# Contaminants of Emerging Concern in the San Francisco Estuary: Triclosan and Triclocarban

## Final Report

Prepared by the Regional Monitoring Program
for Water Quality in the San Francisco Estuary

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## I. Use and Production

Triclosan (TCS or 5-chloro-2-(2,4-dichlorophenoxy)-phenol; Figure 1) is a synthetic chlorinated aromatic compound registered for use as an antimicrobial, bactericide, disinfectant, and fungicide. TCS has been used since the early 1960s as an additive in a wide variety of consumer and industrial products. It is added to cleaning and home products such as antibacterial handsoaps (0.1-0.3% by weight), mouthwash, toothpaste, detergents and deodorants, and other products including furniture, cutting boards, sports equipment, floors, and carpets. Microban®, a slow release product containing TCS, is also incorporated into plastics used in children's toys, kitchen utensils, and other consumer and industrial products, and is even imbedded in some clothing. TCS is also included as an inert ingredient in some pesticides. Over 95% of triclosan's uses are in consumer products that are disposed of in residential drains (Reiss et al., 2002). In 1998 the volume of TCS produced or imported in the US was 10 million lb (4.5 million kg). TCS use may have declined after 1998 because it is not listed in the 2002 and 2006 Toxic Substances Control (TSCA) Inventory Update Rule (IUR) database (Howard and Muir, 2010). Halden and Paull (2005) estimated an annual use of >300,000 kg/yr in the US.

Triclocarban (TCC or 3-(4-chlorophenyl)-1-(3,4-dichlorophenyl)urea; Figure 1) is also a synthetic, chlorinated aromatic compound used as an antimicrobial agent. TCC has been in use since the 1950s and is found in consumer products (~0.5-5% by weight) such as antimicrobial soap bars (2% by weight), deodorant, detergent, and other personal care products. In 2002 the volume of TCC produced or imported in the US was 10 million lb (4.5 million kg); TCC use may have declined thereafter because it was not listed in the 2006 TSCA IUR database (Howard and Muir, 2010). Halden and Paull (2005) estimated an annual use of >330,000 kg/yr in the US.

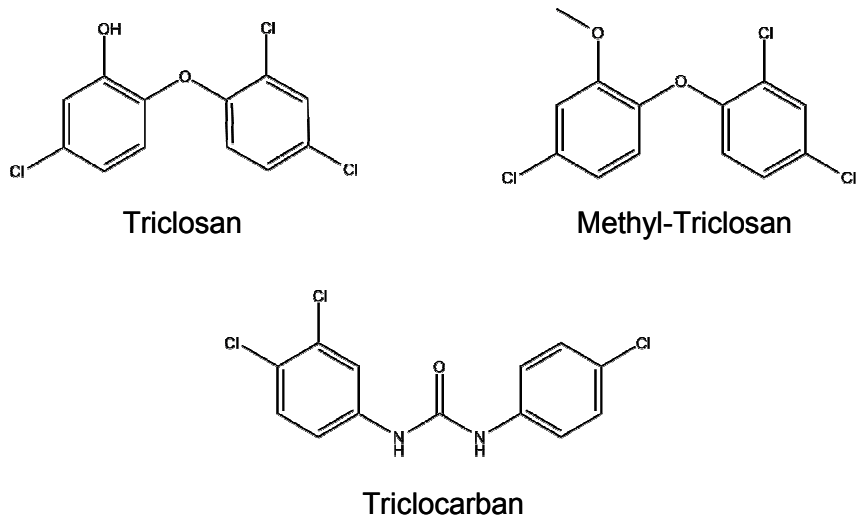



Figure 1. Molecular structures of triclosan, methyl-triclosan, and triclocarban.

## II. Fate in Wastewater Treatment Plants (WWTPs)

Extensive use of TCS and TCC in consumer products has resulted in their transport to WWTPs, where they are not completely removed from effluent during wastewater treatment. Removal efficiencies for TCS and TCC in WWTPs typically range from 60% to >99.5% and are dependent on the type of treatment used (Heidler et al., 2006; Lubliner et al., 2010; Kumar et al., 2010). Conventional activated sludge treatment effectively removes the majority of TCS (typically >90%) and TCC (>86%). In a recent study of the efficiency of various types of treatment in the Pacific Northwest (Lubliner et al., 2010), the use of aeration ditch treatment or nutrient removal technologies increased removal efficiencies to ≥ 93% for TCS, results consistent with other studies (Singer et al., 2002, McAvoy et al., 2002). Enhanced biological nutrient removal plus tertiary filtration was the only treatment technology in the Pacific Northwest study that substantially increased the removal efficiency for TCC (>99.5%).

Sorption to sludge, as a consequence of high affinities for organic matter, and biological degradation are the major removal mechanisms for TCS and TCC during wastewater treatment. In the 2009 USEPA National Sewage Sludge Survey (NSSS), which analyzed sludge from 74 WWTPs across the US, concentrations of TCS and TCC spanned four orders of magnitude. Concentrations of TCS and TCC ranged from 334 to 133,000 ng/g dry (mean ~16,000 ng/g dry) and 187 to 441,000 ng/g dry (mean ~39,000 ng/g dry), respectively. In contrast to the USEPA study, where mean concentrations of TCC in sludge were more than double those for TCS, the mean concentration of TCS in sludge in the Pacific Northwest (21,462 ng/g) was twice as high as the mean concentration of TCC (10,200 ng/g; Lubliner et al., 2010). An estimated 79% of the TCS and 20% of the TCC entering WWTPs is transformed via microbial processes during the treatment process (Singer et al., 2002; Heidler et al., 2006).

Despite their high removal efficiencies, TCS and TCC are commonly detected in WWTP effluent. Studies of wastewater effluents in the US have detected concentrations of TCS and TCC ranging from 10 to 5370 ng/l and <100 to 3045 ng/L, respectively (McAvoy et al., 2002; Glassmeyer et al., 2005; Halden and Paull, 2005; Heidler et al., 2006; Heidler and Halden, 2007; Kumar et al., 2010). In the Pacific Northwest, TCS WWTP effluent concentrations ranged from 1 to 805 ng/L, with lower concentrations reported in tertiary treated effluent and reclaimed water (Lubliner et al., 2010). In the same study, TCC concentrations ranged from 3 to 103 ng/L, with no substantial difference between concentrations in secondary or tertiary treated effluent. Studies have indicated that trickling filter treatment in particular results in TCS effluent concentrations that are more variable and higher on average (Heidler and Halden, 2007).

A number of studies have indicated that TCS and TCC can be transformed to other compounds during wastewater treatment. TCS can be transformed biologically in WWTPs to methyl triclosan, a compound that is lipophilic and more persistent than TCS (Lindstrom et al., 2002; Balmer et al., 2004). Chemical reactions of TCS with free chlorine have been shown to produce chloroform, a probable human carcinogen, and other chlorinated organics including chlorophenoxyphenols and chlorophenols, such as 2,4,6- trichlorophenol, also a probable human carcinogen (Rule et al., 2005; Fiss et al., 2007). In addition, aerobic microbial degradation of TCC may result in the formation of chloroanilines, compounds that are cytotoxic and carcinogenic (Gledhill, 1975).

## III. Fate and Occurrence in the Environment

### Surface Waters

Much more information regarding fate and occurrence is available for TCS than for TCC. Studies suggest that TCS is readily removed from the water column via biodegradation (Singer et al., 2002), photolysis (Aranami and Readman, 2007), and sorption to particles (Wilson et al., 2009). TCS has a photolytic half life of 4 days in seawater and can photodegrade to produce the toxic byproducts 2,8-dichlorodibenzo-*p*-dioxin (2,8-DCDD) and 2,4-dichlorophenol (2,4-DCP), a US Priority Pollutant (Latch et al., 2005; Aranami and Readman, 2007). It is not known, however, if the formation of these compounds is a significant concern in aquatic ecosystems. Similar to TCS, TCC is expected to associate with particles in the water column due to its high affinity for organic matter and may also be degraded by microbes in surface waters. Studies have not yet investigated the photodegradation of TCC in natural waters.

TCS was one of the most frequently detected wastewater contaminants in a 1999-2000 survey of US streams (Kolpin et al., 2002). In this study, TCS was detected in 58% of the sites investigated with median and maximum concentrations of 140 ng/L and 2,300 ng/L, respectively. More recent studies investigating TCS concentrations in coastal areas in the US, including the Hudson River Estuary, the Mississippi River near New Orleans, Charleston Harbor, and embayments in Southern California found much lower TCS concentrations in surface waters (<1 to 26 ng/L; DeLorenzo et al., 2007; Zhang et al., 2007; Wilson et al., 2009; Fair et al., 2009; Singh et al., 2009; Kumar et al., 2010; SCCWRP unpublished data). In contrast to these areas, concentrations of TCS in surface waters near WWTP outfalls or waters with known inputs of raw wastewater reached maxima that were one or two orders of magnitude higher (Glassmeyer et al., 2005; Halden and Paull, 2005; Coogan and LaPoint, 2008). For TCC, reported concentrations in surface waters range from non-detect to 6750 ng/L, though few data are available and most are from studies assessing wastewater impacted surface waters (Halden and Paull, 2005; Sapkota et al., 2007; Coogan and LaPoint, 2008; Kumar et al., 2010). One study reported detection of methyl TCS (41 ng/L) in an effluent dominated stream in Texas (Coogan and LaPoint, 2008).

### Surface Sediments

TCS and TCC are hydrophobic and thus are expected to adsorb to suspended solids and sediments where they can be taken up by benthos and ultimately higher trophic level organisms. Sediment half-lives as long as 540 days have been estimated for both TCS and TCC (Halden and Paull, 2005). Data from sediment cores collected from several US estuaries indicate that TCS and TCC are persistent for decades in subsurface sediments and TCC may be more persistent than TCS (Miller et al., 2008). A recent study indicated that TCS is susceptible to biodegradation in aerobic soils, whereas under anaerobic conditions it is highly resistant to breakdown (Ying and Kookana, 2007). Dechlorination of TCC to the transformation products dichloro-, monochloro-, and unsubstituted carbanilide has been observed in Chesapeake Bay sediments (Miller et al., 2008).

Recent studies indicate that TCS sediment concentrations are comparable among US estuaries. Surface sediments from Chesapeake Bay, the Lower Hudson River Estuary, Narragansett Bay, rivers near Savannah, GA, and Southern California coastal waters contain TCS concentrations ranging from below detection up to 86 ng/g dry (Miller et al., 2008; Wilson et al., 2009; Cantwell et al., 2010; Kumar et al., 2010; SCCWRP, unpublished data). Much fewer data are available for TCC compared to TCS. Concentrations of TCC in Chesapeake Bay sediments were at least an order of magnitude higher than TCS and ranged from 700-1,600 ng/g (mean 1,000 ng/g), though most of these data were collected near a WWTP outfall (Miller et al., 2008). Concentrations of TCC in river sediments near Savannah, GA ranged from 11 to 52 ng/g (mean 29 ng/g; Kumar et al., 2010). Sediment core data from Jamaica Bay, NY indicate that concentrations of TCS and TCC were highest in the mid-1960s to late 1970s, coinciding with increases in commercial production of these compounds, but then declined closer to the surface (post-1995 surface sediments not analyzed; Miller et al., 2008). During that time period peak concentrations of TCC were 25 times higher than those for TCS. The introduction of activated sludge treatment to the WWTPs in 1978 is considered to be responsible for the decrease in concentrations observed over time. Despite improvements in treatment, there is evidence suggesting that TCS sediment concentrations are increasing in some US estuaries (Cantwell et al., 2010).

**Wildlife and Humans**

TCS, methyl triclosan (methyl-TCS), and TCC are relatively hydrophobic compounds (log $K_{ow}$ 4.8, 5.2, and 4.9, respectively) and thus have the potential to bioaccumulate. Few studies have reported on bioaccumulation of these compounds; most of these studies have investigated freshwater organisms and only a small number have analyzed TCC and methyl-TCS. TCS, methyl-TCS, and TCC have been detected in algae (162, 50, and 367 ng/g wet weight or ww, respectively) and snails (60, 50, 300 ng/g ww, respectively) living in a wastewater-impacted creek in Texas (Coogan and LaPoint, 2008). In laboratory studies investigating bioaccumulation in invertebrates, estuarine grass shrimp accumulated methyl-TCS when exposed to TCS (DeLorenzo et al., 2007), and freshwater sediment-dwelling worms exposed to TCC-spiked sediments accumulated TCC and one of its dechlorination products (Higgins et al., 2009). TCS has been detected in the bile of fish living downstream from WWTP discharges in Sweden (240–4,400 ng/g ww; Adolfsson-Erici et al., 2002), plasma of fish in the Detroit River (0.8-10 ng/g ww; Valters et al., 2005), muscle of fish living in Southern California embayments (9-39 ng/g ww), plasma of dolphins living off the coasts of South Carolina and Florida (0.03-0.3 ng/g ww, mean ~0.1 ng/g ww; Fair et al., 2009), and in human milk (<20-300 ng/g lipid) and blood (0.01-38 ng/g ww; Adolfsson-Erici et al., 2002; Allmyr et al., 2006; Allmyr et al., 2008).

Compared to TCS, some data suggest that methyl-TCS may accumulate to a greater extent in tissues. Methyl-TCS was detected in carp (whole body analysis) in Las Vegas Bay at concentrations ranging from 20-2,800 ng/g ww (mean 600 ng/g ww) but TCS was below detection limits (Lieker et al., 2009). Though TCS was not analyzed, methyl-TCS was also detected in fish (fillets) at concentrations up to 35 ng/g ww in Swiss lakes (Balmer et al., 2004). In a recently conducted national pilot study investigating PPCP accumulation in fish at several sites in the US, TCS was not detected in fillets (< 38 ng/g) but methyl-TCS was not analyzed (Ramirez et al., 2009). It has been hypothesized that methyl-TCS will bioaccumulate more than

TCS because it is more persistent in aquatic environments (Lieker et al., 2009). Despite these findings, TCS was recently detected at concentrations ranging from 17 to 31 ng/g in fillets of fish living in an effluent-dominated stream in Texas (Mottaleb et al., 2009). Methyl-TCS was also detected in the plasma (<0.02 ng/g ww) of the Detroit River fish, but at concentrations two to three orders of magnitude lower than TCS.

## IV. Toxicity

Chalew and Halden (2009) recently summarized published environmental concentrations of TCS and TCC and compared them to available toxicity threshold values established using traditional test methods. In their summary, the toxicity threshold values indicate that crustacea are more sensitive than fish to both compounds, algae are the organisms most sensitive to TCS, and crustacea are more sensitive to TCC than algae (Table 1). Fish and crustacea tend to be more sensitive to TCC than TCS, while algae and microbes are more sensitive to TCS than TCC. Inhibitory effects on microorganisms were as low as 25 µg/L for TCS and 100,000 µg/L for TCC.

Table 1. Triclosan (TCS) and Triclocarban (TCC) Toxicity Threshold Values for Aquatic Organisms (adapted from Chalew and Halden, 2009)

| Indicator Organism | Acute Thresholds (µg/L) | | Chronic Thresholds (µg/L) | |
|---|---|---|---|---|
| | TCS | TCC | TCS | TCC |
| Fish | 260 - 440 | 49 - 180 | 34 - 290 | 5 |
| Crustacea | 185 - 390 | 1.9 - 40 | 6 - 182 | 0.06 - 4.7 |
| Algae | 0.2 - 2.8 | 10 - 30 | -- | -- |

There is some overlap in reported environmental concentrations of TCS and TCC and the toxicity threshold values summarized by Chalew and Halden (2009), suggesting the potential for adverse ecological effects in aquatic environments. Fish, crustacea, and algae all have the potential to be affected in surface waters heavily impacted by treated effluent. Concentrations of TCS and TCC typically present in US surface waters have little if any overlap with fish toxicity threshold values. TCS has been detected in surface waters, primarily effluent-dominated, at concentrations comparable to those resulting in acute effects in algae; however, recent studies in US estuaries report surface waters concentrations that are generally an order of magnitude below the lowest toxicity threshold value for toxicity to algae (0.2 µg/L). Crustacea may be adversely affected by TCC in effluent-dominated waters and some surface waters. Chalew and Halden (2009) also concluded that crustacea may be affected by TCS and TCC concentrations present in sediment porewater, which they estimated from available sediment concentrations, and that all of the observed TCC sediment concentrations reported in their study (1,700-24,000 ng/g dry weight, including freshwater and buried sediments) exceed even the highest reported acute toxicity thresholds for crustacea.

Most of the toxicity threshold data currently available are from acute effects studies, which are not representative of the potential effects due to long-term exposure to concentrations

that are typically found in aquatic environments. Though little information is available for TCC, several studies have investigated the potential effects of chronic exposure to TCS and observed a wide range of effects. Laboratory experiments indicate that the toxic mode of action for TCS in microbes is the inhibition of fatty acid and lipid biosynthesis (McMurry et al., 1998; Levy et al., 1999). Studies have suggested that TCS causes endocrine disruption in fish and mammals (Foran et al., 2000; Ishibashi et al., 2004; Crofton et al., 2007), but concentrations in the environment are generally much lower than the exposure concentrations used in these studies. In contrast, endocrine effects in amphibians at environmentally relevant concentrations (0.03 μg/L) have been observed (Veldhoen et al., 2006). TCC has also been identified as an endocrine disrupting compound, albeit a 'new type', because of its potential to amplify synthetic steroidal compounds (Chen et al., 2007). Other effects studies with TCS have reported interference with cellular function in mussels when in vitro and in vivo exposures are used (Canesia et al., 2007) and impacts on the structure and function of algal communities at concentrations occurring near wastewater outfalls (Wilson et al., 2003). Additional concerns of TCS exposure include the potential for indirect effects on algal and aquatic plant grazers due to the toxicity to algae at environmentally relevant concentrations, the development of widespread antibiotic resistance due to the ubiquitous use and presence of TCS in the environment, and the potential toxicity to microbial communities in activated sludge and biosolids, which could adversely impact aquatic environments and the health and fertility of agricultural soils amended with biosolids.

## V. Potential Impact in San Francisco Bay

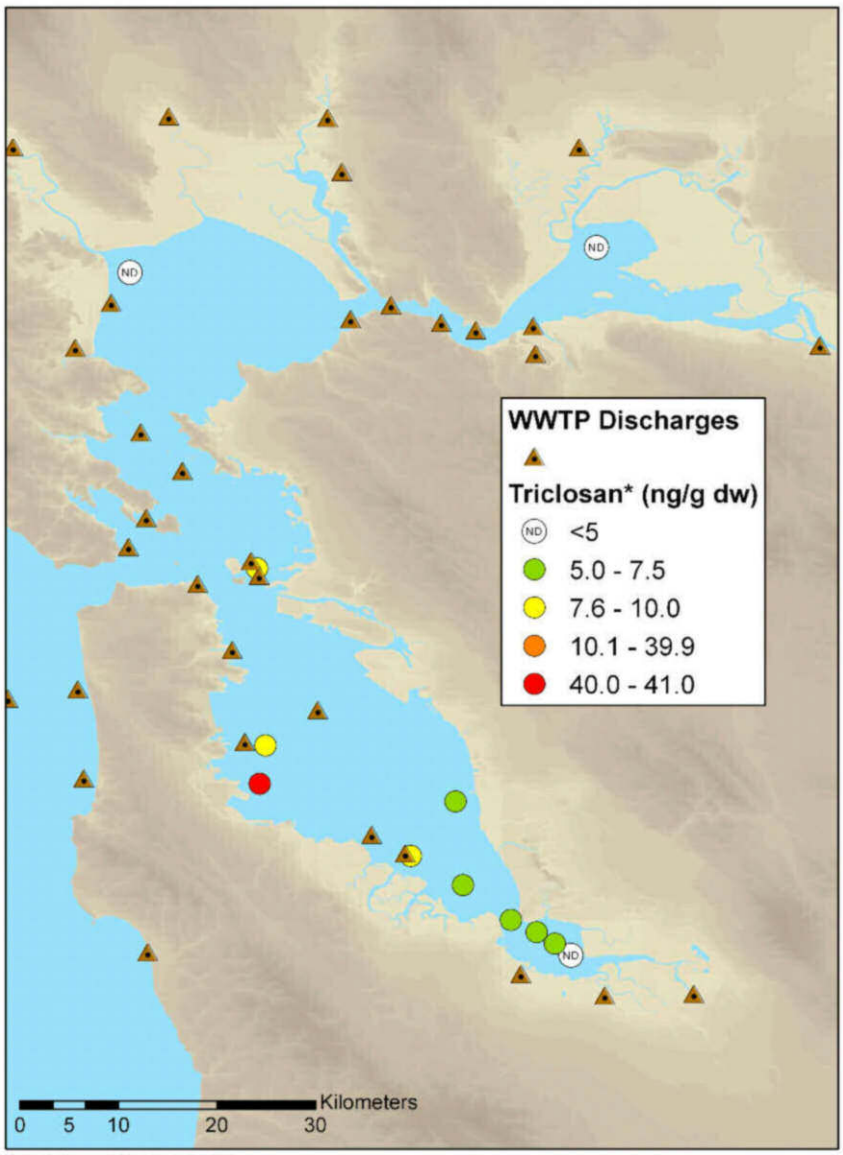
### Bay Data

Mean concentrations (± SD) of TCS in sewage sludge collected from two Bay Area WWTPs in 2008 were 20,800 ± 530 and 15,200 ± 1000 ng/g dry and were very similar to the nationwide average of ~16,000 ng/g (Davis et al., 2009; USEPA, 2009). Similarly, concentrations of TCS in effluent collected from a large Bay Area WWTP in 2006 ranged from <500 to 900 ng/L (Jackson and Sutton, 2008) and were comparable to effluent concentrations observed in other studies. Sewage sludge and wastewater effluent data for TCC were not available.

In a small pilot study conducted in the winter of 2010, co-located samples of surface water, sediments, and resident mussels (n=5 for each matrix) were collected from five shoreline sites spatially distributed throughout the Bay and analyzed for a variety of CECs. TCS was not detected in surface water (< 60 ng/L, whole water) or sediment (< 62 ng/g dry); however, if present at concentrations even an order of magnitude lower than the detection limit, the TCS data would be consistent with concentrations in other US estuaries for surface waters (<1 to 26 ng/L) and sediments (below detection to 86 ng/g dry). These Bay sediment results are consistent with data from a 2008 Bay sediment survey, in which TCS concentrations ranged from < 5 to 40 ng/g dry (Figure 2.). While TCC was also not detected in Bay surface water (< 3 ng/L, whole water), it was detected in sediments at concentrations ranging from <3 to 33 ng/g dry. Concentrations were highest in the Lower South Bay (33 ng/g) and decreased northward (6 ng/g at the South

Bay sites and < 3 ng/g in Central Bay). Overall, the Bay sediment data support the premise that TCS and TCC are likely to co-occur in aquatic environments due to similar production volumes,

Figure 2. Concentrations of triclosan in sediments collected from San Francisco Bay in 2008.




uses, and physical chemical properties (Halden and Paull, 2005). In mussels, TCS was not detected (detection limit 33 ng/g ww) but TCC was detected at two sites (0.7 and 1.5 ng/g ww; detection limit 0.6 ng/g ww).

Sediment porewater concentrations for TCS and TCC were estimated using the maximum sediment concentrations detected in the Bay, an average Bay sediment organic carbon content (~1.5%), and the organic carbon normalized sediment-water partitioning coefficients ($K_{oc}$), recognizing that a number of factors such as fluctuating pH and salinity, and the organic carbon

content and quality of sediments may influence these estimates and result in some variation and uncertainty. Using a $K_{oc}$ of 13,400 for TCS and 31,700 for TCC (Chalew and Halden, 2009), estimated maximum porewater concentrations were 0.2 and 0.07 µg/L for TCS and TCC, respectively.

**Potential Impact of Triclosan and Triclocarban**

Comparison of the available toxicity thresholds to occurrence data for San Francisco Bay suggests that fish, crustacea, and algae are not likely being affected by exposure to TCS or TCC in the water column. Concentrations in Bay surface waters were below detection limits, and if present below these limits, would be one to four orders of magnitude below toxicity thresholds. However, crustaceans living in porewater may be adversely affected by exposure to TCC since maximum estimated porewater concentrations are within the range of concentrations reported to result in chronic toxicity (Table 1). It is important to note that exposure to TCS and TCC via consumption of contaminated prey items or sediments is not accounted for in the toxicity thresholds developed thus far and should also be considered when assessing risk to wildlife. As such, studies investigating the bioavailability and potential for trophic transfer of these compounds are warranted since very little information is available. Additionally, water and sediment near wastewater outfalls or other point sources in the Bay may contain higher concentrations of TCS and TCC which may increase the likelihood of impacts. Few studies investigating the potential for sub-lethal impacts on populations due to long-term exposures to low concentrations of these compounds have been conducted; these are needed to thoroughly assess their risk to wildlife in the Bay.

## VI. Key Information Gaps

- Potential chronic effects on algae and microbes due to long-term exposure to concentrations of triclosan and other antimicrobials that are typically found in aquatic environments.
- The potential for transfer of triclosan and methyl triclosan through the food web to act as a source of exposure to wildlife.
- Concentrations in sediment and biota influenced by Bay Area treatment plant outfalls, where exposures are anticipated to be highest.
- Potential development of widespread antimicrobial resistance due to the presence of triclosan in aquatic environments.
- The identity, extent of use, and potential environmental health impacts of chemicals used as replacements for triclosan.
- Confirm the anticipated small contribution of stormwater runoff relative to municipal wastewater as a pathway of triclosan to Bay surface waters.

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