RMP PPCP Review 2013

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Executive Summary:

Pharmaceuticals and personal care products (PPCPs), as well as many other chemicals, enter the environment through multiple routes and have the potential to damage the local ecosystem. The Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) has convened the Emerging Contaminants Workgroup (ECWG) to provide guidance concerning the issue of chemical contamination in the Bay. The RMP works to cost-effectively identify and monitor chemicals of emerging concern (CEC) to minimize impacts on the Bay.

This report focuses specifically on PPCPs. The RMP has generated monitoring data for over 100 PPCPs. This work was undertaken to identify 'new' chemicals that may pose a threat to the Bay and merit monitoring. The chemicals themselves may not be new, but they may have newfound detection or toxicity in the aquatic environment. In addition, this work reevaluated some chemicals already examined to determine if their potential threat to the Bay had changed since initial assessment.

Three months of research indicated six PPCP chemicals merit monitoring in Bay matrices, while 25 chemicals, both newly identified and previously examined, were delegated into categories of lower priority.

Introduction:

Use of chemicals is very pervasive throughout our society. Issues occur when these chemicals are transported into the environment after their intended use. Contamination of the environment can occur by direct passage of chemicals through wastewater treatment plants (WWTPs), which are not designed to remove them from effluent, direct discharge from animal farms, landfill leaching etc[1]. Once these chemicals enter the environment they may be taken up by wildlife. Previous studies of the Bay have found chemicals of emerging concern in mussel samples as well as cormorant eggs.

The RMP convened the ECWG to provide advice as to which CECs merit further study due to potential adverse impacts on the Bay. Based on ECWG guidance, the RMP has conducted monitoring studies on a list of emerging contaminants that includes poly- and perfluorinated alkyl substances (PFASs), alkylphenols, PPCPs, flame retardants, and pesticides[2,3]. The list includes over 100 different PPCPs.

The purpose of this report is to investigate current literature to determine what other PPCPs may deserve examination via Bay monitoring studies. In addition, some PPCP chemicals for which monitoring data already exist were reevaluated to determine if the assessment of their threat to the Bay had changed based on recent toxicological literature.

Methods:

The method used to find new chemical targets for the CEC list consisted of: a) using articles from SETAC's Multibrief email publication and Environmental Toxicology and Chemistry journal as resources; b) comparing lists of chemicals from individual studies to the current CEC list; and c) focused Google searches.

Once targets were found, a search for 'Predicted No Effect Concentrations' (PNECs) and environmental concentrations was conducted. When a PNEC value was not available, other toxicity thresholds were sought, such as 'No Observable Effect Concentrations' (NOECs). The environmental concentrations reported in the literature were then compared to the toxicity threshold available. The final conclusion on a chemical's threat to the Bay was based on incidence of above-PNEC concentrations reported and locations where this occurred (i.e., estuarine versus freshwater location) since a location similar to the Bay is more relevant. The ability of a chemical to readily biodegrade or bioaccumulate was also taken into consideration.

Results:

After reviewing the chemicals researched they were split into four categories: High priority, Low priority, Uncharacterized, Non-priority

A full list of the chemicals researched and their details can be seen in Table 1.

Table 1. See attached PDF. Chemicals and studies with corresponding location, matrix and concentration are listed. Blue cells signify no PNEC for that chemical was found in the literature. Yellow cells signify at least one of the matrix concentrations is over the listed PNEC.
*The ECOTOX database (http://cfpub.epa.gov/ecotox/quick_query.htm) was used to find the toxicity threshold

High priority

The following chemicals have been added to this list because the reported environmental concentrations are above the literature PNEC values. If the chemical does not have a PNEC value, it was added to this list because it does not readily biodegrade and studies have shown it may be harmful to aquatic ecosystems.

Bisphenol S

Background:

Bisphenols (BP) are monomers used in the resin and plastic industry and are composed of two phenolic rings joined by a carbon or other chemical structure[4,5]. The most common BP is bisphenol A (BPA), a known estrogenic and genotoxic substance[4–6]. Due to these findings and subsequent BPA bans or voluntary manufacturer phase-outs, the use of alternative BPs such as bisphenol S (BPS) has increased[6,7]. The stability of BPS at high temperatures and its resistance to sunlight make it an ideal substitute for BPA[5]. BPS is found in products such as thermal receipt paper, currency, luggage tags and canned foodstuffs[7]. Some studies have shown BPS to exhibit estrogenic activity, genotoxicity and acute toxicity comparable to BPA, making it a chemical of emerging concern[8].

Monitoring and Environmental Fate:

BPS has been found in Dutch river water at concentrations up to 3 ug/L (proximity to WWTPs is unknown), Korean lake sediments at concentrations up to 1970 ng/g and human biological samples (urine) from the US at concentrations up to 21 ng/mL[5,6,8]. No studies have evaluated BPS concentrations in an estuarine environment. BPS in the environment has been an increasing concern due to the recent finding that it does not degrade in seawater or river water. In two different degradation tests, BPS concentration did not change after 60 days[4].

Toxicity:

Several studies have looked at the aquatic toxicity of BPS. One showed zebrafish exposed to 0.5 ug/L BPS experienced reduced egg production and increases in estradiol[7]. Male fish had decreased testosterone[7]. Decreased hatchability and increased malformation were also observed at this concentration[7].

Acute toxicity of BPS for *D. magna*, EC_{50} 76 mg/L, indicates less toxicity than BPA (EC_{50} 24 mg/L)[5].

Recommendations:

The above data suggest BPS may be of concern due to its lack of biodegradation and the fact that it has been measured in aquatic environments at levels higher than those that affect fish populations. There are only a few studies that test BPS concentrations in the aquatic environment and none in estuarine systems.

Benzalkonium Chloride

Background:

Benzalkonium chloride (BAC) is a quaternary ammonium compound used as a broad-spectrum antimicrobial agent for disinfecting and preserving pharmaceutical and cosmetic products[9]. BAC, a cationic surfactant, works as an antimicrobial by disrupting cell membranes[9]. It is a mixture of alkyldimethylbenzyl ammonium chlorides with various alkyl chain lengths (C12-18)[9]. Some common uses for BAC include a disinfecting agent in hospitals, fabric softener, demulsifier, emulsifier, wetting agent, preservative, antiseptic, fungicide, spermicide, and virucide[9]. BAC is a very hydrophobic compound making it mainly associated with solids[9]. Additionally, antibiotic resistance in bacteria can occur after long-term BAC exposure (4 years)[10].

Monitoring and Environmental Fate:

BAC ends up in both water and sediment. It has been documented at 1.34-2.38 ug/L in US rivers downstream of WWTPs and 1.94 ug/L upstream of a WWTP in an Austrian river[11,12]. A study on quaternary ammonium compounds in Hudson

Bay estuary found 1000 - 8900 ng/g BAC in sediment samples[13]. BAC degrades in both the liquid and solid-phase but solid-phase biodegradation is twenty times slower[14]. This suggests a concern for potential environmental accumulation.

Toxicity:

The PNECs derived for BAC are as follows: algae 0.41 ug/L, invertebrate 0.18 ug/L and fish 10.0 ug/L[15]. The observed environmental concentrations of BAC are well above the algae and invertebrate PNEC values, making BAC a contaminant of concern. There is currently no reported sediment PNEC value for BAC.

Recommendations:

Environmental levels of BAC are reported at levels higher than its PNEC values, but these studies monitored rivers, not estuaries. Discharge of BAC into the Bay would most likely lead to greater dilution than into a river. This makes monitoring water levels of BAC a lower priority. However, findings of the Hudson Bay study suggest monitoring BAC in sediment samples may be important. High levels of BAC were found in estuarine sediment in Hudson Bay, which may have implications for San Francisco Bay, another highly populated estuarine environment.

DTDMAC (ditallow-dimethyl-ammonium chloride)

Background:

The quaternary ammonium compound, DTDMAC, is a cationic surfactant used as a fabric softener and antistatic agent[16]. It was removed from use in Europe in 1990 but was not outlawed in the US. DTDMAC has very poor solubility, 0.52 pg/L, making it mostly associated with solids[17]. Additionally, it is not appreciably biodegraded in wastewater treatment plants (WWTPs) due to its sorption to minerals and organic matter[13].

Monitoring and Environmental Fate:

DTDMAC is found in both water and sediment. In the Hudson Bay, the average concentration of DTDMAC in sediment was reported at 26 ug/g, with a high of 110 ug/g[13]. Sediment samples in a Spanish harbor ranged from 42 - 1140 ug/g[13]. Also sediments of rivers in Japan, US and Belgium fell in the range 3 - 69 ug/g[13]. Surface water concentrations (not near WWTPs) of DTDMAC were reported at 34 ug/L in the Netherlands and 25 ug/L in Germany[16,18]. A sampling of 'worst case scenario' rivers in the US, with less than 5 dilution factor, reported 51 mg/L[17].

Toxicity:

The aquatic PNEC value for DTDMAC reported by Beck (2000), 6.2 ug/L, is far below the values of DTDMAC in waterways around the world[19]. A PNEC value for sediment is not reported in the literature. Additionally, a study has shown significant decreases in growth rate of bacterioplankton and in the photosynthetic rate of phytoplankton when exposed to 30 - 100 ug/L DTDMAC[18].

Recommendations

Estuarine water data were not found for DTDMAC, but riverine data reported DTDMAC above both the PNEC and concentrations known to harm organisms. Discharge of DTDMAC into the Bay will have a larger dilution factor than a river so monitoring DTDMAC in the Bay water is not of high concern. However the data do suggest DTDMAC may be present in Bay sediment since it was found in sediment of a similar estuarine location, Hudson Bay. This information, taken with the fact that DTDMAC is non-biodegradable in anaerobic environments and highly sorptive make it a strong candidate for monitoring in sediment[20].

Octocrylene

Background:

Octocrylene (OC) is a UV filter commonly used in sunscreens and personal care products[21]. It protects in UVA and UVB regions and augments the absorption capacity of other UV filters giving those formulations superior performance[21]. OC is highly photostable and highly lipophilic, associating mostly with sediment and particles in the aquatic environment[21]. Additionally, studies have shown this compound to be bioaccumulative in the aquatic food chain[21–23]. *In vitro* studies find OC to be both anti-estrogenic as well as anti-androgenic, suggesting it is capable of altering hormones[22].

Monitoring and Environmental Fate

OC is mostly found in sediments but is also reported in water and fish samples. The highest sediment sample recorded is from a German lake, 642 ug/kg, where recreational activities frequently occur[24]. A similar concentration was seen in Japanese stream sediment that received domestic wastewater[25]. In the same study a reference stream had an OC concentration of 12 ug/kg[25]. The only saltwater study was from Norway, where seawater collected by a recreational beach had 4461 ng/L OC[22]. OC is also known to bioaccumulate and the highest recorded fish tissue sample (from brown trout) is from a Swiss river less than 0.7 km downstream of a WWTP, 2400 ng/g[23]. Also a study of dolphins along the coast of Brazil reported OC concentrations of 89-782 ng/g in their tissue[21].

Toxicity

The literature has no reported PNEC value for water or sediment but an EC_{50} of 50 ug/L has been measured[26]. Because OC is hydrophobic and partitions to sediment, no direct comparison may be made between this EC_{50} and the environmental concentrations reported above.

Recommendation

Few studies found levels of OC in surface water above the ng/L level (e.g., the Norwegian study mentioned above). Since the dilution factor in the Bay is much larger than that in most river/lake systems, monitoring OC in Bay water is a low concern. However, OC is known to partition to the sediment fraction of the aquatic environment[21]. No studies were found that monitored OC in estuarine sediment, making it difficult to characterize the threat of OC to the Bay. But the fact that it bioaccumulates and is highly photostable make it a potential concern for the Bay ecosystem[21–23]. These data taken together implicate OC as a chemical of emerging concern that should be monitored in sediment as well as mussels.

Butyl Benzyl Phthalate (BBP)

This chemical has already been monitored by the RMP. Previous analyses showed its concentration in the Bay to be above the toxicity benchmark 'low apparent effects threshold' (LAET). This threshold measures toxicity of multiple chemicals in sediment at the same time. Since Bay samples were above this marker, BBP will remain on the high priority list.

Bisphenol A

This chemical has already been monitored by the RMP but the previous monitoring method was not sensitive enough so it will remain a high priority due to its reported estrogenicity[5].

Low priority

The following chemicals have been added to this list because there is insufficient evidence in the literature to suggest they are a current threat to the Bay. However, for these chemicals, studies in non-estuarine locations with lower dilution factors found concentrations above the corresponding PNEC. As a result these chemicals may not merit monitoring in the Bay but should be revisited when more information is available.

Oxytetracycline (OTC) and Diclofenac:

OTC and diclofenac are in the 'Low priority' group because both degrade rapidly in water[27–29]. There are incidents where concentrations were above the PNEC, but these are in non-estuarine locations with lower dilution factors than the Bay. As a result these chemicals do not need to be monitored in the Bay, but the literature should be monitored for any new findings.

Fluoxetine:

Only one surface water study reported fluoxetine above the PNEC, 8.1 ng/L[30]. But another study found fathead minnows exposed to fluoxetine at levels below the PNEC, 1 ng/L, became anxious and aggressive (Unpublished, Klaper et al.). A few surface water studies reported fluoxetine above 1 ng/L, but the higher dilution factor expected for the Bay leaves fluoxetine a low priority.

Benzodiazepine:

Environmental concentrations of benzodiazepine were far below the PNEC, 4.3 ug/L[31]. A study found Zebrafish exposed to 1.8 ug/L benzodiazepine experienced altered foraging behavior and were more active[32]. Since only one study found concentrations within the 1.8 ug/L range and this was a stream with a much lower dilution factor than the Bay, benzodiazepine is a low priority.

Galaxolide and Tonalide:

For each chemical, only one study was found with surface water concentrations above the PNEC, and both were in locations with lower dilution factors than the Bay. Additionally, these fragrances are biodegradable and photodegradable. However, both chemicals have been found in aquatic wildlife. The State Panel specifically recommended monitoring galaxolide in water, but I see this and tonalide as low priorities since they do not pose a current threat to the Bay, but have the potential to in the future.

Norfloxacin:

A few, both estuarine and freshwater, studies have reported norfloxacin above its PNEC. Additionally a study found norfloxacin to cause reduced fertility, sperm concentration and serum testosterone in exposed male quails[33]. Although these findings raise concern about norfloxacin, previous sampling in the Bay has not produced any samples positive for norfloxacin (LOD = 53 ng/L, non quantifiable in sediment), making it a low priority.

Bis(2-ethylhexyl) phthalate (DEHP):

A few non-estuarine studies found concentrations above its PNEC values, while one estuarine study found sediment in the Netherlands above the PNEC. DEHP was previously analyzed in the Bay and concentrations were significantly below its PNEC. Another toxicity threshold, the 'low apparent effects threshold' (LAET), which measures toxicity of multiple chemicals in sediment at once, was used as a toxicity benchmark. The LAET for DEHP, 1300 ng/g is more than twice the concentration of DEHP in the Bay, 605 ng/g, but it still remains a possible concern in the Tiered Framework.

Uncharacterized

The following chemicals were added to this list because PNEC values were not available and few studies measured these chemicals in the environment. The lack of data leaves the threat these chemicals pose to the Bay uncharacterized. As of now the suggestion is to not monitor these chemicals in the Bay but keep monitoring them in the literature as new studies present themselves.

Celestolide
Diethylenetriaminepentaacetate (DTPA)
Ethylenediaminetetr acetate (EDTA)
Isothiazolinone
Nitrilotriacetate (NTA)
Alkyltrimethylammonium chloride (ATMAC)
Chlorophene

Non-priority

The following chemicals were added to this list because measured environmental concentrations were all at least a factor of 10 below literature PNEC values. These chemicals are currently of no concern and need not be monitored but should be revisited in future years as more data are published.

Previously analyzed (concentration in Bay samples):

Albuterol (surface water 1 ng/L)
Amitriptyline (surface water 0.6 ng/L mussel 6.2 ng/g dw)
Atenolol (surface water 37 ng/L mussel 13 ng/g dw)
Erythromycin (surface water 41.6 ng/L, sediment 3.4 ng/g)

Newly examined via literature review:

Dialkyl dimethyl - ammonium chloride (DADMAC)
Doxycycline
Lomefloxacin
Metronidazole
Paraxanthine
Phenytoin

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