Effluent discharges to the Southern California Bight from large municipal wastewater treatment facilities from 2005 to 2009

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Abstract

The four largest municipal wastewater treatment facilities (publicly owned treatment works; POTWs) in southern California discharge treated effluent that has historically been the greatest point source of contaminants to the Southern California Bight (SCB). Each POTW conducts flow and effluent chemistry monitoring and testing in compliance with its discharge permit, but the monitoring requirements do not address regional pollutant emissions from multiple sources. Since 1971, SCCWRP has been integrating POTW effluent monitoring data to assess the status and trends of contaminant discharges from multiple sources to the SCB. This study analyzes effluent discharges from the four largest POTWs from 2005 through 2009 in terms of effluent volumes, contaminant mass emissions, average constituent concentrations, and toxicity. These data update a continuous 39-year record of regional POTW effluent discharges. Total effluent volume from large POTWs decreased from 1,497 L x 10^9 in 2005 to 1,184 L x 10^9 in 2009, which was the lowest annual volume since regional assessments began in 1971. Reductions in effluent volume resulted primarily from water conservation and increased recycling of treated effluent for beneficial reuse, even as population continued to grow. Similar to the volume pattern, mass emissions of most monitored constituents decreased from 2005 to 2009, with many constituent loads including suspended solids, BOD, oil/grease, and several metals, dropping to historic lows. Suspended solids emissions decreased 92% between 1971 and 2009, from 295,000 to 25,000 metric tons (mt). Copper emissions decreased 97%, from 535 mt in 1971 to 17 mt in 2009. Although most constituent loads have decreased, average concentrations have been more variable, with several constituents including ammonia-N, chromium, and zinc concentrations increasing from 2005 to 2009. The largest reductions in contaminant loads observed prior to 2005 resulted from improved wastewater treatment, but recent reductions in these loads have been influenced more by declining effluent volume than by effluent quality improvement. Due to significant decreases in large POTW mass emissions since previous comparisons, it is possible that point source contaminant loads are now equaled or exceeded by loads from non-point source runoff; however, more comprehensive and updated regional estimates of runoff loads to the SCB are needed to address this hypothesis.

Introduction

The Southern California Bight (SCB) region is one of the most densely populated coastal regions in the United States (Crossett *et al.* 2004). The five coastal counties bordering the SCB are home to over 17 million people (US Census Bureau 2011). Millions of gallons of domestic, commercial, and industrial wastewater generated by this population are treated and discharged daily by wastewater treatment facilities known as publicly owned treatment works (POTWs). Twenty-three POTWs discharge effluent directly

to the coastal ocean of the SCB. The four largest facilities each discharge over 100 million gallons per day (mgd), and account for 86% of the total POTW effluent volume (Lyon and Stein 2008). These four facilities, hereafter referred to as large POTWs, are the Hyperion Treatment Plant (HTP) operated by the City of Los Angeles, the Joint Water Pollution Control Plant (JWPCP) operated by the Los Angeles County Sanitation Districts, Orange County Sanitation District (OCSD) Reclamation and Treatment Plants, and the City of San Diego's Point Loma Wastewater Treatment Plant (PLWTP) (Figure 1). The combined effluent of the four large POTWs has historically been the greatest point source of contaminants to the SCB since regional assessments began in 1971 (SCCWRP 1973, Steinberger and Stein 2004, Lyon and Stein 2009). Discharges from the 19 smaller POTW facilities are assessed separately at a lesser frequency due to their relatively low volume contribution (Lyon and Stein 2008).

POTW effluent discharges are regulated under the National Pollutant Discharge Elimination System (NPDES) requirements of the federal Clean Water Act (CWA). Each discharging facility is required to monitor its effluent flow and chemistry in compliance with its NPDES permit issued by the California Regional Water Quality Control Boards. Although compliance monitoring by each facility is thorough, there is no requirement to integrate data from multiple dischargers to assess cumulative impact to a regional water body such as the SCB. The lack of a regional perspective poses a challenge to environmental regulators and managers who need to evaluate pollutant loads and trends from multiple sources on a regional scale. 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, track trends, and identify sources of greatest significance. The resulting long-term regional dataset provides a measure to assess the effectiveness of regulatory and management actions, and can aid interpretation of changes observed in the receiving environment.

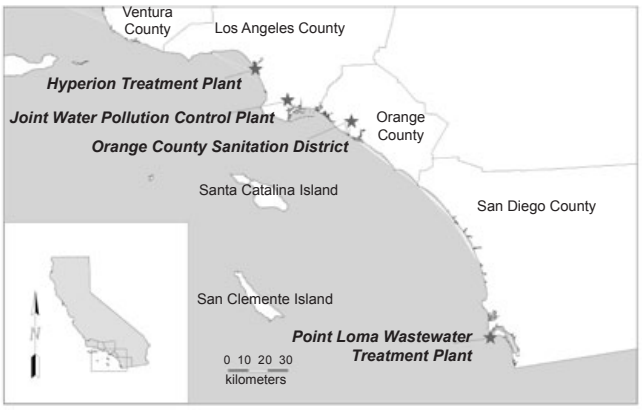

Figure 1. Locations of the four large publicly owned treatment works in the SCB.

The goal of this study was to characterize effluent discharges from the four large POTWs between 2005 and 2009. To achieve this objective, flow and chemistry monitoring data from each of these large POTWs discharging to the SCB were compiled and standardized to allow calculation of cumulative mass emission estimates for the entire bight. Differences in relative contributions between facilities, average constituent concentrations, and toxicity from each facility were also examined. To assess long-term trends, we then compared these effluent data to results from previous SCCWRP assessments, which have compiled a continuous annual dataset of large POTW discharges beginning in 1971. Specifically, we compared the current results to two significant historical periods: the first assessment of discharges prior to implementation of the CWA in 1971 and the period of peak effluent volume discharge in 1989. With the addition of data from the current study, SCCWRP has compiled a continuous 39-year record of large POTW effluent discharges to the SCB, documenting changes in regional loading from the most significant point source of contaminants over the entire time period of the CWA.

Methods

Annual mass emissions estimates for the large POTWs were compiled from effluent flow and chemistry data provided in each facility's discharge monitoring reports. 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 suspended solids, biochemical oxygen demand (BOD), oil and grease, nutrients, and cyanide. Selected metals, phenols, dichlorodiphenyltrichloroethane (DDT), polychlorinated biphenyl (PCB), and polycyclic aromatic hydrocarbons (PAH) were also analyzed. In addition to chemical constituents, acute and chronic toxicity test results were used to determine annual

average toxicity levels for each facility using the most sensitive species tested during each year.

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 or data for a given month were not available, 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 facility. Constituent concentrations below the method detection limit (MDL) were assigned a value of zero for calculating mass emission estimates. Constituent concentrations detected between the MDL and the reporting level (RL), classified as detected but not quantified (DNQ) results, were included in mass emission and average concentration calculations using the estimated values reported by each facility. Estimated DNQ values were included in these calculations to generate mass emission estimates based on all detected results. The inclusion of DNQ estimates differs from the method used by the facilities for permit compliance where DNQ values are treated as zero in calculations, as allowed by their NPDES permits.

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

$$V = \sum_{i=1}^{12} uF_iD_i \qquad \text{Eq. 1}$$

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:

$$ME = \sum_{i=1}^{12} uF_iC_iL \qquad \text{Eq. 2}$$

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).

Annual average flow-weighted concentrations (FWC) were calculated by dividing the annual ME for a given constituent by the total annual effluent volume (V).

$$FWC = u\frac{ME}{V} \qquad \text{Eq. 3}$$

where u was the unit conversion factor for reporting the FWC in the appropriate concentration units.

This approach for calculating FWC occasionally resulted in estimates below the MDL for constituents that had one or more non-detected results. In these cases, the FWC was reported as calculated. Constituents that were consistently not detected resulted in FWC of zero, and were reported as less than the MDL. When more than one MDL was used for a given constituent during the year, the greatest MDL was reported. For summed organic constituents (e.g., Total DDT), when each individual constituent was consistently less than its respective MDL, the total was reported as less than the highest component MDL. Where no MDL was available, the reporting level (RL) was substituted for the MDL.

Historical trends in large POTW mass emissions were analyzed by comparing the current results to data from previous assessments, which combined have compiled a continuous annual record of large POTW discharges to the SCB since 1971 (SCCWRP 1973, Steinberger and Stein 2004, Lyon *et al.* 2006). The historical analysis focused on four annual periods: 1971, 1989, 2005, and 2009. 1971 was the first year regional effluent discharge data were compiled and represents the condition prior to implementation of the federal Clean Water Act (CWA). 1989 represents the temporal midpoint of the dataset and was the period of peak effluent discharge volume. 2005 and 2009 were selected to assess the beginning and end of the current assessment period.

Results

Recent Discharges 2005 to 2009

Combined daily effluent flow rate from the large POTWs was highest in 2005 at 1,083 mgd (4.1 L x 10^9 per day) and decreased in each subsequent year (Table 1). By 2009, the combined effluent flow rate had dropped 21% to 857 mgd (3.2 L x 10^9 per day). Over the 5-year period, HTP and JWPCP each contributed a mean of 31% of the combined flow, while OCSD and PLWTP contributed means of 21% and 17%, respectively. By 2009, there was a slight shift in the relative flow contributions due to increasing diversion of OCSD effluent for reclamation, resulting in reduced discharge by OCSD to a level approaching the same flow contribution of PLWTP.

Secondary treatment capacity as a percentage of total effluent discharge remained relatively stable at around 76% from 2005 to 2009, the same overall level as in the previous assessment of discharges for 2003 to 2004 (Lyon *et al.* 2006). HTP and JWPCP continued to provide secondary treatment to 100% of effluent discharged throughout the current assessment period. PLWTP treated all effluent with advanced primary treatment in compliance with a waiver of the CWA secondary treatment requirement. OCSD discharged a blend of advanced primary and secondary treated effluent. Although OCSD's secondary treatment capacity has been increasing in recent years, the percent of effluent flow receiving secondary treatment actually decreased during the current period, from a high of 71% to 65% in 2009. This relative reduction occurred due to diversion of increasing volumes of highly treated effluent for recycling by the Orange County Water District (OCWD), resulting in discharge of an increased proportion of advanced primary treated effluent, in excess of OCSD's current secondary treatment capacity. Construction of additional secondary treatment capacity is scheduled for completion by the end of 2012, and is expected to allow 100% secondary treatment of OCSD effluent.

Decreasing average daily flow rates resulted in annual combined volumes peaking at 1,497 L x 10^9 in 2005 and declining to 1,184 L x 10^9 in 2009 (Table 2; Figure 2). Following this recent trend in discharge volume, total mass emissions of many constituents also declined over the 5-year period. Suspended solids decreased from 39,000 mt in 2005 to 25,000 mt in 2009 (Table 2). BOD also decreased, from 53,000 mt in 2005 to 39,000 mt in 2009. Oil and grease loads were reduced from over 6,000 mt in 2005 to under 4,000 mt in 2009. Ammonia-N loads decreased slightly from 47,000 mt in 2005 and 2006 to 44,000 mt in 2009. Most metals loads also decreased over the 5-year period, including copper (25 mt to 17 mt), nickel (20 mt to 9 mt), and lead (537 kg to 163 kg). The total zinc load peaked in 2006 at 39 mt and then declined to 26 mt in 2009. Mercury was the only metal with a greater discharged load estimate in 2009 (12 kg) than in 2005 (11 kg).

Table 1. Annual average daily effluent flow rates from the four largest POTWs to the SCB in million gallons per day (mgd), with the percent of effluent receiving secondary treatment shown in italics.

Facility	Year									
	2005		2006		2007		2008		2009	
	(mgd)	(%)	(mgd)	(%)	(mgd)	(%)	(mgd)	(%)	(mgd)	(%)
Hyperion Treatment Plant (HTP)	332	*100*	319	*100*	288	*100*	286	*100*	269	*100*
Joint Water Pollution Control Plant (JWPCP)	323	*100*	316	*100*	309	*100*	296	*100*	280	*100*
Orange County Sanitation District (OCSD)	246	*68*	236	*71*	229	*62*	184	*64*	155	*65*
Point Loma Wastewater Treatment Plant (PLWTP)	183	*0*	170	*0*	161	*0*	162	*0*	153	*0*
Combined Total	**1,083**	***76***	**1,041**	***77***	**987**	***75***	**927**	***75***	**857**	***76***

Table 2. Estimated annual mass emissions from the four largest POTWs to the SCB from 2005 to 2009. nd = not detected. "--" = data were not available.

	Combined Discharges				
Constituent	**2005**	**2006**	**2007**	**2008**	**2009**
Volume (L x 10^9)	1,497	1,438	1,364	1,285	1,184
Settleable Solids (L x 10^3)	190,289	130,595	188,532	158,343	158,491
Suspended Solids (mt)	38,525	36,169	32,162	29,172	24,897
BOD (mt)	53,367	51,062	45,953	42,164	39,223
Oil/grease (mt)	6,444	5,530	4,758	4,174	3,619
Ammonia-N (mt)	46,915	47,333	45,360	45,694	43,910
Nitrate-N (mt)	40	34	42	79	62
Nitrite-N (mt)	51	26	46	58	69
Organic-N (mt)	3,507	3,119	2,532	2,231	2,077
Phosphate-P (mt)	387	293	326	299	--
ortho-Phosphate (mt)	nd	460	271	746	824
Phosphorus (mt)	1,249	1,371	1,304	1,091	1,432
Cyanide (kg)	3,614	4,040	2,650	3,518	3,214
Arsenic (kg)	2,860	2,625	2,376	2,863	2,797
Cadmium (kg)	67	64	83	34	25
Chromium (kg)	2,065	2,311	1,853	1,972	1,836
Copper (kg)	25,307	23,571	20,729	19,831	16,858
Lead (kg)	537	701	384	202	163
Mercury (kg)	11	11	12	15	12
Nickel (kg)	19,539	14,017	12,098	12,295	9,397
Selenium (kg)	6,372	5,574	4,232	5,236	5,662
Silver (kg)	904	742	500	334	234
Zinc (kg)	30,771	39,070	35,427	30,719	25,736
Total DDT (kg)	nd	nd	nd	nd	nd
Total PAH (kg)	23	21	52	6	nd
Total PCB (kg)	nd	nd	nd	nd	nd

The other constituents with increased loads in 2009 were nutrients (nitrate-N, nitrite-N, ortho-phosphate, and phosphorus). Nitrate-N and nitrite-N loads fluctuated, with 2009 estimates of 62 mt and 69 mt, respectively. Phosphorus and ortho-phosphate loads were 1,432 mt and 824 mt, respectively, in 2009.

Individual facility contributions to combined mass emissions varied over time and by constituent. Discharged effluent volume decreased each year from all facilities with one exception (PLWTP from 2007 to 2008). The greatest change in effluent volume occurred at OCSD where volume decreased by 37% over 5 years, from 339 L x 10^9 in 2005 to 213 L x 10^9 in 2009 (Appendix I; Figure 2). Reductions in effluent volumes by the other facilities ranged from 13% (JWPCP) to 19% (HTP). HTP and JWPCP, each contributing on average 31% of the total effluent volume, discharged proportionately low contributions of conventional contaminants, such as solids, BOD, and oil/grease (Figure 3). OCSD and PLWTP accounted for the majority of the solids, BOD, and oil/grease loads. OCSD also contributed disproportionately (i.e., greater than its 21% mean volume contribution) to loads of most metal constituents throughout the assessment period. JWPCP discharged the greatest proportion of cyanide

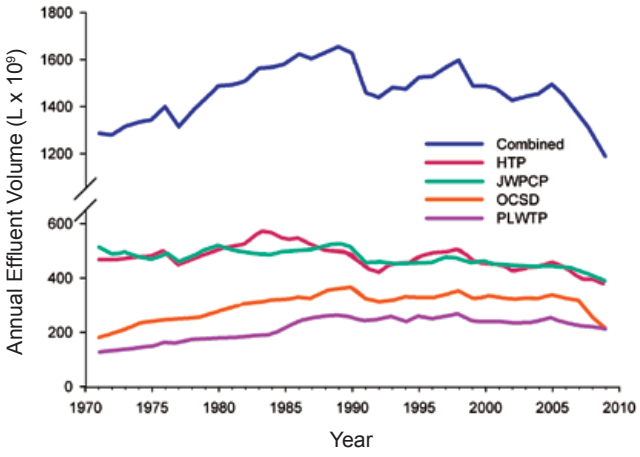

Figure 2. Effluent volumes from large POTWs to the SCB between 1971 and 2009.

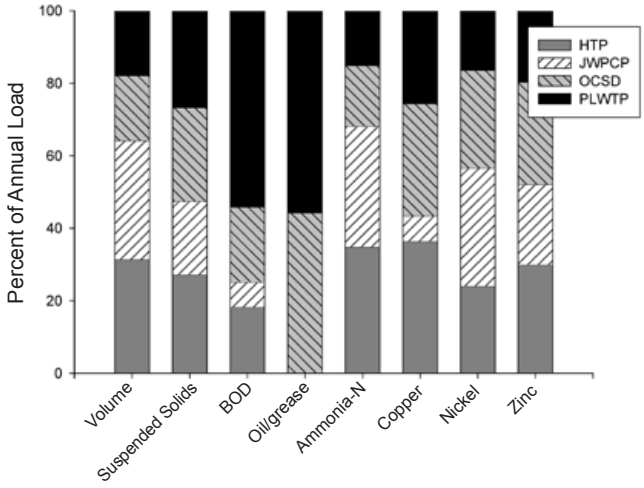

Figure 3. Relative contribution of large POTW mass emissions for selected constituents in 2009.

loads in all years. HTP accounted for the majority of detected PAH constituent loads in most years. Ammonia-N loads from all facilities were generally proportional to the facility volume contributions.

Although total mass emissions of most constituents were lower in 2009 than 2005, changes in combined flow-weighted concentrations were mixed. Of the constituents analyzed and consistently detected by all facilities, combined flow-weighted concentrations of suspended solids, BOD, copper, and nickel decreased from 2005 to 2009 (Table 3). However, settleable solids, ammonia-N, arsenic, chromium, selenium, and zinc concentrations increased. Mass emissions of each of these constituents decreased during the assessment period, indicating that the observed load reductions were influenced more by reduced effluent flow than by effluent quality. Both turbidity and suspended solids concentrations decreased in all facilities' effluent from 2005 to 2009 (Appendix II). Ammonia-N was the only constituent that increased in flow-weighted concentration from each facility during the 5-year period. Changes in all other constituent concentrations were inconsistent among the facilities. Average flow-weighted concentrations of conventional contaminants, including turbidity, suspended solids, BOD, and oil/grease generally varied along the treatment level gradient, with

Table 3. Annual flow-weighted concentrations from the combined discharge of the four largest POTWs to the SCB from 2005 to 2009.

Constituent	Combined FWC					
	2005	2006	2007	2008	2009	% Change 2005-2009
Settleable Solids (ml/L)	0.13	0.09	0.14	0.12	0.13	5%
Suspended Solids (mg/L)	25.74	25.15	23.58	22.70	21.03	-18%
BOD (mg/L)	35.65	35.51	33.69	32.82	33.13	-7%
Ammonia-N (mg/L)	31.34	32.91	33.25	35.56	37.09	18%
Arsenic (µg/L)	1.91	1.83	1.74	2.23	2.36	24%
Chromium (µg/L)	1.38	1.61	1.36	1.53	1.55	12%
Copper (µg/L)	16.91	16.39	15.20	15.43	14.24	-16%
Nickel (µg/L)	13.05	9.75	8.87	9.57	7.94	-39%
Selenium (µg/L)	4.26	3.88	3.10	4.07	4.78	12%
Zinc (µg/L)	20.56	27.17	25.97	23.91	21.74	6%

the lowest values measured in HTP and JWPCP secondary treated effluent, and higher concentrations detected in OCSD blended and PLWTP advanced primary treated effluent. However, ammonia-N concentrations were consistently higher in HTP and JWPCP effluent and have been increasing at all facilities.

Average acute toxicity results for a marine vertebrate test species, the topsmelt *Atherinops affinis*, ranged from 1.68 TUa (JWPCP in 2009) to 2.85 TUa (OCSD in 2005), while results for a marine invertebrate, the mysid *Mysidopsis bahia*, ranged from 1.31 TUa (PLWTP in 2007) to 3.15 TUa (PLWTP in 2005 and 2006; Appendix II). Chronic toxicity was tested using four marine species, including one vertebrate (topsmelt *A. affinis*), two invertebrates (red abalone *Haliotis rufescens* and purple sea urchin *Strongylocentrotus purpuratus*), and one alga (giant kelp *Macrocystis pyrifera*). Direct comparison of toxicity results is difficult due to differences in test species between facilities and years, and differences in dilutions between facilities, however average toxicity results were generally low and all were well within permit limits.

Long-Term Trends 1971 to 2009

Large POTWs discharged a combined volume of 1,288 L x 10^9 in 1971 (Table 4). Volume increased

Table 4. Comparison of mass emissions from the four largest POTWs to the SCB in 2005 and 2009 to two historical time periods: 1971 (pre-CWA) and 1989 (peak volume). nd = not detected. "+" = increased from previously not detected. "--" = data were not available.

Constituent	Combined Discharges				Percent Change		
	1971	1989	2005	2009	1971-2009	1989-2009	2005-2009
Volume (L x 10^9)	1,288	1,658	1,497	1,184	-8%	-29%	-21%
Settleable Solids (L x 10^3)	--	--	190,289	158,491	--	--	-17%
Suspended Solids (mt)	295,119	83,216	38,525	24,897	-92%	-70%	-35%
BOD (mt)	282,194	161,567	53,367	39,223	-86%	-76%	-27%
Oil/grease (mt)	63,166	22,320	6,444	3,619	-94%	-84%	-44%
Ammonia-N (mt)	53,521	45,263	46,915	43,910	-18%	-3%	-6%
Nitrate-N (mt)	308	338	40	62	-80%	-82%	54%
Nitrite-N (mt)	159	78	51	69	-57%	-12%	36%
Organic-N (mt)	17,234	7,178	3,507	2,077	-88%	-71%	-41%
Phosphate-P (mt)	--	--	387	--	--	--	--
ortho-Phosphate (mt)	--	--	nd	824	--	--	+
Phosphorus (mt)	11,713	6,987	1,249	1,432	-88%	-80%	15%
Cyanide (kg)	193,552	11,534	3,614	3,214	-98%	-72%	-11%
Arsenic (kg)	7,863	7,396	2,860	2,797	-64%	-62%	-2%
Cadmium (kg)	53,064	1,719	67	25	-100%	-99%	-62%
Chromium (kg)	666,309	22,137	2,065	1,836	-100%	-92%	-11%
Copper (kg)	535,163	67,219	25,307	16,858	-97%	-75%	-33%
Lead (kg)	239,858	26,983	537	163	-100%	-99%	-70%
Mercury (kg)	2,872	391	11	12	-100%	-97%	14%
Nickel (kg)	326,895	53,510	19,539	9,397	-97%	-82%	-52%
Selenium (kg)	12,710	7,422	6,372	5,662	-55%	-24%	-11%
Silver (kg)	15,071	10,264	904	234	-98%	-98%	-74%
Zinc (kg)	1,833,724	145,184	30,771	25,736	-99%	-82%	-16%
Total DDT (kg)	21,579	22	nd	nd	-100%	-100%	nd
Total PAH (kg)	--	--	23	nd	--	--	-100%
Total PCB (kg)	8,930	nd	nd	nd	-100%	nd	nd

to a peak of 1,658 L x 10^9 in 1989 (Figure 2). Since 1989, volume fluctuated with smaller peaks occurring during the El Niño years of 1998 and 2005, followed by a steady decline through 2009. The 1,184 L x 10^9 effluent volume in 2009 was the lowest total volume discharged since regional assessments began in 1971. HTP and JWPCP effluent volumes have also decreased to historic lows (Figure 2). Although volumes from OCSD and PLWTP have decreased in recent years, they still remain above 1971 levels, due largely to rapid population growth in the counties served by those facilities since the 1970s (US Census Bureau 1995, 2009, 2011).

Mass emissions of all constituents for which data were available in both 1971 and 2009 have decreased over the period, several to historically low levels. The 2009 effluent loads of suspended solids, BOD, oil/grease, organic-N, cadmium, copper, lead, nickel, silver, and zinc were the lowest recorded values for those constituents over the 39-year period. While volume has decreased by 8% since 1971, mass emissions of most constituents have been reduced by 80-100% (Table 4). The minimum percent load reduction was 18% for ammonia-N, from 54,000 mt in 1971 to 44,000 mt in 2009. Between 1989 and 2009, large POTW effluent volume decreased 29% from the historic peak. Mass emissions of all constituents continued to decrease during this period, with the exception of nonchlorinated phenols, which increased from an estimated load of 8 mt in 1989 to 15 mt in 2009. Again the minimum load reduction occurred with ammonia-N, which decreased only 3% from the level discharged in 1989.

Overall reductions in contaminant loads since the first regional assessment in 1971 have been dramatic. In 1971, large POTWs discharged a total of 295 mt x 10^3 of suspended solids to the SCB (Table 4, Figure 4). Even as volume increased through 1989, the discharged mass of suspended solids decreased 72% to 83,000 mt. By 2005, the suspended solids load was again reduced by more than half to 39,000 mt. The discharged load was further reduced by 35% over the most recent period to 25,000 mt in 2009. BOD, oil/grease, and several metals exhibited similar patterns of decreasing mass emissions in each period since 1971. The total load of copper, for example, decreased 87% from 1971 to 1989, then 62% from 1989 to 2005, and finally 33% from 2005 to 2009. Ultimately copper mass emissions were reduced from 535 mt to 17 mt between 1971 and 2009 (Figure 4).

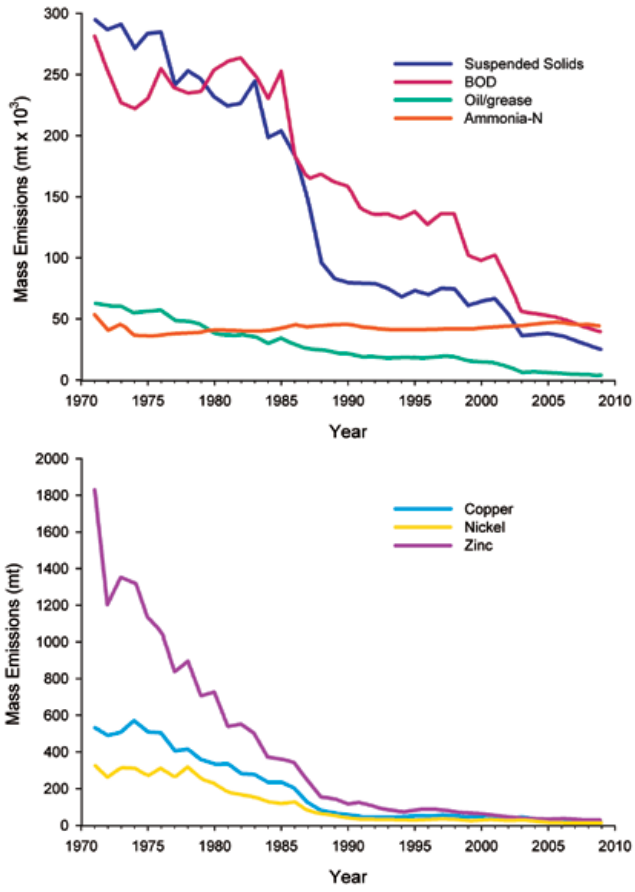

Figure 4. Mass emissions from combined large POTW effluent to the SCB between 1971 and 2009.

Discussion

The 39-year continuous record of regional large POTW effluent discharge data documents a remarkable improvement in effluent quality in response to regulatory and management actions and investment. Overall large POTWs have done an impressive job of reducing contaminant loads from a growing population during the CWA era. Despite 62% population growth in the three counties served by the large POTWs over the past four decades (The combined population of Los Angeles, Orange, and San Diego counties was 9.8 million in 1970 and 15.9 million in 2010), large POTW effluent volume decreased by 2009 to the lowest level recorded since assessments began in 1971. More significant than the reduction in volume, mass emissions of many contaminants have also decreased to historically low levels, including suspended solids, BOD, oil/grease, organic-N, cadmium, copper, lead, nickel, silver, and zinc. Additionally, the organic contaminants total DDT, total PCB, and total PAH, were not detected in large POTW effluent in 2009.

The factors responsible for the reductions in mass emissions observed since 1971 have changed over time. These factors include reductions in effluent flow, improvements in wastewater treatment technologies and processes, source control programs, including pre-treatment of industrial wastewater and pollution prevention. The greatest mass reductions of conventional pollutants (e.g. solids, BOD, oil/grease) and metals loads occurred in the period from 1971 to 1989 (Steinberger and Schiff 2003). This was a period of generally increasing effluent flow; therefore decreases in contaminant loading were primarily influenced by treatment and source control. Improved treatment processes, including advanced primary treatment, cessation of sludge discharge, and the beginning of secondary treatment by JWPCP, resulted in dramatic reductions in combined large POTW mass emissions of conventional pollutants and metals (Steinberger and Schiff 2003). Loads of the organic pollutants, total DDT and total PCB, were virtually eliminated during the 1971 to 1989 period, due primarily to source control rather than improvements in wastewater treatment.

The period from 1989 to 2005 was primarily influenced by improvements in treatment processes and continuing source control at the same time that water conservation and recycling began to slow and reverse the general trend of increasing effluent volume. This period included significant increases in secondary treatment capacity to the current level of 76% of total effluent volume. Both HTP and JWPCP implemented 100% secondary treatment, while OCSD also began providing secondary treatment to a portion of its effluent. Increases in secondary treatment capacity over this period resulted in rapid reductions of conventional and metals loads (Steinberger and Schiff 2003, Steinberger and Stein 2004, Lyon and Stein 2006).

The most recent period from 2005 to 2009 included more modest reductions in most contaminant loads, including conventional pollutants and most metals. This period was characterized by a stable level of secondary treatment (at 76% of total volume) and a steady reduction in flow volume. There were no major improvements to treatment level during this period, therefore decreased mass emissions resulted primarily from reduced effluent flow and continued refinement of existing treatment processes. As constituent concentration trends were variable, the observed decreases in most constituent mass emissions were dominated by the overall reduction in effluent flow.

Three factors influenced the recent effluent flow reductions: infiltration from heavy rainfall at the beginning of the period, ongoing water conservation efforts, and increased diversion of effluent for recycling. Volume peaked in 2005 due to record rainfall in the early part of the year (National Weather Service 2005). Infiltration of surface runoff into the sanitary sewer system caused by the heavy rainfall resulted in increased volume through the POTWs. The record rainfall in 2005 was then followed in subsequent years by lower rainfall totals and a return to normal influent flows to the POTWs. Additionally, efforts to reduce water consumption such as low-flow plumbing fixtures and landscape watering restrictions have continued to reduce influent flows. Finally, recycling of treated effluent for beneficial reuse has reduced effluent volume from the large POTWs. The most significant recent increase in recycling occurred from 2007 to 2009 when OCSD began diverting up to 79 mgd (0.3 L x 10^9 per day) of treated wastewater to OCWD for a major groundwater replenishment project (OCSD 2011). The effluent flow reduction contributed to a 37% decrease in OCSD effluent volume from 2005 to 2009, while decreases from the other facilities ranged from 13 to 19% over the same period.

Continued contaminant load reductions due to improved treatment are likely to continue in the near future. Secondary treatment capacity is still increasing as OCSD completes construction projects designed to treat 100% of effluent at the secondary level by the end of 2012 (OCSD 2011). The additional secondary treatment capacity expected at OCSD provides the potential for continued improvements in total mass emissions as secondary capacity reaches a peak volume in the coming years. Although PLWTP does not employ secondary treatment, it has achieved significant constituent concentration and load reductions with its advanced primary treatment processes. For example, both concentrations and loads of suspended solids, BOD, oil/grease, arsenic, copper, nickel, and zinc decreased in PLWTP effluent in each of the time periods examined (1971-2009, 1989-2009, and 2005-2009). From 1971 to 2009, PLWTP mass emissions of suspended solids and oil/grease decreased by 54 and 61%, respectively. Metals loads were reduced even further, with copper, nickel, and zinc mass emissions each decreasing between 77 and 80% since 1971.

Nutrients generally showed greater variability in load reductions over time than the other classes of constituents. All monitored nutrient load estimates decreased since 1971, however mass emissions of several nutrient constituents increased during the current 5-year period, including nitrate-N, nitrite-N, ortho-phosphate, and phosphorus. Ammonia-N loads have decreased overall but to a lesser degree than most other constituents. The recent increase in ammonia-N concentrations in large POTW effluent have been offset by the reduction in effluent volume, resulting in a relatively minor change in ammonia-N emissions. Increased ammonia-N concentrations were also found in effluent from small POTWs, resulting in a net increase in ammonia-N mass emissions from those facilities between 1971 and 2005 (Lyon and Stein 2008).

Toxicity levels have generally been low from all facilities during the assessment period. Test organisms varied by facility and from year-to-year, making direct comparisons difficult, but all annual flow-weighted average measurements of acute and chronic toxicity were below permit limits (CLA 2010, CSD 2010, LACSD 2010, OCSD 2011). Further, most of the individual toxicity tests resulted in the minimum possible values based on the necessary test dilutions, indicating a very low level of potential toxicity in the receiving environment. Additionally, ecosystem response to reduced contaminant inputs using several different measures, including sediment chemistry, benthic community indices, and organism tissue contamination, have been documented and indicate that the effluent load reductions observed in recent decades have had a measureable effect on the receiving environment (Stein and Cadien 2009).

Following the significant reductions in effluent volume and contaminant mass emissions from large POTWs, it is likely that large POTW discharges of some pollutants are now equaled or exceeded by non-point source runoff loads. Previously modeled estimates generated by Ackerman and Schiff (2003) based on 30-year average rainfall indicate that regional stormwater runoff loads of suspended solids, nitrate-N, cadmium, chromium, copper, lead, mercury, zinc, and total DDT exceed the levels discharged by large POTWs in 2009. Updated and more comprehensive regional runoff loading estimates are needed to assess the relative contributions of point source and non-point source pollutant loading. SCCWRP and the southern California Stormwater Monitoring Coalition (SMC) have initiated an effort to calculate regional runoff mass emissions from stormwater and dry-weather terrestrial runoff based on SMC agencies' routine monitoring data collected in major watersheds throughout the SCB region. The first regional assessment of stormwater loading based on this effort is expected to be completed in 2012.

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Appendix I. Estimated annual mass emissions from each of the four largest POTWs to the SCB from 2005 to 2009. nd = not detected. "--" = data were not available.

Constituent	2005				2006				2007			
	HTP	JWPCP	OCSD	PLWTP	HTP	JWPCP	OCSD	PLWTP	HTP	JWPCP	OCSD	PLWTP
Volume (L x 10^9)	458.7	445.9	339.4	252.8	440.8	437.2	325.4	234.8	397.4	427.4	316.5	223.0
Settleable Solids (L x 10^3)	38,266.4	nd	79,486.9	72,535.6	nd	nd	54,273.9	76,320.7	nd	nd	89,724.7	98,806.8
Suspended Solids (mt)	9,727.2	7,203.4	11,370.6	10,223.9	9,618.9	7,081.6	11,220.4	8,248.4	7,655.0	6,593.7	10,321.2	7,592.2
BOD (mt)	8,942.5	2,678.5	15,447.4	26,298.5	8,681.0	2,193.6	16,302.2	23,885.4	7,514.8	2,687.5	14,475.3	21,275.6
Oil/grease (mt)	122.2	nd	2,844.9	3,477.1	50.3	nd	3,219.6	2,260.5	nd	nd	2,883.6	1,874.1
Ammonia-N (mt)	16,020.3	14,620.4	9,355.5	6,919.0	16,075.6	14,821.9	9,240.2	7,195.5	14,899.6	14,651.5	8,845.7	6,963.0
Nitrate-N (mt)	12.5	3.6	--	24.2	nd	11.3	--	22.8	4.0	5.3	--	32.3
Nitrite-N (mt)	--	50.7	--	--	--	25.8	--	--	--	46.2	--	--
Organic-N (mt)	1,754.0	1,753.0	--	--	1,768.0	1,350.6	--	--	1,559.8	972.3	--	--
Phosphate-P (mt)	--	386.8	--	--	--	293.0	--	--	--	326.3	--	--
ortho-Phosphate (mt)	--	--	--	nd	--	--	--	460.2	--	--	--	270.8
Phosphorus (mt)	1,249.2	--	--	--	1,371.5	--	--	--	1,304.3	--	--	--
Cyanide (kg)	386.4	1,989.4	808.8	429.5	nd	3,791.2	248.3	nd	nd	2,418.0	187.2	45.0
Arsenic (kg)	1,112.5	638.3	821.4	288.1	828.3	704.1	997.8	94.6	721.9	704.9	794.1	155.2
Cadmium (kg)	10.7	nd	21.0	35.0	45.4	13.4	1.1	3.7	11.7	53.1	nd	18.1
Chromium (kg)	424.5	510.0	533.9	596.0	597.9	787.9	507.2	418.2	521.6	588.0	501.5	242.0
Copper (kg)	8,430.5	2,205.2	7,575.2	7,096.0	8,224.8	1,450.5	8,964.8	4,931.3	8,099.8	1,549.4	7,365.3	3,714.8
Lead (kg)	322.5	38.1	176.5	nd	381.9	79.1	174.1	65.7	151.0	118.2	114.5	nd
Mercury (kg)	3.1	nd	7.5	nd	3.4	nd	7.3	nd	4.4	0.4	7.6	nd
Nickel (kg)	3,925.0	8,719.9	4,714.0	2,180.0	3,464.9	4,558.8	3,813.0	2,179.9	3,734.6	3,395.8	3,040.5	1,927.4
Selenium (kg)	561.5	3,445.6	2,095.9	269.2	401.5	2,413.9	2,541.6	217.4	368.4	1,751.6	1,874.4	237.6
Silver (kg)	643.6	nd	256.7	4.0	445.9	38.0	244.4	13.8	291.3	25.5	183.0	nd
Zinc (kg)	10,035.2	4,091.6	10,318.1	6,326.0	11,338.6	10,783.4	11,062.3	5,886.0	10,371.4	10,807.8	9,864.1	4,383.3
Total DDT (kg)	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Total PAH (kg)	16.9	6.2	nd	nd	9.7	10.8	nd	nd	45.5	6.3	nd	nd
Total PCB (kg)	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

Appendix I. Continued

Constituent	2008				2009			
	HTP	JWPCP	OCSD	PLWTP	HTP	JWPCP	OCSD	PLWTP
Volume (L x 10^9)	396.8	409.5	254.5	224.0	371.4	387.4	213.5	211.6
Settleable Solids (L x 10^3)	nd	nd	86,364.4	71,979.1	nd	nd	101,519.2	56,972.0
Suspended Solids (mt)	7,541.5	5,906.6	8,452.5	7,271.5	6,760.2	5,036.4	6,438.6	6,661.8
BOD (mt)	7,138.8	2,628.5	10,919.8	21,476.5	7,146.4	2,712.2	8,118.1	21,246.3
Oil/grease (mt)	nd	nd	2,085.2	2,089.0	nd	nd	1,601.1	2,017.8
Ammonia-N (mt)	15,288.5	15,002.2	8,489.9	6,913.2	15,298.0	14,602.4	7,356.0	6,653.5
Nitrate-N (mt)	41.1	19.7	--	17.6	40.0	nd	--	22.1
Nitrite-N (mt)	--	58.1	--	--	--	68.7	--	--
Organic-N (mt)	1,229.6	1,001.4	--	--	1,346.9	730.4	--	--
Phosphate-P (mt)	--	298.9	--	--	--	--	--	--
ortho-Phosphate (mt)	--	--	--	746.4	--	--	--	824.0
Phosphorus (mt)	1,091.5	--	--	--	1,178.1	253.9	--	--
Cyanide (kg)	nd	3,381.2	60.5	75.8	nd	2,712.2	69.7	432.2
Arsenic (kg)	949.8	842.0	900.4	170.3	843.3	805.9	980.8	166.8
Cadmium (kg)	nd	33.7	0.5	nd	11.9	13.1	nd	nd
Chromium (kg)	521.8	700.9	510.8	238.5	473.4	680.8	343.8	337.7
Copper (kg)	6,805.9	1,511.6	7,053.0	4,460.7	6,133.5	1,182.1	5,221.3	4,320.8
Lead (kg)	nd	100.6	100.9	nd	66.4	52.7	43.6	nd
Mercury (kg)	2.1	7.2	5.4	nd	1.1	5.2	6.0	nd
Nickel (kg)	3,453.8	3,711.9	3,162.7	1,967.1	2,260.6	3,051.3	2,544.0	1,541.6
Selenium (kg)	398.2	2,207.4	2,373.3	256.6	277.0	2,107.2	2,996.5	281.1
Silver (kg)	196.8	21.4	99.9	15.4	155.4	10.1	62.3	6.8
Zinc (kg)	8,463.3	6,640.7	9,930.6	5,684.7	7,701.6	5,688.2	7,267.0	5,079.6
Total DDT (kg)	nd	nd	nd	nd	nd	nd	nd	nd
Total PAH (kg)	5.9	nd	nd	nd	nd	nd	nd	nd
Total PCB (kg)	nd	nd	nd	nd	nd	nd	nd	nd

Appendix II. Estimated annual flow-weighted concentrations from the four large POTWs to the SCB from 2005 to 2009. "--" = data not available. "<" = all results less than the MDL; where MDL was not available, RL was substituted. MDL shown for summed organic constituents refers to the component constituent with the highest MDL. For toxicity results, where more than one species was tested during the year, only results from the most sensitive species are shown.

Constituent	2005				2006				2007				2008				2009			
	HTP	JWPCP	OCSD	PLWTP	HTP	JWPCP	OCSD	PLWTP	HTP	JWPCP	OCSD	PLWTP	HTP	JWPCP	OCSD	PLWTP	HTP	JWPCP	OCSD	PLWTP
Turbidity (NTU)	9.53	6.01	28.24	48.06	10.47	5.76	26.96	42.42	10.08	4.76	25.25	44.03	8.84	5.25	27.77	36.29	8.85	4.67	25.98	37.91
Settleable Solids (ml/L)	0.08	<0.10	0.23	0.29	<0.10	<0.10	0.17	0.33	<0.10	<0.10	0.28	0.44	<0.10	<0.10	0.34	0.32	<0.10	<0.10	0.48	0.27
Suspended Solids (mg/L)	21.21	16.15	33.50	40.44	21.82	16.20	34.48	35.13	19.26	15.43	32.62	34.05	19.00	14.42	33.21	32.46	18.20	13.00	30.16	31.49
BOD (mg/L)	19.50	6.01	45.51	104.03	19.69	5.02	50.10	101.74	18.91	6.29	45.74	95.42	17.99	6.42	42.90	95.86	19.24	7.00	38.03	100.43
Oil/grease (mg/L)	0.27	<1.05	8.38	13.75	0.11	<1.05	9.89	9.63	<3.00	<1.05	9.11	8.41	<3.00	<1.05	8.19	9.32	<3.00	<1.05	7.50	9.54
Ammonia-N (mg/L)	34.93	32.79	27.56	27.37	36.47	33.90	28.40	30.65	37.50	34.28	27.95	31.23	38.53	36.64	33.36	30.86	41.18	37.69	34.46	31.45
Nitrate-N (mg/L)	0.03	0.01	--	0.10	<0.02	0.03	--	0.10	0.01	0.01	--	0.14	0.10	0.05	--	0.08	0.11	<0.01	--	0.10
Nitrite-N (mg/L)	--	0.11	--	--	--	0.06	--	--	--	0.11	--	--	--	0.14	--	--	--	0.18	--	--
Organic-N (mg/L)	3.82	3.93	--	--	4.01	3.09	--	--	3.93	2.28	--	--	3.10	2.45	--	--	3.63	1.89	--	--
Phosphate-P (mg/L)	--	0.87	--	--	--	0.67	--	--	--	0.76	--	--	--	0.73	--	--	--	--	--	--
ortho-Phosphate (mg/L)	--	--	--	<0.20	--	--	--	1.96	--	--	--	1.21	--	--	--	3.33	--	--	--	3.89
Phosphorus (mg/L)	2.72	--	--	--	3.11	--	--	--	3.28	--	--	--	2.75	--	--	--	3.17	0.66	--	--
Cyanide (ug/L)	0.84	4.46	2.38	1.70	<4.00	8.67	0.76	<2.00	<4.00	5.66	0.59	0.20	<4.00	8.26	0.24	0.34	<4.00	7.00	0.33	2.04
Arsenic (ug/L)	2.43	1.43	2.42	1.14	1.88	1.61	3.07	0.40	1.82	1.65	2.51	0.70	2.39	2.06	3.54	0.76	2.27	2.08	4.59	0.79
Cadmium (ug/L)	0.02	<0.01	0.06	0.14	0.10	0.03	0.00	0.02	0.03	0.12	<0.07	0.08	<0.40	0.08	0.00	<0.53	0.03	0.03	<0.07	<0.53
Chromium (ug/L)	0.93	1.14	1.57	2.36	1.36	1.80	1.56	1.78	1.31	1.38	1.58	1.09	1.32	1.71	2.01	1.06	1.27	1.76	1.61	1.60
Copper (ug/L)	18.38	4.95	22.32	28.07	18.66	3.32	27.55	21.01	20.38	3.63	23.27	16.66	17.15	3.69	27.71	19.91	16.51	3.05	24.46	20.42
Lead (ug/L)	0.70	0.09	0.52	<1.40	0.87	0.18	0.54	0.28	0.38	0.28	0.36	<2.00	<2.00	0.25	0.40	<2.00	0.18	0.14	0.20	<2.00
Mercury (ug/L)	0.01	<0.15	0.02	<0.09	0.01	<0.03	0.02	<0.09	0.01	0.00	0.02	<0.09	0.01	0.02	0.02	<0.09	0.00	0.01	0.03	<0.09
Nickel (ug/L)	8.56	19.55	13.89	8.62	7.86	10.43	11.72	9.29	9.40	7.95	9.61	8.64	8.70	9.06	12.43	8.78	6.09	7.88	11.92	7.29
Selenium (ug/L)	1.22	7.73	6.17	1.06	0.91	5.52	7.81	0.93	0.93	4.10	5.92	1.07	1.00	5.39	9.33	1.15	0.75	5.44	14.04	1.33
Silver (ug/L)	1.40	<3.00	0.76	0.02	1.01	0.09	0.75	0.06	0.73	0.06	0.58	<0.40	0.50	0.05	0.39	0.07	0.42	0.03	0.29	0.03
Zinc (ug/L)	21.88	9.18	30.40	25.02	25.72	24.67	34.00	25.07	26.10	25.29	31.17	19.66	21.33	16.22	39.02	25.37	20.73	14.68	34.04	24.01
Total DDT (ug/L)	<0.01	<0.01	<0.01	<0.10	<0.01	<0.01	<0.01	<0.10	<0.01	<0.01	<0.01	<0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total PAH (ug/L)	0.04	0.01	<0.73	<7.68	0.02	0.02	<0.59	<7.68	0.11	0.01	<0.61	<7.68	0.01	<0.49	<0.61	<7.68	<0.36	<0.56	<0.61	<1.80
Total PCB (ug/L)	<0.30	<0.30	<0.20	<4.00	<0.30	<0.30	<0.20	<4.00	<0.49	<0.30	<0.20	<4.00	<0.49	<0.30	<0.30	<4.00	<0.49	<0.20	<0.20	<4.00
Acute Toxicity (TUa)																				
Atherinops affinis	1.70	--	2.85	--	2.02	2.42	2.33	--	2.10	1.89	1.87	--	2.24	1.92	1.85	--	2.23	1.68	2.12	--
Mysidopsis bahia	--	--	--	3.15	--	--	--	3.15	--	--	--	1.31	--	--	--	1.70	--	--	--	3.06
Pimephales promelas	--	0.16	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Chronic Toxicity (TUc)																				
Atherinops affinis	--	--	--	--	--	42.00	--	--	--	42.00	--	--	--	42.00	--	--	--	42.00	--	--
Haliotis rufescens	51.85	--	--	--	62.85	--	--	--	47.60	--	--	79.76	47.60	--	--	117.24	47.60	--	--	--
Macrocystis pyrifera	--	41.95	--	111.39	--	--	--	76.47	--	--	--	--	--	--	--	--	--	--	--	72.13
Strongylocentrotus purpuratus	--	--	55.56	--	--	--	80.28	--	--	--	55.56	--	--	--	62.44	--	--	--	59.14	--