved	0.02	14.1		1.9			
Zinc, Total	214						
Dissolved	4.0	235	237	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	227						

N/A means not analyzed.

Table 1 (continued)
Site 3 – Peters Canyon Channel @ Barranca Parkway on February 21, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	8.6						
Dissolved	4.9	340	150	69	36		
Cadmium, Total	2.0						
Dissolved	0.42	11.2	4.3	42	9.3		
Chromium, Total	8.0						
Dissolved	1.8						
Chromium III, Total	6.3						
Dissolved	0.1	1183	154				
Chromium VI, Total	1.7						
Dissolved	1.7	16	11	1100	50		
Copper, Total	20.3						
Dissolved	3.7	31	19.2	4.8	3.1	1300	
Lead, Total	11.7						
Dissolved	0.22	168	6.5	210	8.1		
Mercury, Total	0.021						
Dissolved	0.0025	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	15.5						
Dissolved	3.4	996	111	74	8.2	610	4600
Selenium, Total	8.2		5.0				
Dissolved	6.5			290	71	170	11000
Silver, Total	0.098						
Dissolved	0.009	16		1.9			
Zinc, Total	122						
Dissolved	9.0	250	252	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	244						

N/A means not analyzed.

Table 1 (continued)
Site 4 – Hines Channel @ Irvine Boulevard on February 21, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	14.0						
Dissolved	9.6	340	150	69	36		
Cadmium, Total	4.1						
Dissolved	1.8	17.1	5.8	42	9.3		
Chromium, Total	14.6						
Dissolved	2.2						
Chromium III, Total	13.2						
Dissolved	0.8	1627	212				
Chromium VI, Total	1.4						
Dissolved	1.4	16	11	1100	50		
Copper, Total	30.8						
Dissolved	8.1	45	26.8	4.8	3.1	1300	
Lead, Total	11.9						
Dissolved	0.16	252	9.8	210	8.1		
Mercury, Total	0.022						
Dissolved	0.003	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	30.3						
Dissolved	7.3	1384	154	74	8.2	610	4600
Selenium, Total	20.2		5.0				
Dissolved	18.4			290	71	170	11000
Silver, Total	0.090						
Dissolved	0.0097	31.2		1.9			
Zinc, Total	127						
Dissolved	10.4	347	350	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	360						

N/A means not analyzed.

Table 1 (continued)
Site 5 – San Joaquin Creek at University Drive on February 21, 2000

Parameter	Concentration (μg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (μg/L)		Saltwater (μg/L)		Human Health (μg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	11.8						
Dissolved	7.2	340	150	69	36		
Cadmium, Total	1.5						
Dissolved	0.13	17.7	5.9	42	9.3		
Chromium, Total	63.9						
Dissolved	2.5						
Chromium III, Total	62.1						
Dissolved	0.70	1671	217				
Chromium VI, Total	1.8						
Dissolved	1.8	16	11	1100	50		
Copper, Total	38.9						
Dissolved	6.3	46	27.5	4.8	3.1	1300	
Lead, Total	33.2						
Dissolved	0.13	261	10.2	210	8.1		
Mercury, Total	0.075						
Dissolved	0.003	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	42.2						
Dissolved	4.2	1423	158	74	8.2	610	4600
Selenium, Total	3.6		5.0				
Dissolved	3.4			290	71	170	11000
Silver, Total	0.21						
Dissolved	0.006	33		1.9			
Zinc, Total	204						
Dissolved	7.5	357	360	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	372						

N/A means not analyzed.

Table 1 (continued)
Site 6 – Santa Ana Delhi Channel @ Mesa Drive on February 21, 2000

Parameter	Concentration (μg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (μg/L)		Saltwater (μg/L)		Human Health (μg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	2.2						
Dissolved	1.8	340	150	69	36		
Cadmium, Total	0.51						
Dissolved	0.10	5.3	2.6	42	9.3		
Chromium, Total	0.64						
Dissolved	0.94						
Chromium III, Total	0						
Dissolved	0	675	88				
Chromium VI, Total	1.9						
Dissolved	1.9	16	11	1100	50		
Copper, Total	21.8						
Dissolved	6.3	16	10.7	4.8	3.1	1300	
Lead, Total	13.3						
Dissolved	0.95	81	3.2	210	8.1		
Mercury, Total	0.034						
Dissolved	0.007	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	5.5						
Dissolved	1.8	558	62	74	8.2	610	4600
Selenium, Total	3.4		5.0				
Dissolved	0.92			290	71	170	11000
Silver, Total	0.073						
Dissolved	0.006	4.9		1.9			
Zinc, Total	136						
Dissolved	35.9	140	141	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	123						

N/A means not analyzed.

Table 1 (continued)
Site 7b – El Modena-Irvine Channel Upstream of Peters Canyon February 21, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	4.4						
Dissolved	4.1	340	150	69	36		
Cadmium, Total	0.33						
Dissolved	0.096	6.0	2.8	42	9.3		
Chromium, Total	<0.042						
Dissolved	3.0						
Chromium III, Total	0						
Dissolved	0	742	96				
Chromium VI, Total	3.7						
Dissolved	3.7	16	11	1100	50		
Copper, Total	8.8						
Dissolved	4.7	18	11.8	4.8	3.1	1300	
Lead, Total	2.5						
Dissolved	0.16	92	3.6	210	8.1		
Mercury, Total	0.0095						
Dissolved	0.003	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	4.0						
Dissolved	2.0	615	68	74	8.2	610	4600
Selenium, Total	3.2		5.0				
Dissolved	2.6			290	71	170	11000
Silver, Total	0.028						
Dissolved	0.0036	6.0		1.9			
Zinc, Total	48.3						
Dissolved	20.9	154	155	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	138						

N/A means not analyzed.

Table 1 (continued)
Site 8 – Sand Canyon Channel @ NE Corner Irvine Boulevard on February 21, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	11.8						
Dissolved	5.8	340	150	69	36		
Cadmium, Total	3.1						
Dissolved	0.34	8.6	3.6	42	9.3		
Chromium, Total	13.5						
Dissolved	1.1						
Chromium III, Total	11.8						
Dissolved	0	968	126				
Chromium VI, Total	1.7						
Dissolved	1.7	16	11	1100	50		
Copper, Total	21.9						
Dissolved	3.8	25	15.6	4.8	3.1	1300	
Lead, Total	10.0						
Dissolved	0.15	130	5.1	210	8.1		
Mercury, Total	0.019						
Dissolved	0.0019	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	29.5						
Dissolved	4.9	810	90	74	8.2	610	4600
Selenium, Total	20.5		5.0				
Dissolved	16.5			290	71	170	11000
Silver, Total	0.099						
Dissolved	0.0023	10.5		1.9			
Zinc, Total	115						
Dissolved	5.6	203	204	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	191						

N/A means not analyzed.

Table 1 (continued)
Site 9 – East Costa Mesa Channel @ Highland Avenue on February 21, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	0.98						
Dissolved	1.5	340	150	69	36		
Cadmium, Total	0.28						
Dissolved	0.098	3.1	1.8	42	9.3		
Chromium, Total	<0.042						
Dissolved	1.1						
Chromium III, Total	0						
Dissolved	0	450	59				
Chromium VI, Total	1.5						
Dissolved	1.5	16	11	1100	50		
Copper, Total	14.0						
Dissolved	8.2	10	7.0	4.8	3.1	1300	
Lead, Total	7.3						
Dissolved	1.2	47	1.8	210	8.1		
Mercury, Total	0.011						
Dissolved	0.004	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	3.1						
Dissolved	1.6	367	41	74	8.2	610	4600
Selenium, Total	0.82		5.0				
Dissolved	0.54			290	71	170	11000
Silver, Total	0.032						
Dissolved	0.005	2.1		1.9			
Zinc, Total	65.2						
Dissolved	38.5	92	93	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	75						

N/A means not analyzed.

Table 1 (continued)
Site 10 – Central Irvine Channel at Monroe on February 21, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	8.5						
Dissolved	5.8	340	150	69	36		
Cadmium, Total	2.8						
Dissolved	1.3	15.2	5.3	42	9.3		
Chromium, Total	3.6						
Dissolved	1.6						
Chromium III, Total	2.82						
Dissolved	0.82	1492	194				
Chromium VI, Total	0.78						
Dissolved	0.78	16	11	1100	50		
Copper, Total	22.4						
Dissolved	7.4	41	24.5	4.8	3.1	1300	
Lead, Total	5.6						
Dissolved	0.16	226	8.8	210	8.1		
Mercury, Total	0.017						
Dissolved	0.003	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	16.5						
Dissolved	5.6	1266	141	74	8.2	610	4600
Selenium, Total	6.7		5.0				
Dissolved	6.1			290	71	170	11000
Silver, Total	0.065						
Dissolved	0.002	26.1		1.9			
Zinc, Total	80.6						
Dissolved	14.7	317	320	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	324						

N/A means not analyzed.

Table 1 (continued)
Site 1 – San Diego Creek @ Campus Drive on May 3, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	8.9						
Dissolved	8.4	340	150	69	36		
Cadmium, Total	0.29						
Dissolved	0.13	36.9	9.7	42	9.3		
Chromium, Total	2.7						
Dissolved	1.2						
Chromium III, Total	1.2						
Dissolved	0	2922	380				
Chromium VI, Total	1.5						
Dissolved	1.5	16	11	1100	50		
Copper, Total	5.9						
Dissolved	4.2	88	49.3	4.8	3.1	1300	
Lead, Total	1.6						
Dissolved	0.05	518	20.2	210	8.1		
Mercury, Total	0.005						
Dissolved	0.001	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	6.9						
Dissolved	4.9	2534	281	74	8.2	610	4600
Selenium, Total	22.1		5.0				
Dissolved	23.0			290	71	170	11000
Silver, Total	0.004U						
Dissolved	0.1	106.9		1.9			
Zinc, Total	11.2						
Dissolved	2.6	636	641	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	736						

N/A means not analyzed.

Table 1 (continued)
Site 2 – San Diego Creek @ Harvard Avenue on May 3, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	5.5						
Dissolved	5.3	340	150	69	36		
Cadmium, Total	0.15						
Dissolved	0.12	27.5	8.0	42	9.3		
Chromium, Total	1.1						
Dissolved	1.2						
Chromium III, Total	0						
Dissolved	0	2336	304				
Chromium VI, Total	2.3						
Dissolved	2.3	16	11	1100	50		
Copper, Total	2						
Dissolved	1.7	68	39.0	4.8	3.1	1300	
Lead, Total	0.03						
Dissolved	0.005U	395	15.4	210	8.1		
Mercury, Total	0.003						
Dissolved	0.002	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	5.5						
Dissolved	5	2011	223	74	8.2	610	4600
Selenium, Total	10.1		5.0				
Dissolved	9.2			290	71	170	11000
Silver, Total	0.004U						
Dissolved	0.07	66.8		1.9			
Zinc, Total	2.8						
Dissolved	2.6	504	509	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	560						

N/A means not analyzed.

Table 1 (continued)
Site 3 – Peters Canyon Channel @ Barranca Parkway on May 3, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	9.3						
Dissolved	9	340	150	69	36		
Cadmium, Total	0.19						
Dissolved	0.14	35.2	9.4	42	9.3		
Chromium, Total	1.2						
Dissolved	0.96						
Chromium III, Total	0						
Dissolved	0	2817	366				
Chromium VI, Total	2.3						
Dissolved	2.3	16	11	1100	50		
Copper, Total	5.3						
Dissolved	4.4	85	47.5	4.8	3.1	1300	
Lead, Total	0.27						
Dissolved	0.02	496	19.3	210	8.1		
Mercury, Total	0.003						
Dissolved	0.002	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	4.4						
Dissolved	3.9	2441	271	74	8.2	610	4600
Selenium, Total	31		5.0				
Dissolved	30.2			290	71	170	11000
Silver, Total	0.004U						
Dissolved	0.04	99.0		1.9			
Zinc, Total	5.8						
Dissolved	2.5	612	617	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	704						

N/A means not analyzed.

Table 1 (continued)
Site 4 – Hines Channel @ Irvine Boulevard on May 3, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	9.2						
Dissolved	9.4	340	150	69	36		
Cadmium, Total	0.71						
Dissolved	0.12	29.0	8.3	42	9.3		
Chromium, Total	5.2						
Dissolved	1.7						
Chromium III, Total	3.6						
Dissolved	0.1	2431	316				
Chromium VI, Total	1.6						
Dissolved	1.6	16	11	1100	50		
Copper, Total	17.3						
Dissolved	10.1	71	40.7	4.8	3.1	1300	
Lead, Total	5.3						
Dissolved	0.04	415	16.2	210	8.1		
Mercury, Total	0.016						
Dissolved	0.002	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	7.1						
Dissolved	5.2	2096	233	74	8.2	610	4600
Selenium, Total	2.9		5.0				
Dissolved	3.3			290	71	170	11000
Silver, Total	0.009						
Dissolved	0.03	72.6		1.9			
Zinc, Total	39.3						
Dissolved	3.8	526	530	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	588						

N/A means not analyzed.

Table 1 (continued)
Site 6 – Santa Ana Delhi Channel @ Mesa Drive on May 3, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria - April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	3						
Dissolved	2.8	340	150	69	36		
Cadmium, Total	0.11						
Dissolved	0.08	34.1	9.2	42	9.3		
Chromium, Total	0.84						
Dissolved	1.8						
Chromium III, Total	0						
Dissolved	0	2752	358				
Chromium VI, Total	1.9						
Dissolved	1.9	16	11	1100	50		
Copper, Total	6.6						
Dissolved	5	82	46.3	4.8	3.1	1300	
Lead, Total	0.45						
Dissolved	0.03	482	18.8	210	8.1		
Mercury, Total	0.002						
Dissolved	0.002	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	4.7						
Dissolved	4.4	2382	265	74	8.2	610	4600
Selenium, Total	11.9		5.0				
Dissolved	11.5			290	71	170	11000
Silver, Total	0.004U						
Dissolved	0.02	94.2		1.9			
Zinc, Total	8.1						
Dissolved	5.4	598	602	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	684						

N/A means not analyzed.

Table 1 (continued)
Site 7b – El Modena-Irvine Channel Upstream of Peters Canyon on May 3, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	4.6						
Dissolved	4.5	340	150	69	36		
Cadmium, Total	0.08						
Dissolved	0.06	25.6	7.6	42	9.3		
Chromium, Total	0.84						
Dissolved	2.2						
Chromium III, Total	0						
Dissolved	0	2212	288				
Chromium VI, Total	2.2						
Dissolved	2.2	16	11	1100	50		
Copper, Total	8.6						
Dissolved	6.9	64	36.9	4.8	3.1	1300	
Lead, Total	0.21						
Dissolved	0.08	370	14.4	210	8.1		
Mercury, Total	0.06						
Dissolved	0.003	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	4.1						
Dissolved	3.9	1901	211	74	8.2	610	4600
Selenium, Total	12.2		5.0				
Dissolved	12.1			290	71	170	11000
Silver, Total	0.004U						
Dissolved	0.02	59.6		1.9			
Zinc, Total	7.3						
Dissolved	4.2	477	481	90	81	9100	69000
Hardness (mg/L$CaCO_3$)	524						

N/A means not analyzed.

Table 1 (continued)
Site 9 – East Costa Mesa Channel @ Highland Avenue on May 3, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	4.5						
Dissolved	3.3	340	150	69	36		
Cadmium, Total	0.57						
Dissolved	0.12	10.8	4.2	42	9.3		
Chromium, Total	4.7						
Dissolved	1.7						
Chromium III, Total	1.9						
Dissolved	0	1151	150				
Chromium VI, Total	2.8						
Dissolved	2.8	16	11	1100	50		
Copper, Total	35.4						
Dissolved	12.2	30	18.7	4.8	3.1	1300	
Lead, Total	66.2						
Dissolved	0.31	162	6.3	210	8.1		
Mercury, Total	0.03						
Dissolved	0.005	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	8.8						
Dissolved	4.5	968	108	74	8.2	610	4600
Selenium, Total	2.7		5.0				
Dissolved	2.8			290	71	170	11000
Silver, Total	0.02						
Dissolved	0.02	15.1		1.9			
Zinc, Total	216						
Dissolved	7.7	243	245	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	236						

N/A means not analyzed.

Table 1 (continued)
Site – 10 Central Irvine Channel at Monroe on May 3, 2000

Parameter	Concentration (µg/L)	National Recommended Water Quality Criteria -- April 1999					
		Freshwater (µg/L)		Saltwater (µg/L)		Human Health (µg/L)	
		CMC	CCC	CMC	CCC	Water+Organism	Organism Only
Arsenic, Total	8.4						
Dissolved	8.2	340	150	69	36		
Cadmium, Total	0.38						
Dissolved	0.19	29.6	8.4	42	9.3		
Chromium, Total	2.7						
Dissolved	2.8						
Chromium III, Total	0.3						
Dissolved	0.4	2472	322				
Chromium VI, Total	2.4						
Dissolved	2.4	16	11	1100	50		
Copper, Total	20.6						
Dissolved	16.9	73	41.4	4.8	3.1	1300	
Lead, Total	1.1						
Dissolved	0.005U	423	16.5	210	8.1		
Mercury, Total	0.005						
Dissolved	0.001	1.4	0.77	1.8	0.94	0.05	0.051
Nickel, Total	6						
Dissolved	5.2	2132	237	74	8.2	610	4600
Selenium, Total	33.5		5.0				
Dissolved	36.2			290	71	170	11000
Silver, Total	0.004U						
Dissolved	0.01	75.2		1.9			
Zinc, Total	11.8						
Dissolved	2.9	535	539	90	81	9100	69000
Hardness (mg/L $CaCO_3$)	600						

N/A means not analyzed.

To estimate the dissolved chromium III, which is the basis for regulating chromium III, the total chromium VI was subtracted from the total chromium. The total dissolved chromium VI (i.e., the total chromium VI) was subtracted from the total dissolved chromium reported by Battelle. Often this value was zero or slightly less than zero, indicating that the dissolved chromium III concentrations in the sample were very low and not a threat to cause toxicity to aquatic life. The data presented in Table 3 show that the concentrations of arsenic, cadmium, chromium III and VI, lead, mercury, nickel, silver and zinc were below the freshwater water quality criteria in the samples from all locations for the four dates of sampling.

Presented below is a discussion of the analytical data for several of the metals measured in this project.

Selenium.
Selenium was present in the Upper Newport Bay Watershed stormwater runoff collected on February 12 and 21, 2000, and the dry weather flow on May 31, 2000, at concentrations above the US EPA CTR criterion. The concentrations of total selenium exceeded the 5.0 μg/L freshwater chronic Criterion Continuous Concentration (CCC) at many of the sampling sites on February 12 and 21, 2000, and May 31, 2000. Table 4 presents the selenium data obtained during this study. Figure 2 presents a map of the sampling stations used in the 319(h) Upper Newport Bay Watershed studies. Figures 3, 4 and 5 present the same map with the selenium concentrations found at the sampling stations for each of the dates sampled.

Table 4
Upper Newport Bay Watershed Total Selenium Concentrations μg/L

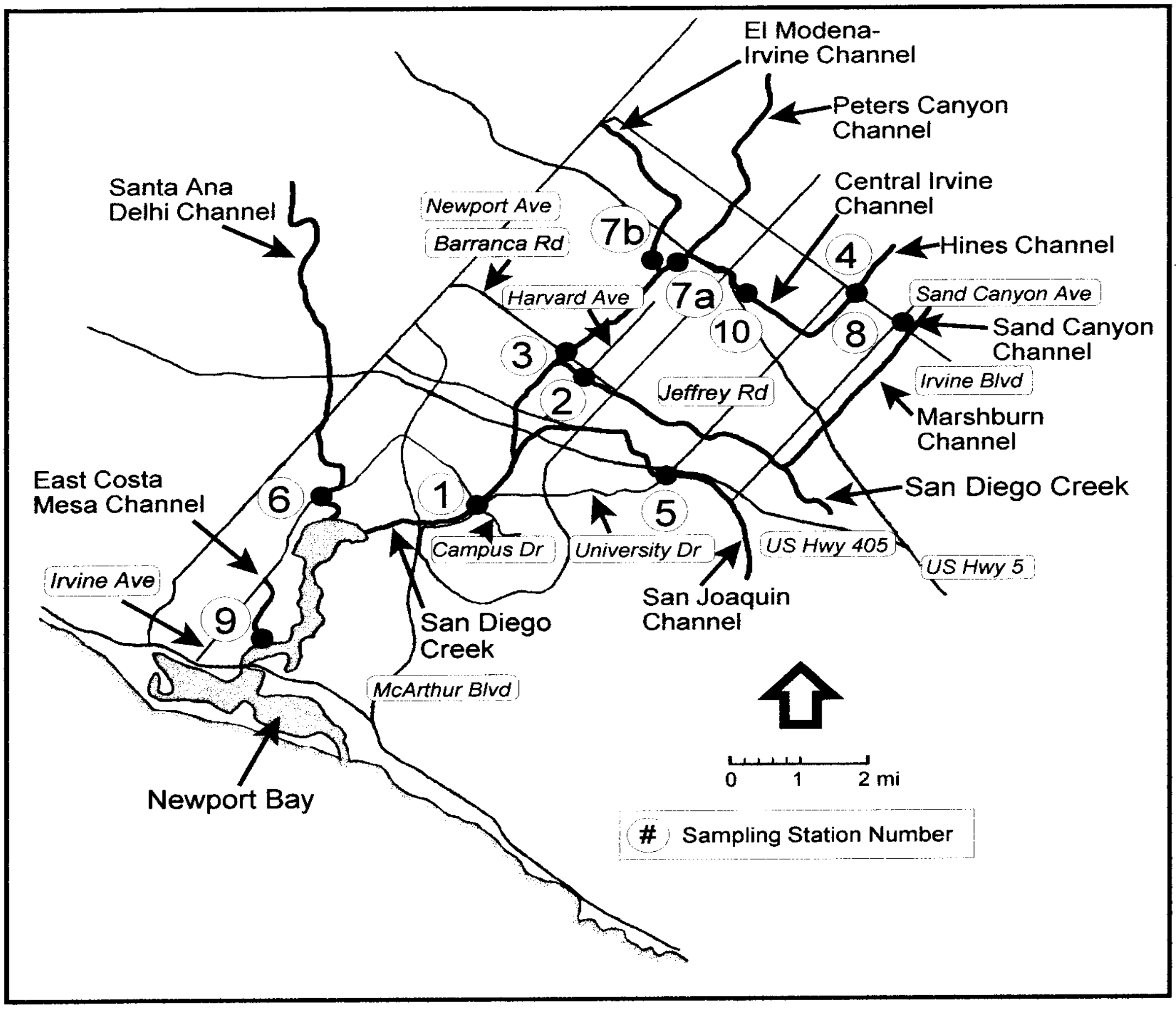
Station	Sampling Date			
	1/25/00	2/12/00	2/21/00	5/31/00
1	15.6	7.4	5.4	22.1
2	-	5.2	5.4	10.1
3	-	11.7	8.2	31
4	-	26.5	20.2	2.9
5	-	3.9	3.6	-
6	-	<0.39	3.4	11.9
7	-	11.6	3.2	12.2
8	-	24.8	20.5	-
9	-	4.0	0.82	2.7
10	-	13.9	6.7	33.5

- No analysis made.

The highest wet weather concentrations of total selenium were found at Site 4, Hines Channel at Irvine Boulevard, just below the Hines and El Modeno nurseries. The concentration generally decreased downstream from that location on both sampling dates. On February 12, the concentrations were 26.5, 13.9, 11.7, and 7.4 μg/L at Sites 4 (Hines Channel at Irvine Boulevard), 10 (Central Irvine Channel at Monroe), 3 (Peters Canyon Channel at Barranca Parkway), and 1 (San Diego Creek at Campus Drive), respectively. On February 21, the total selenium concentrations were 20.2, 6.7, 8.2, and 5.4 μg/L, respectively at those sampling sites. Site 1, which is an integrator station for the San Diego Creek Watershed, was also sampled on January 25, 2000. The selenium concentration at that time was 15.6 μg/L.

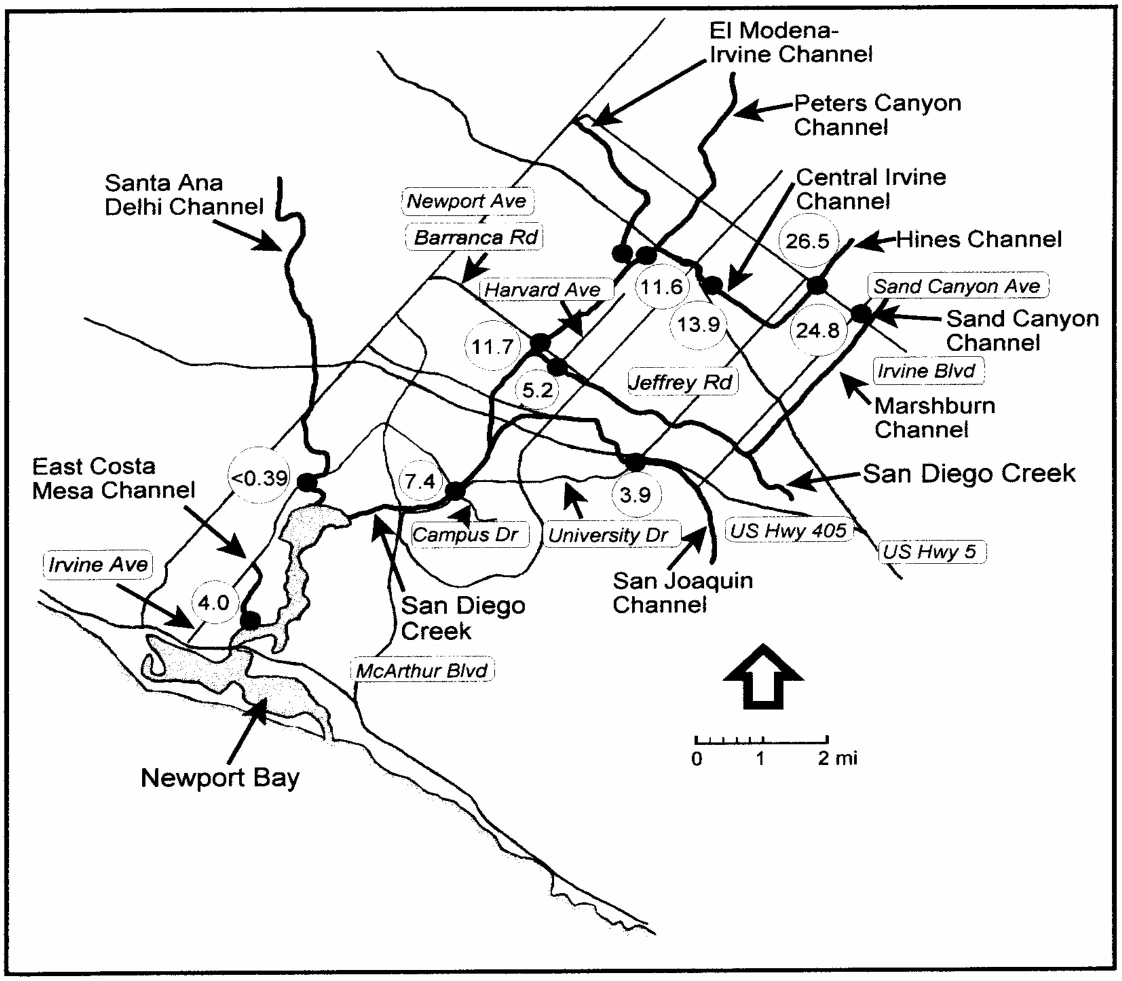
The concentrations of total selenium at Site 8 (Sand Canyon Channel at NE Irvine Boulevard) were about the same as they had been at Site 4 on the two sampling occasions. Concentrations at Site 8 were 24.8 and 20.5 μg/L on February 12 and 21, respectively. The Sand Canyon Channel, whose watershed is devoted to agriculture, is tributary to Marshburn Channel, a principal tributary of upper San Diego Creek upstream of Site 2. Total selenium concentrations at Site 2 (San Diego Creek at Harvard Avenue) were 5.2 and 5.4 μg/L, respectively, on the February 12 and 21 sampling dates.

Figure 2



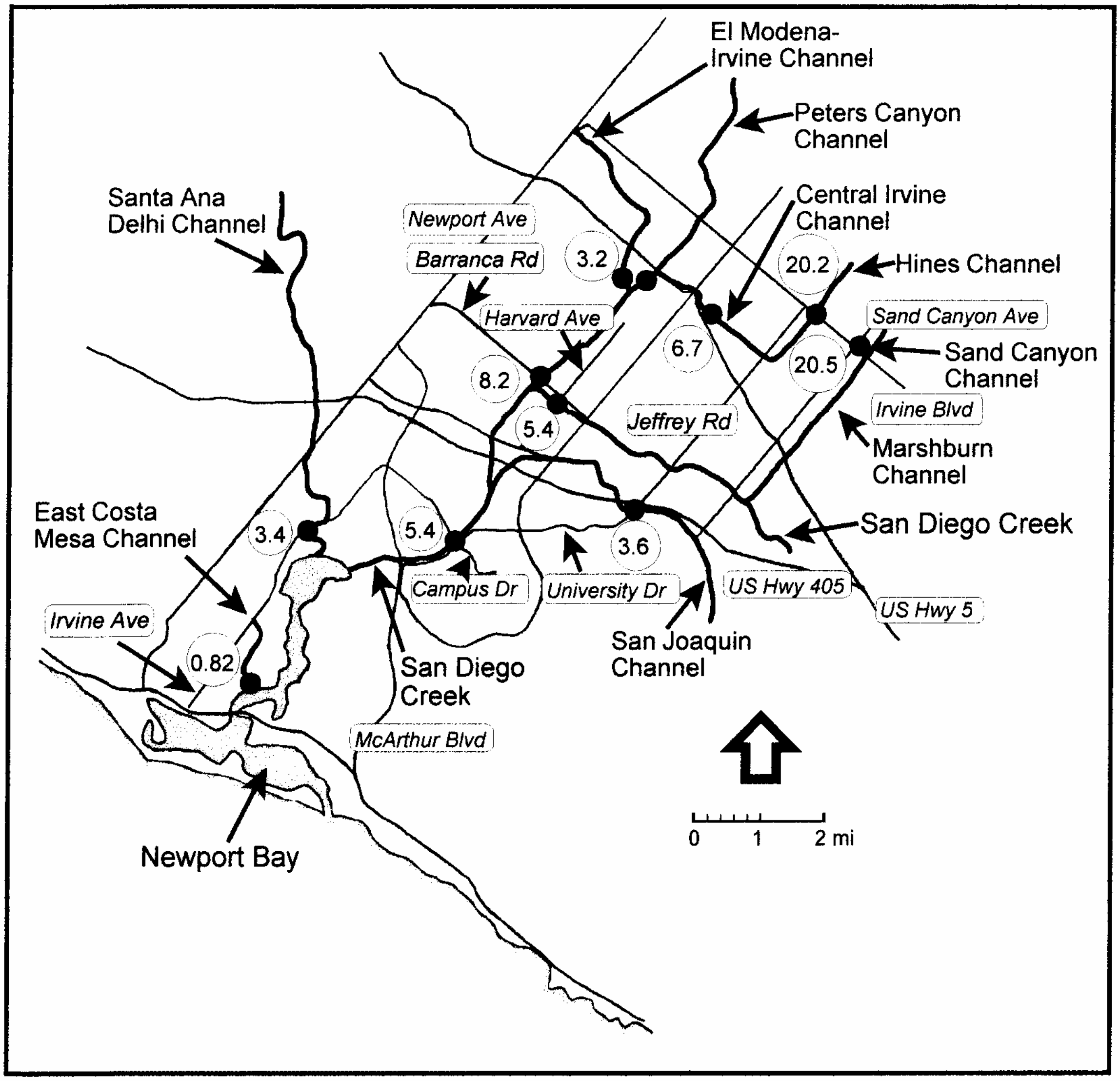
Newport Bay Watershed Sampling Sites

Figure 3



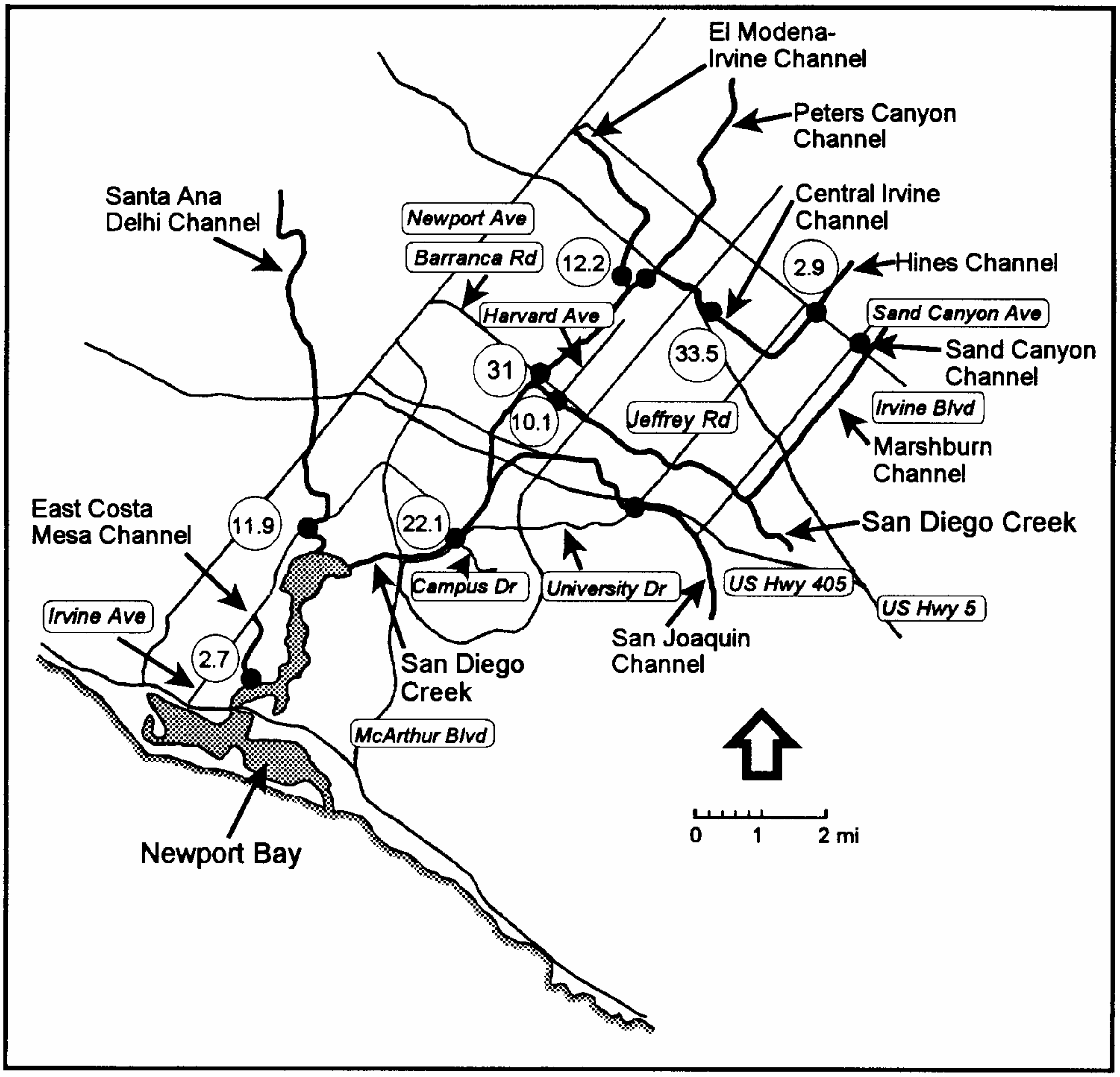
Total Selenium Concentrations (µg/L)
February 12, 2000
(Wet Weather Sampling)

Figure 4



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

Figure 5



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

Selenium concentrations measured in water in the El Modena–Irvine Channel (Site 7a, b) were 11.6 and 3.2 µg/L; the higher concentration was associated with higher hardness of the water. For most of the other sites whose selenium concentrations were above the CCC, also, the higher concentrations were associated with higher hardness. Concentrations of selenium in the Santa Ana Delhi Channel (Site 6), East Costa Mesa Channel (Site 9) and San Joaquin Creek at University Drive (Site 5) were below the 5.0 µg/L CCC on both sampling dates.

The dry weather flow sampling that took place on May 31, 2000, also showed elevated concentrations of selenium compared to the CTR criterion, where under stormwater runoff conditions of February 12 and 21, the Hines Channel samples had the highest concentrations. On May 31, 2000, the highest concentrations (33.5 µg/L) were found in the Central Irvine Channel. It is believed that the results for the total selenium obtained at Station 4 (Hines Channel at Irvine Blvd.) on May 31, 2000, as reported by Battelle, are unreliable. This is based on the fact that the dissolved selenium found in this sample was greater than the total selenium.

The San Diego Creek at Campus Drive sample contained 22.1 µg/L of selenium. The Santa Ana Delhi Channel at Mesa Drive contained 11.9 µg/L of selenium. From the pattern of selenium concentrations found under dry and wet weather flow conditions, it appears that the selenium found in the Upper Newport Bay Watershed San Diego Creek tributaries could be derived from shallow groundwater discharge to the tributaries. Studies should be completed that examine the origin of the dry weather flow.

While no selenium measurements were made in the Upper Newport Bay waters in this study, based on the concentration of selenium in the tributaries to the Bay during dry weather flow and the stormwater runoff events sampled, there is a potential for water quality problems due to selenium in the Bay. However, since the OCPFRD (1999) does not analyze for selenium in its Upper Newport Bay samples, it is suggested that samples of the Bay waters be analyzed for selenium to confirm that the concentrations of dissolved selenium in the marine waters of the Bay, i.e., outside of the freshwater lens formed during stormwater runoff events, do not exceed the CTR marine water quality criteria for dissolved selenium of a CMC of 290 µg/L and a CCC of 71 µg/L.

There is considerable interest in selenium as a cause of water quality problems in the Sacramento River and San Joaquin River Delta and San Francisco Bay. This has stimulated research on the fate and effects of selenium in these waters. There were a number of papers presented at the CALFED Bay-Delta Program Science Conference held in Sacramento in October 2000 that provided information on selenium within the Delta and San Francisco Bay water and organisms. The paper by Stewart, *et al*. (2000) provides the results of studies that show that some fish in the Delta are accumulating selenium to critical levels. Based on these studies, it appears that there is need to broaden the scope of assessing the potential impacts of selenium on aquatic ecosystems to determine whether excessive concentrations of selenium are occurring in aquatic life. In addition to measuring the concentrations of selenium in Upper Newport Bay waters, there is need to measure the concentrations of selenium in Upper Newport Bay aquatic life to be certain that the concentrations found in aquatic organism tissue do not exceed critical levels for the aquatic life.

In addition to concern about the effects of selenium on aquatic life, there is also concern about its effects on waterfowl reproduction. The Kesterson area in the Central Valley, California, demonstrated that elevated concentrations of selenium in waterfowl could cause mutagenic effects in ducklings. Based on the experience in the Kesterson area and other areas, studies should be conducted of the waterfowl that are reproducing in the Upper Newport Bay Watershed to determine whether selenium is causing adverse effects to waterfowl.

While the CTR criteria for selenium in marine waters is based on dissolved forms, the paper by Schlekat, *et al*. (2000) demonstrated that particulate selenium in aquatic sediments can be taken up by bivalves and, therefore, be made available through the food web to higher trophic level organisms. Louma of the USGS, Menlo Park, California, believes that the elevated concentrations of selenium that are being found in Delta sturgeon may be due to sturgeon eating bivalves that have accumulated selenium from the water and/or sediments.

Stover, *et al*. (2000) have recently published a paper in which they have reported that elevated concentrations of selenium in a freshwater stream did not bioaccumulate as expected to critical levels in fish and zooplankton. It is evident that total concentrations of selenium above the CTR criteria of 5 µg/L can occur without adverse effects to aquatic life. Consequently, the water quality significance-beneficial use impairment associated with finding selenium in Upper Newport Bay tributaries (freshwater) at concentrations above the CTR criterion for total selenium of 5 µg/L needs to be evaluated.

The SARWQCB (2000) has indicated that a TMDL needs to be developed to control the excessive concentrations of selenium in San Diego Creek and Upper and Lower Newport Bay. This TMDL is to be developed by the SARWQCB. The first phase of this TMDL should be an assessment of whether the concentrations of selenium in aquatic life and wildlife exceed or approach critical tissue residues.

Arsenic

The situation with respect to assessing whether there is an exceedance of the human health arsenic criteria in the samples of Upper Newport Bay tributary waters sampled for heavy metals in this study depends on whether the US EPA (1999a) National Recommended Water Quality Criteria – Correction are used or whether the CTR criteria, promulgated by the US EPA (2000a) Region 9 for California, are used. In April 1999, the US EPA issued its National Recommended Water Quality Criteria – Correction. The Agency lists as criteria for arsenic for protection of human health through bioaccumulation, of “Water + Organisms,” 0.018 µg/L, and “Organisms Only,” 0.14 µg/L. According to P. Woods (pers. comm..) of US EPA Region 9, the Region did not include the 1999 National Recommended arsenic criteria for protection of human health through bioaccumulation in the CTR criteria. The Region did not recommend any criteria for protection of human health associated with the bioaccumulation of arsenic to excessive levels in edible organisms and edible organisms and water.

The regulation of arsenic has been in a state of flux with respect to protection of human health from consumption of arsenic in drinking water and in organisms that have developed in the water of concern. Until recently, the US EPA MCL for drinking water was 50 µg/L. This concentration represents a significant human health cancer risk. The US EPA (2001) has recently announced that the Agency has decreased the drinking water MCL to 10.0 µg/L. This MCL is still about 20 times the April 1999 risk-based criterion for consumption of water. There has been considerable concern over the years about the US EPA's approach toward regulating arsenic, in that it has been recognized for many years that the drinking water MCL for arsenic of 50 µg/L results in a significantly higher human health risk (on the order of one additional cancer in 1,000 people) compared to the Agency's approach for regulating other potential carcinogens, which is typically set at one additional cancer in every 100,000 or 1,000,000 people.

One of the problems with regulating arsenic the same as other potential carcinogens, such as many of the priority pollutants, is that arsenic occurs naturally in many surface and ground waters at concentrations that represent significant human health risks for causing cancer through drinking water. If the Agency followed a consistent approach for regulating arsenic as it uses for regulating many other carcinogens, it would cause massive expenditures for treating domestic water supplies to remove arsenic. The Agency has evidently determined that such expenditures are not appropriate, from both the additional protection from carcinogens perspective and the politics of causing public water supplies to have to greatly increase the cost of treatment.

For the purposes of this report, the US EPA (1999a) Recommended Water Quality Criteria for protection of human health from bioaccumulation of arsenic in edible aquatic organisms are compared to the concentrations found in the Upper Newport Bay Watershed tributaries. It is important to emphasize, however, that under the current regulatory requirements, the excessive concentrations of arsenic found in Upper Newport Bay tributaries, compared to the 1999 recommended human health criteria, do not represent violations of the CTR criteria, since the CTR criteria does not provide a value for protection of human health from bioaccumulation of arsenic.

Table 4 presents a summary of the arsenic data collected in Upper Newport Bay tributaries in winter/spring 2000. A review of the heavy metal data on the samples collected during stormwater runoff events that occurred on February 12 and 21, 2000 and during dry weather flow, May 31, 2000, shows that the concentrations of arsenic in the tributaries of Upper Newport Bay were in the range from about 1 µg/L to 19 µg/L. The highest concentrations of dissolved arsenic, found at Site 4 (Hines Channel @ Irvine Boulevard), were 12.4 and 9.6 µg/L for the two stormwater runoff sampling dates. Concentrations decreased downstream on both dates to 4.9 µg/L at Site 3 in Peters Canyon Channel. Higher concentrations (between about 6 and 11 µg/L) were also reported at Sites 5 (San Joaquin Creek at University Drive), Site 7b (El Modena–Irvine Channel) and Site 8 (Sand Canyon Channel at NE Irvine Boulevard). Concentrations at the three sampling sites nearest to discharge to Newport Bay ranged from 1.5 to 4.4 µg/L.

Table 4
Upper Newport Bay Watershed Total and Dissolved Arsenic Concentrations µg/L

Station	Sampling Date							
	01/25/00		02/12/00		02/21/00		05/31/00	
	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
1	8.9	6.1	13.1	4.1	9.4	4.2	8.9	8.4
2	-	-	17.8	3.6	11.9	4.7	5.5	5.3
3	-	-	12.9	4.9	8.6	4.9	9.3	9.0
4	-	-	17.9	12.4	14.0	9.6	9.2	9.4
5	-	-	13.2	10.7	11.8	7.2	-	-
6	-	-	2.6	1.6	2.2	1.8	3.0	2.8
7b	-	-	19.3	7.9	4.4	4.1	4.6	4.5
8	-	-	9.3	7.6	11.8	5.8	-	-
9	-	-	2.9	2.1	0.98	1.5	4.5	3.3
10	-	-	17.7	8.2	8.5	5.8	8.4	8.2

- = No sample collected.

While concentrations of dissolved arsenic at the 10 Upper Newport Bay Watershed sampling locations did not exceed the National Recommended Water Quality Criteria (US EPA, 1999a) for freshwater aquatic life, they did consistently exceed the human health criteria for Water plus Organisms (0.018 µg/L) and Organisms Only (0.14 µg/L). Further, some of the arsenic concentrations exceeded the recently adopted US EPA MCL for drinking water. The exceedance of the recently adopted arsenic MCL would not represent a violation of a water quality objective since the waters in the Upper Newport Bay Watershed for San Diego Creek and its tributaries are not designated for domestic water supply use.

The SARWQCB (2000) has reported that the WRCB State Mussel Watch (SMW) monitoring found that the concentrations of arsenic in mussels exceeded the California Office of Environmental Health Hazard Assessment (OEHHA) screening value of 1.0 mg/kg in mussels collected from the Turning Basin, the Highway 1 Bridge and the Rhine Channel area. The SMW only analyzed samples for arsenic on two occasions, in 1994 and in 1996. Of the seven samples analyzed for arsenic, all seven exceeded the OEHHA screening value of 1.0 mg/kg, and ranged from 1.2 mg/kg to 1.5 mg/kg.

According to the SARWQCB (2000), the WRCB Toxic Substances Monitoring (TSM) found that concentrations of arsenic in fish fillet tissue from samples collected from Newport Bay exceeded the OEHHA screening value of 1.0 mg/kg. However, the TSM did not find arsenic above the screening value of 1.0 mg/kg in any of the whole fish samples collected from San Diego Creek and tributaries.

In summary, SARWQCB (2000) reports that in the Upper Newport Bay at the Pacific Coast Highway (PCH) Bridge, the arsenic exceeded the tissue bioaccumulation screening values and that the arsenic found was above OEHHA screening values in fish fillets but was not detected in one of two most recent (1995) TSM samples. The OCPFRD (1999) stormwater monitoring program does not include measurements of arsenic. If the arsenic data obtained in this 319(h) study for the winter/spring 2000 are representative of the conditions that have existed over the years in the tributaries of Upper Newport Bay, then it appears that the excessive concentrations of arsenic compared to US EPA national recommended criteria for protection of human health found in Upper Newport Bay tributaries in the February 2000 stormwater runoff and May 2000 dry weather flow are not bioaccumulating to excessive levels in fish within tributary waters. There is need to examine fish tissue from Upper Newport Bay tributaries to determine if these fish contain excessive arsenic compared to OEHHA screening values.

Copper

Table 5 presents a summary of the copper data collected in Upper Newport Bay tributaries in winter/spring 2000. Copper concentrations were below the National Recommended Water Quality Criteria (April 1999) at all sites except Site 9 in the East Costa Mesa Channel. The dissolved copper concentration there was 14.2 μg/L (CMC–12 μg/L; CCC–8.0 μg/L) on February 12, 2000, and 8.2 μg/L (CMC–10 μg/L; CCC–7.0 μg/L) on February 21, 2000. These concentrations are at the low end of the range of dissolved copper concentrations reported by OCPFRD (1998) for the period 9/25/97 to 3/29/98 (13 to 67 μg/L).

Based on the studies of urban area street and highway stormwater runoff that have been conducted in large municipalities throughout California (Lee, 1998), the most likely source of the elevated concentrations of copper found in the Upper Newport Bay tributaries is street and highway runoff. Vehicular traffic is a known source of elevated copper in street runoff.

All streets and highways in this watershed as well as elsewhere are expected to have concentrations of dissolved copper above the CTR criterion. While the concentrations of dissolved copper in street and highway runoff are expected to exceed the CTR criterion, this does not mean that the dissolved copper in this runoff is adverse to aquatic life-related beneficial uses of the receiving waters for the runoff. The high concentrations of suspended particulates and the elevated concentrations of carbonates in the receiving waters for the highway and street runoff quickly convert the dissolved copper to particulate copper.

Also, the low hardness associated with highway and street runoff leads to a lower hardness-adjusted criterion than would be applicable to the Upper Newport Bay Watershed receiving waters for the runoff. The monitoring that has been done over the past four years in the Upper Newport Bay Watershed, in this and its predecessor, the 205(j) study (Lee and Taylor, 1999), shows that the hardness in the receiving waters would be expected to be considerably elevated above the hardness of the highway and street runoff. Therefore, as soon as the highway and street runoff enters the receiving waters, the CTR criterion applicable to the copper associated with the highway and street runoff will be significantly increased. This then leads to the situation found in this study where the dissolved copper in the Upper Newport Bay tributaries sampled in the winter/spring 2000 did not exceed the freshwater CTR hardness-adjusted criterion.

Table 5
Upper Newport Bay Watershed Total and Dissolved Copper Concentrations, µg/L

Station	Sampling Date							
	01/25/00		02/12/00		02/21/00		05/31/00	
	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
1	28.5	5.5	39.7	2.9	23.1	2.4	5.9	4.2
2	-	-	65.8	2.3	42.3	2.4	2.0	1.7
3	-	-	35.9	3.2	20.3	3.7	22.4	7.4
4	-	-	26.6	7.5	30.8	8.1	17.3	70.1
5	-	-	12.8	8.0	38.9	6.3	-	-
6	-	-	14.9	6.6	21.8	6.3	6.6	5.0
7b	-	-	55.0	4.1	8.8	4.7	8.6	6.9
8	-	-	10.4	5.2	21.9	3.8	-	-
9	-	-	18.6	14.2	14.0	8.2	35.4	12.2
10	-	-	41.2	5.8	22.4	7.4	20.6	16.9

- = No sample collected.

The water quality significance of copper discharged to Upper Newport Bay from its tributaries is another area that needs further investigation. The OCPFRD (1999) and SARWQCB (2000) sampling of Upper Newport Bay waters has shown that, at times, the copper present in these waters exceeds the CTR criterion of a CMC of 4.8 µg/L and a CCC of 3.1 µg/L for marine waters. There is need to evaluate whether these exceedances reflect an adverse impact to aquatic life. This issue is discussed further below.

An issue that has not been addressed in the implementation of the CTR criteria is that of the appropriate criterion to use for freshwater lenses that form in marine bays like Upper Newport Bay associated with stormwater runoff events. As discussed by Lee and Taylor (1999), many stormwater runoff events into Upper Newport Bay lead to about a one-meter-thick freshwater marine water lens that extends down the Bay sometimes as far as the Pacific Coast Highway bridge. This lens will have salinity from less than about half a ppt to several ppt. If the freshwater criterion is used for the copper in this lens, then there would be no violation of the CTR criterion. However, if the marine water criterion is used, there are significant violations of the copper criterion. The US EPA (2000) CTR does not address how the criteria should be applied to freshwater lenses in marine bays. According to Wood, US EPA Region IX (pers. comm.), the CTR addresses salinities equal to or less than 1 ppt and those that are equal to or greater than 10 ppt more than 95 percent of the time. Regulatory clarification is needed where freshwater streams empty into estuaries.

Loads and Export Coefficients for Heavy Metals

Table 6 presents a summary of land use for the watersheds upstream of the sampling stations. Station 5 (San Joaquin Channel at University Drive) had a land use upstream of the sampling location of primarily open space with a secondary use of agriculture. Station 6 (Santa Ana Channel at Mesa Drive) watershed is 95 percent developed with commercial/residential uses. Station 7b is primarily devoted to residential use with some commercial area. Station 8 (Sand Canyon Avenue - northeast corner of Irvine Blvd) watershed is devoted to agricultural use. Station 9 (East Costa Mesa Channel at Highland Drive) watershed is devoted primarily to residential with a small amount of commercial use. All other sampling stations had a mixture of residential and agricultural uses, and Stations 1, 2, 3, 4, 7a and 10 also had nursery use within the sub-watershed.

February 12, 2000, Storm Event. The February 12, 2000, storm event resulted in 0.72 in. of rain at the Campus Drive rain gage with about 0.29 in. of runoff at this location. This storm could be viewed as “typical” for the season. Table 6 provides volume and constituent concentration for copper and selenium for both total and dissolved forms for the February 12, 2000, event**.**

Table 6
Summary of Sampling Station Watershed Dominant Land Uses

Station	Location	Dominant Land Use
1	San Diego Creek at Campus Drive	Mixed residential, agricultural, nursery
2	San Diego Creek at Harvard Avenue	Mixed residential, agricultural, nursery
3	Peters Canyon Channel at Barranca Parkway	Mixed residential, agricultural, nursery
4	Hines Channel at Irvine Blvd	Nursery, agricultural
5	San Joaquin Channel at University Drive	Agricultural, open space
6	Santa Ana Delhi Channel at Mesa Drive	Residential, commercial
7a	Peters Canyon Channel at Walnut Avenue	Residential, agricultural, nursery
7b	El Modena Irvine Channel upstream of Peters Canyon Channel	Residential, some commercial
8	Sand Canyon Avenue-NE corner of Irvine Blvd.	Agricultural
9	East Costa Mesa Channel at Highland Dr.	Residential, commercial
10	Central Irvine Channel at Monroe	Agricultural, residential, nursery
Station	**Location**	**Dominant Land Use**
1	San Diego Creek at Campus Drive	Mixed residential, agricultural, nursery
2	San Diego Creek at Harvard Avenue	Mixed residential, agricultural, nursery
3	Peters Canyon Channel at Barranca Parkway	Mixed residential, agricultural, nursery
4	Hines Channel at Irvine Blvd	Nursery, agricultural
5	San Joaquin Channel at University Drive	Agricultural, open space
6	Santa Ana Delhi Channel at Mesa Drive	Residential, commercial
7a	Peters Canyon Channel at Walnut Avenue	Residential, agricultural, nursery
7b	El Modena Irvine Channel upstream of Peters Canyon Channel	Residential, some commercial
8	Sand Canyon Avenue-NE corner of Irvine Blvd.	Agricultural
9	East Costa Mesa Channel at Highland Dr.	Residential, commercial
10	Central Irvine Channel at Monroe	Agricultural, residential, nursery

Table 7
Runoff Volume and Constituent Concentration – Metals
February 12, 2000, Storm Event

Station No.	Runoff Volume (f^3)	Copper Total (µg/L)	Copper Dissolved (µg/L)	Selenium Total (µg/L)	Selenium Dissolved (µg/L)
1	74,553,372	39.7	2.9	7.4	4.0
2	1,9436,220	65.8	2.3	5.2	1.9
3	7,961,166	35.9	3.2	11.7	9.3
4	203,104	26.6	7.5	26.5	20.2
5	336,922	12.8	8.0	4.6	4.6
6	13,710,060	14.9	6.6	2.9	2.9
7a	4,403,548	55.0	4.1	11.6	9.7
8	29,544	10.4	5.2	26.9	26.9
9	611,484	18.6	14.2	4.0	1.0
10	1,076,184	41.2	5.8	13.9	11.8

Table 8 provides loads for the specified constituents in pounds for the February 12 storm event.

Table 8
Load in Pounds of Selected Constituents
February 12, 2000 Storm Event

Station No.	Total/ Dissolved Copper	Total/ Dissolved Selenium
1	184.77/13.50	34.44/18.62
2	79.84/2.79	6.31/2.31
3	17.84/1.59	5.81/4.62
4	0.34/0.10	0.34/0.26
5	0.27/0.17	0.10/0.10
6	12.75/5.65	2.48/2.48
7a	15.12/1.13	3.19/2.67
8	0.02/0.01	0.05/0.05
9	0.71/0.54	0.153/0.038
10	2.77/0.39	0.934/0.793

Table 9 presents that data given in Table 8 in terms of pounds of constituent per acre of tributary drainage area to provide an estimate of the relative contributions of land uses that are represented at each sampling station.

Table 9
Pounds of Selected Constituents per Acre of Tributary Area
February 12, 2000, Storm Event
(All values lb/acre × 10^{-5})

Station No.	Total/ Dissolved Copper	Total/ Dissolved Selenium
1	260.1/19.0	48.5/26.2
2	296.1/10.4	23.4/8.6
3	61.7/5.5	20.1/16.0
4	54.7/15.4	54.5/41.5
5	30.4/19.0	10.9/10.9
6	115.2/57.0	22.4/22.4
7a	118.7/8.8	25.0/20.9
8	19.0/9.5	49.1/49.1
9	82.1/62.4	17.7/4.4
10	126.6/17.8	42.7/36.3

The data for metals exhibit a somewhat different characteristic, with "urban" stations exhibiting the highest loadings and agriculture/open space (Stations 5 and 8) exhibiting the lowest loadings. It is also interesting to note that selenium loading is highest in the Peters Canyon Channel watershed (Stations 3, 4, 7 and 8) and lower in other watersheds (Stations 5, 6 and 9). However, Station 3, the most downstream point in the Peters Canyon watershed, is comparatively low, indicating potential dilution once the upstream flow reaches this location.

February 21, 2000 Storm Event. The February 21, 2000, storm event resulted in 1.28 in. of rain at the Campus Drive rain gage with about 0.43 inches of runoff at this location. This storm could be viewed as on the high end of a "typical" storm for the season. Table 10 provides loads for the specified constituents in pounds for the February 21, 2000, storm event.

Table 10
Runoff Volume and Constituent Concentration – Metals

Station No.	Runoff Volume (cfs)	Copper Total (µg/L)	Copper Dissolved (µg/L)	Selenium Total (µg/L)	Selenium Dissolved (µg/L)
1	110,147,220	23.1	2.4	5.4	3.3
2	64,213,380	42.3	2.4	5.4	2.0
3	31,085,460	20.3	3.7	8.2	6.5
4	300,072	30.8	8.1	20.2	18.4
5	497,778	38.9	6.3	3.6	3.4
6	20,487,834	21.8	6.3	3.4	0.92
7b	14,520,960	8.8	4.7	3.2	2.6
8	43,650	21.9	3.8	20.5	16.5
9	903,423	14.0	8.2	0.8	0.5
10	1,589,984	22.4	7.4	6.7	6.1

Table 11
Load in Pounds of Selected Constituents
February 21, 2000, Storm Event

Sta. No.	Total/Dissolved Copper	Total/Dissolved Selenium
1	158.84/16.50	37.13/22.69
2	169.57/9.60	21.65/8.02
3	39.39/7.18	15.91/12.61
4	0.58/0.15	0.38/0.35
5	1.21/0.20	0.11/0.11
6	27.88/8.06	4.35/1.18
7b	7.98/4.26	2.90/2.36
8	0.06/0.01	0.06/0.05
9	0.79/0.46	0.05/0.03
10	2.22/0.74	0.67/0.61

Table 12
Pounds of Selected Constituents per Acre of Tributary Area
(All values lbs/acre × 10^{-5})

Sta. No.	Total/Dissolved Copper	Total/Dissolved Selenium
1	233.5/23.2	52.3/31.9
2	629.0/35.7	80.3/29.7
3	136.2/24.8	55.0/43.6
4	93.5/24.6	61.3/55.9
5	136.6/22.1	12.6/12.0
6	253.5/73.3	39.5/10.7
7b	103.9/55.5	37.8/30.7
8	59.4/9.9	55.4/44.6
9	91.3/53.4	5.3/3.5
10	101.7/33.6	30.4/27.7

Dry Weather Loads

Estimates were also made for annual dry weather loading using the data from the May 31, 2000, dry-weather sampling event. Total annual dry weather loads were computed for stations where gaged discharge data were available. Gaged stream data is only available for Stations 1, 3, 6, 9 and 10. The total annual load was estimated by averaging the dry weather flow data for a period of 4 years (1991-94 flow data from OCFPRD). The computed dry weather volumes are shown in Table 13. Table 14 provides the results of this analysis.

Table 13
Estimated Dry Weather Annual Runoff Volumes

Station No.	Estimated Annual Volume (cubic feet)
1	408,916,800
3	282,772,800
6	763,723,080
9	4,625,280
10	5,150,880

Table 14
Estimated Dry Weather Annual Load Data (lbs)

Sta. No.	Total/Dissolved Copper	Total/Dissolved Selenium
1	150.61/122.53	587.14/587.14
3	93.56/77.67	547.24/533.11
6	316.67/238.39	567.36/548.29
9	10.22/3.52	0.81/0.81
10	6.62/5.43	11.64/11.64

Table 15 provides annual load data expressed in terms of pounds per tributary acre. Values are computed for those stations where data are available.

Table 15
Dry Weather Annual Load per Acre of Tributary Area
(All values in lbs/acre $\times \cdot 10^{-5}$)

Site No.	Total/Dissolved Copper	Total/Dissolved Selenium
1	212.0/172.5	826.5/826.5
3	347.0/288.1	2029.6/1977.2
6	2878.8/2167.2	5157.8/4984.5
9	1181.5/406.9	93.6/93.6
10	302.8/248.4	532.5/532.5

Only two metals were also included in the load calculations. Copper loads may be better characterized by OCPFRD NPDES permit stormwater runoff data than the limited single grab sample analysis performed here. Rigorous total load calculations would include the use of constituent concentrations calculated from flow-weighted composite samples taken over the entire runoff hydrograph. OCPFRD data was obtained for two locations for the February 12 storm event as a comparison. Total and dissolved copper concentrations at Station 1 are 39.7 µg/L and 2.9 µg/L at Campus Drive as reported herein. OCPFRD data indicates average values of 20.9 µg/L and 14 µg/L respectively, based on an average of flow-weighted samples taken at five intervals over the hydrograph. While the OCPFRD data do not represent a complete flow-weighted composite analysis, it is clear that the results can vary from the single grab sample used in this study by almost a factor of five.

A complete composite analysis would include flow-weighted sampling over the entire hydrograph. This is not generally practical for large watersheds where runoff time is long, requiring the changing of sample bottles and the problem of sample holding times. At Station 6 the total and dissolved copper values reported herein are 30.46 µg/L and 13.25 µg/L respectively, whereas OCPFRD total and dissolved copper data for the same storm are 14.9 µg/L and 6.6 µg/L respectively. Here the values vary by a factor of about two. This analysis illustrates the potential variability that may be encountered in the load data computed for this study, that results from using a single data point as the average constituent concentration over the entire runoff hydrograph.

Selenium load data has not previously been developed by the OCPFRD. Wet weather selenium load data shows a fairly consistent export rate throughout the watershed (Tables 6-5 and 6-9). Exceptions are at stations 5 and 9, where loads are generally about one-half of other areas. Station 5 serves agriculture and open space area on Sand Canyon, and station 9 serves a residential area in Costa Mesa. Dry weather flow data tends to reflect the wet weather loads, with station 9 exhibiting the lowest export rate (data are not available for station 5) and station 6 exhibiting the highest export rate (Santa Ana Delhi Channel). It is also interesting to note that station 6 exhibits the highest copper export rate per acre as well. The relatively high metal loadings from station 6 may reflect the industrial/commercial uses in this watershed.

Managing Exceedances of Water Quality Objectives for Heavy Metals

Lee and Jones-Lee (2000a) and Lee and Taylor (1999) have discussed the approach that should be followed when an exceedance of a heavy metal criteria/standard/objective is found in urban area stormwater runoff. This section of this report is based primarily on Lee and Jones-Lee (2000a). As they discuss, the first step in developing an appropriate heavy metal TMDL control program as well as the development of site-specific wet weather standards is monitoring of the stormwater runoff to insure that the analytical results reliably assess the total and dissolved heavy metal content of the runoff waters. "Clean" sampling and analytical procedures must be used for this purpose. Much of the data that has been generated on the concentrations of heavy metals in stormwater runoff and ambient waters may overestimate the real concentrations present due to sample contamination during sampling and handling. The US EPA (1997) has provided guidance on the analysis of heavy metals and other constituents with sufficient sensitivity and reliability to develop reliable heavy metal data in stormwater runoff and ambient waters for the runoff.

If "clean" sampling and analytical procedures show that the total and/or dissolved heavy metals are present in the runoff waters in excess of the US EPA worst-case-based water quality criteria or state standards based on these criteria, then an assessment should be made of whether the exceedance of a criterion/standard represents an "administrative" exceedance in which the concentrations measured are above the standard, but this exceedance does not represent an actual impairment of the designated beneficial uses of the receiving waters for the stormwater runoff. Since copper, zinc, cadmium, lead and nickel are of concern in urban area and highway stormwater runoff because of their potential to cause aquatic life toxicity, studies need to be done to determine if the stormwater runoff is toxic to a suite of sensitive toxicity test organisms. If toxicity is found, then toxicity investigation evaluations (TIEs) should be conducted to determine the cause of the toxicity.

Studies of this type have been conducted at several locations in California in the San Francisco Bay region, Sacramento, Stockton and Orange County. These studies have shown that the heavy metals in urban stormwater runoff from residential areas exceed US EPA worst-case-based water quality criteria/state standards. These studies have also shown that urban stormwater runoff is toxic to fresh and marine water zooplankton *Ceriodaphnia* and *Mysidopsis*. TIEs conducted on this toxicity have shown that it is not due to the potentially toxic heavy metals in the stormwater runoff, but is due to the organophosphate pesticides diazinon and chlorpyrifos. Therefore, with respect to potential water column impacts, the exceedance of the heavy metal water quality criteria/standards in urban area street and highway runoff is likely to be an administrative exceedance that is not impairing the beneficial uses of the receiving waters for the stormwater runoff. Under these conditions it is appropriate to first modify the water quality standards for the heavy metals using US EPA (1994b) guidance to develop a wet weather standard that will reflect the fact that the heavy metals in the urban area and highway stormwater runoff are in nontoxic forms. Further, even if the heavy metals in the runoff were toxic, it is unlikely that aquatic organisms in the receiving waters would receive a critical exposure because of the short-term nature of the runoff event and/or the rapid dilution that occurs of the runoff water in the receiving waters.

Since the US EPA guidance for site-specific water quality criteria/standards does not adequately address the discharge of some forms of heavy metals which do not equilibrate during the time that the Water Effects Ratio (WER) toxicity tests are conducted, it can occur that US EPA guidance does not adequately adjust for receiving water characteristics and source forms of heavy metals that influence their toxicity. This situation has been found in San Francisco Bay where stormwater runoff from urban streets and highways causes the Bay waters to have concentrations of copper above WER-adjusted criteria/standards, yet the waters are nontoxic to aquatic life that are highly sensitive to copper. Under these conditions, as discussed by Lee and Jones-Lee (1995a), it may be necessary to work with elected officials to cause the US EPA to modify its Independent Application Policy which requires that chemically based water quality standards must be achieved even though heavy metals, etc., are found through appropriate toxicity testing to be in nontoxic forms.

Regulatory Issues

The US EPA's (1990) stormwater management program required that NPDES-permitted urban area and highway stormwater management areas control **pollution** (impairment of uses) to the maximum extent practicable (MEP) using best management practices (BMPs). The Agency did not define and has still not defined MEP and BMPs.

The US EPA has, however, determined that, ultimately, NPDES-permitted urban area and highway stormwater management agencies must control the concentrations of constituents in the stormwater runoff so that they do not cause or contribute to violations of a water quality standard by any amount more than once every three years. While the time frame for compliance with this requirement has not been specified, recent US EPA actions in California, in connection with promulgation of the California Toxics Rule (CTR) (US EPA, 2000a), indicate compliance with the CTR water quality criteria in NPDES-permitted stormwater runoff at the point of discharge could be required within five years. As discussed by Lee and Jones-Lee (2000a) urban area street and highway stormwater runoff contains a variety of chemical constituents, such as heavy metals, certain organics, nutrients and pathogen-indicator organisms (coliforms) at concentrations in the discharge to receiving waters in excess of receiving water water quality standards. This, in turn, could require that the stormwater management agency control/treat NPDES-permitted urban area and highway stormwater runoff so that the concentrations of regulated constituents do not cause violations of water quality standards at the point of discharge to the receiving waters. In California and many other areas, urban area and highway stormwater runoff is not allowed a mixing zone, and, therefore, the application of water quality standards compliance to the discharge is in the discharge waters to the receiving waters.

Coincidentally with the implementation of the US EPA stormwater runoff water quality management program is the implementation of a total maximum daily load (TMDL) control of constituents in NPDES-permitted as well as non-permitted discharges that cause water quality standards violations that have resulted in the waterbody with the violation being placed on the US EPA Clean Water Act 303(d) list of "impaired" waterbodies. While urban area and highway stormwater runoff is commonly referred to as a "non-point source" discharge, for the purpose of regulating stormwater runoff impacts the US EPA classifies municipal storm water runoff as a point source discharge. It is, therefore, subject to TMDL requirements applied to domestic and industrial wastewater discharges. This means that, as being implemented now in California, if the receiving waters for an NPDES-permitted urban area and highway stormwater runoff are listed on the 303(d) list of impaired waterbodies for constituents that are in urban area and highway stormwater runoff above water quality standards at the point of discharge, the stormwater runoff managers can be required to manage stormwater runoff of the constituents in the runoff that cause or contribute to water quality standards violations. As a result, they can receive a TMDL "wasteload" allocation as part of the implementation of the TMDL program.

Under these conditions, the BMP ratcheting-down process is waived in favor of the TMDL regulatory process, where compliance with regulatory standards can be required in accord with TMDL program implementation requirements. In California and in several other areas, heavy metals in NPDES-permitted urban area and highway stormwater runoff that are at concentrations above water quality standards in the runoff waters are subject to TMDL requirements for the control of the concentrations of these constituents. This is the situation that exists with respect to controlling the copper concentrations in Upper Newport Bay waters.

Jones-Lee and Lee (1998a) and Taylor (1999) have discussed the fact that conventional BMPs will not treat urban stormwater heavy metals to achieve water quality standards. This means that either source control BMPs or advanced wastewater treatment BMPs will be needed to control copper concentrations in urban area and highway stormwater runoff so that they do not cause or contribute to violations of applicable water quality objectives. It is, therefore, imperative that before any BMPs are implemented, a proper evaluation of the water quality use impairment caused by a stormwater runoff constituent such as copper, be determined.

Managing Urban Area Stormwater Runoff Water Quality Impacts

The key to developing a technically valid TMDL goal and site-specific wet weather standards for heavy metals in urban stormwater runoff is a reliable assessment of the impact of the heavy metals on the beneficial uses of the receiving waters. The current US EPA regulatory approach of focusing on heavy metal concentrations relative to worst-case-based water quality criteria/state standards based on these criteria tends to significantly over-regulate heavy metals in urban area and highway stormwater runoff. The US EPA provides some opportunity to adjust the worst case water quality standard for site-specific conditions. The development of an appropriate TMDL goal requires that the testing/evaluation be done to adjust the worst-case-based criteria/standards to the characteristics of the source and the receiving waters. This approach has recently been applied to South San Francisco Bay (Anonymous, *Estuary*, 2000) where, through adjustment of the marine water quality objective for copper, it appears that the exceedance of the US EPA criterion will be eliminated. Presented below is a summary of the issues that should be considered in developing a water quality management program for heavy metals in urban area stormwater runoff.

Assessing Potential Water Quality Problems

Urban stormwater runoff contains elevated concentrations of a variety of constituents that, under certain conditions, may be adverse to the beneficial uses of the receiving water for the discharge/ runoff. Of particular concern are heavy metals. Many of the constituents of concern in discharges/runoff are in particulate forms and, therefore, tend to accumulate in the receiving water sediments to cause these sediments to contain elevated concentrations of potentially toxic chemical constituents. As a result, there may be need to control both dissolved and particulate forms of chemical constituents in stormwater runoff in order to protect the designated beneficial uses of the receiving waters for the runoff.

The first step in developing an appropriate TMDL goal is to determine the impact of the existing runoff on the beneficial uses of the receiving waters. The mechanical comparison of the chemical concentration/characteristics of the stormwater to worst-case-based water quality criteria/standards can lead to erroneous conclusions about adverse impacts of the constituents present in the stormwater runoff above water quality standards. The US EPA (1987) Gold Book criteria, as well as the 1999 (US EPA, 1999a) update of these criteria, are designed to be worst case, which would be protective of aquatic life and other beneficial uses under essentially all conditions. There are few waterbodies where the application of worst-case-based water quality criteria as they are being implemented into discharge limits does not result in excessive treatment compared to that needed to protect beneficial uses.

Need to Incorporate Aquatic Chemistry. It is recognized that concentrations of constituents in the receiving waters above worst-case-based water quality standards can readily occur in most waterbodies without significant adverse impacts on beneficial uses. There are situations, however, where an exceedance of a worst-case-based criterion/standard represents a significant potential threat to the beneficial uses of a waterbody. A basic problem with using US EPA water quality criteria as discharge limits includes the failure to properly incorporate the aquatic chemistry of constituents into their implementation as state standards and NPDES discharge limits. It has been well known since the 1960s that many chemical constituents exist in a variety of chemical forms, only some of which are toxic/available. Further, ambient waters and their sediments contain a wide variety of constituents which detoxify/immobilize toxic/available forms of potential pollutants such as heavy metals, organics, etc. In general, it is not possible to reliably extrapolate from a concentration of a chemical constituent measured using standard chemical analytical procedures to the concentration of toxic/available forms in the receiving water. There are a wide variety of physical, chemical and biological factors that influence this extrapolation which are rarely quantified.

While the US EPA (1995) took the necessary action to focus the regulation of some heavy metals in ambient waters based on dissolved forms, even dissolved forms of some heavy metals in many waters tend to be over-regulated because the heavy metals interact with dissolved organic matter to form nontoxic/non-available complexes. Allen and Hansen (1996) have reviewed the importance of considering trace metal speciation in application of water quality criteria to state standards and discharge limits. This approach is especially important for copper since it tends to form a variety of nontoxic organic complexes. The US EPA has not extended the regulations of heavy metals based on dissolved form to the many other constituents that occur in particulate or dissolved forms where the particulate forms are nontoxic and non-available. This leads to over-regulation of many organics that tend to sorb onto particulates in waterbodies.

Duration of Exposure. A key factor that is not properly incorporated into the application of US EPA water quality criteria and state standards based on these criteria is the duration of exposure that various types of organisms can experience without adverse impacts due to toxic/available forms of a constituent. The current regulatory approach involving no more than one exceedance by any amount every three years is well known to significantly over-regulate most chemical constituents in most waterbodies. It too is based on worst case assumptions that are rarely experienced.

The approach that has been adopted by the US EPA of basing the water quality criteria/state standards on a one-hour average or a four-day average concentration in the water of concern is more of the conservative nature built into these criteria/standards. The one-hour and four-day average criteria for acute and chronic criteria, respectively, are contrived for ease of implementation of a criterion/standard. They are not based on finding that an exceedance of a water quality criterion for acute and chronic toxicity above the criterion value necessarily represents toxic or available conditions.

Inappropriate Independent Application Policy. Yet another factor that makes the approach used for implementing US EPA water quality criteria into discharge limits is the US EPA's policy of independent application of the chemically-based criteria/standards, where these numeric values must be met even if properly conducted aquatic life toxicity tests show that the constituents of concern are in nontoxic/non-available forms. These issues were discussed by Lee and Jones-Lee (1995a). It is recognized that the appropriate approach for implementing US EPA water quality criteria involves the use of the criteria as a screen for potential adverse impacts, where the responsible parties for the discharge work with the regulatory agencies and the public in determining whether the exceedance of the criterion in a waterbody represents a significant use impairment of the waterbody. This approach has been discussed by Lee and Jones-Lee (1995b).

Need for Site-Specific Evaluation. A site-specific evaluation should be conducted to determine whether a particular discharge of stormwater runoff is significantly impairing the beneficial uses of the receiving waters for the runoff. An Evaluation Monitoring approach (discussed below) of the type developed by Lee and Jones-Lee (1996a, 1997b) and Jones-Lee and Lee (1998b) provides a technically valid, cost-effective procedure for evaluating the degree of treatment of stormwater runoff needed to protect the beneficial uses of receiving waters.

The Evaluation Monitoring approach shifts the emphasis in water quality evaluation and management from a chemical concentration-based approach to a chemical impact-based approach. For example, rather than focusing on the concentration of a potentially toxic heavy metal or organic and then trying to extrapolate from the concentrations measured in stormwater runoff or ambient water, Evaluation Monitoring screens for potential toxicity in the runoff and receiving waters using a suite of toxicity tests that utilize sensitive test organisms. If a discharge/runoff and the associated receiving waters are nontoxic, then it may be possible to rule out a large number of the chemical constituents which are regulated based on exceedance of worst-case-based water quality criteria and state standards as a significant threat to the beneficial uses of the receiving waters for the runoff.

Similarly, for constituents that tend to bioaccumulate to excessive levels, such as mercury, in edible aquatic organisms, causing these organisms to be a threat to human health through their consumption, Evaluation Monitoring focuses on screening edible fish/shellfish to determine if excessive bioaccumulation is a water quality problem in a waterbody. If the fish in a waterbody do not contain excessive concentrations of potentially bioaccumulatable chemicals (e.g., Hg), then it is possible to assess that the discharge of such chemicals in stormwater runoff does not lead to excessive bioaccumulation. If, however, excessive tissue residues are found, then it is necessary to determine whether the discharge of these constituents is in a bioavailable form and remains in this form or converts to this form within the receiving waters for the discharge/runoff.

Summary of Approach. A review of existing water quality characteristic data for the stormwater runoff and the receiving waters should be conducted to determine if there is an exceedance of a heavy metal receiving water water quality standard that is caused or contributed to by the stormwater runoff. If an exceedance is found, then determine if a real water quality use impairment (pollution) of the receiving water is occurring in the receiving waters for the stormwater runoff that is due to constituents in the stormwater runoff. The purpose of this effort is to determine if the stormwater runoff is causing or significantly contributing to pollution of the receiving waters for the stormwater runoff. This approach will assess whether the exceedance of the water quality standard is an “administrative” exceedance relative to the highly protective nature of worst-case-based water quality criteria/standards when applied to many constituents in most waterbodies.

If an inadequate database exists to determine if a violation of a water quality standard or a receiving water use impairment is occurring, then initiate a water quality monitoring/evaluation program designed to evaluate whether a significant water quality use impairment is occurring in the stormwater runoff’s receiving waters. Use the Evaluation Monitoring approach in evaluating whether a significant water quality problem exists in the receiving waters for the runoff. Generally, for potentially toxic constituents, this program will involve assessing whether the numbers and types of desirable forms of aquatic life are significantly altered by the toxic pulses of runoff waters.

Addressing Administrative Exceedances of Water Quality Standards. If a water quality standard violation occurs without a significant use impairment of the receiving waters, then petition the regulatory agencies for a “variance” from having to meet water quality standards in the runoff receiving waters based on there being no use impairment occurring in the receiving waters due to the stormwater runoff-associated constituents. This effort will enable stormwater runoff water quality managers to reveal and appropriately address the over-regulation that arises from the US EPA’s Independent Applicability Policy and the use of worst-case-based water quality criteria/standards.

This effort should include the opportunity to adjust the receiving water standards (wet weather standards)/stormwater discharge limits and/or the designated uses of the receiving waters to protect the designated beneficial uses of receiving waters for the stormwater runoff without significant unnecessary expenditures for chemical constituent control. These adjustments should be based on appropriately conducted receiving water studies that focus on assessing chemical impacts, rather than the traditional approach of measuring chemical concentrations and loads. The US EPA (1994b), in their Water Quality Standards Handbook, provides guidance on how the worst-case-based water quality criteria can be adjusted for site-specific conditions. It is important to understand, however, that the Agency’s approach for developing site-specific criteria/standards can still lead to over-regulation since it does not fully account for the aqueous environmental chemistry of constituents as they may impact the beneficial uses of a waterbody.

Determining the Cause of the Pollution and the Source of the Pollutant. If a water quality use impairment is found in the receiving waters for the stormwater runoff, determine the specific causes of the use impairment and, through forensic studies, whether the toxic/available form of the specific constituent(s) responsible for the use impairment is derived from the stormwater runoff of concern. Also determine the relative significance of the stormwater runoff versus other sources of the specific constituents responsible for the use impairment as a cause of the use impairment. The relative contribution information is needed to evaluate the potential improvement in the receiving water water quality as a result of implementation of the proposed BMPs.

Managing Contaminated Sediment Quality Issues
The aquatic sediments near points of urban area and highway stormwater runoff can contain elevated concentrations of a variety of chemical constituents that are potential pollutants that have been derived, at least in part, from stormwater runoff. Increasing regulatory attention is being given at the federal and state level to managing the water quality impacts of chemical constituents in aquatic sediments. This is leading to the development of an aquatic "Superfund" - aquafund-like program in which principal responsible parties (PRPs) are being designated to pay for contaminated sediment remediation. Further, the NPDES wastewater and/or stormwater discharge permits for suspected sources of the constituents that are present in the sediments at elevated concentrations are being modified to reduce the input of the associated constituents. The California Water Resources Control Board (WRCB, 1998) has adopted the Bay Protection and Toxic Hot Spot Cleanup Program Policy that implements a California aquatic sediment aquafund. Lee and Jones-Lee (1998c) have discussed the significant technical problems with the BPTCP toxic hot spot cleanup Policy. This Policy, as adopted, will lead to inappropriate designation of toxic hot spots and the naming of PRPs for their remediation.

Reliable Evaluation of the Water Quality Significance of Chemical Constituents in Aquatic Sediments. There is considerable misinformation on how to reliably evaluate whether a chemical constituent or group of constituents present in an aquatic sediment are significantly impairing the beneficial uses of the waterbody in which the sediments are located. There are basically two approaches being advocated. One of these is a chemical concentration approach, which focuses on identifying elevated concentrations of a chemical constituent that at some locations and under certain conditions is in a form that is adverse to the organism assemblages present within or on the sediments. The other is a biological effects-based approach which focuses on measuring chemical impacts rather than chemical concentrations.

There are situations where constituents in sediments that are of concern because of their potential to bioaccumulate to excessive levels in higher trophic level edible organisms (fish and shellfish) serve as important sources of hazardous chemicals in fish that are used as food. There are also situations where the elevated concentrations of potentially toxic or bioaccumulatable chemicals in sediments are in nontoxic non-bioavailable forms. It is well established since the 1960s that there is no relationship between the concentrations of chemical constituents in sediments and their toxicity/availability for bioaccumulation. As discussed by Lee and Jones-Lee (1992), (Lee and Jones, 1994, 1996b, 2000b), and Lee and Taylor (1999) the toxicity/availability of chemical constituents in aquatic sediments is determined by the concentration of many of the bulk parameters of the sediments such as TOC, sulfides, carbonates, clays, iron and aluminum oxides, etc., that interact with the potential pollutants to cause them to be nontoxic. The US EPA has recently released guidance for bioaccumulation testing and interpretation for the purpose of sediment quality assessment (US EPA, 2000b).

Some regulatory agencies at the federal and state level such as the US EPA (Keating, 1998), have adopted or are in the process of adopting sediment quality guidelines based on co-occurrence approaches. Since this approach involves relating the total concentration of a chemical constituent in sediments to a water quality impact, co-occurrence-based guidelines are technically invalid. Lee and Jones-Lee (1993a,b; 1996b,c), as well as many others such as O'Connor (1999a,b) have discussed the unreliability of co-occurrence-based guidelines.

O'Connor (1999a), based on a critical review of the NOAA and US EPA data, concluded, "*All these criteria are better than random selections in identifying toxic sediment but they are not reliable. They are all more often wrong than right and should not be used, by themselves, to imply anything about biological significance of chemical data.*" Co-occurrence-based sediment guidelines are unreliable and should not be used even as screening values to infer that a concentration of a chemical constituent in aquatic sediments is responsible for any water quality impacts that may be associated with those sediments. Such an association can readily lead to erroneous conclusions on the chemicals responsible for aquatic life toxicity and the sources of those constituents.

The SARWQCB (2000), as part of developing the problem statement for the TMDL for toxic substances in Upper Newport Bay and San Diego Creek, has devoted considerable attention to reporting on the BPTCP studies that were conducted in Upper Newport Bay in the mid 1990s. Lee and Taylor (1999) have reviewed these studies and have discussed that the approach used, which focuses on co-occurrence-based approaches, is technically invalid. While the US EPA has in the past been potentially supportive of the use of co-occurrence-based approaches for developing sediment quality guidelines, in July 2000 the Agency (US EPA, 2000b) has indicated that the primary basis for regulating constituents in sediments should be sediment toxicity and bioaccumulation measurements. In this recent review by the Agency, it is stated:

> "*The EqP* [equilibrium partitioning] *approach to developing sediment guidelines for the protection of benthic organisms offers advantages over empirical approaches, which derive guidelines from paired sediment chemical concentration and biological effects data. The data used in empirical approaches typically originate from sediments containing a mixture of contaminants, making it difficult to ascribe the cause of toxicity to a particular chemical. By contrast, the EqP theory accounts for the bioavailability of chemicals, using individual chemical data. The EqP theory thus facilitates the identification of causative agents of toxicity and the establishment of targets for pollutant reduction measures.*"

The reference to the empirical approaches is concerned with the co-occurrence-based values of the type that were used in the BPTCP and that are presented in the SARWQCB 2000. The Agency also states:

> "*The EPA does not recommend that ESGs* [Equilibrium Partitioning Sediment Guidelines] *be adopted as numeric criteria. Rather, EPA recommends that States and Tribes use their narrative water quality criteria to protect sediment quality as determined necessary to protect and maintain designated uses. Under this approach, the narrative criteria can be implemented using whole sediment toxicity tests (along with benthic community assessments, if desired) as the primary indicator for assessing water quality and determining whether waters are attaining the applicable water quality standards with respect to sediment toxicity... .*"

The US EPA's draft July 2000 recommended approach of focusing on biological effects-based assessments of chemical constituents in sediments is similar to that recommended by Lee and Jones (1992). They discussed the unreliability of trying to use chemically based approaches to assess sediment toxicity or their potential to contain bioavailable forms of chemical constituents that could bioaccumulate to excessive levels in edible aquatic life.

At this time, there has not been a reliable assessment of the water quality problems, if any, associated with the accumulation of constituents derived from urban stormwater runoff or any other source in Upper Newport Bay sediments. Lee and Taylor (1999), conclude, based on the studies that have been done, that it is unlikely that the chemical constituents in the sediments of Upper Newport Bay are having a significant impact on the beneficial uses of the Bay. The first phase of any TMDL to control the concentrations of constituents in Upper Newport Bay and Lower Newport Bay sediments, should be devoted to a proper evaluation of what, if any, significant water quality problems are occurring in the Bays due to chemical constituents in the sediments. Further, an assessment should be made of the magnitude of the improvement of the Bays' water quality-beneficial uses that will occur associated with removal of chemically contaminated sediments from the Bay or restrictions of discharge of constituents from urban and rural sources to the Bay.

Specific Components of Suggested Approach. The approach that can be followed in evaluating whether elevated concentrations of a heavy metal in stormwater runoff that accumulate in sediments represent a potential cause of water quality impairment in the receiving waters and, therefore, should be subject to TMDL limitations, includes the following.

Aquatic Life Toxicity

- Determine if the sediments are toxic using several sensitive test organisms and several appropriate toxicity test reference sites. Conduct toxicity tests at three sites (minimum) in the area of concern quarterly for a year.
- If the sediments are toxic, determine if the aquatic life assemblages associated with the toxic sediments are significantly different from those present in the reference areas as well as nearby apparently less impacted sediments than those of primary concern.
- Determine if there is an aquatic organism assemblage gradient that is apparently related to toxicity in the sediments of concern.
- If there is a significant aquatic organism assemblage gradient that persists for an extended period of time that is apparently related to toxicity of the sediments of concern, evaluate the water quality significance of this toxicity. Also evaluate the potential improvement in the designated beneficial uses of the waterbody if the toxic sediments were remediated.

  It is important to note that this evaluation program has not thus far included any attempt to determine the cause of the sediment toxicity.
- Evaluate the potential cost of sediment remediation.
- If sediment toxicity appears to be a significant cause of a water quality use impairment and it appears to be economically feasible to remediate the contaminated sediments to eliminate the sediment toxicity, then proceed with evaluation of the cause of sediment toxicity.
- Conduct sediment chemistry/toxicity investigations (sediment TIEs) to determine the constituents that are in the sediments that are responsible for the toxicity.
- Do not use co-occurrence-based sediment quality guidelines to "associate" the presence of chemical constituents in aquatic sediments with constituents that are toxic to aquatic life that cause significantly altered organism assemblages.

Excessive Bioaccumulation

- Determine if edible fish/shellfish from the waterbody, preferably in the area of concern, contain excessive concentrations of potentially hazardous chemicals that would cause the use of these fish as food to be a threat to human health. US EPA (1999b) provides guidance on conducting bioaccumulation investigations. Use a human health-based guideline consumption rate of one meal of local fish per week. Evaluate if this consumption rate is appropriate for local populations that are consuming the fish from the waterbody of concern.
- Determine the chemical characteristics of the sediments twice per year (late spring and fall).
- Determine the concentrations of the suite of heavy metals, PAHs, chlorinated hydrocarbon pesticides, PCBs and dioxins. Analyze the sediments for those chemical constituents that have been found to be present in excessive concentrations in edible fish taken from the waterbody.
- If the sediments of concern contain elevated concentrations of constituents that have accumulated in edible aquatic life tissue to cause the use of the aquatic life as food to be considered a threat to human health, utilize the US EPA/COE (1991, 1998) and the US EPA (2000c,d) procedures to assess the bioavailability of the constituents of concern in the sediments.

This information should be used to determine whether the elevated concentrations of chemical constituents that are potentially bioaccumulatable in a sediment are contributing to the excessive bioaccumulation problem within organisms taken from the waterbody in which the sediments are located. The benthic invertebrate sampling can help identify the sediment sources of constituents that are bioaccumulating to excessive levels.

Forensic Source Studies

In order to control the development of future contaminated sediments and water column toxicity/bioaccumulation problems, it is necessary to define the source(s) of the constituents that have been and/or could be causing water quality problems. In some situations this is relatively obvious, in that there is a single discharger that is isolated from all other sources of the same types of constituents of concern responsible for the sediment or water column toxicity or excessive bioaccumulation. However, in many situations, such as in bays or in major urban industrial areas, there will be multiple discharges/sources of the same general types of constituents that are causing the water quality problem. Under these conditions it is necessary to conduct a forensic study to determine the specific source(s) of the specific constituent(s) responsible for the adverse impact on water quality.

This type of study should not follow the approach of using elevated concentrations of constituents in the sediments to define the constituent(s) responsible for the toxic hot spot (toxicity source or source of the bioaccumulatable chemicals) in which a source of the elevated concentrations of the constituents is any discharger that has the same constituents in the discharge as were "associated" with the toxic hot spot. Such an approach is technically invalid in that it ignores the aqueous environmental chemistry of chemical constituents that controls the toxic/available forms of potential pollutants.

All copper from all sources in all waterbodies is not equally toxic. The same situation applies to many other constituents. While tentative sources of potential pollutants can be identified through association based on elevated concentrations, detailed site-specific investigations must be conducted to confirm that a potential source is in fact a real source of pollutants whose stormwater NPDES permit or discharge limits should be modified to control the input of pollutants.

These forensic studies must include detailed consideration of the aqueous environmental chemistry of the constituents of concern within the waterbodies of concern to determine whether a particular discharge of a potential pollutant of concern is toxic/bioavailable at the discharge and/or converts to toxic/bioavailable forms within the receiving waters for the discharge that accumulate/are present at sufficient concentrations to cause a water quality use impairment at the point of concern.

When there are multiple sources of potentially significant constituents, then an attempt to quantify the relative contributions of each source should be made. Again, this should not be done based on a total concentration mass load approach. As discussed by Lee and Jones-Lee (1996d), it should be based on a site-specific evaluation of the aqueous environmental chemistry/toxicology of the constituents derived from each source.

Selection and Economic Evaluation of BMPs

Select a BMP(s)/treatment process(es) to control the specific constituents responsible for the use impairment. The BMP/treatment process selection should be based on the specific chemical species that cause a water quality use impairment in the receiving waters, rather than the total concentrations of the constituent. For example, focus the BMP on removing those forms of dissolved copper that are significantly adverse to beneficial uses in the receiving waters for the runoff rather than on total copper, much of which is in a nontoxic form.

Evaluation of Cost Effectiveness of a BMP(s) in Controlling Significant Pollution. If the development and operation of the proposed stormwater runoff BMP appears to be economically feasible, then estimate the potential improvement in the designated beneficial uses that will occur relative to the unregulated or under-regulated sources of the same pollutant(s) responsible for the use impairment. If the potential improvements in the receiving water's designated beneficial uses is limited compared to projected costs to eliminate the use impairment, then the community leaders, regulatory agencies, environmental groups and public groups that are interested in appropriate use of funds should be consulted to evaluate if the expenditures for stormwater runoff chemical constituent control is the best use of the funds potentially available to meet societal needs.

Evaluation of the Efficacy of the BMP(s). Evaluate the efficacy of the stormwater runoff BMP in controlling existing use impairments as well as preventing new use impairments. The traditional approach of measuring the removal of a chemical constituent(s) such as a heavy metal across a structural BMP such as a filter, detention basin, etc., does not evaluate whether the BMP/treatment process causes an improvement in the receiving water's impaired uses. BMP/treatment process efficacy evaluations must be based on evaluating the improvements that the BMP/treatment process causes or, for new developments, is expected to cause in the receiving water beneficial uses. This will require site-specific studies of the impact of the development and operation of the BMP/treatment process on the receiving waters' beneficial uses for the treated discharge.

Detection of Future Stormwater Runoff Water Quality Problems.
Develop an ongoing monitoring/evaluation program to search for subtle and new water quality use impairments. An important component of a properly developed and implemented stormwater runoff water quality management program is the funding of a stakeholder consensus-based monitoring/evaluation program to detect subtle water quality problems that were not detected in the initial search for real significant water quality use impairments. This program should be designed to detect new water quality use impairments that arise from the use of new or expanded-use chemicals that become part of stormwater runoff. The search for undetected and new problems should be repeated every five years to coincide with the NPDES permit cycle.

Watershed-Based Approach
The stormwater runoff BMP selection should be formulated/implemented on a watershed-based water quality management program in which the stakeholders for the management of the stormwater runoff water quality and the beneficial uses of the receiving waters and downstream waters for the stormwater runoff that could be impacted by the runoff, work together in a consensus-based approach to formulate, implement and evaluate the stormwater runoff water quality management program.

Funding of Site-Specific Evaluation
While some potential dischargers of chemical constituents that could be adverse to the beneficial uses of a waterbody assert that it is the responsibility of the regulatory agency to prove that their discharge has or is, in fact, causing pollution-impairment of the beneficial uses of a waterbody, the burden of proof for water pollution control should be on the discharger rather than the impacted public/regulatory agencies. However, in adopting this approach it is incumbent on the regulatory agencies to carefully specify the conditions under which potential polluters are designated. Approaches such as those adopted by the California Water Resources Control Board in its BPTCP Policy (WRCB, 1998), in which "association" of elevated concentrations of chemical constituents is used to designate a toxic hot spot, should not be considered since they can lead to frivolous designation of pollutants and/or responsible parties for contaminated sediment cleanup and NPDES permit modification.

It is important to understand that the adversarial regulatory system that exists today cannot tolerate frivolous designation of toxic hot spots. There are a number of examples where the designation of pollutants in sediments have been made using co-occurrence-based approaches that cause the public to have to spend large amounts of funds cleaning up contaminated sediments under conditions where this expenditure will not result in an improvement of the beneficial uses of a waterbody. This type of situation that occurred with copper in San Diego Bay has been discussed by Jones-Lee and Lee (1994).

The implementation of higher quality science and engineering into water quality management will require a substantial increase in site-specific evaluations compared to the approach that is being used today to develop regulatory requirements for a particular discharge/runoff. The discharger should be given the option of either complying with worst-case-based chemical constituent control or complying with an appropriate assessment of the real impacts that chemical constituents in discharges/runoff have on the beneficial uses of a waterbody. Adoption of this approach would encourage dischargers, both public and private, to invest in watershed-based, stakeholder consensus-developed receiving water evaluations in order to improve the cost-effectiveness of expenditures for water pollution control.

A Technically Valid Water Quality Management Approach - A Water Quality Triad

The US EPA, as part of adopting a chemical concentration-based approach in the early 1980s, opted for a bureaucratically simple to administer but technically invalid approach. While some of the Agency staff claim that this approach is highly successful, in fact, it is strongly contrary to the public's interests. In order to avoid waste of public and private funds chasing ghosts of problems associated with exceedance of a worst-case-based water quality criterion/standard, there is need to elevate the quality of science and engineering to the current level of understanding of how chemical constituents impact aquatic life and other beneficial uses of waterbodies.

The water quality triad approach is evolving as a regulatory approach in which the current science and engineering can be incorporated into defining a real significant water quality use impairment and the approach that should be used for its control/remediation. A water quality triad evaluation of potential beneficial use impairments of a waterbody is based on a non-numeric, best professional judgment, integrated assessment of information on aquatic organism assemblages, toxicity, bioaccumulation and chemical information. It involves determination of the numbers, types and characteristics of aquatic life present in a waterbody relative to the habitat characteristics. It also involves an assessment of aquatic life toxicity to a suite of sensitive test organisms relative to appropriate reference controls, as well as the use of chemical techniques (toxicity investigation evaluations) to determine, through toxicity assessments on the fractionated sample, the chemical constituents responsible for aquatic life toxicity.

As discussed by Lee and Jones-Lee (1999a), the water quality triad should be implemented through a panel of experts in the topic area of concern, where this panel critically evaluates the adequacy of the current data/information base in defining a real significant water quality use impairment and the cause/source of the constituents responsible for the use impairment. If an inadequate database is available for a reliable evaluation, then the discharger(s) should work with the regulatory agencies and the public to develop the additional information needed. When this information is available it should be critically reviewed by the triad expert panel and a decision should be rendered by the panel on the magnitude of the water quality problem that exists, its significance to the public's interests and approaches with associated costs for its control/ remediation. This information should then be used by the regulatory agency to implement a technically valid, cost-effective water quality management program.

Addressing Disagreements Among Experts

It is recommended (Lee, 1999a) that a public interactive peer review of technical issues be conducted in order to resolve disagreements among experts, including the water quality triad panel members, on complex technical issues. By adopting a public interactive peer review process, anyone who peer-reviews a topic must be prepared to defend these reviews in a public arena where those who find that the reviews are inadequate have the opportunity to point out the inadequacies of these reviews under a situation where the review board has the opportunity to hear an exchange of discussion of issues and receive written documentation with appropriate references in support of positions by the parties involved.

The peer review should not be conducted by a single individual but should involve the development of a peer review panel consisting of at least three knowledgeable individuals. The selection of the peer reviewers for the peer review panel should be a public process where the peer reviewers are knowledgeable and will take the time to fully review the pertinent information on the topic. They should review not only the regulatory board staff's discussion on issues, but also the comments made by others on the lack of validity of the staff's approach as well as those of the project proponents and others who commented on the issues.

The peer review panel should present the preliminary results of their reviews in a public meeting where the public has the opportunity to question and comment on the adequacy of the review. The reviewers then should be given the opportunity to make revisions in their review based on any new information obtained and develop a final review which is then submitted to the Board, where again the public would have the opportunity to comment on its adequacy. The peer reviewers should be adequately compensated for their time and expenses associated with the peer review process.

Conclusions

The development of TMDL goals to control heavy metals in stormwater runoff that exceed a water quality standard requires a detailed investigation of the water quality beneficial use impairment that is caused by the heavy metals for which a TMDL must be developed. This effort should lead to site-specific TMDL goals that will protect the beneficial uses without unnecessary expenditures for heavy metal control. The stormwater runoff BMP development approach recommended herein is designed to transform the development of stormwater runoff BMPs to one that incorporates current science and engineering information into water quality management. Adoption of this approach will enable stormwater runoff water quality managers to select, implement and properly evaluate the efficacy of stormwater runoff water quality BMPs that will cost-effectively address real water quality use impairments in the receiving waters for the runoff in a technically valid manner. This is the approach that is recommended for addressing the exceedance of the CTR criterion for copper that occurs in Upper Newport Bay waters.

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References

Allen, H. E. and Hansen, D. J., "The Importance of Trace Metal Speciation to Water Quality Criteria," *Water Environment Research,* 68:42-54 (1996).

Anonymous, "Delisting Copper," *Estuary*, Vol. 9, No. 6, pp. 5-6 and 8, December (2000).

Gerstenberg, G., "Management Plan Upper Newport Bay Ecological Reserve," State of California Resource Agency Department of Fish and Game, Newport Beach, CA (undated).

Jones-Lee, A. and Lee, G. F., "Evaluation of the Water Quality Significance of Copper in San Diego Bay Sediments," Division Environmental Chemistry, American Chemical Society meeting, extended abstract, Washington, DC, pp. 107-108, March (1994).

Jones-Lee, A. and Lee, G. F., "Stormwater Managers Beware of Snake-Oil BMPs for Water Quality Management," Report of G. Fred Lee and Associates, El Macero, CA. Available from www.gfredlee.com (1998a).

Jones-Lee, A. and Lee, G. F., "Evaluation Monitoring as an Alternative to Conventional Water Quality Monitoring for Water Quality Characterization/Management," Proc. of the NWQMC National Conference *Monitoring: Critical Foundations to Protect Our Waters*, US Environmental Protection Agency, Washington, D.C., pp. 499-512 (1998b).

Keating, J., "Use of Sediment Chemistry and Toxicity Tests to Interpret Narrative Standards for Sediment Quality," Presented at US EPA Meeting on Water Quality Standards, Water Quality Criteria and Implementation, Including Water Quality-Based Permitting, Philadelphia, PA, August (1998).

Lee, G. F., "Assessment of Potential Urban Area and Highway Stormwater Runoff Water Quality Standards Compliance Problems," Report to CA State Storm Water Quality Task Force Stormwater Science Work Group, G. Fred Lee & Associates, El Macero, CA, December (1998).

Lee, G. F., "Public Interactive Peer Review Process for Water Quality Technical Dispute Resolution: A Guide For Implementation of H&S Code Section 57004 for Conducting Peer Review of Proposed Policy," Report of G. Fred Lee & Associates, El Macero CA, October (1999a).

Lee, G. F. and Jones, R. A., "Sediment Quality Criteria Development: Problems with Current Approaches," Workshop notes, 1992 National R & D Conference on the Control of Hazardous Materials, Hazardous Materials Control Research Institute, Greenbelt, MD, 120pp, February (1992).

Lee, G. F. and Jones-Lee, A., "Sediment Quality Criteria: Numeric Chemical- vs. Biological Effects-Based Approaches," Proc. *Water Environment Federation National Conference, Surface Water Quality & Ecology,* pp. 389-400 (1993a).

Lee, G. F. and Jones-Lee, A., "Equilibrium Partitioning-Based Values: Are They Reliable for Screening Contaminated Sediment?" Letter to the editor of *Environ. Sci. & Technol.*, 27:994 (1993b).

Lee, G. F. and Jones-Lee, A., "Contaminated Dredged Sediment Disposal Criteria," Proc. ASCE "Dredged 94" Second International Conference on Dredging and Dredged Materials Placement, Orlando, FL, pp. 121-130 (1994).

Lee, G. F. and Jones-Lee, A., "Independent Applicability of Chemical and Biological Criteria/Standards and Effluent Toxicity Testing," *The National Environmental Journal*, 5(1):60-63, (1995a), Part II, "An Alternative Approach," 5(2):66-67 (1995a).

Lee, G. F. and Jones-Lee, A., "Appropriate Use of Numeric Chemical Water Quality Criteria," *Health and Ecological Risk Assessment*, 1:5-11. Letter to the Editor, Supplemental Discussion, 1996, 2:233-234 (1995b).

Lee, G. F. and Jones-Lee, A., "Assessing Water Quality Impacts of Stormwater Runoff," North American Water & Environment Congress, Published on CD-ROM, Amer. Soc. Civil Engr., New York, NY. Available at: www.gfredlee.com (1996a).

Lee, G. F. and Jones-Lee, A., "Evaluation of the Water Quality Significance of the Chemical Constituents in Aquatic Sediments: Coupling Sediment Quality Evaluation Results to Significant Water Quality Impacts," In: WEFTEC '96, Surface Water Quality and Ecology I & II, Vol 4, pp. 317-328, Proc. Water Environ. Fed. Annual Conference (1996b).

Lee, G. F. and Jones-Lee, A., "'Co-Occurrence' in Sediment Quality Assessment," Report of G. Fred Lee & Associates, El Macero, CA. Available from www.gfredlee.com (1996c).

Lee, G. F. and Jones-Lee, A., "Summary of Issues Pertinent to Regulating Bioaccumulatable Chemicals," Report of G. Fred Lee & Associates, El Macero, CA, September (1996d).

Lee, G. F. and Jones-Lee, A. "Chromium Speciation: Key to Reliable Control of Chromium Toxicity to Aquatic Life," Presented at the American Chemical Society National Meeting poster session, San Francisco, CA, April (1997a).

Lee, G. F. and Jones-Lee, A., "Development and Implementation of Evaluation Monitoring for Stormwater Runoff Water Quality Impact Assessment and Management," Report of G. Fred Lee & Associates, El Macero, CA, June (1997b).

Lee, G. F. and Jones-Lee, A., "Under-Regulation of Chromium in Ambient Waters," Learned Discourses: Timely Scientific Opinions, *SETAC News* 18(4):22 July (1998a).

Lee, G. F. and Jones-Lee, A., "Under-Regulation of Chromium in Ambient Waters - Expanded Discussion," Report of G. Fred Lee & Associates, February (1998b).

Lee, G. F. and Jones-Lee, A., "Comments on 'Draft Functional Equivalent Document Water Quality Control Policy for Guidance on the Development of Regional Toxic Hot Spot Cleanup Plans' Developed by Division of Water Quality, State Water Resources Control Board, March 1998," Submitted to the State Water Quality Resources Control Board, G. Fred Lee & Associates, El Macero, CA. Available from www.gfredlee.com (1998c).

Lee, G. F., and Jones-Lee, A., "Appropriate Use of Chemical Information in a Best Professional Judgment Water Quality Weight of Evidence Evaluation," Report of G. Fred Lee & Associates, El Macero, CA (1999a).

Lee, G. F. and Jones-Lee, A., "Development of TMDLs and Wet Weather Standards for the Control of Heavy Metals in Urban Stormwater Runoff," Proceedings WEFTECH 2000 Water Environment Federation annual meeting, Anaheim, CA, October (2000a).

Lee, G. F. and Jones-Lee, A., "Water Quality Aspects of Dredging and Dredged Sediment Disposal," In: Handbook of Dredging Engineering, McGraw Hill pp. 9-23 to 9-59 (originally published in 1992). An updated version of this chapter which will appear in the 2nd edition of this handbook is available from www.gfredlee.com (2000b).

Lee, G. F., and Taylor, S., "Results of Aquatic Life Toxicity Studies Conducted During 1997-99 in the Upper Newport Bay Watershed, and Review of Existing Water Quality Characteristics of Upper Newport Bay, Orange County CA and its Watershed," Submitted to State Water Resources Control Board, Santa Ana Regional Water Quality Control Board, and Orange County Public Facilities and Resources Department, to meet the requirements of the US EPA 205(j) project, Report of G. Fred Lee & Associates, El Macero, California October (1999). (The aquatic toxicity part of this report is available from www.gfredlee.com.)

Lee, G. F., Taylor, S., and County of Orange Public Facilities and Resources Department, "Upper Newport Bay Water Quality Enhancement Project, Final Report," Agreement Nos. 8-023-258-0 and 8-174-250-0, submitted to State Water Resources Control Board, Santa Ana Regional Water Quality Control Board and Orange County Public Facilities and Resources Department to meet the requirements of the US EPA 319(h) Project, G. Fred Lee & Associates, El Macero, CA and RBF Consulting, Irvine, CA, May (2001).

OCEMA. "Land Use within the Upper Newport Bay Watershed." Provided by R. Boon. (1990).

O'Connor, T. P., "Sediment Quality Guidelines Do Not Guide," Learned Discourses: Timely Scientific Opinions, *SETAC News*, January (1999a).

O'Connor, T. P., "Sediment Quality Guidelines Reply-to-Reply," Learned Discourses: Timely Scientific Opinions, *SETAC News*, May (1999b).

OCPFRD, "NPDES Annual Progress Report," Orange County NPDES Stormwater Program, County of Orange and the Orange County Flood Control District, Santa Ana, CA, November 15 (1998, 1999).

SARWQCB, "Final Problem Statement for the Total Maximum Daily Load for Toxic Substances in Newport Bay and San Diego Creek," California Regional Water Quality Control Board Santa Ana Region, Riverside, CA., December 15 (2000).

Schlekat, C. E.; Dowdle, P. R.; Lee, B. G.; Luoma, S. N. and Oremland, R. S., "Bioavailability of Particle-Associated Se to the Bivalve *Potamocorbula amurensis*," *Environmental Science and Technology*, Vol. 34, No. 21, pp. 4504-4510 (2000).

Simons, Li and Associates, "Project Report for San Diego Creek, Facility F05 From Jamboree Road to Jeffrey Road, Phase I: Hydrologic, Hydraulic and Sedimentation Study," Report to Orange County Environmental Management Agency by Simons, Li and Associates, Santa Ana, CA, October (1987).

Stewart, A. R.; Louma, S. N.; Doblin, M.; Hieb, K. and Miles, K., "Bioaccumulation of Selenium in the Food Web of San Francisco Bay: Importance of Feeding Relationships," CALFED Bay-Delta Program Science Conference, Sacramento, CA, October (2000).

Stover, E. L.; Fort, D. J.; Copenhaver, M. B. and Stanford, C. C., "Evaluating Site Specific Impact of Selenium on Aquatic Ecosystems," Proceedings of the Water Environmental Federation-CD-ROM, WEFTEC 2000 73rd Annual Conference, October (2000).

Taylor, S., "Watershed Stormwater Runoff BMP Retrofit Evaluation, An Analysis of Cost and Benefit," ASCE International Water Resources Engineering Conference, Washington DC, August (1999).

US EPA, *Quality Criteria for Water 1986*, EPA 440/5-86-001, US Environmental Protection Agency, Office of Water Regulations and Standards, Washington, DC (1987).

US EPA, "National Pollutant Discharge Elimination System Permit Application Regulations for Stormwater Discharges; Final Rule," US Environmental Protection Agency, 40 CFR Parts 122, 123 and 124, *Federal Register* 55(222):47990-48091, November 16 (1990).

US. EPA, "Water Quality Standards Handbook: Second Edition," U.S. Environmental Protection Agency, Office of Water, EPA-823-B-94-005, Washington, DC (1994b).

US EPA, "Stay of Federal Water Quality Criteria for Metals; Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants; States' Compliance--Revision of Metals Criteria; Final Rules," *Federal Register*, 60(86): 22228-22237 (1995).

US EPA, "Methods and Guidance for Analysis of Water," US Environmental Protection Agency, EPA 821-C-97-001, Washington DC, April (1997).

US EPA, "National Recommended Water Quality Criteria-Correction," US Environmental Protection Agency, Office of Water, EPA 822-Z-99-001, Washington DC, April (1999a).

US EPA, "Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California; Rule," US Environmental Protection Agency, Region 9, *Federal Register* 40 CFR Part 131, Vol. 65, No. 97, [FRL-6587-9], RIN 2040-AC44, San Francisco, CA., May 18 (2000a).

US EPA, "Draft Implementation Framework for the Use of Equilibrium Partitioning Sediment Guidelines, Guidance for Using Equilibrium Partitioning Sediment Guidelines (ESGs) in Water Quality Programs," US Environmental Protection Agency, Office of Water, Washington, DC, July (2000b).

US EPA, "Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment, Status and Needs," US Environmental Protection Agency, Office of Water, EPA-823-R-00-001, Washington, DC, February (2000c).

US EPA, "Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment, Status and Needs," US Environmental Protection Agency, EPA-823-R-00-001 and EPA-823-R-00-002, Washington, DC, February (2000d).

US ESA, "National Primary Drinking Water Regulations; Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring; Final Rule," US Environmental Protection Agency, Federal Register 66(14):6975-7066, 40 CFR Parts 9, 141 and 142, January 22 (2001).

US EPA/US COE, "Evaluation of Dredged Material Proposed for Ocean Disposal-Testing Manual," US Environmental Protection Agency, Office of Water, EPA-503/8-91/001, Washington, DC (1991).

US EPA/COE, "Evaluation of Dredged Material Proposed for Discharge in Waters of the US: Testing Manual: Inland Testing Manual," EPA-823-B-98-004, US Environmental Protection Agency/Corps of Engineers, Washington, DC, February (1998).

WRCB, "Water Quality Control Policy for Guidance on Development of Regional Toxic Hot Spot Cleanup Plans," CA Water Resources Control Board, Sacramento, CA, September (1998).