Characteristics of dredged material disposal to the Southern California Bight between 1991 and 1997

Andrea Steinberger, Eric Stein, and Kenneth C. Schiff

ABSTRACT - Harbors in the Southern California Bight (SCB) are dredged annually in order to maintain shipping lanes and ensure navigability for recreational and economic purposes. There are several possible fates for dredged sediments, including their use for beach replenishment and disposal at upland sites; however, the majority of dredged sediments are discharged to the ocean at designated sites on the continental shelf of the SCB. These sediments may contain contaminants that have been deposited over time from a variety of sources, including runoff from surrounding watersheds. Consequently, it is important to understand whether dredged materials are a significant source of contaminants to the SCB, necessitating greater management concern.

The goal of this study was to evaluate pollutant loading to the SCB from the ocean disposal of dredged materials between 1991 and 1997, and to gauge the relative significance of contaminant inputs from dredged materials by comparison to discharges from large municipal wastewater treatment facilities (POTWs). Between 1991 and 1997, 2,681,247 cubic meters of sediments were dredged from southern California harbors and bays, and discharged to designated sites within the SCB. Of the 42 permitted dredging projects that contributed to this quantity, 14 conducted chemical analyses on the sediments disposed, representing 82% of the total volume discharged. Data from these 14 projects were used to estimate constituent mass emissions and average concentrations of the disposed sediments. Between 1991 and 1997, dredged materials contributed 0.03% of the discharge volume from large POTWs and dredged materials combined, while contributing over seven times the amount of solids that were discharged by large POTWs. Over the seven-year period analyzed, dredged materials represented a significant portion of the constituent load for several contaminants, including chromium, lead, mercury, PAHs, and PCBs. Furthermore, the relative dredged material contributions to the combined constituent load increased from the previous seven-year period between 1984 and 1990. Given that large POTWs have historically been the most significant point source of contaminants to the SCB, the comparability of contaminant inputs from dredged materials exemplifies the significance of dredged material disposal as a source of pollutant loading to the coastal environment.

INTRODUCTION

Since 1931 a variety of waste materials such as refinery wastes, chemical wastes, filter cake, oil drilling wastes, radioactive wastes, military explosives, refuse, and garbage have been disposed of at designated disposal sites in the Southern California Bight (SCB) SCCWRP 1973). With the passage of the Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA) and the 1988 Ocean Dumping Ban Act, ocean disposal has been mostly limited to sediments dredged from within the harbors and bays of the SCB (U.S. Congress 1987). Nonetheless, significant volumes of sediment are dredged every year in order to maintain shipping lanes and ensure navigability of the harbors and bays for both economic and recreational purposes (EPA/COE 1991).

Dredged sediments can be used for beach replenishment projects if the sediments are determined to be clean and have a comparable grain size to sand at the intended replenishment site (Appendix I) (EPA/COE 1991). Dredged sediments that are highly contaminated must be either left undisturbed or removed, treated, and disposed of at an upland site. The majority of sediments, however, are classified in between these two extremes and are discharged to open ocean disposal sites. Between 1991 and 1997, three designated disposal sites existed within the SCB to receive discharges of dredged sediments. These sites were the LA-2 Los Angeles site, LA-3 Newport site, and the LA-5 Pt. Loma site (Figure 1, Appendix II). These disposal sites were characterized as having minimal on-site resources, and occurred in regions of the SCB where any potential transport of the sediments was considered negligible. As a

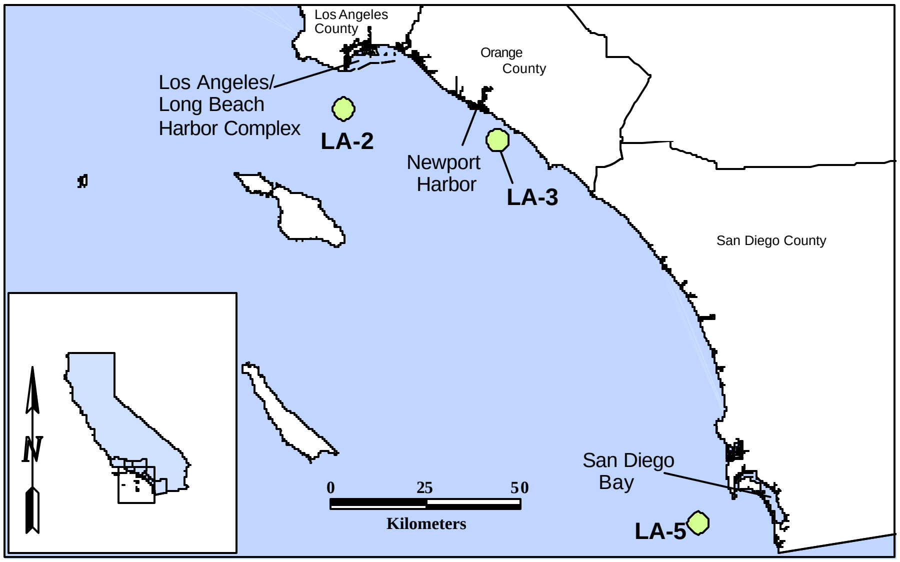

Figure 1. Designated disposal sites in the Southern California Bight.

consequence of disposal at such designated sites, dredged material disposal has been considered a relatively benign activity. To date, little effort has been directed toward quantifying and evaluating the significance of dredged materials as a source of pollutants to the SCB. This information is necessary in order to understand whether they are a significant source of contaminants to the SCB, necessitating greater management concern.

The purpose of this study was to evaluate pollutant loading to the SCB from dredged sediments permitted for ocean disposal between 1991 and 1997. This evaluation consisted of three components: (1) Cumulative mass emissions discharged over this seven-year period were evaluated in terms of quantities per year, per disposal site, and per source harbor (i.e., Los Angeles/Long Beach [LA/LB], Newport, and San Diego); (2) Average concentrations of a suite of constituents were calculated based on the harbor from which the sediments were dredged; (3) Mass emissions from dredged materials over two time periods—1984-1990 and 1991-1997—were compared to total emissions from large municipal wastewater treatment facilities (POTWs) over the same time periods. Historically, large POTWs have been the most significant point source of contaminants to the SCB, so comparison to the large POTWs provides some understanding of the relative significance of dredged materials to overall contamination discharged to the SCB.

METHODS

Information on dredged disposal projects conducted within the SCB between 1991 and 1997 was obtained from the U.S. Army Corps of Engineers (COE) regional offices in Los Angeles, Ventura, and San Diego, and through the Ocean Disposal Database (ODD) (U.S. COE). The ODD is a compilation of dredged material disposal information dating back to 1976, which is maintained by the COE in compliance with the MPRSA. Chemistry and volume information from sediment evaluation studies was used to calculate constituent mass emissions and volume-weighted concentrations for dredged materials disposed to the SCB. Data for dredged material inputs disposed to the SCB between 1984 and 1990 were obtained from Schiff and Cross (1992).

Mass emission estimates were calculated based on total emissions per year, per disposal site, and per harbor. Volume-weighted average concentrations were calculated based only on the harbor from which the dredged materials were derived. Concentrations and mass emissions of 18 constituents were estimated, including several metals, pesticides, and other organic compounds. Fourteen of the total 42 projects conducted between 1991 and 1997 performed sediment chemistry analyses; chemistry data from these projects were used to estimate mass emissions and average concentrations. Final tabulations of sediment volumes included the volumes from all 42 projects.

Constituent mass emissions were calculated as the product of the reported constituent concentration for a given project, the volume of dredged material from the particular project, and a density conversion factor. These mass emissions were then summed over all projects for a given constituent:

$$ME_{const} = \sum_{I=1}^{n} (V_i * C_i * D)$$

where

ME_{const} = Estimated mass emissions of a particular constituent
V_i = Total dredge volume for the *i* th project
C_i = Constituent concentration for the *i* th project
D = Density conversion factor = 1.087 mt/yd^3
n = Number of permitted projects

The density conversion factor varied with the type of material dredged (i.e., sand, silt, or clay); however, it was assumed constant for the estimates made in this study. The value used in these estimates was derived from the average density of dredged materials from 17 projects conducted in southern California between 1976 and 1978 (Schiff and Cross 1992). The densities of materials from these projects ranged from 0.969 mt/yd^3 to 1.361 mt/yd^3, with a mean density of 1.087 mt/yd^3. This conversion factor was required to convert sediment volumes to a mass quantity.

Volume-weighted average constituent concentrations were calculated for the three dredged material source harbors (LA/LB Harbor, Newport Harbor, and San Diego Harbor). Average concentrations were calculated by dividing the total constituent mass emissions for a given harbor by the total volume of dredged materials derived from that harbor, excluding volumes from projects that did not conduct sediment chemistry analyses prior to disposal:

$$VWC_{const} = D^{-1} * \frac{ME_{const}}{\sum_{i=1}^{n} V_i}$$

where

VWC_{const} = Volume-weighted concentration of a particular constituent
D = Density conversion factor = 1.087 mt/yd^3
ME_{const} = Mass emissions of a particular constituent
V_i = Total dredge volume for the *i* th project
n = Number of permitted projects.

Reported concentrations that were below the detection level for a given constituent were set to zero for estimating mass emissions and average concentrations. Estimated mass emissions that resulted in a zero value were reported as not detected (nd). Where average estimated concentrations resulted in zero values, these were reported as less than the maximum reporting level used for the given constituent within the source harbor complex.

Data obtained from the ODD were verified by information from technical reports required for the COE permitting process. There was conflicting information, data from the technical reports were used; however, when technical reports could not be located, information from the ODD was used.

The cumulative constituent mass emissions from dredged materials during two periods, 1984-1990 (Schiff and Cross 1992) and 1991-1997, were compared to the cumulative loads from large POTWs from the same time periods (Raco-Rands and Steinberger 2001). Comparisons were made by calculating the percent of contributions from each source, dredged materials and large POTWs, to the cumulative load from both sources combined over the two periods.

RESULTS

Dredged Material Disposal 1991-1997

The total volume of dredged materials disposed to the SCB between 1991 and 1997 was 2,681,247 m^3, corresponding to almost 4 million metric tons (mt) of sediment (Table 1). These sediments were discharged by 42 individual projects, of which 14 conducted sediment chemistry analyses on intended dredged sediments. These 14 projects represented 82% of the total volume of dredged materials disposed to the SCB between 1991 and 1997. The majority of projects conducted between 1991 and 1997 discharged less than 1,000 cubic meters (m^3) each (Figure 2). None of these projects were required to test for contamination in dredged sediments; however, these projects contributed a negligible fraction of the total sediments disposed to the SCB. During the study period, the greatest yearly volumes of dredged material were disposed in 1993 (25% of total) and 1997 (57% of total) (Figure 3). No dredging projects were conducted in 1994.

Twenty-seven dredging projects derived sediments from Newport Harbor, corresponding to only 2.5% of the total volume of sediments dredged between 1991 and 1997 (Figure 4, Table 1). All Newport Harbor projects were discharged to the LA-3 disposal site. Only one of these 27 projects conducted sediment chemistry analyses. This single project represented 85% of the total volume of sediments dredged from Newport Harbor; mass emission and concentration estimates from Newport Harbor were therefore only based on this one project.

Table 1. Estimated mass emissions of dredge materials (a) disposed at three designated disposal sites in the SCB between 1991 and 1997; (b) disposed per year to all sites within the SCB between 1991 and 1997; and (c) discharged from the three major harbors to the SCB between 1991 and 1997.

	(a) Disposal Site			(b) Year						(c) Harbor			
Constituent	LA2	LA3	LA5	1991	1992	1993	1995	1996	1997	Los Angeles/ Long Beach Harbor Complex	Newport Harbor	San Diego Bay	**TOTAL**[a]
Number of Projects	4	28	10	18	10	7	2	2	3	5	27	10	42
Volume (m^3)	595,011	73,631	2,012,605	59,639	101,233	670,553	225,327	103,144	1,521,351	600,363	68,279	2,012,605	2,681,247
Mass of Total Solids (mt x 10^3)	846	105	2862	85	144	953	320	147	2,163	854	97	2862	3,812
TOC (mt)	6,186	515	15,862	25	934	7,928	3,543	1255	8,879	6,214	487	15,862	22,563
Cadmium (mt)	0.14	0.08	1.6	0.02	0.02	0.23	0.39	0.08	1.1	0.14	0.08	1.6	1.9
Chromium (mt)	32	2.9	61	3.7	4.8	36	10.2	4.6	38	33	2.6	61	97
Copper (mt)	36	1.9	105	5.2	5.3	45	20	6.0	61	36	1.6	105	143
Lead (mt)	22	1.9	63	2.0	3.3	23	12	3.2	44	22	1.8	63	87
Mercury (mt)	0.14	0.01	0.38	0.04	0.02	0.17	0.08	0.05	0.18	0.14	0.01	0.38	0.54
Nickel (mt)	24	1.5	18	1.2	3.6	23	2.5	1.3	12	24	1.4	18	43
Selenium (mt)	nd	0.03	0.49	na	nd	0.003	0.07	nd	0.44	nd	0.03	0.49	0.52
Silver (mt)	0.20	0.02	1.3	0.03	0.03	0.27	0.39	0.10	0.73	0.21	0.01	1.3	1.6
Zinc (mt)	79	5.7	163	13	12	89	41	12	81	79	5.1	163	248
Petroleum Hydrocarbons (mt)	17	0.84	38	0.002	2.7	40	0.02	na	13	18	na	38	55
Aldrin (kg)	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Chlordanes (kg)	nd	0.34	1.9	nd	nd	nd	nd	nd	2.3	nd	0.34	1.9	2.3
Dieldrin (kg)	nd	0.07	0.07	nd	nd	nd	nd	nd	0.14	nd	0.07	0.07	0.14
Total DDT (kg)	1.5	12	2.4	0.83	nd	0.64	1.8	0.63	12	1.6	12	2.4	16
Total Organotins (kg)	2,943	1.4	6173	0.32	nd	1.8	16	2,943	6,156	2,943	1.4	6,173	9,117
Total PAH (kg)	25	19	1,353	94	0.97	89	771	76	366	25	19	1,353	1,397
Total PCB (kg)	4.1	nd	56	14	nd	3.6	37	4.1	2.1	4.1	nd	56	61

[a] The sum of each individual subsection, a, b, and c, is represented by this total.
na = Not analyzed; not estimable.
nd = Not detected.
mt = Metric ton.
1 mt = 1,000 kg.

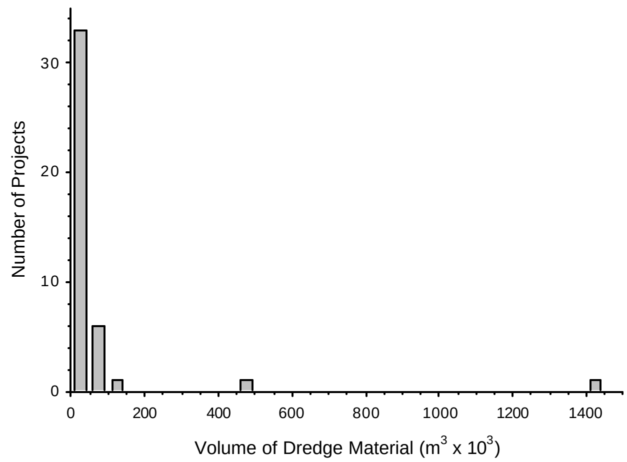

Figure 2. Frequency distribution of dredged material volumes by project, between 1991 and 1997 (n=42).

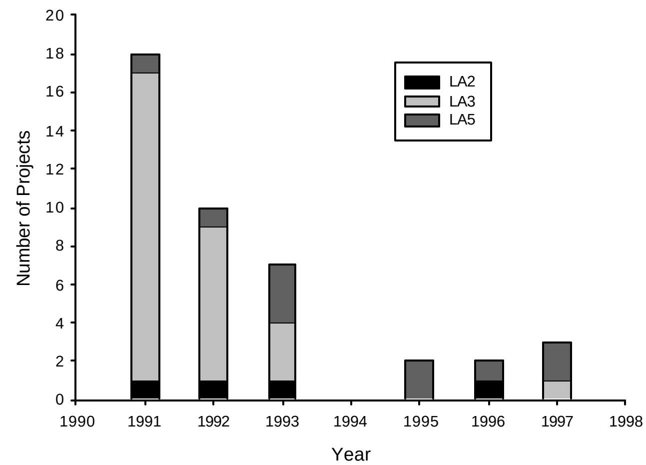

Figure 4. Number of dredging projects permitted per disposal site and year between 1991 and 1997; there were no permitted dredging projects in 1994.

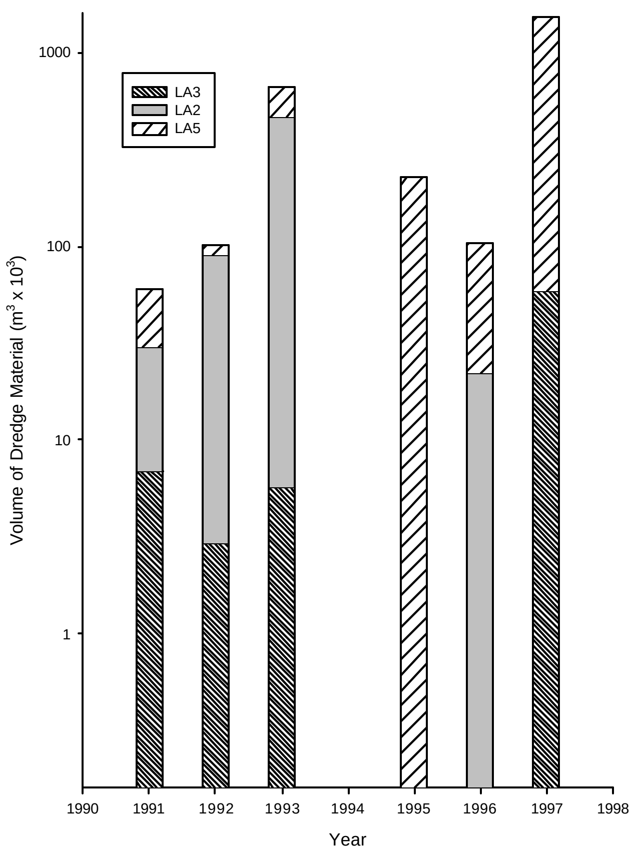

Figure 3. Dredged material volumes discharged per year per disposal site.

The highest concentrations of total DDT (145 ng/g) were found in sediments from Newport Harbor, which exceeded concentrations at the other harbors by two orders of magnitude (Table 2). As a result, constituent emissions of total DDT were greatest from Newport Harbor, representing 75% of total DDT emissions to the SCB from dredged material disposal (Table 1). This quantity was disproportionately higher than the total volume contribution from this harbor.

Five projects were conducted within LA/LB Harbor between 1991 and 1997, representing 22% of the total dredged material volume disposed to the SCB (Table 1). Four of these projects (99% of the volume) discharged to the LA-2 disposal site; one project (1% of the volume) was disposed of at the LA-3 disposal site. Four of the five dredging projects conducted sediment chemistry analyses, although the fifth project was the continuation of a project from a previous year, so sediment chemistry results were assumed to be the same for the second year of the project. Consequently, this project was not excluded from loading and concentration estimates. Emissions of nickel were greatest from the LA/LB Harbor complex, representing approximately 56% of the total nickel discharged to the SCB from dredge projects. For the majority of metals, and total organic carbon (TOC), the highest constituent concentrations were found in sediments from the LA/LB Harbor complex (Table 2).

Seventy-five percent of the total volume of sediments discharged to the SCB between 1991 and 1997 was dredged from San Diego Bay by ten

Table 2. Constituent concentrations (dry weight) from sediment chemistry analyses of dredging projects in southern California harbors and bays between 1991 and 1997.

	Los Angeles/ Long Beach Harbor Complex			Newport Harbor			San Diego Bay		
Constituent	Mean	SD	N	Mean	SD	N	Mean	SD	N
TOC (%)	0.73	0.37	5	0.59	-	1	0.56	0.61	9
Cadmium (ug/g)	0.17	0.08	5	1.0	-	1	0.57	0.58	9
Chromium (ug/g)	38	4	5	31	-	1	22	17	9
Copper (ug/g)	43	7	5	20	-	1	37	37	9
Lead (ug/g)	26	11	5	22	-	1	22	16	9
Mercury (ug/g)	0.17	0.12	5	0.15	-	1	0.13	0.23	9
Nickel (ug/g)	28	6	5	16	-	1	6.2	4.5	9
Selenium (ug/g)	< 0.96	-	3	0.33	-	1	0.17	0.15	8
Silver (ug/g)	0.25	0.43	5	0.12	-	1	0.47	0.62	9
Zinc (ug/g)	93	14	5	62	-	1	57	78	9
Petroleum Hydrocarbons (ug/g)	23	51	3	na	-	0	76	172	6
Total Organotins (ug/g)	3.5	47	4	0.02	-	1	2.3	1.1	8
Aldrin (ng/g)	< 2	-	3	< 0.05	-	1	< 2.9	-	8
Chlordanes (ng/g)	< 80	-	3	4.1	-	1	2.9	25	7
Dieldrin (ng/g)	< 2	-	2	0.86	-	1	0.02	0.81	8
Total DDT (ng/g)	1.9	13	5	145	-	1	0.88	3.7	8
Total PAH (ng/g)	29	155	5	225	-	1	475	1084	9
Total PCB (ng/g)	5.0	75	3	< 20	-	1	21	126	8

< = Less than the maximum reporting level used for analyses for all projects from the given source location.
Dash = Not applicable.
SD = Standard deviation.
N = Number of samples.

dredging projects (Table 1). All ten projects discharged sediments at the LA-5 disposal site; nine of the ten projects conducted sediment chemistry analyses, representing 99.6% of the total volume from this harbor. Constituent mass emissions in sediments dredged from San Diego Bay were higher than emissions from LA/LB and Newport harbors for all constituents except total DDT and nickel (Table 1). The greater quantity of constituent emissions from San Diego Bay was, in large part, a result of the larger quantity of sediment dredged from this harbor relative to the other harbors, resulting mainly from one project. However, in several cases (i.e., chromium, mercury, zinc, and total DDT), constituent concentrations from San Diego Bay were lower than concentrations at Newport and LA/LB harbors (Table 2). On the other hand, the highest concentrations of silver (0.47 ug/g), total PAHs (475 ng/g), total PCBs (21 ng/g), and petroleum hydrocarbons (76 ug/g) were found in sediments from San Diego Bay. Because of the larger volume of sediments discharged from San Diego Bay, the greatest contaminant loadings occurred at the LA-5 disposal site (Table 1). All constituent loads, with the exceptions of nickel and total DDT, were discharged in the greatest quantities to the LA-5 site.

The large volume of sediments dredged from San Diego Bay were, in large part, attributable to the U.S. Navy Channel Deepening project conducted in 1997, which removed 1,442,903 m^3 of sediment from the main channel of San Diego Bay (Table 3). This channel deepening project comprised 72% of the total volume of dredged materials derived from San Diego Bay, and 54% of the total sediment volume from all projects disposed to the SCB between 1991 and 1997. For the majority of constituents (69%), this single project provided greater than 50% of the total constituent mass emissions from sediments originating from San Diego Bay, and greater than 35% of the total constituent mass emissions discharged from all dredging projects conducted within the SCB between 1991 and 1997.

Table 3. Constituent mass emissions and volumes from the U.S. Navy Channel Deepening Project, conducted in 1997 and discharged to LA-5 from San Diego Bay. Results are compared to cumulative mass emissions from projects conducted within San Diego Bay (SD) and from all projects conducted between 1991 and 1997. Percentages represent the contribution of the U.S. Navy Channel Deepening Project to cumulative constituent emissions from San Diego Bay projects and from all projects conducted between 1991 and 1997.

Constituent	U.S. Navy Channel Deepening Project 1997	San Diego Bay Projects 1991-1997	All Projects 1991-1997	% of SD Bay	% of Total
Number of Projects	1	10	42	10.0	2.4
Volume (m^3)	1,442,903	2,012,605	2,681,247	71.7	53.8
Mass of Total Solids (mt x 10^3)	2,052	2,862	3,812	71.7	53.8
TOC (mt)	8,206	15,862	22,563	51.7	36.4
Cadmium (mt)	1.0	1.6	1.9	62.8	54.0
Chromium (mt)	35	61	97	56.9	36.0
Copper (mt)	59	105	143	56.6	41.6
Lead (mt)	41	63	87	65.0	47.2
Mercury (mt)	0.16	0.38	0.54	43.1	30.4
Nickel (mt)	10	18	43	57.9	23.9
Selenium (mt)	0.41	0.49	0.52	83.4	78.9
Silver (mt)	0.72	1.3	1.6	54.0	44.9
Zinc (mt)	74	163	248	45.3	29.8
Petroleum Hydrocarbons (mt)	na	38	55	-	-
Aldrin (kg)	nd	nd	nd	-	-
Chlordanes (kg)	na	1.9	2.3	-	-
Dieldrin (kg)	nd	0.07	0.14	-	-
Total DDT (kg)	nd	2.4	16	-	-
Total Organotins (kg)	6,155	6,173	9,117	99.7	67.5
Total PAH (kg)	298	1,353	1,397	22.1	21.4
Total PCB (kg)	2.1	56	61	3.6	3.4

na = Not analyzed, or not reported.
nd = Not detected.
dash = Not applicable.

Historical Dredged Material Disposal and Comparison to Large POTWs

Between 1984 and 1997, 93 dredging projects disposed of 7,191,388 m^3 of dredged material to the SCB, corresponding to over 10 million mt of solids (Table 4). Metal constituents such as zinc (1,082 mt), copper (554 mt), lead (366 mt), and chromium (331 mt), were the most significant constituent loads discharged to the SCB via dredged materials over the 14-year time period. In addition, TOC (22,563 mt), total PAHs (1,397 kg), and total PCBs (248 kg) were also discharged in notable quantities.

During both the 1984-1990 and 1991-1997 time periods, dredged materials contributed a notable fraction of the overall contaminant load from dredged materials and large POTWs combined. Between 1984 and 1990, inputs from the ocean disposal of dredged sediments represented over 25% of the chromium, copper, lead, mercury, zinc, and total PCB load discharged to the Bight from these two sources. Between 1991 and 1997, dredged materials became a more significant source of several constituent emissions discharged to the SCB (Table 5). Between 1991 and 1997, dredged materials provided greater contributions of chromium (64.6%), lead (86.7%), mercury (57.8%), total PAHs (71.6%), and total

Table 4. Historical constituent mass emissions from dredged material disposal in the SCB between 1984 and 1997.

Constituent	1984[a]	1985[a]	1986[a]	1987[a]	1988[a]	1989[a]	1990[a]	1991	1992	1993	1995	1996	1997	TOTAL
Number of Projects:	6	11	8	9	5	7	5	18	10	7	2	2	3	93
Volume (m^3)	580,041	761,783	248,137	1,798,992	379,450	123,506	618,232	59,639	101,233	670,553	225,327	103,144	1,521,351	7,191,388
Mass of Total Solids (mt x 10^3)	825	1083	353	2558	540	176	879	85	144	953	320	147	2,163	10,225
TOC (mt)	-	-	-	-	-	-	-	25	934	7,928	3,543	1255	8,879	22,563
Arsenic (mt)	7.1	4.8	1.6	10	1.4	0.22	0.35	-	-	-	-	-	-	26
Cadmium (mt)	3.6	0.96	0.44	4.1	0.9	0.09	0.29	0.02	0.02	0.23	0.39	0.08	1.1	12
Chromium (mt)	27	81	14	67	13	4.1	30	3.7	4.8	36	10.2	4.6	38	331
Copper (mt)	76	77	17	126	41	3.6	70	5.2	5.3	45	20	6.0	61	554
Lead (mt)	36	57	14	113	34	2.3	23	2.0	3.3	23	12	3.2	44	366
Mercury (mt)	0.25	0.24	0.09	1.6	0.07	0.02	0.27	0.04	0.02	0.17	0.08	0.05	0.18	3.1
Nickel (mt)	11	13	3.9	16	11	2.4	12	1.2	3.6	23	2.5	1.3	12	111
Selenium (mt)	-	-	-	-	-	-	-	na	nd	0.003	0.07	nd	0.44	0.5
Silver (mt)	0.52	0.63	0.26	0.67	0.32	0.11	2.1	0.03	0.03	0.27	0.39	0.10	0.73	6.2
Zinc (mt)	99	122	42	449	45	9.6	67	13	12	89	41	12	81	1,082
Petroleum Hydrocarbons (mt)	-	-	-	-	-	-	-	0.002	2.7	40	0.02	na	13	55
Aldrin (kg)	-	-	-	-	-	-	-	nd	nd	nd	nd	nd	nd	nd
Chlordanes (kg)	-	-	-	-	-	-	-	nd	nd	nd	nd	nd	2.3	2
Dieldrin (kg)	-	-	-	-	-	-	-	nd	nd	nd	nd	nd	0.14	0.14
Total DDT (kg)	-	-	-	-	-	-	-	0.83	nd	0.64	1.8	0.63	12	16
Total Organotins (kg)	-	-	-	-	-	-	-	0.32	nd	1.8	16	2,943	6,156	9,117
Total PAH (kg)	-	-	-	-	-	-	-	94	0.97	89	771	76	366	1,397
Total PCB (kg)	64	40	12	61	9.2	1.3	nd	14	nd	3.6	37	4.1	2.1	248

[a] (Schiff and Cross 1992).

Dash = Not applicable/not included in assessment.

nd = Not detected.

Table 5. Cumulative constituent mass emissions discharged to the SCB between 1991 and 1997 from large POTWs and dredged materials.

Constituent	*Cummulative 1991-1997 Mass Emissions* Large POTWs[a]	Dredge Materials	Total	*Percent of Total* Large POTWs	Dredge Materials
Volume (L x 10^9)	10,480	2.7	10,483	99.97	0.03
Solids (mt x 10^3)	520	3,812	4,332	12.0	88.0
Cadmium (mt)	4.8	1.9	6.7	72.3	27.7
Chromium (mt)	53	97	150	35.4	64.6
Copper (mt)	348	143	491	70.8	29.2
Lead (mt)	13	87	100	13.3	86.7
Mercury (mt)	0.39	0.54	0.93	42.2	57.8
Nickel (mt)	221	43	264	83.7	16.3
Selenium (mt)	52	0.52	52	99.0	1.0
Silver (mt)	43	1.6	44	96.5	3.5
Zinc (mt)	635	248	883	72.0	28.0
Total DDT (kg)	43	16	59	73.0	27.0
Total PAH (kg)	555	1,397	1,952	28.4	71.6
Total PCB (kg)	nd	61	61	-	100

[a] (Raco-Rands and Steinberger 2001).
nd = Not detected.
Dash = Not applicable.

PCBs (100%) than were discharged by large POTWs. Dredged materials provided insignificant contributions of selenium (1.0%) and silver (3.5%) relative to discharges from large POTWs over this same time period.

DISCUSSION

Dredged material inputs to the SCB are a significant source when analyzed in comparison to large POTWs, historically the most significant point source of contaminants to the SCB, and have increased in relative importance from the 1980s to the 1990s. This is despite the fact that constituent mass emissions estimated for dredged materials probably underestimate the true load. Projects that discharge sediments without conducting chemical analyses potentially represent an additional source of contaminants of unknown measure. For example, between 1991 and 1997, projects representing 18% of the total sediments disposed to the SCB did not conduct prior chemical analyses. Projects that do not perform sediment chemistry analyses are typically small in volume, and are assumed to represent an insignificant source of contaminants (Appendix I) (EPA/COE 1991); however, because of the inherent variability in sediment contamination, this cannot be quantified or known with complete certainty. In addition, projects that did conduct sediment chemistry analyses varied in the constituents they measured, leading to gaps in the data collected. As a result, estimates for only 18 constituents could be calculated. These inconsistent reporting practices confounded efforts to make reliable contaminant load estimates for all of the constituents that could possibly be present in dredged sediments.

The increased inter-decadal significance of dredged materials to total loading in the SCB was largely a result of the relatively consistent contributions from dredged materials combined with improvement of effluent quality from large POTWs (Raco-Rands and Steinberger 2001). This trend will probably continue as large POTWs implement more advanced methods of wastewater treatment in upcoming years, and ultimately could result in dredged materials becoming a leading source of contamination to the continental shelf.

Sources of contamination to harbor sediments include, among other sources, atmospheric deposition of pollutants (Stolzenbach *et al.* 2001), various port and naval activities (Eganhouse *et al.* 1990), and leeching of contaminants from antifouling paints used for ship hulls (Johnson *et al.* 1998). Of particular interest, though, is the role of dredged harbor sediments as a potential indicator of contaminants introduced from the watershed(s) surrounding a given harbor via stormwater runoff. Pollutants entering the aquatic environment in a harbor via stormwater runoff may become complexed within the sediments. Over time, these constituents may accumulate in the sediments and, when dredged, become a significant source of contaminants to the SCB. Consequently, increases in the quantity and quality of contamination reaching the harbors and bays of the SCB via stormwater runoff may potentially result in additional contamination to the sediments. Based on the trends revealed in this study, monitoring of dredged material inputs is necessary for making proper management decisions regarding southern California's coastal resources. Moreover, as stormwater runoff becomes a greater concern to environmental managers, the relative significance of dredged material disposal and its potential connection to stormwater contamination may become a subject of future interest.

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Appendix I. Dredge Material Regulations and Testing Procedures

The disposal of dredged materials is regulated by the COE and the U.S. Environmental Protection Agency (EPA) under guidelines outlined in the EPA Code of Federal Regulations (title 33 parts 320-330 and 335-338, and 40 parts 220-228, respectively) (EPA/COE 1991). Materials dredged from the waterways of the U.S. are classified as (a) suitable for use in beach replenishment, (b) suitable for ocean disposal at a designated site, or (c) unsuitable for ocean disposal. These designations are determined by means of a tiered sediment evaluation approach. The first two tiers of the evaluation examine existing information and historical knowledge of a site to determine whether further testing is required. Disposal from small dredging projects is typically authorized without progressing to further tiers of the sediment evaluation process. More extensive analysis occurs at the third and fourth tiers for sediments lacking historical chemical perspective, for larger projects where there is a greater risk of impact, or for projects for which the existing data is insufficient to determine the possible impact of disposal.

Sediment characterizations are established by comparing samples from the intended dredge site to control and reference sediments meant to typify sediment conditions at the disposal site had no disposal ever taken place. Materials deemed unsuitable for ocean disposal must be either left undisturbed or removed, treated, and disposed of at an upland disposal site. Projects that pass testing requirements are permitted by the COE and disposed of at a designated ocean disposal site. The tiered approach to testing is meant to provide a systematic and cost-effective method of evaluating dredge materials for the purpose of making sound management decisions.

Ocean disposal sites are chosen such that the impact of dredge material disposal will be minimal. Disposal sites are characterized by minimal on-site resources, and occur in regions of the continental shelf where further transport of the deposited materials is believed to be negligible (EPA/COE 1991).

Appendix II. Designated disposal sites in the Southern California Bight[a].

Disposal Site	Coordinates (center)	Datum	Diameter of Site (miles)	Nearest Distance from Land (miles)	Depth Range(m)
LA-2 (Los Angeles)	33º37'06" N 118º17'24" W	NAD 1983	0.6	6.0	118-320
LA-3[b] (Newport Beach)	33º31'38" N 117º54'36" W	NAD 1927	1.0	4.8	435-455
LA-5 (San Diego-100 Fathom)	32º36'50" N 117º20'38" W	NAD 1927	1.1	6.9	130-190

[a] Data obtained from the Ocean Disposal Database (U.S. COE), unless otherwise noted.

[b](Marine Bioassay Laboratories 1988).