
How effective has the Clean Water Act been at reducing pollutant mass emissions to the Southern California Bight over the past 35 years?

Greg S. Lyon and Eric D. Stein

ABSTRACT

The federal Clean Water Act (CWA) has regulated discharges of contaminants since 1972. Most of the effort over the past 35 years has focused on controlling point source discharges, although recent attention has shifted to address management of non-point sources. Hundreds of billions of dollars have been spent nationally to implement CWA requirements; however, regional evaluations of the effectiveness of the CWA at improving water quality are lacking. This is primarily due to the fact that monitoring programs mandated by the CWA do not require integration of data from multiple dischargers or classes of dischargers to assess cumulative effects. A rare opportunity exists in southern California to assess CWA effectiveness by integrating mass emissions data from all major sources of contaminants to the Southern California Bight (SCB) from 1971 to 2000. Sources of contaminants to the SCB include large and small publicly owned treatment works (POTWs), power generating stations, industrial facilities, oil platforms, dredged material, and storm water runoff from a watershed area of over 14,000 km². While the coastal population grew by 56% and total effluent volume increased 31% since 1971, mass emissions of nearly all constituents decreased since passage of the CWA, most by greater than 65%. The median decrease in metals emissions was 88%, while total DDT and PCB emissions each decreased by three orders of magnitude. Large POTWs were the dominant point source of many contaminants to the SCB, accounting for more than 50% of the total annual discharge volume. However, large POTWs also accounted for the most significant reductions in pollutant discharge to the SCB, with most pollutant loads being reduced by greater than 90% compared to pre-CWA levels. As point source treatment has improved, the relative contribution of

non-point sources, such as storm water runoff has increased. For example, metals contributions from storm water have increased from 6% of the total to 34% of the total annual load between 1971 and 2000. Despite the increased importance of storm water discharges, regional monitoring and data compilation of this source is lacking, making it difficult to accurately assess trends in non-point source discharge. Future efforts to integrate data from storm water monitoring programs and include dry weather runoff monitoring should improve the accuracy of regional mass emission estimates.

INTRODUCTION

The federal Clean Water Act (CWA) has been the backbone of surface water quality protection in the United States since 1972. The CWA mandates technology based effluent limits for point source dischargers and has provided funding for major infrastructure improvements to help achieve those endpoints (Copeland 2002). Hundreds of billions of dollars have been spent nationally by federal, state, and local authorities since 1972 to implement the CWA requirements (Knopman and Smith 1993, Copeland 2002). During the first 2 decades after passage of the CWA, management efforts focused on controlling point source discharges, such as those from publicly owned treatment works (POTWs) and industrial facilities. More recently, attention has shifted to managing non-point sources, such as storm water runoff.

Although the success of the CWA at improving water quality is widely acknowledged, documentation from large scale long-term studies of water quality trends is lacking. Localized studies have documented improved downstream water quality associated with increased treatment of effluent from individual point sources (Knopman and Smith 1993).

However, evaluation of the CWA on a broader scale has been largely anecdotal due to a lack of consistent and integrated monitoring data (Knopman and Smith 1993). While the CWA requires discharges to be permitted under the National Pollutant Discharge Elimination System (NPDES), the permits are issued to individual facilities with different monitoring requirements and do not require integration of data from multiple dischargers or classes of dischargers to assess the cumulative impact to a water body. This poses a challenge to environmental resource managers who need to evaluate pollutant loads and trends from all sources on a regional or larger scale.

In the absence of consistent national data, long-term regional datasets can be used to evaluate the effectiveness of the CWA on a broad scale. A unique long-term regional dataset exists for the Southern California Bight (SCB), which is an important ecological, recreational, and economic resource adjacent to one of the most densely populated coastal regions in the United States (Culliton et al. 1990). Since 1971, the Southern California Coastal Water Research Project (SCCWRP) has been compiling and analyzing effluent data from all major point-source dischargers to the coastal waters of the SCB. These discharge data are used to calculate total mass emission estimates for selected contaminants. Mass emission estimates can be used by environmental resource managers to assess total pollutant loading to the SCB, to compare the relative impact of a particular source to other sources, to evaluate the effect of management actions, and to assess trends over time since the inception of the CWA.

The five coastal counties bordering the SCB are home to over 16 million people (US Census Bureau 2000), with 60 point sources discharging over 4.7 billion liters of treated effluent per day into the coastal ocean. The major point sources of pollutant discharge to the SCB are large (>500 million liters/day) and small (<100 million liters/day) POTWs, power generating stations (PGS), industrial facilities, oil platforms, and dredged materials (Steinberger and Schiff 2003a, 2003b, 2003c, Steinberger et al. 2003, Steinberger and Stein 2004, Steinberger et al. 2004). In addition, following the approximately 35 annual storm events, runoff drains an area of over 14,000 km² and flows untreated to the SCB via storm drains, creeks, and rivers (Ackerman and Schiff 2003).

The goal of this study is to assess the effectiveness of the CWA at improving water quality through-

out the SCB since its passage. This study takes advantage of one of the longest consistent regional data sets in the United States by integrating and synthesizing discharge data from all major pollutant sources to the SCB between 1971 and 2000. Specifically, we examine total mass emission loads of selected contaminants, relative contributions from major sources, trends in mass emissions and relative contributions of different sources.

METHODS

Trends in regional mass emissions and relative pollutant contributions by each major source (large and small POTWs, power generating stations, oil platforms, industrial facilities, dredge material, and storm water) were evaluated for three key time points over a 30-year period. These time points correspond to substantial changes in CWA regulatory and management practices. The initial time point, 1971, represented emissions at the time of CWA passage. The late 1980s to mid 1990s were used to represent a time where the majority of point sources were implementing NPDES requirements, while regulatory and management attention began to shift to management of non-point pollutant sources. Finally, we assessed 2000 to represent the most recent year where data from all the major discharge sources has been compiled and is available. Mass emissions estimates for all available sources in 1971 were obtained from SCCWRP (1973). The 1971 storm water estimates were based on a small-scale study with the results extrapolated to the entire SCB based on estimated flow volumes. No data were available for PGS or oil platforms from 1971. Data for the remaining time periods was compiled from discharger monitoring reports.

Annual mass emissions data for each class of point source discharger were compiled from flow and chemistry data provided in each discharger's NPDES monitoring reports. Constituent concentration data were standardized to monthly time steps. For constituents analyzed more than once per month, the arithmetic mean of all results in a given month was calculated. Where the frequency of constituent analysis was less than monthly, the arithmetic mean of available data within the given year was calculated and used to populate months for which no data existed. The monthly flow and concentration data were then used to calculate annual discharge volumes and constituent mass emissions for each discharger. Constituent concentrations below the reporting level were assigned a value of zero for calculating ME.

The annual discharge volume (V) for each discharger was calculated from the sum of the monthly effluent volumes:

$$V = \sum_{i=1}^{12} uF_iD_i$$

where F_i was the mean daily flow for the month i , D_i was the number of days that discharge occurred during the month i , and u was the unit conversion factor for calculating the volume in liters (L).

Mass emission estimates (ME) were calculated from the product of the mean daily flow, the monthly constituent concentration, the number of days in the given month, and a unit conversion factor. MEs were calculated for each constituent for each month, and then summed over all months in the year to obtain an annual estimate:

$$ME = \sum_{i=1}^{12} uF_iC_iD_i$$

where C_i was the reported constituent concentration for the month i , and u was the appropriate unit conversion factor for calculating the ME in metric tons (mt), kilograms (kg), or liters (L). The annual discharge volumes and mass emissions for each discharger were then summed to find the total volume and constituent mass emissions for each source. Constituents included in this assessment were selected based on the availability of data and on the known influence of these constituents in the marine environment. General constituents included solids, biochemical oxygen demand (BOD), oil and grease, ammonia, nitrate, phosphorus, and cyanide. Selected metals, phenols, dichlorodiphenyltrichloroethane (DDT), polychlorinated biphenyl (PCB), and polycyclic aromatic hydrocarbons (PAH) were also analyzed.

Annual discharge volume and mass emissions from the POTWs and industrial facilities were based on analysis of final effluent from each facility. Discharges from PGS consist of a combination of in-plant wastes and non-contact cooling water. In-plant wastes varied by facility but generally included sanitary waste, metal cleaning waste, boiler blowdown, and retention basin waste which were injected into the cooling water flow prior to discharge (Steinberger and Stein 2004). Flow and constituent concentration data from the in-plant waste sources were used in our analysis. Data from the combined waste discharge were not used because the cooling water is drawn from the receiving water and could contain background concentrations of all constituents

with the exception of residual chlorine, which is added to prevent fouling of the cooling system.

Oil platforms also discharge a combination of several waste streams. These include discharges from well drilling and maintenance, oil and gas production, and daily platform operation. Drilling and maintenance discharges are variable and intermittent, while production and operation discharges occur on a regular basis. Produced water is the primary discharge associated with the production of oil and gas, and is the greatest source of contaminants originating from offshore oil facilities (Steinberger et al. 2004). Produced water is a hypersaline brine that occurs with the oil and gas in a reservoir and must be separated from the petroleum and discharged from the platform. Treated sanitary wastes from oil platform operations contribute less than 1% of the non-cooling water volume discharged. Cooling water provides the greatest volume discharge from oil platforms, but is drawn in from the surrounding seawater and should represent background constituent levels, with only chlorine added to prevent fouling of the cooling system. Therefore, only produced water is included in our volume and mass emission estimates from this source.

Dredge projects vary considerably in number and total volume from year to year. To compensate for this inter-annual variability, we calculated averages based on several years data. Dredge disposal data were obtained from the Army Corps of Engineers Ocean Disposal Database (Steinberger et al. 2003) and averaged to provide estimates of annual volume and constituent mass emissions for 2000.

Storm water runoff estimates were based on a simple model utilizing watershed area, rainfall, and water quality data for each land use in the watershed. A modeling approach was used for this study due to the large spatial scale of the SCB and the limited availability of storm water monitoring data. Schiff (1997) found that only 5% of the watershed area and 2% of the annual runoff volume to the SCB were representatively monitored in 1994. The model extrapolated data from monitored watersheds to the remaining area of the SCB watershed to obtain annual mass emission estimates:

$$ME = A * i * c * C * k$$

where A was the drainage area, i was the rainfall amount, c was the runoff coefficient, C was the constituent concentration, and k was the appropriate unit

conversion factor. The total SCB watershed area was adjusted by excluding catchments greater than 52 km² upstream of dams to more accurately represent the actual runoff reaching the coastal ocean. The adjusted area included 191 watersheds covering 14,652 km². The rainfall amount used in the model was a 30-year average to eliminate variability due to differences in the amount of rain between years. Constituent concentrations used in the model were based on storm water monitoring data collected by county storm water agencies during the 1990s

(Ackerman and Schiff 2003). The same model data were used for the 1990s and the 2000 comparison because the rainfall and concentration data used to calibrate and validate the model were long-term averages that spanned both time periods.

RESULTS

Trends in Mass Emissions

Between 1971 and 2000, the effluent volume discharged to the SCB increased by 31% (Table 1).

Table 1. Estimated annual mass emissions from all sources to the SCB from 1971 to 2000.

Constituent	Units	Combined Totals			Percent Change
		1971	1989	2000	1971-2000
Flow Volume	(L x 10 ⁹)	2,135	2,944	2,794	31%
Suspended Solids	mt	583,406	207,366	187,552	-68%
Settleable Solids	(L x 10 ³)	--	--	348,298	--
Mass of Total Solids	mt	2,800	916,000	635,000	22579%
BOD	mt	294,342	166,998	100,646	-66%
Oil and Grease	mt	73,389	22,760	15,671	-79%
Ammonia-N	mt	57,246	48,298	46,766	-18%
Nitrate-N	mt	1,290	2,280	2,462	91%
Phosphorus	mt	12,110	6,858	2,456	-80%
Cyanide	kg	213,000	13,663	9,551	-96%
Arsenic	kg	7,900	12,091	3,789	-52%
Cadmium	kg	68,200	4,172	1,226	-98%
Chromium	kg	719,000	62,437	26,480	-96%
Copper	kg	581,000	154,488	99,493	-83%
Lead	kg	358,000	75,657	20,112	-94%
Mercury	kg	4,460	1,041	167	-96%
Nickel	kg	372,000	72,834	44,789	-88%
Selenium	kg	13,000	7,617	10,081	-22%
Silver	kg	17,600	11,261	4,449	-75%
Zinc	kg	1,991,000	385,120	223,578	-89%
Combined Metals	kg	4,132,160	786,718	434,164	-89%
Phenols	kg	269,000	6,483	115,196	-57%
Chlorinated Phenols	kg	--	--	4,221	--
Non-chlorinated Phenols	kg	20,000	--	58,060	190%
Total DDT	kg	35,699	41	24	-100%
Total PCB	kg	37,192	31	12	-100%
Total PAH	kg	--	--	973	--

"--" = Constituent was not analyzed or data were not available

However, over the same time period, total mass emissions of nearly all constituents decreased by more than 50% (Figure 1). Total suspended solids, BOD, oil and grease, phosphorus, and cyanide loads all decreased by greater than 65%. Of the general constituents, nitrate-N was the only constituent load that increased between 1971 and 2000. Nitrate-N emissions increased 91% to 2,462 mt by 2000, primarily from storm water runoff. Annual emissions of all metals analyzed decreased between 22% (selenium) and 98% (cadmium), with a median reduction of 88%. Total DDT and PCB each decreased by three orders of magnitude between 1971 and 2000. Overall phenols decreased by 57%, while the measured emissions of non-chlorinated phenols increased 190% to over 58 mt in 2000.

The majority of the total pollutant load reduction is attributable to improvements in effluent quality from the largest class of discharger. Large POTWs were the primary source of most constituents analyzed in all three time periods; however, the predominance of this source has declined since 1971. Major reductions in mass emissions from large POTWs occurred from 1971 to 1989, with further reductions between 1989 and 2000. For example, annual chromium emissions in 1971 were 666 mt, but dropped to 22 and 4.8 mt by 1989 and 2000, respectively. Suspended solids, BOD, cyanide, several other metals, and total DDT all follow this general trend (Table 2). As mass emissions from large POTW effluent decreased, the number of constituents discharged primarily by other sources

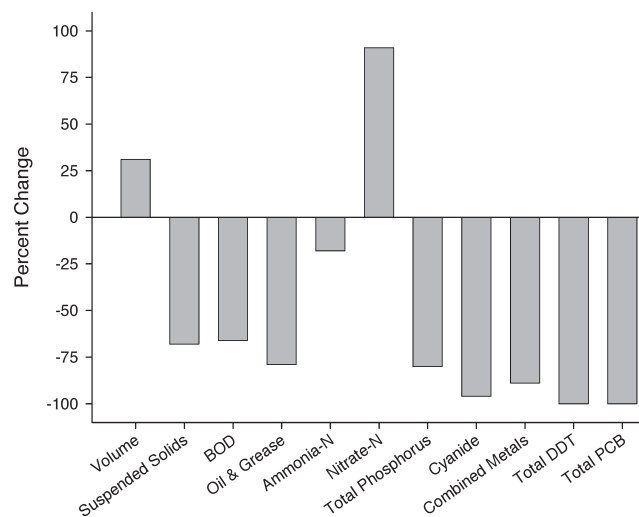


Figure 1. Percent change in total discharge volume and mass emissions of selected constituents from 1971 to 2000.

increased. In 1971, only four constituents were discharged primarily by sources other than large POTWs, including nitrate-N and phenols from storm water runoff, non-chlorinated phenols from industrial facilities, and PCB from dredged material. In 1989, other sources contributed the greatest proportion of six constituents: nitrate-N and suspended solids from storm water runoff, phenols from industrial facilities, and chromium, lead and PCB from dredged material. By 2000, the number of constituents primarily discharged by sources other than large POTWs increased to nine, including suspended solids, nitrate-N, several metals, and DDT.

Reductions in mass emissions from point sources such as large POTWs have resulted in increased relative contribution of other sources. The relative contribution of combined metals from large POTWs in 1971 was 89%, but by 1989 the contribution from large POTWs decreased to 43%, and further decreased to 39% by 2000 (Table 3). As percent contributions from large POTWs declined, those from dredged material and storm water runoff increased (Figure 2). The combined metals contributions from dredged materials rose from 4% in 1971 to 24% in 2000. Storm water runoff contributed 6% of the combined metals load in 1971, and this contribution rose to 19% and 34% by 1990 and 2000, respectively. Storm water runoff was the dominant source of nitrate-N in all three time periods examined in this study. The relative contribution from storm water runoff of nearly all constituents including suspended solids, phosphorus, most metals, and DDT increased over the study period.

Mass Emissions in 2000

Total combined volume discharged to the SCB from all sources in 2000 was nearly $2.8 \text{ L} \times 10^{12}$ (Table 1). The load of suspended solids was 187,552 mt, and settleable solids exceeded $348 \text{ L} \times 10^6$. Ammonia-N emissions were nearly $47 \text{ mt} \times 10^3$, while nitrate-N and total phosphorus loads were both approximately $2.5 \text{ mt} \times 10^3$. Discharge of BOD totaled nearly $101 \text{ mt} \times 10^3$. Oil and grease emissions were 15,671 mt. Combined discharge of the ten metals included in this assessment was 434 mt, with zinc accounting for over 50% of the total metals load. Total PAH emissions were 973 kg. Total DDT and PCB discharges were relatively low at 24 and 12 kg, respectively.

Large POTWs and storm water runoff were the predominant sources of contaminants to the SCB in

Table 2. Estimated annual mass emissions from each source to the SCB from 1971 to 2000.

Constituent	Units	Large POTWs			Small POTWs			Power Stations			Industrial Facilities			Oil Platforms			Dredged Material			Stormwater Runoff		
		1971	1989	2000	1971	1989	2000	1971	1994	2000	1971	1989	2000	1971	1980	2000	1971	84-90 avg	91-97 avg	1971	1990	2000
Number of Facilities or Projects		4	4	4	21	14	15	14	11	96	5	7	--	21	23	--	7	7	--	--	--	--
Flow Volume	(L x 10 ⁶)	1,289	1,658	1,489	95	189	194	4	20	185	14	12	--	5	6	--	1	1	566	1,073	1,073	1,073
Suspended Solids	mt	295,000	83,000	64,631	8,200	2,984	1,819	48	94	6,206	234	8	--	3,100	3,000	--	--	--	274,000	118,000	118,000	118,000
Settleable Solids	(L x 10 ³)	--	--	307,549	--	--	22,740	--	18,000	--	--	9	--	--	--	--	--	--	--	--	--	--
Mass of Total Solids	mt	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2,800	916,000	635,000	--	--	--
BOD	mt	282,000	162,000	97,744	11,000	4,751	2,882	0	0	1,342	247	20	--	--	--	--	--	--	--	--	--	--
Oil and Grease	mt	63,000	22,000	14,840	4,200	460	676	15	51	1,789	145	4	--	140	100	--	--	--	4,400	--	--	--
Ammonia-N	mt	54,000	45,000	42,567	1,600	2,716	3,401	0	2	1,206	176	22	--	--	368	--	--	--	440	406	406	406
Nitrate-N	mt	310	340	279	--	--	150	--	93	--	--	--	--	--	--	--	--	--	980	1,940	1,940	1,940
Phosphorus	mt	11,700	6,300	1,898	--	--	--	--	--	--	--	--	--	--	--	--	--	--	410	558	558	558
Cyanide	kg	194,000	12,000	9,200	8,000	670	347	0	nd	--	973	nd	--	20	4	--	--	--	11,000	--	--	--
Arsenic	kg	7,900	7,400	3,400	--	840	166	1	0	--	149	218	--	1	5	--	3,700	--	--	--	--	--
Cadmium	kg	53,000	1,700	80	--	530	421	0	nd	--	28	0	--	--	1	--	14,000	1,500	310	1,200	414	414
Chromium	kg	666,000	22,000	4,800	--	840	92	9	3	--	28	1	--	60	83	--	28,000	34,000	16,000	25,000	5,500	5,500
Copper	kg	535,000	67,000	51,000	--	3,400	822	--	1,277	16	201	24	--	10	31	--	28,000	59,000	24,000	18,000	23,600	23,600
Lead	kg	240,000	27,000	600	--	2,900	88	--	329	0	5	1	--	3	2.6	--	28,000	40,000	14,000	90,000	5,420	5,420
Mercury	kg	2,900	390	20	--	230	2	0	nd	--	0	nd	--	5	0	--	1,500	360	90	60	56	56
Nickel	kg	327,000	54,000	32,000	--	2,800	520	12	1	--	882	18	--	300	10	--	28,000	9,800	7,200	17,000	5,040	5,040
Selenium	kg	13,000	7,400	8,500	--	--	261	nd	nd	--	--	933	--	--	nd	--	--	--	170	--	217	217
Silver	kg	15,000	10,000	4,100	--	580	88	19	nd	--	0	0	--	2	1	--	1,500	660	260	1,100	--	--
Zinc	kg	1,834,000	145,000	66,000	--	12,000	8,202	119	28	--	391	57	--	610	291	--	56,000	119,000	41,000	101,000	108,000	108,000
Combined Metals	kg	3,693,800	341,890	170,500	--	24,120	10,662	1,767	49	--	1,684	1,253	--	991	425	--	185,000	288,020	103,030	253,360	148,247	148,247
Phenols	kg	--	--	113,000	--	--	nd	--	--	--	3,883	8	--	2,600	2,188	--	--	--	--	269,000	--	--
Chlorinated Phenols	kg	--	--	4,200	--	--	21	--	--	--	--	nd	--	--	--	--	--	--	--	--	--	--
Non-chlorinated Phenols	kg	--	--	58,000	--	--	56	--	--	20,000	--	4	--	--	--	--	--	--	--	--	--	--
Total DDT	kg	21,560	22	2.0	--	nd	0.0005	--	--	--	--	nd	--	--	--	--	14,000	--	3	119	19	19
Total PCB	kg	8,946	nd	nd	--	nd	nd	--	--	--	--	nd	--	--	--	--	28,000	31	12	246	--	--
Total PAH	kg	--	--	740	--	--	nd	--	--	--	--	nd	--	--	nd	--	--	--	233	--	--	--

nd = Not detected
"--" = Constituent was not analyzed or data were not available

Table 3. Relative contribution from each source to overall mass emissions to the SCB from 1971 to 2000.

Constituent	Units	Large POTWs			Small POTWs			PGS			Industrial Facilities			Oil Platforms			Dredged Material		Stormwater Runoff				
		1971	1989	2000	1971	1989	2000	1971	1994	2000	1971	1989	2000	1971	1990	2000	1971	84-90 avg	91-97 avg	1971	1990	2000	
Flow Volume	(L x 10 ⁹)	60%	56%	53%	4.4%	6.4%	6.9%	--	0.1%	0.7%	0.4%	8.7%	0.5%	0.4%	--	0.2%	0.2%	--	<0.1%	<0.1%	27%	36%	38%
Suspended Solids	mt	51%	40%	34%	1.4%	1.4%	1.0%	--	<0.1%	<0.1%	<0.1%	1.1%	0.1%	<0.1%	--	1.5%	1.6%	--	--	47%	57%	63%	
Settleable Solids	(L x 10 ³)	--	--	88%	--	--	6.5%	--	--	5.2%	<0.1%	--	--	<0.1%	--	--	--	--	--	--	--	--	--
Mass of Total Solids	mt	--	--	--	--	--	--	--	--	--	--	--	--	--	--	100%	100%	100%	100%	--	--	--	--
BOD	mt	96%	97%	97%	3.7%	2.8%	2.9%	--	<0.1%	<0.1%	<0.1%	0.5%	0.1%	<0.1%	--	--	--	--	--	--	--	--	--
Oil and Grease	mt	86%	97%	95%	5.7%	2.0%	4.3%	--	<0.1%	0.3%	<0.1%	2.4%	0.6%	<0.1%	--	0.6%	0.6%	--	--	6.0%	--	--	--
Ammonia-N	mt	94%	93%	91%	2.8%	5.6%	7.3%	--	<0.1%	<0.1%	<0.1%	2.1%	0.4%	<0.1%	--	0.8%	--	--	--	0.8%	0.8%	0.9%	0.9%
Nitrate-N	mt	24%	15%	11%	--	--	6.1%	--	--	3.8%	--	--	--	--	--	--	--	--	--	--	7.6%	8.1%	7.9%
Phosphorus	mt	97%	92%	77%	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.4%	8.1%	23%
Cyanide	kg	91%	88%	96%	3.8%	4.9%	3.6%	--	<0.1%	nd	nd	--	7.1%	nd	--	0.1%	<0.1%	--	--	5.2%	--	--	--
Arsenic	kg	100%	61%	90%	--	6.9%	4.4%	--	<0.1%	<0.1%	5.8%	--	1.2%	5.8%	--	<0.1%	0.1%	--	31%	--	--	--	--
Cadmium	kg	78%	41%	6.5%	--	13%	34%	--	<0.1%	nd	<0.1%	--	0.7%	<0.1%	--	<0.1%	0.1%	--	21%	36%	1.8%	10%	34%
Chromium	kg	93%	35%	18%	--	1.3%	0.3%	--	<0.1%	<0.1%	<0.1%	--	<0.1%	<0.1%	--	0.1%	0.3%	--	3.9%	54%	3.5%	8.8%	21%
Copper	kg	92%	43%	51%	--	2.2%	0.8%	--	0.8%	<0.1%	<0.1%	--	0.1%	<0.1%	--	<0.1%	<0.1%	--	4.8%	38%	3.1%	15%	24%
Lead	kg	67%	36%	3.0%	--	3.8%	0.4%	--	0.4%	<0.1%	<0.1%	--	<0.1%	<0.1%	--	<0.1%	<0.1%	--	7.8%	53%	25%	7.2%	27%
Mercury	kg	65%	37%	12%	--	22%	0.9%	--	<0.1%	nd	nd	--	<0.1%	nd	--	0.5%	<0.1%	--	34%	35%	1.3%	5.4%	33%
Nickel	kg	88%	74%	71%	--	3.8%	1.2%	--	<0.1%	<0.1%	<0.1%	--	1.2%	<0.1%	--	0.4%	<0.1%	--	7.5%	13%	4.6%	6.9%	11%
Selenium	kg	100%	97%	84%	--	2.6%	--	--	nd	nd	nd	--	--	9.3%	--	--	nd	--	--	1.7%	--	2.8%	2.2%
Silver	kg	85%	89%	92%	--	5.2%	2.0%	--	0.2%	nd	nd	--	<0.1%	<0.1%	--	<0.1%	<0.1%	--	8.5%	5.9%	6.3%	--	--
Zinc	kg	92%	38%	30%	--	3.1%	3.7%	--	<0.1%	<0.1%	<0.1%	--	0.1%	<0.1%	--	0.2%	0.1%	--	2.8%	31%	5.1%	28%	48%
Combined Metals	kg	89%	43%	39%	--	3.1%	2.5%	--	0.2%	<0.1%	<0.1%	--	0.2%	0.3%	--	0.1%	0.1%	--	4.5%	34%	6.1%	19%	34%
Phenols	kg	--	--	98%	--	--	nd	--	--	--	<0.1%	--	60%	<0.1%	--	40%	1.9%	--	--	100%	--	--	--
Chlorinated Phenols	kg	--	--	100%	--	--	0.5%	--	--	--	nd	--	--	nd	--	--	--	--	--	--	--	--	--
Non-chlorinated Phenols	kg	--	--	100%	--	--	0.1%	--	--	--	<0.1%	--	100%	<0.1%	--	--	--	--	--	--	--	--	--
Total DDT	kg	60%	53%	6.2%	--	nd	<0.1%	--	--	--	nd	--	--	nd	--	--	--	--	39%	--	0.3%	47%	80%
Total PCB	kg	24%	nd	nd	--	nd	nd	--	--	--	nd	--	--	nd	--	--	--	--	75%	100%	0.7%	--	--
Total PAH	kg	--	--	76%	--	--	nd	--	--	--	nd	--	--	nd	--	--	--	--	24%	--	--	--	--

nd = Not detected
 "--" = Constituent was not analyzed or data were not available

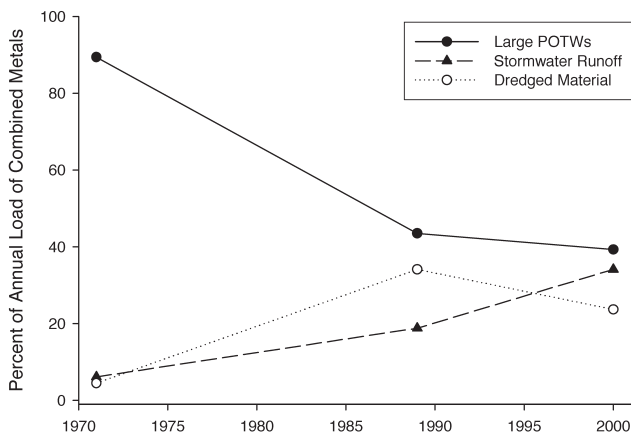


Figure 2. Relative contribution to combined metals emissions from major sources between 1971 and 2000.

2000. Effluent from large POTWs accounted for 53% of the total volume and contributed the greatest mass emissions of 15 of the 24 constituents analyzed in this study (Table 3). Copper emissions from large POTWs accounted for 51% of the total annual load, while each of the other constituents discharged primarily by large POTWs accounted for greater than 70% of the total load (Figure 3). These constituents were settleable solids, BOD, oil and grease, ammonia-N, total phosphorus, cyanide, arsenic, nickel, selenium, silver, PAH, and phenols, including chlorinated and non-chlorinated congeners. Storm water runoff provided an estimated 38% of the total volume, and was the predominant source of suspended solids, nitrate-N, zinc, and total DDT (Figure 3). Storm water contributed significant proportions of other metals, ranging from 2.2% of the selenium load to nearly 34% of the cadmium load. Storm water runoff was also a significant source of phosphorus to the SCB, accounting for 23% of the known load.

Mass emissions from the remaining sources were generally less influential, but included significant contributions of several constituents. Dredged material provided the least volume discharged to the SCB, but was the greatest source of total solids, chromium, lead, and mercury. Dredged sediments also contained the only detectable levels of PCBs, and contributed 13% and 24% of the total DDT and PAH load, respectively. Small POTWs discharged approximately 7% of the total annual volume and a proportionate amount of ammonia-N, nitrate-N, and settleable solids. Small POTW effluent was the primary source of only one constituent, contributing 34% of the total cadmium load. Discharges from

PGS, industrial facilities, and oil platforms were relatively minor. These sources each contributed less than 1% of the total discharge volume and pollutant load for most constituents.

DISCUSSION

This study generated three important conclusions about the effectiveness of the CWA at improving water quality in the SCB. First, overall water quality in the SCB has improved dramatically since imple-

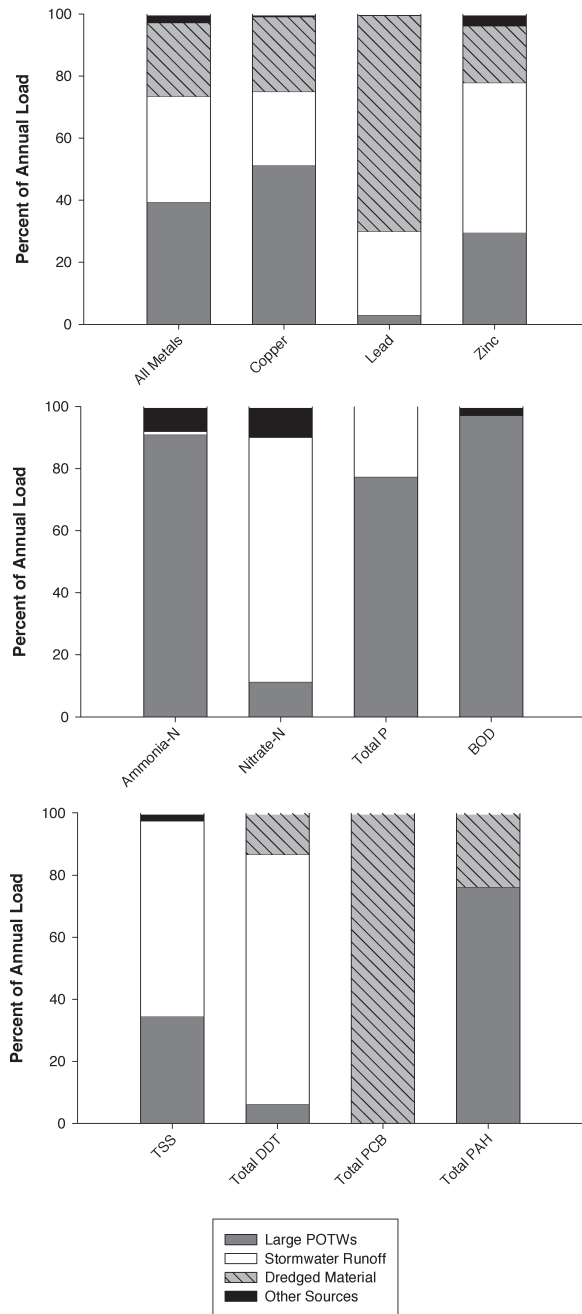


Figure 3. Relative contribution of selected constituents to overall mass emissions to the SCB from major sources in 2000.

mentation of the CWA. Second, the influence of non-point contaminant sources has increased as point source treatment has improved. Lastly, this study demonstrates that better data integration is required to improve the precision of regional mass emissions estimates, particularly for non-point sources.

Combined mass emissions to the SCB have declined dramatically since the passage of the CWA, even as the coastal population and discharge volume increased. Between 1970 and 2000 the population of the five coastal counties bordering the SCB increased 56%, to over 16 million. During that time the total annual volume discharged to the SCB increased 31%, however, mass emissions of nearly all constituents we examined decreased (Figure 4). Reductions in mass emissions resulted from improved treatment practices mandated under the CWA and source control measures that allowed increases in effluent volume to be over 20% less than corresponding increases in population. Bans on the use of DDT and PCBs, and strict regulation of heavy metals such as lead and mercury over the study period, have also contributed to the decline. Cessation of sludge discharge to the ocean in the 1980s and increased secondary treatment capacity by POTWs in response to CWA requirements has also contributed to significant effluent quality improvements (Raco-Rands and Steinberger 2001, Steinberger and Schiff 2003a).

The greatest reductions in contaminant loading have been from point source discharges. Large

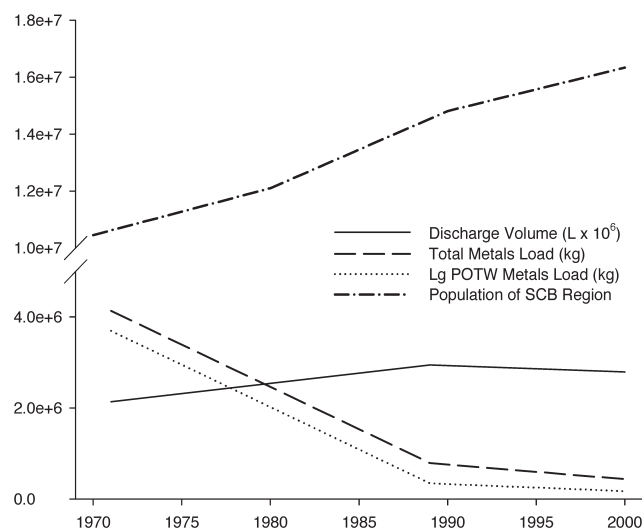


Figure 4. Trends in population of coastal counties adjacent to the SCB, combined discharge volume, and total metals loads from all sources and large POTWs from 1970 to 2000.

POTWs have been responsible for the most dramatic reductions in contaminant mass emissions. Many of the contaminant loads from large POTWs were reduced by greater than 90% from pre-CWA levels (Steinberger and Schiff 2003a). Contaminant loads from other point sources have also declined since 1971. Mass emissions from small POTWs decreased substantially even as effluent volume doubled over the past 30 years. Both discharge volume and contaminant emissions from industrial facilities decreased by more than 90% between 1971 and 2000. Much of this reduction is because the number of industrial facilities discharging to the SCB declined from an estimated 96 in 1971 to just 7 in 2000, due in part to the CWA, which restricted the types and quantities of industrial wastes that could be discharged to coastal waters. Nevertheless, large POTWs remain the most significant source of pollutant load to the SCB in 2000 mainly due to the sheer volume of material discharged on a daily basis (4 L x 10⁶/day).

The spatial and temporal patterns of contaminant mass emissions to the SCB correspond with improved environmental quality in the coastal ocean. Regional assessments of water quality and sediment chemistry have been conducted throughout the SCB in 1970-71, 1994, 1998, and 2003. The most recent assessment found that sediments with contaminant levels that posed a moderate to high risk of adverse biological impacts were concentrated near large POTW outfalls and in urban estuaries and marinas (Schiff et al. 2006). These include areas where the most dominant sources of contaminants, i.e. large POTWs and urban runoff, enter the coastal ocean. Since 1970-71, concentrations of metals in the sediments surrounding the large POTW outfalls have decreased, following the trend of declining effluent concentrations. For example, sediment lead concentrations in 1971 averaged 71 mg/kg near large POTW outfalls, but were only 9.2 mg/kg in 2003 (SCCWRP 1973, Schiff et al. 2006). This represents an 87% decrease in sediment concentration while the large POTW effluent concentration was reduced by 99%. Copper and zinc concentrations exhibit similar correspondence with sediment concentrations, which have declined by 72% and 75%, respectively, while effluent concentrations decreased by 90% and 96%, respectively.

As mass emissions from point sources have decreased, the relative contribution of storm water runoff has increased (Schiff 1997, Bay et al. 1999). This pattern has also been observed in other coastal

regions of the United States. Boesch et al. (2001) found that reductions in pollutant discharges in areas such as the Chesapeake Bay, Long Island Sound, and New York Harbor were primarily due to improvements in point source treatment. Boesch et al. (2001) also reported that management efforts directed at point sources have resulted in shifts in the relative importance of sources, with emissions from non-point sources remaining stable or even increasing over time.

Although annual contaminant loads may be dominated by discharges from large POTWs, storm water runoff becomes the primary management concern during wet weather, and can potentially become the dominant annual source in years with above average rainfall. In southern California, rain falls on average only 35 days a year, resulting in storm flows during an average of 55 days or 15% of the year (National Weather Service, Stein and Tiefenthaler 2004). The short, intense nature of storm water runoff to the SCB increases the acute impact of storm water emissions. To examine the difference in daily loads between an intermittent source, storm water runoff, and a relatively constant source, large POTWs, we compared the annual storm water runoff emissions per storm flow day to large POTW average daily emissions. The average daily load of copper from large POTWs was 140 kg per day in 2000, while the load from storm water runoff was an estimated 429 kg per storm flow day (Figure 5).

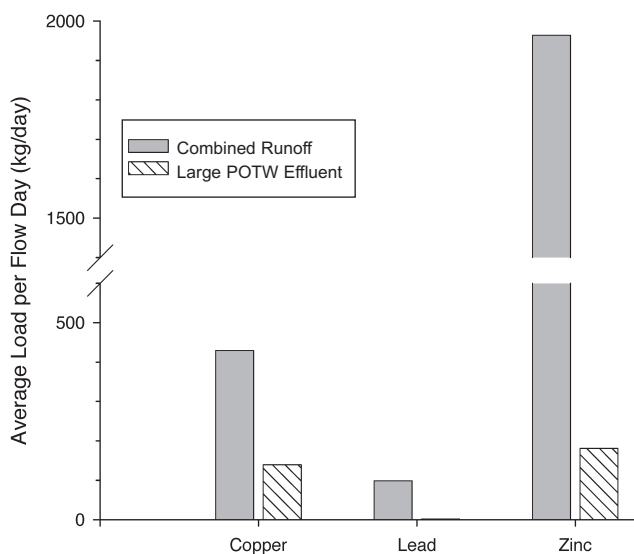


Figure 5. Estimated daily mass emission rates from stormwater runoff and large POTWs. Stormwater runoff is based on 55 storm flow days per year.

Therefore, during storm periods, emissions from storm water runoff become the dominant contaminant source to the SCB.

It is important to note that the estimates of storm water discharge used in this study were derived from a regional model based on monitoring data from a limited number of storms and watersheds, extrapolated to the entire region based on land use and rainfall patterns (Ackerman and Schiff 2003). This approach was necessary because there is currently no regional program to coordinate storm water monitoring approaches and compile the results for regional estimates of mass emissions, as there is for point sources. However, such a program is being contemplated by the Stormwater Monitoring Coalition (a partnership of storm water dischargers, regulatory agencies, and research entities). Once this program is established it will allow for more refined estimates of status and trends of storm water mass emissions.

Regional storm water estimates also do not account for contributions from dry season (non storm) runoff, which can be a significant source of contaminant loading in arid, urban watersheds, such as those found in southern California (McPherson et al. 2002, Stein and Tiefenthaler 2004, Stein and Ackerman 2007). A coarse estimate of the regional contribution of dry weather metals loading was generated by extrapolating dry weather metals loading data from six greater Los Angeles watersheds to the entire SCB watershed area (Stein and Ackerman 2007). Based on these estimates, dry weather runoff would contribute 14, 1.1, and 85 mt of copper, lead, and zinc, respectively to the SCB (Table 4). Including the contribution of dry weather runoff would increase estimated annual non point source emissions to the SCB by 58% (copper) to 79% (zinc) compared to emissions from storm water alone (see Table 1 vs. Table 4). If dry weather runoff estimates were included in the total annual load, relative contributions from combined non point source runoff would account for 31, 33, and 63% of annual lead, copper, and zinc emissions, respectively (Table 4).

Our estimates of dry weather mass emissions likely overestimate the actual contribution because 1) the Los Angeles area watersheds were more urbanized than the SCB region as a whole (63% vs. 35%), and 2) streams in the Los Angeles area receive discharge of tertiary treated POTW effluent while many other watersheds in southern California do not. However, our values provide a general estimate of the contribution of dry weather runoff to total annual

Table 4. Annual mass emissions of selected metals including estimated dry weather runoff contributions in 2000. Percent of total annual load is shown in parentheses. Totals are different than those shown in Table 1 due to the inclusion of dry weather runoff.

Constituent	Units	Stormwater Runoff	+ Dry Weather Runoff	= Combined Runoff	Large POTW Effluent	Other Sources	Total (incl. Dry Weather Runoff)
Copper	mt	24 (21%)	14 (12%)	38 (33%)	51 (45%)	25 (22%)	114 (100%)
Lead	mt	5.4 (26%)	1.1 (5%)	6.5 (31%)	0.6 (3%)	14 (66%)	21.2 (100%)
Zinc	mt	108 (35%)	85 (28%)	193 (63%)	66 (21%)	49 (16%)	308 (100%)

loading to the SCB and suggest that future studies should focus more attention on quantifying both storm and non-storm (dry weather) contributions to overall mass emissions.

Despite some uncertainties that limit the precision of our mass emissions estimates, this study indicates that implementation of the CWA has had a significant effect on water quality in the SCB. Overall pollutant inputs have decreased dramatically since 1971 as source control efforts and improved point source treatment practices have proven effective. Although mass emissions declined, large POTWs remained the dominant source of many pollutants on an annual scale. Non-point source runoff was also a significant source of contaminants, and became the primary source of pollutant load during storm water conditions. Future efforts to integrate data from the storm water monitoring programs on a regional scale and to include dry weather runoff monitoring should improve the accuracy of mass emission estimates from this increasingly important source.

LITERATURE CITED

Ackerman, D. and K. Schiff. 2003. Modeling storm water mass emissions to the Southern California Bight. *Journal of Environmental Engineering* 129:308-317.

Bay, S., B.H. Jones and K. Schiff. 1999. Study of the impact of stormwater discharge on Santa Monica Bay. Prepared for the Los Angeles County Department of Public Works. Alhambra, CA.

Boesch, D.F., R.H. Burroughs, J.E. Baker, R.P. Mason, C.L. Rowe and R.L. Siefert. 2001. Marine pollution in the United States. Prepared for the Pew Oceans Commission. Arlington, VA.

Copeland, C. 2002. Clean Water Act: A summary of the law. Congressional Research Service. Washington, DC.

Culliton, T., M. Warren, T. Goodspeed, D. Remer, C. Blackwell and J. McDonough III. 1990. Fifty years of population changes along the nations coasts. Report No. 2: Coastal Trends Series. National Oceanic and Atmospheric Administration, Strategic Assessment Branch. Rockville, MD.

Knopman, D.S. and R.A. Smith. 1993. 20 years of the Clean Water Act. *Environment* 35:16-41.

McPherson, T.N., S.J. Burian, H.J. Turin, M.K. Stenstrom and I.H. Suffet. 2002. Comparison of the pollutant loads in dry and wet weather runoff in a southern California urban watershed. *Water Science and Technology* 45:255-261.

National Weather Service. Public information statement: Driest rain season on record in Los Angeles. http://www.wrh.noaa.gov/lox/Assets/pns_07_01_07.pdf

Raco-Rands, V.E. and A. Steinberger. 2001. Characteristics of effluents from large municipal wastewater treatment facilities in 1997. pp. 28-44 in: S.B. Weisberg and D. Elmore (eds.), Southern California Coastal Water Research Project 1999-2000 Annual Report. Westminster, CA.

Schiff, K. 1997. Review of existing storm water monitoring programs for estimating Bight-wide mass emissions from urban runoff. pp. 44-55 in: S.B. Weisberg, C. Francisco and D. Hallock (eds.), Southern California Coastal Water Research Project 1996 Annual Report. Westminster, CA.

Schiff, K., K. Maruya and K. Christensen. 2006. Southern California Bight 2003 Regional Monitoring Program: II. Sediment Chemistry. Southern

California Coastal Water Research Project. Westminister, CA.

Southern California Coastal Water Research Project (SCCWRP). 1973. The ecology of the Southern California Bight: Implications for water quality management. Three-year report of the Southern California Coastal Water Research Project. El Segundo, CA.

Stein, E.D. and D. Ackerman. 2007. Dry weather water quality loadings in arid urban watersheds of the Los Angeles basin, California, USA. *Journal of the American Water Resources Association* 43:398-413.

Stein, E.D. and L. Tiefenthaler. 2004. Characterization of dry weather metals and bacteria in Ballona Creek. Technical Report 427. Southern California Coastal Water Research Project. Westminister, CA.

Steinberger, A. and K.C. Schiff. 2003a. Characteristics of effluents from large municipal wastewater treatment facilities in 2000. pp. 2-13 *in*: S.B. Weisberg and D. Elmore (eds.), Southern California Coastal Water Research Project 2001-2002 Biennial Report. Westminister, CA.

Steinberger, A. and K.C. Schiff. 2003b. Characteristics of effluents from non-power industrial facilities in 2000. pp. 31-46 *in*: S.B. Weisberg and D. Elmore (eds.), Southern California Coastal Water Research Project 2001-2002 Biennial Report. Westminister, CA.

Steinberger, A. and K.C. Schiff. 2003c. Characteristics of effluents from small municipal wastewater treatment facilities in 2000. pp. 14-30 *in*: S.B. Weisberg and D. Elmore (eds.), Southern California Coastal Water Research Project 2001-2002 Biennial Report. Westminister, CA.

Steinberger, A. and E.D. Stein. 2004. Characteristics of effluents from power generating stations in the Southern California Bight in 2000. pp. 31-40 *in*: S.B. Weisberg and D. Elmore (eds.), Southern California Coastal Water Research Project 2003-2004 Biennial Report. Westminister, CA.

Steinberger, A., E.D. Stein and V. Raco-Rands. 2004. Offshore oil platform discharges to the Pacific outer continental shelf along the coast of southern California in 1996 and 2000. pp. 16-30 *in*: S.B. Weisberg and D. Elmore (eds.), Southern California

Coastal Water Research Project 2003-2004 Biennial Report. Westminister, CA.

Steinberger, A., E. Stein and K. Schiff. 2003. Characteristics of dredged material disposal to the Southern California Bight between 1991 and 1997. pp. 47-57 *in*: S.B. Weisberg and D. Elmore (eds.), Southern California Coastal Water Research Project 2001-2002 Biennial Report. Westminister, CA.

US Census Bureau. 2000. Population of California counties by decennial census. <http://www.census.gov/population/cencounts/ca190090.txt>

ACKNOWLEDGMENTS

The authors would like to thank the personnel at each discharge facility and the Regional Water Quality Control Boards for providing data and assistance in understanding how the data were collected and analyzed. We would also like to thank earlier SCCWRP staff who began compilation of the SCB mass emissions database, including Valerie Raco-Rands, Andrea Steinberger, and Dawn Petschauer.