Contaminants of emerging concern in municipal wastewater effluents and marine receiving water

Doris E.Vidal-Dorsch, Steven M. Bay, Keith A. Maruya, Shane A. Snyder[1], Rebecca A. Trenholm[1] and Brett J. Vanderford[1]

Abstract

The occurrence and concentrations of contaminants of emerging concern (CECs) were investigated in municipal effluents and in marine receiving water. Final effluent from four large Publicly Owned Treatment Works (POTWs), seawater collected near the respective POTW outfall discharges and a reference station were collected quarterly, over a year, and analyzed for 56 CECs. Several CECs were detected in effluents; naproxen, gemfibrozil, atenolol, and TCPP were the compounds most frequently found and with the highest concentrations (>1 µg/L). Gemfibrozil and naproxen had the highest seawater concentrations (0.0009 and 0.0007 µg/L) and also were among the most frequently detected compounds. Effluent dilution factors ranged from >400 to ~1000. Fewer CECs were detected, and at lower concentrations, in seawater collected from the reference station than at the outfall sites. Effluent concentrations for some CECs (e.g., pharmaceuticals) were inversely related to the degree of wastewater treatment. This trend was not found in seawater samples. Few temporal differences were observed in effluent or seawater samples. Effluent CEC concentrations were lower than those currently known for chronic toxicity thresholds. Nevertheless, the evaluation of potential chronic effects for CECs is uncertain because aquatic life toxicity thresholds have only been developed for a few compounds. Additional data are needed to further understand the significance of the CECs presence and concentrations in marine environments.

Introduction

Recent studies have identified the presence of contaminants of emerging concern (CECs) in effluents and in receiving waters, where CECs can potentially affect aquatic organisms. For example, national surveys have found CECs in surface waters of rivers, streams and lakes, as well as in ground and drinking water (Kolpin *et al.* 2002, Kolpin *et al.* 2004, Glassmeyer *et al.* 2005, Sedlak *et al.* 2005, Snyder 2008). Moreover, some studies showed that their occurrence in fresh water systems has the potential to cause adverse effects in fish and their populations (Folmar *et al.* 2001, Snyder *et al.* 2004, Kidd *et al.* 2007). However, knowledge of CEC presence and effects in marine environments is still very limited. In southern California (USA), more than one billion gallons of treated wastewater effluent is discharged daily into the ocean from municipal wastewater outfalls operated by publicly owned treatment works (POTWs; Lyon *et al.* 2006). These POTWs service approximately 17 million people, yet little is known about the presence of CECs in their discharges.

Diverse types of compounds can be present in effluent mixtures including CECs such as steroid hormones, pharmaceutical and personal care products

[1] *Southern Nevada Water Authority, Las Vegas, NV*

[2] *University of Arizona, Tucson, AZ*

(PPCPs), industrial and commercial compounds (ICCs), as well as current use pesticides (CUPs). Many of these compounds are likely present in POTW effluents because primary and secondary wastewater treatments were not specifically designed to remove them (Baronti *et al.* 2000, Snyder 2008). Thus, effluent discharges are potentially a major source of CECs into aquatic environments. Once released to the environment, some CECs may accumulate in fish tissue (Snyder *et al.* 2004), and can cause biological effects (Tilton *et al.* 2002, Todorov *et al.* 2002, Liney *et al.* 2006, Alvarez *et al.* 2009).

In southern California, a study observed biological responses indicative of exposure to endocrine disruptors in marine flatfish living near POTW outfall discharges (Rempel *et al.* 2006). Indicators of endocrine disruption found in male fish collected from areas near large POTW outfalls included higher incidence of elevated concentrations of plasma vitellogenin and estradiol. Localized studies looking at gonad histology found no evidence of pathologies (e.g., testis-ova) in flatfish collected near one of the POTW discharge areas (Deng *et al.* 2007). Nevertheless, it is likely that POTW discharges are contributing CECs into aquatic coastal environments, yet neither the effluents nor the receiving waters have been thoroughly investigated in this regard.

The present study characterizes the occurrence and concentrations of a diverse suite of CECs in POTW effluents and in seawater collected near POTW effluent discharges from the four largest municipal wastewater facilities in southern California. To investigate the compounds fate we analyzed CECs in the receiving water and a reference area. The analysis of CECs in the reference area also helped us to describe background conditions. We studied primary and secondary treated effluents to investigate the CECs variation in concentrations resulting from different types of effluent treatments. This study was part of a comprehensive project to investigate the source, fate and effects of CECs in southern California coastal waters.

Methods

Study Overview

A suite of 56 analytes including PPCPs, hormones, CUPs, and ICCs was measured in the samples. A total of 50 compounds where analyzed on a quantitative basis, and six of them on a semi-quantitative (Table SI-1 in Supplemental Information (SI)). The effluent CECs were selected based on their predicted environmental behavior (e.g., water solubility), high frequency of occurrence in other studies, and availability of analytical methods for their detection. The collected wastewater samples represent final effluents with different degrees of treatment (primary, secondary, or a combination). In addition, near seafloor seawater samples were collected from areas where the POTW effluents were discharged into the ocean. Effluent and seawater samples were collected quarterly, over one year, to investigate temporal variability.

Sample Collection and Preservation

Each effluent sample consisted of a two-liter peak flow grab of final effluent from each of the four major POTWs in southern California. The effluents used for this study were provided by participating sanitation districts, which included: City of Los Angeles (LA), Los Angeles County Sanitation Districts (PV), Orange County Sanitation District (OC) and City of San Diego (SD; Figure 1). Additional information regarding effluent treatments is provided in Table 1. Samples were collected in two one-liter, glass, silanized, amber bottles according to Vanderford and Snyder (2006). Prior to collection, 1 g of sodium azide and 50 mg of ascorbic acid were added to each bottle. These compounds prevented microbial degradation of the analytes (sodium azide) and quenched residual oxidants that may have remained in the sample (ascorbic acid). Once preserved, the samples were immediately placed on ice and held at 4°C. Once received by the analyzing laboratory the samples were stored at 4°C until extraction. All samples (effluent or seawater) were stored under the same conditions and extracted within 28 days of collection. The samples were filtered prior to extraction using 90 mm GF/F filters (Whatman, England).

Two-liter seawater samples were collected from five stations in the Southern California Bight, four located near POTW effluent discharge areas and a reference area (Figure 1). Each station was located using a differential global positioning system. Samples were collected using a Teflon coated Niskin bottle. The depth at which the seawater samples were taken was site specific: 61 m at LA, 59 m at PV, 54 m at OC and 95 m at SD. In general, seawater samples were collected near the seafloor (about 2 m above the bottom) and as close to the discharge as possible. Seawater samples from the reference site were collected off of Dana Point (California,

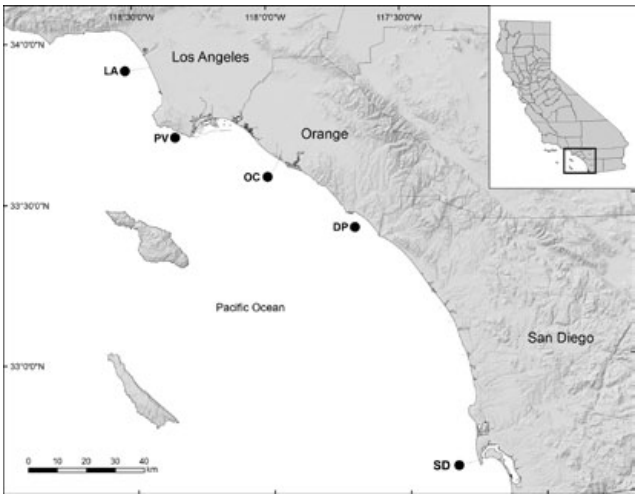

Figure 1. Study site locations.

USA) at a depth of 52 m. Each seawater sample was preserved and processed as previously described for the effluent samples. Further information regarding sample preservation, processing and container cleaning procedures can be found elsewhere (Trenholm *et al*. 2006). The seawater samples from the effluent discharge areas were collected the same day in which their respective POTW effluent samples were collected. Effluent and seawater samples were collected every three months beginning in the summer of 2006 and ending in spring of 2007.

Solid-phase Extraction and Liquid/Liquid Extraction

Filtered samples were extracted using 500 mg hydrophilic–lipophilic balance (HLB) solid phase extraction (SPE) cartridges from Waters Corp. (Milliford, MA). All extractions were performed using an Autotrace automated SPE system (Zymark Corp., Hopkington, MA). The SPE cartridges were conditioned with 5 ml dichloromethane (DCM), 5 ml methyl tert-butyl ether (MTBE), 5 ml of methanol, and 5 ml of reagent water (Barnstead Nanopure). One-liter samples were spiked with a solution of isotopically labeled standards that contained isotope stable analogues for most analytes. Isotopes were spiked post-filtration in POTW effluent samples. Samples were loaded onto conditioned SPE cartridges at 15 ml/minute. After sample loading, the SPE cartridges were rinsed with 5 ml reagent water and dried for 60 minutes with nitrogen. The cartridges were eluted into two separate fractions, the first fraction (F1), was used for LC–MS/MS and GC–MS/MS analysis and was eluted with 5 ml of methanol followed by 5 ml of 10/90 (v/v) methanol/MTBE. This extract was collected in a 15-ml calibrated glass vial (Zymark Corp., Hopkington, MA). The second fraction (F2) was eluted with 10 ml of DCM and collected in a separate 15-ml vial. The F1 extract

Table 1. Effluent and treatment plant characteristics.

Outfall Station	Treatment Plant	Effluent Treatment	Discharge Capacity (MGD[1])	Outfall Distance from Shoreline (km)	Outfall Depth (m)
LA	Hyperion Treatment Plant (City of Los Angeles)	Secondary[2, 3]	320	8	60
PV	Joint Water Pollution Control Plant (Los Angeles County Sanitation Districts)	Secondary	320	8	61
OC	Orange County Sanitation District Plant	Secondary/ Primary (50/50%)	320	8	60
SD	Point Loma Wastewater Treatment Plant (City of San Diego)	Advance Primary[3, 4]	170	7.2	94-98

[1] Millions of gallons per day

[2] Secondary: sedimentation and activated sludge

[3] This effluent was not disinfected

[4] Advanced Primary: sedimentation and screening

was concentrated to a final volume of 1 ml with a gentle stream of nitrogen (N), subsequently 500 µl were removed from F1 and placed into a 2-ml autosampler vial for LC/ MS/MS analysis, while the remaining 500 µl were retained for liquid/liquid extraction. The F2 extract was concentrated to 3 ml with a gentle stream of nitrogen.

Before analysis, a liquid/liquid extraction (LLE) was performed on the remaining 500 µl from F1. Initially, 2.5 ml of a 25% sodium chloride (w/v) solution was added to F1 and vortexed. After that, 3 ml of 10/90 (v/v) DCM/hexane solution was added to F1 and vortexed. Samples were allowed to settle; the organic top layer was removed and combined with F2. The F1 solution was extracted twice; the resulting extracts were combined with F2. Finally, the combined organic extracts were concentrated with a gentle stream of nitrogen to 1 ml. Then 2 ml of iso-octane were added and the extract was concentrated to 450 µl. Subsequently, 25 µl of the internal solution of standards were added. The extract was adjusted to a final volume of 500 µl using iso-octane and transferred to a 2-ml autosampler vial. Complete details of the methods have been previously published (Vanderford *et al*. 2003, Trenholm *et al*. 2006, Vanderford and Snyder 2006, Benotti *et al*. 2009).

Gas Chromatography Tandem Mass Spectrometry

For this study, a Varian (Walnut Creek, CA) CP-3800 Gas Chromatograph with a CP-8400 autosampler and Varian 2200 mass spectrometer was used for all gas chromatography tandem mass spectrometry (GC–MS/MS) analyses. The injector (Varian 1177) was operated in splitless mode with a Siltek™ deactivated glass liner with glass frit (Restek, Bellefonte, PA). The analytes were separated on a 30 m x 0.25 mm ID x 0.25 µm DB5-MS column (J & W, Agilent, Palo Alto, CA) using a 1.0 ml/minute helium flow, the initial pressure pulse was of 45 PSI for 0.85 minutes. The temperature program was: 90°C, held for 2.0 minutes; 90 to 150°C at 20°C/minute; 150 to 280°C at 3°C/minute, held for 5.0 minutes; 280 to 315°C at 30°C/minute, held for 2.5 minutes. An injection volume of 2 µl was used for all analyses. Mass spectrometry was performed using multiple reaction monitoring (MRM) in positive electron impact mode for all analytes.

Liquid Chromatography Tandem Mass Spectrometry

Liquid chromatography tandem mass spectrometry (LC-MS/MS) methods were used to analyze non steroid compounds (Vanderford and Snyder 2006) and steroid compounds (Benotti *et al.* 2009). Six compounds were analyzed in semi-quantitative basis, which included acetaminophen, erythromycin, hydrocodone, oxybenzone, ibuprofen and iopromide (Vanderford *et al.* 2003). LC–MS/MS was performed using an API 4000 triple quadrupole mass spectrometer (ABSCIEX, Foster City, CA) equipped with an Agilent 1100 LC (Palo Alto, CA) and HTC-PAL autosampler (CTC Analytics, Zwingen, Switzerland). Analytes were monitored using MRM with electrospray ionization (ESI) in positive and negative modes and atmospheric pressure chemical ionization (APCI) in positive mode (Trenholm *et al.* 2006).

Quality Control and Quality Assurance

Labeled surrogates were added before SPE to monitor analyte recoveries and matrix interference. Isotopically labeled surrogates were chosen to represent a variety of compound classes used this study, since not all individual analytes had isotopically labeled analogues available. Matrix spikes were also performed using POTW effluent and seawater samples with percent recoveries typically ranging from 80 to 120%. The GC–MS/MS analytes were adjusted to their experimentally determined mass balance correction factors, which ranged from 0.5 to 1.0; compound recoveries and data were also adjusted accordingly.

Reporting limits (RLs) were selected based on a value of 3 to 5 times the method detection limit (MDL) and set as the lowest calibration point, for a signal to noise ratio greater than 10 for each analyte. The RLs for CECs in water and effluent ranged from 0.0002 to 0.05 µg/L (Table 2). Some compounds had reporting limits greater than three times the MDL (bisphenol A, nonylphenol, atenolol, triclosan & BHT), because trace amounts of blank contamination for these analytes were unavoidable. For GC–MS/MS, analyte quantitation was performed using an internal standard calibration with linear or quadratic regression with $1/x^2$ weighting. LC–MS/MS quantitation was performed using isotope dilution with linear or quadratic regression with 1/x2 weighting. The GC–MS/ MS calibration points were at 10, 25, 50, 100, 250 and 500 µg/L, while LC–MS/MS calibration points were at 1.0, 2.5, 5.0, 10, 25, 50, 100 and 200 µg/L. Correlation coefficients were consistently 0.99 or greater. Additional

Table 2. Reporting limits (RL), median concentration, minimum and maximum (Min, Max), and percent occurrence of detected CEC analytes in POTW effluent (N = 16). Compounds investigated but not commonly detected in the effluents included diazinon, lindane, methoxychlor, metolachlor, ethinylestradiol, hydroxyanisole, octachlorostyrene, diazepam, enalapril, erythromycin, fluoxetine, musk ketone, risperidone, simvastatin, simvastatin hydroxy acid, tonalide, traseolide, and vinclozolin.

Analytical Group	Analyte	RL (µg/L)	Median (µg/L)	Min (µg/L)	Max (µg/L)	Percent Occurrence
PPCP	Naproxen	0.005	2.3	0.05	13.1	100
PPCP	Gemfibrozil	0.0025	3.25	2.4	3.8	100
PPCP	Atenolol	0.0025	2.2	1.2	3.14	100
ICC	TCPP	0.05	1.1	0.61	2.7	100
PPCP	Sulfamethoxazole	0.0025	0.92	0.48	2.04	100
PPCP	Triclosan	0.01	0.79	0.31	1.5	100
ICC	N,N-diethyl-meta-toluamide	0.025	0.64	0.1	1.97	100
ICC	Octylphenol	0.025	0.69	0.21	1.55	100
PPCP	Trimethoprim	0.0025	0.62	0.39	0.98	100
ICC	Benzophenone	0.025	0.42	0.07	2.7	100
ICC	Bisphenol A	0.05	0.46	0.21	1.6	100
PPCP	Meprobamate	0.0025	0.35	0.3	0.57	100
ICC	Butylated hydroxytoluene	0.025	0.29	0.16	0.84	100
PPCP	Carbamazepine	0.005	0.27	0.22	0.36	100
PPCP	Dilantin	0.01	0.24	0.13	0.34	100
PPCP	Diclofenac	0.0025	0.13	0.07	0.18	100
PPCP	Atorvastatin	0.0025	0.11	0.07	0.15	100
Hormone	Estrone	0.0002	0.04	0.01	0.12	100
ICC	Nonylphenol	0.08	1.42	ND	7.2	94
PPCP	Ibuprofen*	0.05	1.45	ND	12	94
ICC	Butylated hydroxyanisole	0.025	0.14	ND	0.23	94
PPCP	p-Hydroxy atorvastatin	0.005	0.14	ND	0.19	94
PPCP	o-Hydroxy atorvastatin	0.005	0.1	ND	0.17	94
Hormone	Testosterone	0.0005	0.01	ND	0.09	75
Hormone	Progesterone	0.0005	0.005	ND	0.05	63
Hormone	Estradiol	0.0005	0.003	ND	0.03	63
CUP	Atrazine	0.0025	0.003	ND	0.02	63
ICC	Butylbenzyl phthalate	0.05	0.14	ND	1.5	56
ICC	Dioctyl phthalate	0.05	ND	ND	1.42	50
PPCP	Acetaminophen*	0.5	ND	ND	11	44
PPCP	Oxybenzone*	0.5	ND	ND	3.6	44
PPCP	Iopromide*	0.5	ND	ND	0.58	44
PPCP	Galaxolide	0.025	ND	ND	2.7	13
PPCP	Hydrocodone*	0.1	ND	ND	0.11	13
ICC	TCEP	0.05	ND	ND	1.7	13

ND= Not detected

* Semi-quantitative measurement (see methods)

quality assurance and quality control descriptions for the methods described have been previously published (Trenholm *et al.* 2006, Vanderford and Snyder 2006).

Data Analysis

Descriptive statistics and analysis of variance techniques were used to analyze data. After chemical analysis the data were averaged by chemical. When the compound was below detection, half of the reporting limit for that particular chemical was used in the average calculation (Antweiler and Taylor 2008). Then, the data were grouped in PPCPs, hormone, CUP and ICCs categories to investigate concentrations and occurrences. The average

concentrations were summed for each CEC group. To investigate seasonal trends the data were further grouped by collection event. To study effluent type trends the data were grouped by station or effluent. Within each group, normality was determined with the Kolmogorov-Smirnov test. Data were analyzed with one-way analyses of variance (ANOVA). Tukey tests were subsequently used to compare groups with significant differences. Mean values were considered statistically different when $p < 0.05$. These statistical tests were conducted with Sigma Stat 2.03 software (Chicago, IL).

Results

Occurrence and Concentrations of CECs in Effluent

The majority of CECs investigated were found in the POTW effluent samples evaluated. Of the 56 effluent CECs analyzed, 35 were detected in at least one effluent sample (Table 2). Eighteen CECs were found in all samples (100% occurrence). Industrial and commercial compounds and PPCPs were among the CECs with the highest concentrations in POTW effluent samples. Naproxen, gemfibrozil, atenolol, and TCPP (tris chloroisopropyl phosphate) were not only found in 100% of the effluent samples, but they were also found at the highest average concentrations (>1 µg/L). The artificial hormone ethinylestradiol was not detected in any of the effluent samples at an RL of 0.001 µg/L. In contrast estradiol, testosterone, progesterone and estrone were commonly detected (ranging between 100 and 63% occurrence). Most CUPs investigated were found at very low concentrations or not detected. The diverse types of CECs found in the effluents reflected the domestic and industrial waste inputs that the POTWs receive.

Occurrence and Concentrations of CECs in Seawater

Some CECs were found at low levels in seawater samples. 20 of the 56 target CECs were detected at least once in seawater samples (Table 3). Only PPCPs and ICCs were found in seawater; there were no detections of CUPs or hormones. No single CEC was detected in 100% of seawater samples. Atenolol and gemfibrozil were the CECs most frequently found in seawater with occurrences of 90%. Trimethoprim, naproxen, gemfibrozil,

Table 3. Reporting limits (RL), median concentration, minimum and maximum (Min, Max), and percent occurrence of detected CEC analytes in seawater (N= 20).

Analytical Group	Analyte	RL (µg/L)	Median (µg/L)	Min (µg/L)	Max (µg/L)	Percent Occurrence
PPCP	Gemfibrozil	0.00025	0.0009	ND	0.013	90
PPCP	Atenolol	0.00025	0.0004	ND	0.011	90
PPCP	Naproxen	0.0005	0.0007	ND	0.026	75
PPCP	Sulfamethoxazole	0.00025	0.0005	ND	0.0034	70
PPCP	Trimethoprim	0.00025	0.0007	ND	0.0021	60
PPCP	Meprobamate	0.00025	ND	ND	0.0015	50
ICC	Butylated hydroxytoluene	0.025	ND	ND	0.17	40
PPCP	Triclosan	0.001	ND	ND	0.0061	40
PPCP	Diclofenac	0.00025	ND	ND	0.0006	40
ICC	Nonylphenol	0.08	ND	ND	0.23	35
PPCP	Ibuprofen*	0.005	ND	ND	0.03	30
PPCP	Acetaminophen*	0.005	ND	ND	0.011	30
PPCP	Oxybenzone*	0.005	ND	ND	0.0089	30
PPCP	Risperidone	0.00025	ND	ND	0.0014	30
PPCP	Carbamazepine	0.005	ND	ND	0.0009	25
ICC	Benzophenone	0.025	ND	ND	0.057	15
PPCP	Atorvastatin	0.0025	ND	ND	0.0004	15
ICC	Dioctyl phthalate	0.05	ND	ND	0.085	10
ICC	TCPP	0.05	ND	ND	0.056	10
ICC	Octylphenol	0.025	ND	ND	0.042	10

ND= Not detected

* Semi-quantitative measurement (see methods)

sulfamethoxazole, and atenolol were found at the highest median concentrations, which ranged between 0.0004 and 0.0009 µg/L. Hormones and CUPs were not detected in any seawater sample.

In general, fewer CECs were detected at the reference site (Dana Point), and those that were detected occurred at lesser concentrations when compared to the other effluent discharge areas. Concentrations of PPCPs and ICCs were the lowest at DP (Figure 2). Other compound groups were not detected. Only gemfibrozil (at an average concentration of 0.0005 µg/L) and sulfamethoxazole (0.0004 µg/L) were detected in seawater from DP (a range of two to six compounds were detected at the outfall discharge areas). Butylated hydroxytoluene, dioctyl phthalate, acetaminophen, oxybenzone, risperidone, gemfibrozil, and sulfamethoxazole were detected at the outfall stations at concentrations that ranged from 0.085 to 0.0006 µg/L.

The low occurrence and concentration of CECs in seawater relative to the effluents reflected the dilution that these compounds undergo in the ocean after discharge. Southern California POTWs discharge treated effluents to coastal waters through marine outfalls that are designed to provide rapid dilution of the effluent (>100x within the zone of initial dilution). In this study we measured CEC dilution factors of >400 (Table 4). For some of the compounds detected in seawater, such as trimethoprim, naproxen, sulfamethoxazole, and gemfibrozil the dilution factors were >1000.

The concentrations of effluent CECs were at least two orders of magnitude higher in effluent

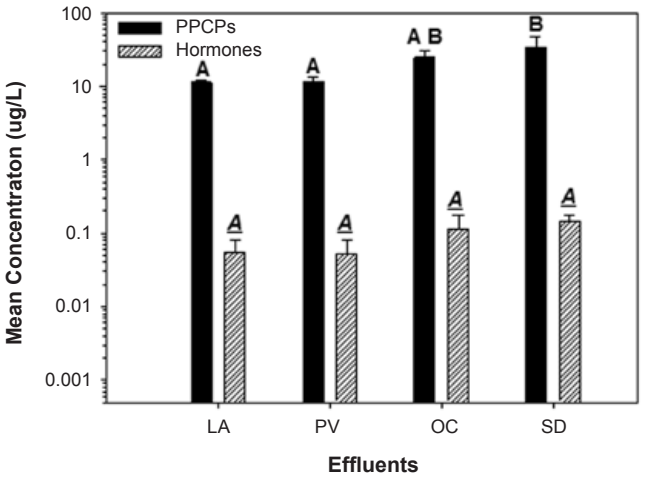

Figure 2. Mean concentrations (+ standard deviation) of pharmaceutical and personal care products (average of 32 PPCPs) and industrial and commercial compounds (average of 13 ICCs) in seawater. Different symbols represent significantly different averages (N = 4; p <0.05). No CUPs or hormones were detected at these sites.

than concentrations found in seawater. The most frequently detected compounds in both effluent and seawater were naproxen and gemfibrozil. Other PPCPs detected at high frequencies in both effluent and seawater were atenolol, meprobamate, sulfamethoxazole and trimethoprim. The ICC detected with the highest frequency and concentration in effluent and seawater was nonylphenol.

Effluent Type Variability

Average PPCPs concentrations were significantly lower in secondary treated effluents when compared

Table 4. Mean concentration, occurrence, and dilution factor for CECs with 100% frequency of occurrence in effluent samples.

Chemical	Seawater		Effluent	Dilution Factor
	Mean[1] (µg/L)	Percent Occurrence	Mean[2] (µg/L)	
Naproxen	0.0035	75	4.26	1217
Trimethoprim	0.0005	60	0.62	1244
Sulfamethoxazole	0.0008	70	0.92	1147
Gemfibrozil	0.003	90	3.15	1051
Meprobamate	0.0004	50	0.38	954
Atenolol	0.0023	90	2.13	927
Triclosan	0.0017	40	0.76	447

[1] Average of 20 samples

[2] Average of 16 samples

to effluents receiving lower degrees of treatment (Figure 3). We also observed higher concentrations at SD or OC for nine individual PPCPs, while five compounds were higher at LA or PV. An example of a PPCP found at a higher concentration in SD or OC effluents was naproxen. The average naproxen concentrations were 13 µg/L in SD and 6 µg/L in OC effluents, compared to 0.2 µg/L in LA and 0.4 µg/L in PV effluents. An example of a PPCP that was detected at statistically similar ($p > 0.05$) concentrations in all effluents was carbamazepine, which was found at levels ranging from 0.4 to 0.2 µg/L. Similar average concentrations were measured for other compound groups such as hormones, ICCs, and CUPs.

In general, lower average PPCP concentrations were not observed in seawater samples from areas receiving secondary treated effluents when compared to the other studied sites. Average seawater PPCP concentrations were relatively higher at OC and SD (which received effluents with a lower degree of treatment) when compared to the LA and PV sites. But these differences were not statistically significant ($p > 0.05$).

Temporal Variability

Temporal differences were not found among effluent or seawater CECs concentrations. In general, CEC concentrations in the effluent samples were similar among the four quarterly events investigated (Figure 4A). For example, the average concentrations of gemfibrozil were 3.4 µg/L for the summer, 3.2 µg/L for the fall, 2.7 µg/L for the winter, and 2.9 µg/L for the spring sampling events.

Similarly, there was little temporal variability in seawater samples (Figure 4B). For example, the summer average concentration of naproxen was 0.003 µg/L, 0.007 µg/L for the fall, 0.004 µg/L for the winter, and 0.006 µg/L for the spring. Two exceptions were gemfibrozil and butylated hydroxyanisole, which were present at significantly lower concentrations in the summer sampling. Significantly different concentrations among events were not observed for any of the other compounds.

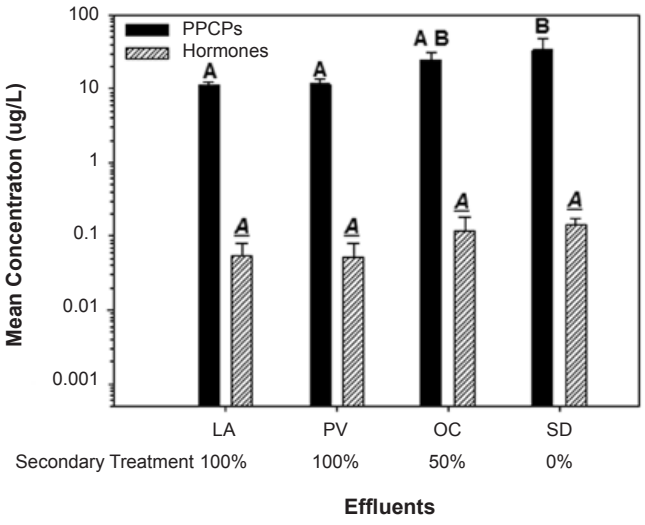

Figure 3. Mean effluent concentrations (+ standard deviation) of pharmaceutical and personal care products (average of 32 PPCPs) and hormones (average of 5). Symbols represent significantly different averages (N = 4; p <0.05). LA and PV effluents received 100% secondary treatment, OC effluent received 50% secondary treatment and 50% primary treatment, SD effluent received 0% secondary treatment.

Discussion

Diverse types of CECs were found in POTW effluents and their frequency of detection and concentrations were similar to, or higher than, effluents from other parts of USA. Of the compounds ubiquitously found in effluent samples from this study, the analgesics ibuprofen and naproxen, the antibiotic sulfamethoxazole, the cholesterol inhibitor gemfibrozil, and the surfactant degradation product nonylphenol have been found in other effluent samples by more than 10 studies throughout the USA (Glassmeyer *et al.* 2007). Effluent concentrations of gemfibrozil, naproxen, atenolol, ibuprofen, and sulfamethoxazole in the present study were higher than those typically found in other studies (Table 5). However, effluent PPCP concentrations were below available thresholds of chronic toxicity effects (Fent *et al.* 2006). The evaluation of potential chronic effects for CECs is uncertain however, because aquatic life toxicity thresholds have only been developed for some of these compounds. For example of the 32 PPCPs analyzed in this study, chronic toxicity thresholds are reported for 9 of them (Fent *et al.* 2006).

Calculated loadings for analytes investigated in this study showed that estimated annual CEC mass emissions to the southern California Bight were comparable to, or higher than, some priority pollutants. For example, annual mass emissions of the four most abundant CECs (naproxen, gemfibrozil, atenolol, and ibuprofen) ranged from 4,538 kg to 2,825 kg (calculated following the methods of Schiff *et al.* 2000). In 2000, the combined emissions of large POTWs to the southern California Bight were 4,221 kg for PAHs and

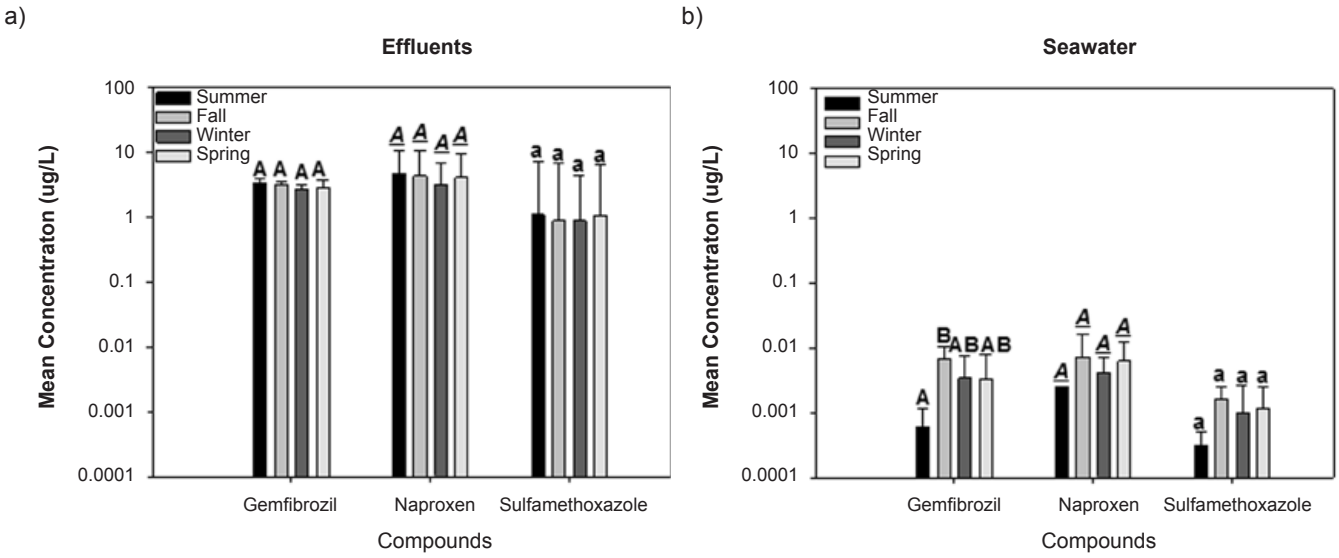

Figure 4. Mean concentrations (+ standard deviations) of gemfibrozil, naproxen, and sulfamethoxazole in effluent (a) and seawater (b). Different symbols represent significantly different averages within each sampling event (N = 4; p <0.05).

740 kg for chlorinated phenols (Lyon and Stein 2009). The combined mass emission of all CECs measured was 37,304 kg a year. The results of this study do not represent input changes from different day times which may influence the mass emissions (Nelson *et al.* 2011). The environmental significance of these chemical loadings needs to be more thoroughly investigated.

Effluent CEC concentrations for some constituents were inversely related to the degree of treatment the effluents received. Statistically significantly lower concentrations of some PPCPs were observed in secondary treated effluents (e.g., naproxen and triclosan) compared to lesser levels of treatment (primary or partially secondary treated effluents). The biological processes used during secondary treatment partially removed some CECs through biodegradation and sorption that advanced primary treatment did not (Drewes *et al.* 2008, USEPA 2010). In our study, we also observed that carbamazepine did not seem to be affected by treatment type. Previous studies have found that carbamazepine is very persistent despite secondary treatment and could be used as a biomarker of anthropogenic pollution in the environment (Clara *et al.* 2004). In addition, we did not find any apparent differences in CEC concentrations related to effluent disinfection treatments.

Seawater CEC concentrations at the initial zone of dilution were orders of magnitude lower than those found in effluents, which reflects the level of dilution and dispersion the effluents undergo in the ocean. Marine discharges in southern California have been engineered for maximum dilution upon discharge. Dilution ratios >100 are common in southern California POTW outfalls (Joe Gully, personal communication; LACSD) and we found this level of dilution in our data. Besides dilution, other factors may be responsible for the low seawater CECs concentrations found in this study such as rapid chemical transformation (Boxall *et al.* 2004).

The occurrence and concentrations of seawater CECs were lowest at the reference station, indicating that this area was appropriately selected to be a reference site. We detected fewer analytes when compared to the effluent discharge areas. However, some analytes were detected at DP despite its distance from the main POTW discharge areas. The presence of some CECs at DP may reflect the transport of compounds from the effluent discharge areas. But it could also reflect inputs from small POTW discharges near the area, and from other types of discharge inputes (e.g., non-point sources). Other freshwater studies have also found low occurrence and concentrations of CECs in reference areas, which reflected urban contributions of CECs to the environment (Kolpin *et al.* 2004, Barnes *et al.* 2008, Benotti *et al.* 2009). Additional studies in coastal areas are needed to investigate other CEC sources, such as small POTW discharges and storm water discharges. Additional studies at other reference areas are also needed to further characterize background conditions.

Little temporal variation was observed in effluent or seawater CECs concentrations. Although a couple

Table 5. Comparison of minimum (Min) and maximum (Max) compound concentrations in seawater, freshwater (water) and final effluent (units as µg/L) in Southern California (SoCA), the United States (USA), America (other than USA and including Canada) and Europe. Values have been provided for water and effluent.

Water					Effluent				
Matrix	**Region**	**Min**	**Max**	**Reference**	**Matrix**	**Region**	**Min**	**Max**	**Reference**
		Gemfibrozil					**Gemfibrozil**		
Seawater	SoCA	<0.0003	0.01	This study	Effluent	SoCA	2.4	3.8	This study
Water	America	0.0003	0.5	A, B		USA	0.07	2.0	a, b
		Naproxen				America	0.08	2.1	c, d
Seawater	SoCA	<0.0005	0.03	This study		Europe	0.18	4.8	e, f
Water	USA	0.0016	0.15	C			**Naproxen**		
	America	0.0008	0.06	B, D	Effluent	SoCA	0.05	13.1	This study
	Europe	<0.003	0.31	E		USA	0.01	6.3	g, a
		Atenolol				America	0.19	33.9	h, i
Seawater	SoCA	<0.0003	0.01	This study		Europe	0.25	0.3	e, f
Water	Europe	0.03	0.16	F, G			**Atenolol**		
	USA	0.017	0.25	H, I	Effluent	SoCA	1.2	3.1	This study
		Ibuprofen				USA	0.1	1.2	j, k
Seawater	SoCA	<0.0005	<0.03	This study		Europe	0.001	0.6	l
Water	USA	0.017	0.67	C, J			**Ibuprofen**		
	America	0.0001	0.02	B	Effluent	SoCA	0.0047	12	This study
	Europe	<0.0003	2.37	F, K		USA	0.001	5.3	k, m
		Sulfamethoxazole				America	0.007	50	h, n
Water	SoCA	<0.0003	0.003	This study		Europe	0.018	7.1	f, e
	USA	0.001	0.007	L			**Sulfamethoxazole**		
	America	0.002	0.048	B	Effluent	SoCA	0.48	2.0	This study
	Europe	0.0005	0.073	F		USA	0.11	0.8	m, o
						America	0.10	0.4	p, c
						Europe	0.02	0.1	e

A (Mimeault et al. 2005)
B (Chen et al. 2006)
C (Boyd et al. 2004)
D (Gibson et al. 2007)
E (Antonic and Heath 2007)
F (Kasprzyk-Hordern et al. 2008)
G (Bendz et al. 2005)
H (Zuccato et al. 2005)
I (Gros et al. 2006)
J (Focazio et al. 2008)
K (Roberts and Thomas 2006)
L (Arikan et al. 2008)

a (Drewes et al. 2002)
b (Spongberg and Witter 2008)
c (Gagne et al. 2006)
d (Lee et al. 2005)
e (Bendz et al. 2005)
f (Rabiet et al. 2006)
g (Thomas and Foster 2005)
h (Hua et al. 2006)
i (Metcalfe et al. 2003)
j (Gomez et al. 2006)
k (Gros et al. 2006)
l (Kasprzyk-Hordern et al. 2008)
m (Palmer et al. 2008)
n (Suchara et al. 2008)
o (Glassmeyer et al. 2005)
p (Chen et al. 2006)

of compounds showed lower concentrations in seawater during the summer, this trend was not observed for the majority of detected compounds. Other studies in southern California and Iowa freshwater environments found that the concentrations of some PPCPs and ICCs were seasonal. The highest concentrations and occurrences were found when the river flows were low (Kolpin *et al.* 2004, Loraine and Pettigrove 2006). However, seasonal differences may not play a strong role in near bottom seawater, where temperature and other oceanographic conditions are relatively constant most of the year. The lower summer concentrations observed in seawater for compounds such as gemfibrozil could indicate differences in analysis processes during that sampling event.

When compared to other aquatic systems, near bottom seawater CEC concentrations in southern California were among the lowest reported (Table 5). For the compounds found at the highest concentrations in effluent (e.g., gemfibrozil, naproxen, atenolol, ibuprofen, and sulfamethoxazole), the maximum concentrations found in southern California seawater were usually at least one order of magnitude lower than those found in other studies. Despite their presence at low levels, we still have a very poor understanding of their interactions with other compounds and their potential for chronic toxicity.

It is difficult to determine the environmental significance of low CEC levels in seawater at this point in time, because toxicity thresholds for aquatic life have only been developed for a few CECs. For example, the maximum concentration of nonylphenol (NP) found in our study was 0.23 µg/L, this value is lower than the USEPA aquatic life objective of 1.7 µg/L for seawater (Brooke and Thursby 2005). A population effect was found for ethinylestradiol at concentrations of 0.005 µg/L (Kidd *et al.* 2007), this CEC was not found at detectable levels in our effluent or seawater samples (RL= 0.001 µg/L). A balanced assessment of the threat posed by low levels of CECs in marine and coastal environments is still needed. Such an assessment needs to consider CEC persistence and mobility, interactions with other contaminants (e.g., priority pollutants), and the conditions of exposure that could lead to bioaccumulation and sublethal toxicity.

Literature Cited

Alvarez, D.A., W.L. Cranor, S. Perkins, V.L. Schroeder, L.R. Iwanowicz, R.C. Clark, C.P. Guy, A.E. Pinkney, V.S. Blazer and J.E. Mullican. 2009. Reproductive health of bass in the Potomac, USA, Drainage: Part 2. Seasonal occurrence of persistent and emerging organic contaminants. *Environmental Toxicology and Chemistry* 28:1084-1095.

Antonic, J. and E. Heath. 2007. Determination of NSAIDs in river sediment samples. *Analytical and Bioanalytical Chemistry* 387:1337-1342.

Antweiler, R.C. and H.E. Taylor. 2008. Evaluation of statistical treatments of left-censored environmental data using coincident uncensored data sets: I. Summary statistics. *Environmental Science Technology* 42:3732-3738.

Arikan, O.A., C. Rice and E. Codling. 2008. Occurrence of antibiotics and hormones in a major agricultural watershed. *Desalination* 226:121-133.

Barnes, K.K., D.W. Kolpin, E.T. Furlong, S.D. Zaugg, M.T. Meyer and L.B. Barber. 2008. A national reconnaissance of pharmaceuticals and other organic wastewater contaminants in the United States - I Groundwater. *Science of the Total Environment* 402:192-200.

Baronti, C., R. Curini, G. D'Ascenzo, A.D. Corcia, A. Gentili and R. Samperi. 2000. Monitoring natural and synthetic estrogens at activated sludge sewage treatment plants and ina receiving river water. *Environmental Science & Technology* 34:5059-5066.

Bendz, D., N.A. Paxeus, T.R. Ginn and F.J. Loge. 2005. Occurrence and fate of pharmaceutically active compounds in the environment, a case study: Hoje River in Sweden. *Journal of Hazardous Materials* 122:195-204.

Benotti, M., Rebecca A. Trenholm, Brett J. Vanderford, Janie C. Holady, Benjamin D. Stanford and Shane A. Snyder. 2009. Pharmaceuticals and endocrine disrupting compounds in US drinking water. *Environmental Science & Technology* 43:597-603.

Boxall, A.B.A., C.J. Sinclair, K. Fenner, D. Kolpin and S.J. Maund. 2004. When synthetic chemicals degrade in the environment. *Environmental Science & Technology* 38:368A-375A.

Boyd, G.R., J.M. Palmeri, S.Y. Zhang and D.A. Grimm. 2004. Pharmaceuticals and personal care products (PPCPs) and endocrine disrupting chemicals (EDCs) in stormwater canals and Bayou St. John in

New Orleans, Louisiana, USA. *Science of the Total Environment* 333:137-148.

Brooke, L. and G. Thursby. 2005. Ambient Aquatic Life Water Quality Criteria - Nonylphenol. EPA-822-R-05-005. United States Environmental Protection Agency Office of Water. Washington, DC.

Chen, M., K. Ohman, C. Metcalfe, M.G. Ikonomou, P.L. Amatya and J. Wilson. 2006. Pharmaceuticals and endocrine disruptors in wastewater treatment effluents and in the water supply system of Calgary, Alberta, Canada. *Water Quality Research Journal of Canada* 41:351-364.

Clara, M., B. Strenn and N. Kreuzinger. 2004 Carbamazepine as a possible anthropogenic marker in the aquatic environment: Investigations on the behaviour of Carbamazepine in wastewater treatment and during groundwater infiltration. *Water Research* 38:947-954.

Deng, X., M.A. Rempel and J. Armstrong. 2007. Seasonal evaluation of reproductive status and exposure to environmental estrogens in hornyhead turbot at the municipal wastewater outfall of Orange County, CA. *Environmental Toxicology* 22:464-471.

Drewes, J.E. and S.A. Snyder. 2008. Contributions of Household Chemicals to Sewage and Their Relevance to Municipal Wastewater Systems and the Environment. Water Environment Research Foundation (WERF). Alexandria, VA.

Drewes, J.E., T. Heberer and K. Reddersen. 2002. Fate of pharmaceuticals during indirect potable reuse. *Water Science and Technology* 46:73-80.

Fent, K., A.A. Weston and D. Caminada. 2006 Ecotoxicology of human pharmaceuticals. *Aquatic Toxicology* 76:122-159.

Focazio, M.J., D.W. Kolpin, K.K. Barnes, E.T. Furlong, M.T. Meyer, S.D. Zaugg, L.B. Barber and E.M. Thurman. 2008. A national reconnaissance for pharmaceuticals and other organic wastewater contaminants in the United States - II) Untreated drinking water sources. *Science of the Total Environment* 402:201-216.

Folmar, L., G.R. Gardner, M.P. Schreibman, C.L. Magliulo, L.J. Mills, G. Zaroogian, R.E. Gutjahr-Gobell, R. Haebler, D.B. Horowitz and N.D. Denslow. 2001. Vitellogenin-induced pathology in male summer flounder (*Paralichthys dentatus*). *Aquatic Toxicology* 51:431-441.

Gagne, F., C. Blaise and C. Andre. 2006. Occurrence of pharmaceutical products in a municipal effluent and toxicity to rainbow trout (*Oncorhynchus mykiss*) hepatocytes. *Ecotoxicology and Environmental Safety* 64:329-336.

Gibson, R., E. Becerril-Bravo, V. Silva-Castro and B. Jimenez. 2007. Determination of acidic pharmaceuticals and potential endocrine, disrupting compounds in wastewaters and spring waters by selective elution and analysis by gas chromatography-mass spectrometry. *Journal of Chromatography A* 1169:31-39.

Glassmeyer, S.T., E.T. Furlong, D.W. Kolpin, J.D. Cahill, S.D. Zaugg, S.L. Werner, M.T. Meyer and D.D. Kryak. 2005. Transport of chemical and microbial compounds from known wastewater discharges: Potential for use as indicators of human fecal contamination. *Environmental Science & Technology* 39:5157-5169.

Glassmeyer, S.T., D.W. Kolpin, E.T. Furlong and M.J. Focazio. 2007. Environmental presence and persistence of pharmaceuticals an overview. pp. 3-41 *in*: D.S. Aga (ed.), Fate of Pharmaceuticals in the Environment and in Water Treatment Systems. CRC Press. Boca Raton, FL.

Gomez, M.J., M. Petrovic, F.-A.A. R. and D. Barcelo. 2006. Determination of pharmaceuticals of various therapeutic classes by solid-phase extraction and liquid chromatography-tandem mass spectrometry analysis in hospital effluent wastewaters. *Journal of Chromatography A* 1114 224-233.

Gros, M., M. Petrovic and D. Barcelo. 2006. Development of a multi-residue analytical methodology based on liquid chromatography- tandem mass spectrometry (LC-MS/MS) for screening and trace level determination of pharmaceuticals in surface and wastewaters. *Talanta* 70:678-690.

Gross, B., J. Montgomery-Brown, A. Naumann and M. Reinhard. 2004. Occurrence and fate of pharmaceuticals and alkylphenol ethoxylate metabolites in an effluent-dominated river and wetland. *Environmental Toxicology and Chemistry* 23:2074-2083.

Hua, W.Y., E.R. Bennett, X.S. Maio, C.D. Metcalfe and R.J. Letcher. 2006. Seasonality effects on pharmaceuticals and s-triazine herbicides in wastewater effluent and surface water from the Canadian side

of the upper Detroit River. *Environmental Toxicology and Chemistry* 25:2356-2365.

Kasprzyk-Hordern, B., R.M. Dinsdale and A.J. Guwy. 2008. The occurrence of pharmaceuticals, personal care products, endocrine disruptors and illicit drugs in surface water in South Wales, UK. *Water Research* 42:3498-3518.

Kidd, K.A., P.J. Blanchfield, K.H. Mills, V. P. Palace, R.E. Evans, J.M. Lazorchak and R.W. Flick. 2007 Collapse of a fish population after exposure to a synthetic estrogen. *Proceedings of the National Academy of Sciences, USA* 104:8897-8901.

Kidd, K.A., P.J. Blanchfield, K.H. Mills, V.P. Palace, R.E. Evans, J.M. Lazorchak and R.W. Flick. 2007. Collapse of a fish population after exposure to a synthetic estrogen. *Proceedings of the National Academy of Sciences of the United States of America (PNAS)*8897-8901.

Kolpin, D.W., E.T. Furlong, M.T. Meyer, E.M. Thurman, S.D. Zaugg, L.B. Barber and H.T. Buxton. 2002. Pharmaceuticals, hormones and other organic wastewater contaminants in U.S. streams, 1999-2000: A national reconnaissance. *Environmental Science and Technology* 36:1202-1211.

Kolpin, D.W., M. Skopec, M.T. Meyer, E.T. Furlong and S.D. Zaugg. 2004. Urban contribution of pharmaceuticals and other organic wastewater contaminants to streams during differing flow condition. *Science of the Total Environment* 328:119-130.

Lee, H.B., T.E. Peart and M.L. Svoboda. 2005. Determination of endocrine-disrupting phenols, acidic pharmaceuticals, and personal-care products in sewage by solid-phase extraction and gas chromatography-mass spectrometry. *Journal of Chromatography A* 1094:122-129.

Liney, K.E., J.A. Hagger, C.R. Tyler, M.H. Depledge, T.S. Galloway and S. Jobling. 2006. Health effects in fish of long-term exposure to effluents from wastewater treatment works. *Environmental Health Perspectives* 114:81-88.

Loraine, G.A. and M.E. Pettigrove. 2006. Seasonal variations in concentrations of pharmaceuticals and personal care products in drinking water and reclaimed wastewater in southern California. *Environmental Science and Technology* 40.

Lyon, G. and E. Stein. 2009. How effective has the Clean Water Act been at reducing pollutant mass emissions to the Southern California Bight over the past 35 years? *Environmental Monitoring and Assessment* 154:413-426.

Lyon, G.S., D. Petschauer and E.D. Stein. 2006. Effluent discharges to the Southern California Bight from large municipal wastewater treatment facilities in 2003 and 2004. pp. 1-16 *in*: Stephen B. Weisberg and Karlene Miller (eds.), Southern California Coastal Water Research Project 2005-06 Biennial Report. Westminster, CA.

Metcalfe, C.D., B.G. Koenig, D.T. Bennie, M. Servos, T.A. Ternes and R. Hirsch. 2003. Occurrence of neutral and acidic drugs in the effluents of Canadian sewage treatment plants. *Environmental Toxicology and Chemistry* 22:2872-2880.

Mimeault, C., A. Woodhouse, X.S. Miao, C.D. Metcalfe, T.W. Moon and V.L. Trudeau. 2005. The human lipid regulator, gemfibrozil bioconcentrates and reduces testosterone in the goldfish, *Carassius auratus*. *Aquatic Toxicology* 73:44-54.

Nelson, E.D., H. Do, R.S. Lewis and S.A. Carr. 2011. Diurnal variability of pharmaceutical, personal care product, estrogen and alkylphenol concentrations in effluent from a tertiary wastewater treatment facility. *Environmental Science & Technology* 45:1228-1234.

Palmer, P.M., L.R. Wilson, P. O'Keefe, R. Sheridan, T. King and C.Y. Chen. 2008. Sources of pharmaceutical pollution in the New York City Watershed. *Science of the Total Environment* 394:90-102.

Rabiet, M., A. Togola, F. Brissaud, J.L. Seidel, H. Budzinski and F. Elbaz-Poulichet. 2006. Consequences of treated water recycling as regards pharmaceuticals and drugs in surface and ground waters of a medium-sized Mediterranean catchment. *Environmental Science & Technology* 40:5282-5288.

Rempel, M.A., J. Reyes, S. Steinert, W. Hwang, J. Armstrong, K. Sakamoto, K. Kelley and D. Schlenk. 2006. Evaluation of relationships between reproductive metrics, gender and vitellogenin expression in demersal flatfish collected near the municipal wastewater outfall of Orange County, California, USA. *Aquatic Toxicology* 77:241-249.

Roberts, P.H. and K.V. Thomas. 2006. The occurrence of selected pharmaceuticals in wastewater

effluent and surface waters of the lower Tyne catchment. *Science of the Total Environment* 356:143-153.

Schiff, K., J.M. Allen, E.Y. Zeng and S.M. Bay. 2000. Southern California. *Marine Pollution Bulletin* 41:76-93.

Sedlak, D.L., K. Pinkston and C.H. Huang. 2005. Occurrence Survey of Pharmaceutically Active Compounds. AWWA Research Foundation. Denver, CO.

Snyder, E.M., S.A. Snyder, K.L. Kelley, T.S. Gross, D.L. Villaneuve, S.G. Fitzgerald, S.A. Villalobos and J.P. Giesy. 2004. Reproductive responses of common carp (*Cyprinus carpio)* exposed in cages to influent of the Las Vegas Wash in Lake Mead, Nevada, from late winter to early spring. *Environmental Science & Technology* 38:6385-6395.

Snyder, S.A. 2008. Occurrence, treatment, and toxicological relevance of EDCs and pharmaceuticals in water. *Ozone-Science & Engineering* 30:65-69.

Spongberg, A.L. and J.D. Witter. 2008. Pharmaceutical compounds in the wastewater process stream in Northwest Ohio. *Science of the Total Environment* 397:148-157.

Suchara, E.A., D. Budziak, E. Martendal, L.L.F. Costa and E. Carasek. 2008. A combination of statistical and analytical evaluation methods as a new optimization strategy for the quantification of pharmaceutical residues in sewage effluent. *Analytica Chimica Acta* 613:169-176.

Thomas, P.M. and G.D. Foster. 2005. Tracking acidic pharmaceuticals, caffeine, and triclosan through the wastewater treatment process. *Environmental Toxicology and Chemistry* 24:25-30.

Tilton, F., W.H. Benson and D. Schlenk. 2002. Evaluation of estrogenic activity from a municipal wastewater treatment plant with predominantly domestic input. *Aquatic Toxicology* 61:211-224.

Todorov, J.R., A.A. Elskus, D. Schlenk, P.L. Ferguson, B.J. Brownawell and A.E. McElroy. 2002. Estrogenic responses of larval sunshine bass (*Morone saxatilis* x *M. Chrysops*) exposed to New York city sewage effluent. *Marine Environmental Research* 54:691-695.

Trenholm, R.A., B.J. Vanderford, S.A. Snyder and D.J. Rexing. 2006. Broad range analysis of endocrine disruptors and pharmaceuticals using gas chromatography and liquid chromatography tandem mass spectrometry. *Chemoshere* 65:1990-1998.

United States Environmental Protection Agency (USEPA). 2010. Treating contaminants of emerging concern. A literature review database. USEPA Office of Water, Engineering and Analysis Division. Washington, DC.

Vanderford, B.J., R.A. Pearson, D.J. Rexing and S.A. Snyder. 2003. Analysis of endocrine disruptors, pharmaceuticals, and personal care products in water using liquid chromatography/tandem mass spectrometry. *Analytical Chemistry* 75:6265-6274.

Vanderford, B.J. and S.A. Snyder. 2006. Analysis of pharmaceuticals in water by isotope dilution liquid chromatography/tandem mass spectrometry. *Environmental Science & Technology* 40:7312-7320.

Zuccato, E., S. Castiglioni and R. Fanelli. 2005. Identification of the pharmaceuticals for human use contaminating the Italian aquatic environment. *Journal of Hazardous Materials* 122:205-209.

Acknowledgments

The authors wish to acknowledge partial research funding, support and assistance from the Los Angeles Sanitation Districts, Orange County Sanitation District, City of San Diego Public Utilities Department, Wastewater Branch, Environmental Monitoring and Technical Services Division and the City of Los Angeles, Environmental Monitoring Division; we particularly would like to thank Joe Gully, Jeff Armstrong, Tim Stebbins and Curtis Cash for their support on this project. We also thank the following people for assistance on the project: Darrin Greenstein, Diana Young, and Monica Mays from SCCWRP; Jesus Reyes from CSULB; and Janie Zeigler from SNWA. We thank Ken Schiff, Kevin Kelley and Dan Schlenk for providing valuable editorial assistance on the manuscript.

Supplemental Information

Supplemental information is available at ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/AnnualReports/2011AnnualReport/ar11_SupplementalInfo_CEC_POTW_Marine.pdf