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Per and Polyfluoroalkyl Substances (PFASs) in San Francisco Bay: Synthesis and Strategy

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Glossary of Acronyms of Perfluoroalkyl and Polyfluoroalkyl Substances (PFASs)

Subclass	Chemicals	Chain length	Acronym
Perfluoroalkyl carboxylic acids (PFCAs)	Perfluorobutanoic acid	C4	PFBA
	Perfluoropentanoic acid	C5	PFPeA
	Perfluorohexanoic acid	C6	PFHxA
	Perfluoroheptanoic acid	C7	PFHpA
	Perfluorooctanoic acid*	C8	PFOA
	Perfluorononanoic acid*	C9	PFNA
	Perfluorodecanoic acid*	C10	PFDA
	Perfluorundecanoic acid*	C11	PFUnDA
	Perfluorododecanoic acid*	C12	PFDoA
Perfluoroalkyl sulfonic acids (PFSAs)	Perfluorobutane sulfonic acid	C4	PFBS
	Perfluoropentane sulfonic acid	C5	PFPeS
	Perfluorohexane sulfonic acid*	C6	PFHxS
	Perfluoroheptane sulfonic acid*	C7	PFHpS
	Perfluorooctane sulfonic acid*	C8	PFOS
Perfluoroalkyl sulfonamido substances	N-Ethyl-perfluorooctane sulfonamido ethanol*		N-EtFOSE
	N-Methyl-perfluorooctane sulfonamido ethanol*		N-MeFOSE
	N-Ethyl-perfluorooctane sulfonamido acetic acid*		N-Et-PFOSA-AcOH
	N-Methyl-perfluooctane sulfonamido acetic acid*		N-Me-PFOSA-AcOH
	Perfluorooctane sulfonamide*		PFOSA

*Indicates a long-chain perfluoroalkyl or polyfluoroalkyl substance

Glossary (Continued)

Fluorotelomer alcohols (FTOHs)	6:2 Fluorotelomer alcohol		6:2 FTOH
	8:2 Fluorotelomer alcohol*		8:2 FTOH
Polyfluoroalkyl phosphoic acid esters (PAPs)	6:2 Fluorotelomer phosphate diester		6:2 diPAP
	6:2/8:2 Fluorotelomer phosphate diester*		6:2/8:2 diPAP
	8:2 Fluorotelomer phosphate diester*		8:2 diPAP
Perfluoroalkyl phosphinic acids (PFPiAs)	C6/C6 Perfluorophosphinic acid		C6/C6 PFPiA
	C6/C8 Perfluorophosphinic acid*		C6/C8 PFPiA
Fluorotelomer sulfonic acids (FTSs)	6:2 Fluorotelomer sulfonic acid		6:2 FTS
	8:2 Fluorotelomer sulfonic acid*		8:2 FTS
Polyfluoropolyethers (PFPEs)	Ammonium 4,8-dioxa-3H-perfluorononanoate		ADONA

Executive Summary

Perfluoroalkyl and polyfluoroalkyl substances (PFASs) are a broad class of fluorine-rich specialty chemicals. Some types of PFASs, and in particular the perfluoroalkyl forms, possess thermal stability, non-reactivity, and surfactant properties, making them useful for many different types of applications. More than 4,700 PFASs are used in consumer, commercial and industrial applications, including food packaging materials, waterproof textiles, stain-resistant carpets and furniture, fire-suppression foams, processing aids for the production of fluoropolymers like Teflon, mist suppressants in metal-plating, and hydraulic aviation fluids.

Perfluoroalkyl substances are fully fluorinated, meaning that no carbon-hydrogen bonds are present and only fluorine atoms are bonded to the carbon backbone of the molecule. In contrast, polyfluoroalkyl substances are *not* fully fluorinated, meaning that carbons may also have bonds to hydrogen, oxygen, or other atoms in addition to fluorine. Some polyfluoroalkyl substances can degrade to perfluoroalkyl substances; these compounds are referred to as "precursors" of the perfluoroalkyl transformation products.

The carbon-fluorine bonds in PFASs are some of the strongest known to science, which means PFASs (or, in the case of precursors, their perfluoroalkyl transformation products) show extremely high persistence in the environment. Well-studied members of the perfluoroalkyl family, including perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), have been shown to be highly toxic. Other perfluoroalkyl substances have received little to no testing; however, structural similarities suggest that they are likely to trigger similar concerns for human and ecological health.

At present, much of the regulatory focus has been on the long-chain perfluoralkyl chemicals (generally containing seven to eight carbons), such as PFOS and PFOA, in part based on their extensive toxicity profiles, their multi-year half lives in human blood, and past production volumes. The industry is shifting to alternatives that include the short-chain compounds containing four to six fluorinated carbons; however, there is very little toxicological information about these alternatives available, and there is concern that these short-chain compounds may be similarly problematic. While the short-chain PFASs have much shorter half-lives in humans, they are more mobile in groundwater and less amenable to treatment via sorption technologies, which are typically employed to remove PFOS and PFOA from drinking water. Even less is known about the many members of the polyfluoroalkyl family, which have also seen increasing use as alternatives to PFOS and PFOA. For the polyfluoroalkyl substances, with the exception of a handful of compounds, we do not know which specific compounds are in use, making targeted analysis of environmental samples particularly challenging.

In the US, production of PFOS was phased out by 2002, and production of PFOA was phased out by 2015. These federal actions were part of a broader international collaboration to reduce human and environmental risks associated with exposure to these compounds. PFOS was restricted under the Stockholm Convention in 2009 as an Annex B chemical, allowing some specific exceptions to a total ban on PFOS. PFOS and PFOA production continues in some

countries, such as China and India. In addition, global production of related replacements, including short-chain perfluoroalkyl substances and polyfluoroalkyl substances mentioned above, means continuing use of and exposure to compounds that may potentially pose similar risks.

The Regional Monitoring Program for Water Quality in the San Francisco Bay (RMP), administered by the San Francisco Estuary Institute (SFEI), has undertaken a series of monitoring and research projects to evaluate PFASs in San Francisco Bay. The RMP has found that PFASs are widely detected in San Francisco Bay matrices including water and sediment. These contaminants are also ubiquitous in Bay biota including fish, bird eggs, and harbor seals.

In particular, concentrations of PFOS in Bay harbor seals and bird eggs in 2004 and 2006 were some of the highest detected globally. Current PFOS concentrations in South Bay bird eggs may pose a risk to hatching success, according to available toxicity data. In addition, current sport fish PFOS concentrations may pose risks to humans eating high-fish diets, according to consumption guidelines from the State of Michigan. As a result, PFOS has been identified as a moderate concern for San Francisco Bay, according to the RMP's tiered, risk-based framework that guides monitoring and management actions on emerging contaminants in the Bay.

Recent monitoring suggests decreases in PFOS concentrations in seals and cormorants, likely as a result of changing use patterns that include the nationwide phase-out in 2002. However, concentrations of other members of the PFAS family, such as PFOA, have remained relatively constant, albeit it at substantially lower levels overall. Meanwhile, a number of "precursors" that degrade to the more persistent PFOS or PFOA have been detected in sediments.

Stormwater and wastewater are pathways by which PFASs enter the Bay; use of a conservative tracer model suggests that while these are significant pathways they may not be the only pathways. Studies of Bay Area stormwater and wastewater also suggest that a significant fraction of the PFASs discharged are of unknown chemical composition. Analysis of wastewater data over multiple years is consistent with manufacturing and use trends including decreasing average levels of PFOS and PFOA (not statistically significant) and statistically significant increasing levels of short-chain perfluoroalkyl substances. In contrast, stormwater has not been analyzed with frequency; the most recent data available are from samples collected in the winter of 2010/2011.

Previously, all PFASs other than PFOS had been considered possible concerns for the Bay, a designation that indicates uncertainty and reflects the lack of clear toxicity thresholds. Based on an updated literature review and discussion with international PFAS experts, it is now considered appropriate to classify the long-chain carboxylate perfluoroalkyl substances such as PFOA as moderate concerns for the Bay. The rationale for including long-chain carboxylates as moderate concern chemicals is based on the pervasive detection of these compounds in biota, the knowledge that these compounds do not degrade under environmental conditions, and the identification of adverse responses in mammalian systems at concentrations observed in Bay seals.

For the remaining PFASs observed in San Francisco Bay, there is little available toxicity data. According to RMP studies, short-chain perfluoroalkyl substances such as PFBS, PFBA, and PFHxA are present at increasing levels in effluent, but appear to be less bioaccumulative, with no to low detections observed in bird eggs, seals, and fish. It is unclear whether these compounds are less toxic than PFOS and PFOA. Polyfluoroalkyl substances, including precursors that degrade to PFOS and PFOA, have been detected in sediment; tissue studies are not available. At the present time, insufficient toxicity information exists to evaluate whether these compounds pose a risk. Given this level of uncertainty, they must be considered possible concerns for the Bay.

Looking to the future, a three-element monitoring strategy for PFASs in San Francisco Bay is recommended. First, the designation of PFOS, PFOA, and long-chain carboxylates as moderate concerns for the Bay supports continuation of routine monitoring of cormorant eggs and sport fish for a subset of PFASs that includes these target analytes, as part of the RMP Status and Trends program. Continued monitoring will allow the RMP to identify temporal trends in these contaminants.

Second, a special study of harbor seals and margin sediment samples using newly established, non-targeted methods is recommended to identify unknown PFASs. As apex predators, harbor seals are an ideal matrix for identifying unknown PFASs that are bioaccumulative. Additional study of this species can also be used to establish temporal trends for PFOS, for which significant historical data already exist. Meanwhile, margin sediment samples are a preferred matrix for determining which unknown PFASs may be in current use in urban settings.

Finally, an updated study of stormwater is recommended for exploring trends and evaluating the presence of PFOS and PFOA precursors and alternatives. Relatively little data is available for this matrix; an analysis reflecting current levels of PFASs in stormwater would assist efforts to establish the relative contributions of stormwater and wastewater to the Bay and its wildlife.

1.0 Introduction and Overview of PFAS Chemistry, Uses, Concerns and Management

1.1 Objectives of this Report

Perfluoroalkyl and polyfluoroalkyl substances (PFASs) are a class of fluorine-rich chemicals with extremely high persistence. Well-studied members of this family have been shown to be highly toxic, while others have received little to no testing. Concentrations of one PFAS, perfluorooctane sulfonate (PFOS), in Bay Area seals and bird eggs in 2004/2006 were some of the highest detected globally (Sedlak and Greig 2012). As a result, PFOS has been identified as a moderate concern for San Francisco Bay. Recent monitoring suggests decreases in PFOS concentrations in seals and cormorant eggs, likely as a result of changing use patterns that include a nationwide phase-out in 2002.

However, concentrations of some members of the PFAS family, including PFOA and other commonly monitored perfluoroalkyl carboxylates, have remained relatively constant, albeit it at substantially lower levels overall. Meanwhile, a number of "precursor" PFASs, which degrade to the more persistent PFOS or PFOA, have been detected in sediments. Recent studies of Bay Area stormwater and wastewater suggest that a significant fraction of discharged precursor compounds are of unknown chemical composition. All PFASs other than PFOS have been previously classified as possible concerns for the Bay.

The purpose of this document is threefold. First, this report has compiled existing San Francisco Bay PFAS data collected by the RMP and other scientists into one document. Second, this report reviews the classification of PFASs detected in the Bay using the RMP's tiered risk framework that guides monitoring and management actions on emerging contaminants in San Francisco Bay (Sutton et al. 2013; Sutton and Sedlak 2015). Based on an updated literature review and discuss with the RMP Emerging Contaminant PFAS experts, we are recommending that PFOS remain in the category of moderate concern. In addition, we recommend that the long-chain carboxylates also be classified as moderate concern. All other PFASs are appropriately classified as possible concerns.

Lastly, this report recommends a monitoring strategy for the RMP for PFASs that includes routine monitoring of cormorant eggs and sportfish for a subset of PFASs that includes PFOS and PFOA (13 analytes total) as part of the RMP Status and Trends program. It is also recommended that a special study of seals and margin sediments be conducted using non-targeted methods to assure that alternatives and potential precursors are also being monitored. Lastly, an updated study of stormwater would be helpful for assessing loads and trends and evaluating the presence of alternatives and precursors.

1.2 PFASs: Structure and Uses

Per and polyfluoroalkyl substances (PFASs) are a large class of specialty chemicals that tend to be thermally stable, chemically inert, and excellent surfactants, making them highly useful for many applications. More than 4,700 PFASs are used in consumer, commercial and industrial

applications, including food packaging materials, waterproof textiles, stain-resistant carpets and furniture, fire-suppression foams, processing aids for the production of fluoropolymers like Teflon, and uses in the metal-plating and aviation industries (KEMI 2015)(OECD 2018). A list of acronyms for several of PFASs detected in San Francisco Bay is included in the Glossary (p. vi).

1.2.1 Perfluoroalkyl Substances

Perfluoroalkyl substances contain a carbon spine onto which fluorine atoms are attached; at the end of the chain is a functional group such as sulfonate or carboxylate. Perfluoroalkyl substances are fully fluorinated, meaning that only fluorine atoms are bonded to the perfluoroalkyl carbon chain and no carbon-hydrogen bonds are present.

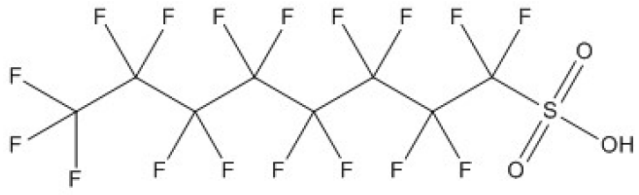
Much of the focus on PFASs to date has been on the perfluoroalkyl acids that include perfluoroalkyl sulfonates and perfluoroalkyl carboxylates, which are fully fluorinated classes of chemicals with a sulfonate or carboxylate group at the end, respectively. Two of the most well-known perfluoroalkyl substances are perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), eight carbon chain structures with a sulfonate and carboxylate at the end, respectively.

In addition, some perfluoroalkyl substances can transform to perfluoroalkyl acids such as PFOS and PFOA: examples include sulfonamide-containing compounds such as perfluorooctane sulfonamide (PFOSA), which can transform to sulfonates such as PFOS. Substances that can transform to perfluoroalkyl acids are often referred to as “perfluoroalkyl acid precursors” or “precursors” for short. Perfluoroalkyl acids do not undergo further degradation in the environment.

Frequently, PFASs are classified in groups by the number of carbons in the structure; PFOS and PFOA are referred to as C8 compounds. Perfluoroalkyl sulfonates C6 and above and perfluoroalkyl carboxylates C7 and above are bioaccumulative and toxic (Buck et al. 2011; Wang et al. 2015) and are referred to as long-chain perfluoroalkyl acids. As use of these long-chain perfluoroalkyl acids has been restricted (e.g., PFOS and PFOA), industries have substituted short-chain perfluoroalkyl acids such as the C4 compound perfluorobutane sulfonate (PFBS), as well as short-chain polyfluoroalkyl substances that cannot transform to the long-chain perfluoroalkyl acids.

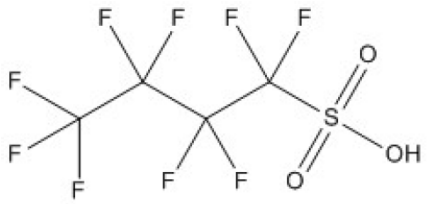
1.2.2 Polyfluoroalkyl Substances

Similar to perfluoroalkyl acids, polyfluoroalkyl substances contain carbon chains with fluorines attached; however, polyfluoroalkyl substances are not fully fluorinated, meaning that the carbon chains may contain bonds to hydrogen, oxygen, or other atoms in addition to fluorine.



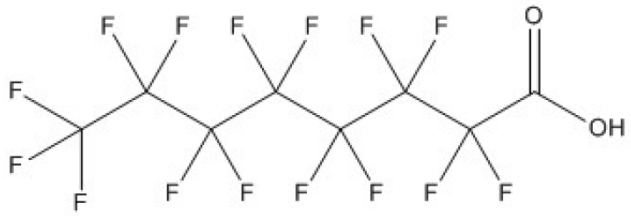
Perfluorooctane sulfonic acid (PFOS)

Long-chain perfluoroalkyl sulfonate



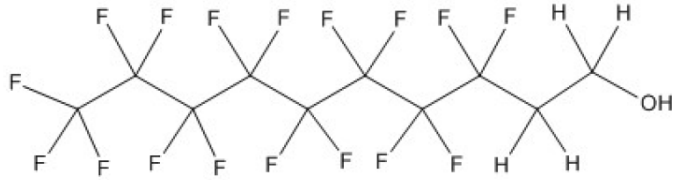
Perfluorobutane sulfonic acid (PFBS)

Short-chain perfluoroalkyl sulfonate



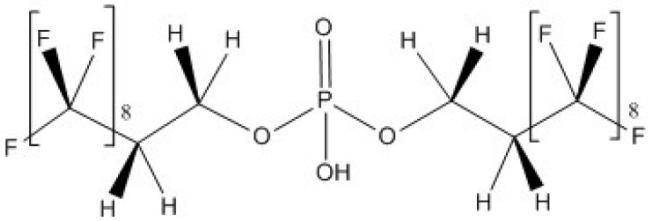
Perfluorooctanoic acid (PFOA)

Long-chain perfluoroalkyl carboxylate



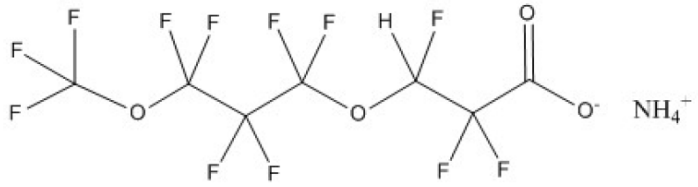
8:2 Fluorotelomer alcohol (8:2 FTOH)
(or 2-perfluorooctylethanol)

Polyfluoroalkyl substance



8:2 Polyfluoroalkylphosphate diester

Polyfluoroalkyl substance



Ammonium 4,8-dioxa-3H-perfluorononanoate (ADONA)

Polyfluoroalkyl substance

Figure 1 Structures of Several Perfluoroalkyl and Polyfluoroalkyl Substances. Boxes designate the compound classes of each substance. From the California Biomonitoring Program 2015.

Some polyfluoroalkyl substances can transform to perfluoroalkyl substances such as PFOS and PFOA: examples include mono, di, and tri esters of the polyfluoroalkyl phosphates (referred to as mono-, di- and triPAPs) and fluorotelomer alcohols, which can transform to perfluoroalkyl carboxylates such as PFOA. Polyfluoroalkyl substances that can transform to perfluoroalkyl substances are also referred to as perfluoroalkyl acid precursors. A polyfluoroalkyl compound can only transform to a perfluoroalkyl acid that contains the same or shorter length of perfluoroalkyl group, meaning, for example, that a C6 precursor cannot form PFOS or PFOA. Additionally, the functional group in the precursor adjacent to the perfluoroalkyl group will determine whether a perfluoroalkyl sulfonate or carboxylate or other species is likely to form.

1.3 Uses of PFASs

As a result of the strong carbon-fluorine bond, PFASs are thermally and chemically quite stable (KEMI 2015). Many PFASs are both oil and water repelling, making them excellent surfactants and surface coatings for "water-proof" and "stain-proof" textiles, carpets, and paper. These unique chemical properties have led to widespread use of PFASs in many consumer, commercial, and industrial applications around the globe (KEMI 2015; Kissa 2001).

The largest volumes of PFASs are used as processing aids in the production of fluoropolymers such as polytetrafluoroethylene (PTFE or Teflon), the non-stick coating used in cookware, and polyvinylidene fluoride (PVDF), a specialty plastic used in applications requiring the highest purity, such as in the chemical, semiconductor, medical and defense industries, as well as in lithium-ion batteries (KEMI 2015). A small number of perfluoroalkyl carboxylate compounds are the primary processing aids in use. Perfluoroalkyl carboxylates were also reportedly used in aqueous film-forming foams (AFFF) for fire suppression (Prevedouros et al. 2006), and consumer and industrial uses such as self-shine floor polishes, metal cleaners, varnishes, and paper, leather, and textile treatments.

PFOS and PFOS precursors were used extensively for carpet treatments, water-resistant coatings for clothing, grease and water-proof coatings for paper products, and AFFF (Paul et al. 2009). It is estimated that PFASs comprise 2 to 3% of textile fibers and 15% of the carpet by weight (KEMI 2015). Other uses of PFASs include metal finishing, insecticides, ski waxes, floor polishes, medical inhalers, fuel additives, cosmetics, and lubricants (KEMI 2015; Prevedouros et al. 2006).

Over the last two decades, restrictions on the use of C8 chemicals, particularly PFOS, have resulted in the phase-out of production of these compounds in North America and Europe; this has been somewhat offset by increased production in Brazil, Russia, India and China. For example, production of PFOS in China increased from 30 tons in 2001 to close to 250 tons in 2011 (Xie et al. 2013). Similarly, in Brazil, PFOS is produced (30 t/y) in order to make the insecticide sulfluramid, which is sold throughout South America to control leaf-cutting ants (Lofstedt Gilljam et al. 2016). Sulfluramid degrades to PFOS in the environment.

In North America and Europe, the market is shifting from long-chain structures to alternatives such as short-chain PFASs; non-fluorinated compounds such as propylated naphthalenes and

siloxanes (e.g., for use as water repelling agents); and even nonchemical alternatives (e.g., natural control measures for insecticide applications) (OECD 2013).

In addition, an unintended consequence of international action to protect the ozone layer has created the potential for additional exposures to short-chain PFASs. Among the chlorofluorocarbon (CFC)-replacement compounds permitted under the Montreal Protocol are four carbon substances that degrade to the C4 perfluorocarboxylate PFBA in the atmosphere (e.g., HFC-329p, HFE-7100/7200) (MacInnis et al. 2017). Levels of these CFC-replacement compounds are increasing in the atmosphere (MacInnis et al. 2017).

1.4 Growing Concerns: Ubiquitous Contamination, Hot Spots, and Toxicity Studies

1.4.1 Widely Detected Contaminants with Uniquely High Bay Biota Concentrations

As with many high production volume chemicals that are thermally stable, chemically inert, and do not biodegrade, PFASs are widely detected in the environment. With the advent of new analytical techniques in the late 1990s, by the early 2000s researchers were able to identify the presence of PFOS and related compounds in zooplankton, bivalves, reptiles, fish, birds, and mammals residing in urban areas. More surprising and disturbing was the detection of these compounds in animals residing in very remote and pristine areas such as the Arctic and Pacific Ocean (Giesy and Kannan 2001), suggesting that some of these chemicals can be quite mobile.

PFASs, particularly the long-chain compounds, bioaccumulate in the food web, with apex predators such as polar bears, sea otters, and seals having some of the highest concentrations (Giesy and Kannan 2001; Houde et al. 2006; Houde et al. 2011). However, unlike hydrophobic compounds such as PCBs and PAHs, which concentrate in the fatty tissues of animals, PFOS and PFASs bind to proteins and tend to accumulate in blood, liver, eggs, and the fatty acid binding proteins in cells (Houde et al. 2011).

In 2006, the RMP began monitoring PFASs in cormorant eggs (*Phalacrocorax auritus*) and archived Pacific harbor seal (*Phoca vitulina richardii*) samples from 2004. Concentrations of PFOS in eggs and harbor seal blood from the South Bay were some of the highest observed relative to birds and seals from other monitoring sites around the world (Sedlak and Greig 2012).

1.4.2 Toxicity

Exposure to perfluoroalkyl acids has been associated with a wide range of toxic effects, with most studies focused on PFOA and PFOS. Studies based on laboratory animals and human populations exposed to higher concentrations provide evidence that well-studied PFASs such as PFOS and PFOA can be classified as multi-system toxicants and developmental toxicants (DeWitt, 2015). Studies across species and chemicals suggest that PFOA and PFOS tend to

cause liver damage, adverse developmental effects, and suppression of the immune system (Lau et al. 2007; Wang et al. 2017b). Several mouse studies indicate that in utero exposure may be particularly disruptive, with effects on metabolism, the immune system, and cancer (Hines et al. 2009)(DeWitt, 2015; Tucker 2015).

A large epidemiological study including nearly 70,000 participants was conducted by the C8 Science Panel on communities in the Mid-Ohio Valley, who were likely exposed to PFOA released from DuPont's Washington Works plant in Parkersburg, West Virginia (Barry et al. 2013; Steenland and Woskie 2012). Community residents showed elevated PFOA blood concentrations compared to the general population. The panel found probable links between PFOA exposure and high cholesterol, ulcerative colitis, thyroid disease, testicular cancer, kidney cancer, and pregnancy-induced hypertension in this population.

Based on this study and others, USEPA concluded that there is Suggestive Evidence of Carcinogenic Potential for both PFOA and PFOS (USEPA 2016). PFOS and PFOA are also classified by the National Toxicology Program as an immune hazard based on evidence for suppressed immune response in animal and human studies (Program 2016). The International Agency for Research on Cancer (IARC) has classified PFOA as possibly carcinogenic to humans (Group 2B).

USEPA has established a combined drinking water health advisory for PFOS and PFOA of 70 parts per trillion (ppt) based on adverse health effects such as developmental effects to fetuses, cancer (e.g., testicular and kidney), liver damage, immune effects, and other adverse outcomes (https://www.epa.gov/ground-water-and-drinking-water/drinking-water-health-advisories-pfoa-and-pfos). Health advisories are non-enforceable and non-regulatory; they are designed to provide guidance to drinking water purveyors on the health effects, analytical methods, and treatment technologies. Several states have proposed lower drinking water advisories/standards: the State of Minnesota proposed guidelines are 35 ppt for PFOA and 25 ppt for PFOS; the State of Vermont has established a health advisory for the sum of PFOA and PFOS of 20 ppt; and New Jersey has established a Maximum Contaminant Level for PFOA of 14 ppt. Based on the recent contamination of drinking water in Fayetteville, NC, the North Carolina Department of Environmental Protection has established a provisional health goal of 140 ppt for a new alternative to PFOA, GenX.

Laboratory studies indicate that PFASs may have different impacts depending upon carbon chain length and functional group. In the limited studies available, long-chain compounds tend to be more persistent in the body, and have greater toxicity to the liver and reproductive system (DeWitt, 2015)(Wang et al. 2013). This trend cannot be easily generalized, and there is insufficient information to conclude that short-chain compounds or alternatives are safer (Wang et al. 2015). As an example, in a study of algal growth, the long-chain chemicals PFOS and PFDoA inhibited algal growth whereas PFOA did not (Liu et al. 2008). Similarly, the C6 perfluorocarboxylate PFHxA has been reported to have higher acute toxicity for a few aquatic species than PFOA, highlighting that different species can have very different sensitivities (Wang et al 2015).

Impacts can vary by species and sex. The toxicity thresholds for PFOS for the aquatic midge, *Chironomus tentans*, was found to be three orders of magnitude lower than for other aquatic organisms such as cladocerans (e.g., small crustacean such as water fleas (Ding and Peijnenburg (2013)).

There is also a wide range in how rapidly different animal species eliminate PFASs once exposed. In rats, the elimination half-life for PFOS in serum is approximately 100 days; for humans it is 5.4 years (Appendix Table 1). In monkeys, females tend to have faster elimination rates than males; however, this is not universally observed across species. Comparison of carboxylates to sulfonate compounds with the same carbon chain lengths (e.g., C4 to C8, Appendix Table 1) suggests that carboxylates are eliminated faster than sulfonates. This is attributed to the presence of one more fluorine atom in the sulfonates versus the carboxylates (Knepper and Lange, 2012). Rapid elimination does not necessarily mean reduced risk, particularly if the organism is exposed to PFASs on an on-going basis (Wang et al. 2015).

Further complicating a full understanding of the effects of PFAS exposure are both the rapidly growing number of new PFASs that have not been well studied, as well as the relatively unexplored potential impacts of exposures to mixtures of PFASs (Wang et al. 2017b). For example, only two alternatives, ADONA and GenX (perfluoroalkyl ether carboxylic acids) have toxicological profiles reported; they have been shown to cause liver damage in rats and may fit regulatory toxicity criteria developed for PFOA (Wang et al. 2015). The available information suggests that based on the similar structure of PFAS alternatives to PFOA and other long-chain perfluoroalkyl acids, the alternatives will likely have similar toxicological profiles (Wang et al. 2014; Wang et al. 2017b).

1.5 Fate in the Environment and Degradation Products

As a class, PFASs are quite diverse; however, in general, the fluorine-carbon bond is resistant to chemical and biological degradation, thermal decomposition, and oxidation. The two most studied compounds, PFOS and PFOA, have negligible vapor pressures, high water solubility, and moderate affinity for surfaces (Paul et al. 2009; Prevedouros et al. 2006). These properties make PFOS and PFOA suitable candidates for pilot contaminant transport modeling efforts focusing on transport via the water column, rather than transport via sediment.

The fate of individual PFASs is dependent on the chain length and functional groups that are attached. Typically, charged, ionic PFASs including the perfluoroalkyl carboxylates and sulfonates such as PFOA and PFOS are more water soluble and less volatile than neutral compounds such as fluorotelomer alcohols (Ahrens et al. 2011). PFOS and PFOA have low vapor pressures and are primarily detected in water, along with sediment and biota (Ahrens et al. 2011). Meanwhile, fluorotelomer alcohols can be transported long distances through the atmosphere before being deposited and then undergoing degradation to the carboxylates (Ellis et al. 2004); detection of PFASs in the Arctic is attributed in part to atmospheric transport of the neutral compounds.

Chemical properties such as the sediment organic carbon distribution coefficient (log K_{OC}), frequently used to effectively model behavior of hydrophobic compounds such as PAHs and

PCBs, are not as reliable for PFASs due to their ability to be both lipophobic and hydrophobic. Despite this limitation, these coefficients may indicate the relative propensity for adsorption of these compounds to sediment. In general, long-chain compounds have a higher affinity for sorption to soils and sediments; short-chain compounds (<C7) tend to have a higher affinity for the aqueous phase (Ahrens et al. 2011). Sulfonates have higher affinity for sediment than carboxylates (Higgins and Luthy 2006). Of note, some precursors, particularly the perfluorooctyl sulfonamide acetic acids such as N-MeFOSAA and N-EtFOSAA that transform to PFOS, have higher affinities for sediment than perfluoroalkyl substances. Some precursors, such as those found in a number of AFFF formulations (Place and Field 2012), contain positively charged functional groups that may enhance sorption to negatively charged soils. Unfortunately, very little empirical information is available regarding the chemical properties of many precursors as well as the broader class of PFASs.

With respect to presence in biota, long-chain perfluoroalkyl acids also tend to be more bioaccumulative (Conder et al. 2008). In general, sulfonates are more bioaccumulative than carboxylates (Conder et al. 2008). Little data on bioaccumulation potential is available for other members of the PFAS family.

As mentioned above, some PFASs are precursors that can degrade in the environment to the perfluoroalkyl carboxylates (e.g., PFOA) and perfluoroalkyl sulfonates (e.g., PFOS) (Higgins and Luthy 2006). For example, it is estimated that the fluorotelomer alcohols, which are precursors to the perfluoroalkyl carboxylates, have a half-life in the atmosphere of approximately 20 days (Ellis et al. 2003). In animals, the transformation reactions may be equally fast. The half-life for the PFOS precursor PFOSA in common carp is estimated to be approximately seven days (Chen et al. 2015). Precursors may therefore be considered active sources of perfluoroalkyl substances to the Bay environment.

Once in the Bay, persistent perfluoroalkyl sulfonates and perfluoroalkyl carboxylates are likely to remain for long periods of time, subject only to burial and transport out the Golden Gate. In general, as a result of high water solubility, volatility, and persistence, different PFASs can be transported in ocean and atmospheric currents throughout the globe (Wang et al. 2017a). Final deposition is believed to be deep oceans and sediments (Prevedouros et al. 2006)(Zhang et al. 2017).

1.6 Management Actions

1.6.1 International

There is widespread international collaboration to reduce human and environmental risks associated with exposure to long-chain perfluorinated chemicals. In 2009, PFOS, its salts, and its basic building block, perfluorooctane sulfonyl fluoride (PSOF), were added to the list of persistent organic pollutants restricted from production and use by the Stockholm Convention (Annex B). The Stockholm Convention allows for specific accepted purposes of these chemicals, such as photo imaging, semi-conductor, or aviation hydraulic fluids, because "technically feasible alternatives to PFOS are not available to date." The Stockholm Convention also has fairly broad exemptions, including liquid crystal display industries, metal plating, electric parts for color printers and copy machines, insecticides, carpets, leather and apparel,

textiles and upholstery, paper and packaging, coatings, rubber and plastics. The regulation banned the production and use of fire-fighting foams with more than 0.001% by weight of PFOS (10 mg/kg) by 2011.

In the European Union, PFOS, PFOA, PFHxS, and long-chain perfluoroalkyl carboxylates (C11 through C14) have been added to the Candidate List of Substances of Very High Concern for Authorization under the European Chemicals Regulation (REACH). The Candidate List includes chemicals that are carcinogens, mutagens, reproductive toxicant, or persistent, bioaccumulative or toxic; these chemicals are subject to review and possible additional restrictions. Similarly, Canada has developed its own national voluntary agreements and regulations to significantly reduce and work towards eliminating products containing PFOS, PFOA, and residual long-chain perfluoroalkyl carboxylates and residual precursors from products sold in Canada.

1.6.2 Federal

Phase-out of production of C8 compounds by US manufacturers of these chemicals began in the 2000s, with the major manufacturer of PFOS and related compounds (3M) agreeing to cease production in the US by 2002. Of note, PFOS-based AFFF formulations were phased out in 2007 when they were removed from the U.S. military's Qualified Products List (personal communication with Dr. Jennifer Field), although many military bases may contain stockpiled PFOS-based AFFF formulations. The phase-out of C8 compounds was expanded with the 2010/2015 PFOA Stewardship Program established by USEPA, which included a total of eight major companies in the PFAS industry. Participating companies committed to eliminating PFOA, its precursors, and related long-chain chemicals from company emissions and products by 2015. Final reports from the program showed that participating companies met these goals.

This program was extended globally through an initiative under the Strategic Approach to International Chemical Management (SAICM). Information collected through this initiative showed that manufacturers in China and India were not involved in the reductions and were instead scaling up production as companies in Europe, the US and Japan were scaling down (SAICM/ICCM.4/INF/21 2015).

To complement the phase-out of long-chain perfluoroalkyl sulfonates and carboxylates, USEPA has published a series of Long-Chain Perfluoroalkyl Carboxylate and Perfluoroalkyl Sulfonate Chemical Substances Significant New Use Rules (SNURs) and amendments between 2002 and 2015 to control and restrict the reintroduction of chemicals included in the phase-out. The SNURs require manufacturers and importers of specified PFASs to notify USEPA of their intent to manufacture or process these chemicals. USEPA would have the opportunity to review and limit the activity if necessary to protect human and environmental health. The SNURs provided exemptions for specified continuing uses of these chemicals that were expected to be low volume, low exposure, and low release. The exemptions included uses in the photographic and imaging industry, semiconductor industry, and aviation industry. The SNURs provided an exemption for chemicals that were imported as part of a manufactured article, with the exception of carpets.

The articles exemption under the SNURs may be significant. A number of researchers have identified PFOA, fluorotelomers, and PFASs in food packaging and textiles (Schaider et al. 2017; Greenpeace, 2015). A recent study showed that weathering of precursors in textiles resulted in the production of significant concentrations of PFOA, PFNA, PFDA and other long-chain carboxylates and fluorotelomer alcohols (van de Veen et al. 2017).

1.6.3 California

At the state level, the California Environmental Protection Agency's Office of Environmental Health Hazard Assessment (OEHHA) has listed PFOA and PFOS as causing reproductive toxicity under the Safe Drinking Water and Toxic Environmental Act of 1986, also known as Proposition 65 (CA EPA, November 2017). The law requires OEHHA to publish and annually revise the list of chemicals known to cause cancer or reproductive toxicity. The law requires businesses to inform California residents about their potential exposure to listed chemicals, and also prohibits the release of these chemicals into water and onto land where the chemicals can contaminate drinking water sources.

The California Legislature is considering legislation (AB 958, Ting and Quirk, as amended July 20, 2017) that would require DTSC to evaluate food packaging that contains PFASs as a potential Priority Product regulated under DTSC's Safer Consumer Products Program. The bill passed the Assembly and is currently being reviewed by the Senate. The Safer Consumer Products Program was established in 2013 to provide a regulatory framework to reduce toxic chemicals in consumer products, make it easier for businesses and consumers to identify harmful chemicals in products, develop safer alternatives to potentially harmful products, and avoid previous patterns of banning chemicals and products on a case-by-case basis without evaluating alternatives in a more systematic way that would encourage the development of safer products.

Under the Safer Consumer Products Program, DTSC has placed a high priority on evaluating the use of PFASs in carpets, rugs, indoor upholstered furniture and their care and treatment products. DTSC considers this one of the largest potential sources of exposures of PFASs from consumer products. DTSC has proposed to list carpets and rugs containing PFASs as a Priority Product (Safer Consumer Products 2018). Manufacturers of Priority Products must produce an alternatives analysis; depending on the results, the chemical may be limited in its use.

The entire PFAS class is also listed as priority chemicals in the Biomonitoring California program, which was implemented in 2006 to conduct biomonitoring studies in California to identify highly exposed communities and inform management decisions, although to date the laboratory monitors a limited number of PFASs.

In summary, the manufacture and use of PFOS and PFOA has ceased in North America and the European Union, a result of relatively aggressive management actions. However, other countries such as China, Brazil, and India are continuing to manufacture, use and distribute long-chain PFASs. PFOS, PFOA and other long-chain PFASs can be imported into the US as part of manufactured articles that are not subject to regulatory review. PFOA and long-chain PFASs, including long-chain precursors, continue to be detected in food packaging and outdoor clothing (Schaider et al. 2017; Greenpeace 2016). A recent study showed that weathering of precursors in

textiles resulted in the production of significant concentrations of PFOA and other PFASs (van der Veen et al. 2017). In addition to import of these compounds, it is likely that there are significant reservoirs of residual PFOS, PFOA and their precursors in both the environment and in urban settings residential/commercial/industrial facilities as a result of decades of use. Lastly, a number of PFAS compounds are still manufactured in the US, such as the alternative GenX, which is manufactured by Chemours in Fayetteville, North Carolina.

2.0 Summary of PFAS Occurrence and Trends in San Francisco Bay

The RMP has monitored PFASs in water, sediment, bivalves, prey fish (whole fish), sport fish (fillets), bird eggs and harbor seals (serum). The RMP has consistently monitored for the following 12 perfluoroalkyl acids and one precursor in all matrices:

- Sulfonates: perfluorobutane sulfonate (PFBS, C4), perfluorohexane sulfonate (PFHxS, C6), and PFOS (C8);
- Carboxylates: perfluorobutanoic acid (PFBA, C4), perfluoropentanoic acid (PFPeA, C5), perfluorohexanoic acid (PFHxA, C6), perfluoroheptanoic acid (PFHpA, C7), PFOA (C8), perfluorononanoic acid (PFNA, C9), perfluorodecanoic acid (PFDA, C10), perfluoroundecanoic acid (PFUnDA, C11), and perfluorododecanoic acid (PFDoDA, C12); and
- PFOS precursor: perfluorooctane sulfonamide (PFOSA, C8).

Analytical capabilities have evolved substantially since the first RMP PFAS study was initiated in 2007. Through *pro bono* collaborations and special studies, a wide range of precursors have been examined in selected matrices.

2.1 PFASs in San Francisco Bay: Abiotic Environment

2.1.1 Water

Surface water has been collected during the summer at five ambient Bay sites (2009) and during the winter at five nearshore sites (2009/2010) and analyzed for the standard 13 PFASs as well as four PFOS precursors. In ambient Bay surface water, PFOA was detected in the highest concentrations (1.4 to 8.6 ng/L) followed by PFOS (2.4 to 6.5 ng/L) (Appendix Table 2a, Figure 2).

The highest concentrations of PFASs were observed near the margins, at the Cooley Landing site in the Lower South Bay. Concentrations of PFOS, PFOA, PFHxA, PFPeA, PFHpA, and PFBA

at this site were 44, 76, 220, 150, 67, and 62 ng/L, respectively, and were an order of magnitude higher than those observed at the ambient Bay sites.

The source of PFASs to surface water near the Cooley Landing site is unknown; the area includes a number of heavy industries such as a steel fabricator, auto salvage yard, and a former hazardous waste and solvent recycler. The solvent recycler was the subject of a USEPA hazardous waste cleanup due to the release of organic solvents to groundwater. It is not known whether this facility accepted PFAS-contaminated material. Concentrations in water in this area approached a proposed PFOS threshold of 50 ng/L for the protection of predator birds consuming aquatic organisms (Rostkowski et al. 2006).

In general, PFOS and many of the short-chain carboxylates such as PFBA, PFPeA, PFHxA and PFHpA were detected in ambient and margin water samples collected in the South Bay. The North and Central Bay sites had low to nondetectable concentrations of PFASs, with the exception of stormwater-influenced margin site in San Leandro Bay. PFOS precursors including PFOSA were not detected, with the exception of one margin sample in the South Bay that contained N-methyl perfluorooctane sulfonamide at a concentration near the detection limit (Appendix Table 2b).

Excluding the elevated concentrations at the Cooley Landing site, the range of concentrations of PFOA and PFOS observed in San Francisco Bay water are generally lower than reported in an initial study of Tokyo Bay (154 to 192 and 12.7 to 25.4 ng/L for PFOA and PFOS, respectively) (Yamashita et al. 2005); a more comprehensive assessment of Tokyo Bay conducted in 2004 through 2006 and involving the collection of 480 water samples indicated that the average concentrations of PFOA and PFOS, 12.0 and 3.7 ng/L, respectively, are much closer to the concentrations observed in the San Francisco Bay (Sakurai et al. 2010). Ranges of PFOA reported in Lake Ontario (1.8 to 6.7 ng/L) were generally comparable to San Francisco Bay, while for PFOS (3.6 to 37.6 ng/L) the range included levels higher than typically reported in the Bay (Furdui et al. 2008). Concentrations of PFOA and PFOS in the remaining Great Lakes (e.g., Superior, Huron, and Erie), Narragansett Bay, and Hong Kong coastal waters (<MDL to 5.8 and <0.15 to 5.3 ng/L, for PFOA and PFOS, respectively) (Benskin et al. 2012; Furdui et al. 2008; So et al. 2004) were also comparable to those observed in San Francisco Bay. Concentrations in the Eastern Pacific open ocean are lower, 0.136 to 0.142 and 0.054 to 0.078 ng/L for PFOA and PFOS, respectively (Yamashita et al. 2005).

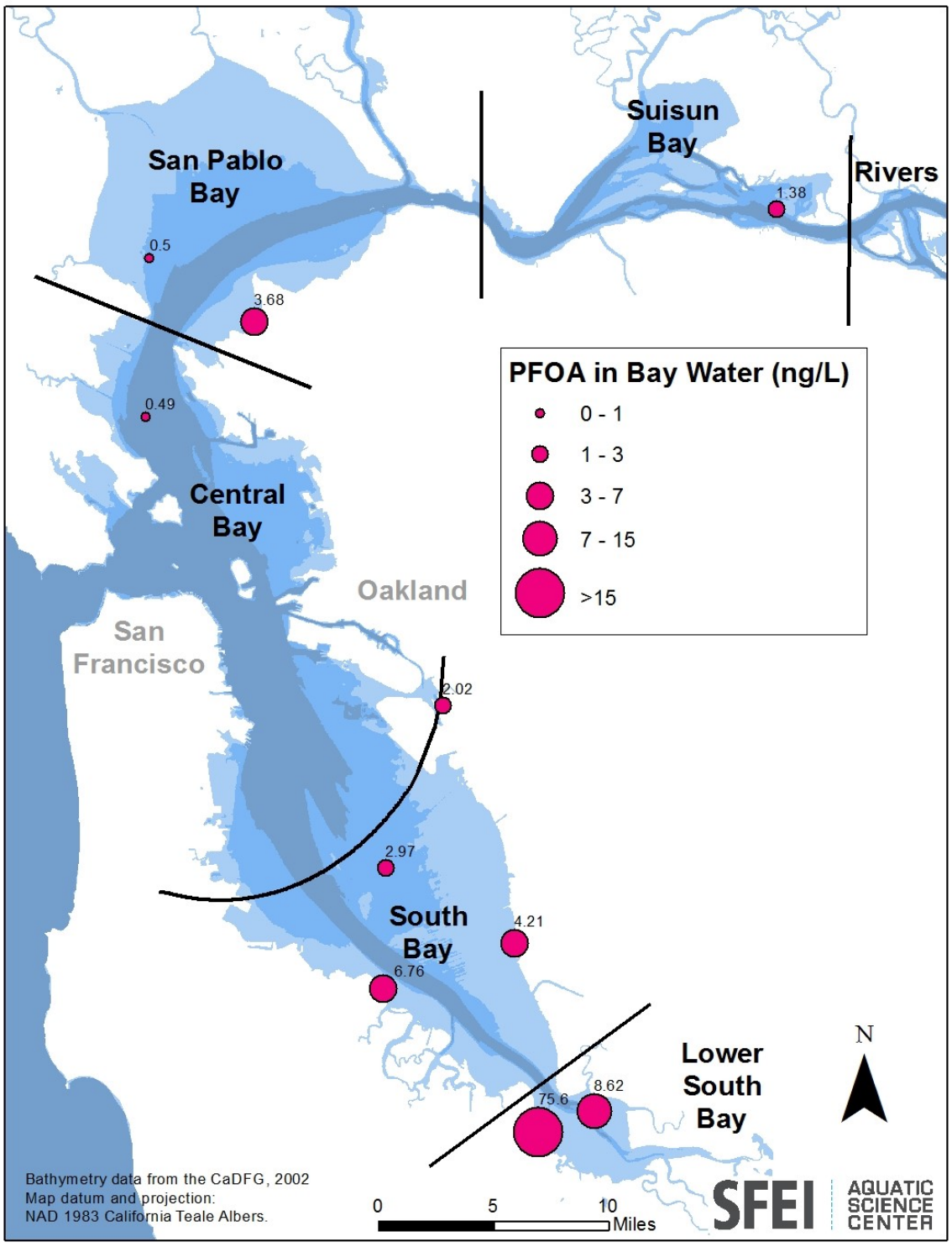


Figure 2 Concentrations of PFOA in Surface Water (ng/L)

2.1.2 Sediment

The RMP collected sediment for PFAS analyses in 2009/2010 (11 locations), 2012 (12 locations), and 2014 (27 locations) (Figure 3, Appendix Table 3a). In 2012 and 2014, in addition to the standard suite of 13 PFASs, sediment was also analyzed for a number of additional PFASs. For the 2012 samples, three were targeted for perfluoroalkyl acid precursors, polyfluorinated phosphonates, and perfluoroalkyl phosphinates; for the 2014 samples, 10 of the 27 samples were targeted for perfluoroalkyl acid precursors and polyfluorinated phosphonates.

Prior to the RMP work, in 2004, researchers at Stanford University analyzed sediment for PFOS, PFOA, PFOSA (a PFOS precursor), PFNA, PFDA, PFUnDA and PFDoDA compounds from five locations in the Bay and one site in Tomales Bay (Higgins et al. 2005).

Across all years, PFOS was detected most frequently (~70%) and in the highest concentrations, ranging from 0.2 to 3.4 ng/g dry weight (dw). PFOS concentrations were highest in the South Bay, Lower South Bay, and the southern sloughs (Figure 4), and ranged from 0.45 to 3.4 ng/g, with an average concentration of 1.6 ng/g. In contrast, for the Central and North Bays, concentrations ranged from non-detect to 1.24 ng/g. PFOS was not detected at over half of these central and northern sites. PFOA, PFDA, PFNA, and the PFOS precursor, PFOSA, were the next most frequently detected compounds in sediment, ranging in concentration from 0.11 to 1.1 ng/g, 0.08 to 0.5, 0.11 to 0.56, and 0.13 to 0.86, respectively. As shown on Figure 4, Central and North Bay sediments had much lower concentrations of PFOA, PFDA, PFNA, and PFOSA in contrast to the South Bay. In general, margins had higher concentrations than the ambient Bay samples; for PFDA, PFOS and PFOA, the difference was statistically significant ($p < 0.05$). Short-chain PFASs such as PFBA were largely not detected in sediment.

PFOS precursors, such as methyl and ethyl sulfonamido acetic acids, were detected mainly in the South Bay, and individual concentrations ranged from 0.12 to 2.6 ng/g (Appendix Table 3b). The phosphate ether class of precursors (e.g., di-PAPs) were largely not detected in Bay-wide samples collected in 2014. Di-PAPs were detected in 2012; however, these precursors were measured using a method still in development, and as such it is likely that the findings from the finalized method used in 2014 reflect actual conditions in the Bay. The perfluoroalkyl phosphinates were also largely not detected.

The concentrations of PFOS and PFOA in San Francisco Bay sediment are typical of other urbanized estuaries and lakes. Sakurai et al. (2010) conducted a comprehensive grid survey of Tokyo Bay sediments, collecting 60 samples over a two-year period (2004 to 2006). Similar to San Francisco Bay sediments, the median concentration of PFOS (0.61 ng/g dw) was higher than PFOA (0.21 ng/g dw). Higher concentrations (approximately 1.0 ng/g dw) were observed closer to shore and potential sources. Concentrations of PFOS and PFOA in one sample of Baltimore Harbor sediment were 0.846 and 0.390 ng/g dw, respectively (Higgins et al. 2005). Concentrations of PFOS and PFOA in Lake Ontario sediments near Toronto were much higher, ranging from 27 to 47 ng/g and 9.0 to 17 ng/g (Myers et al. 2012).

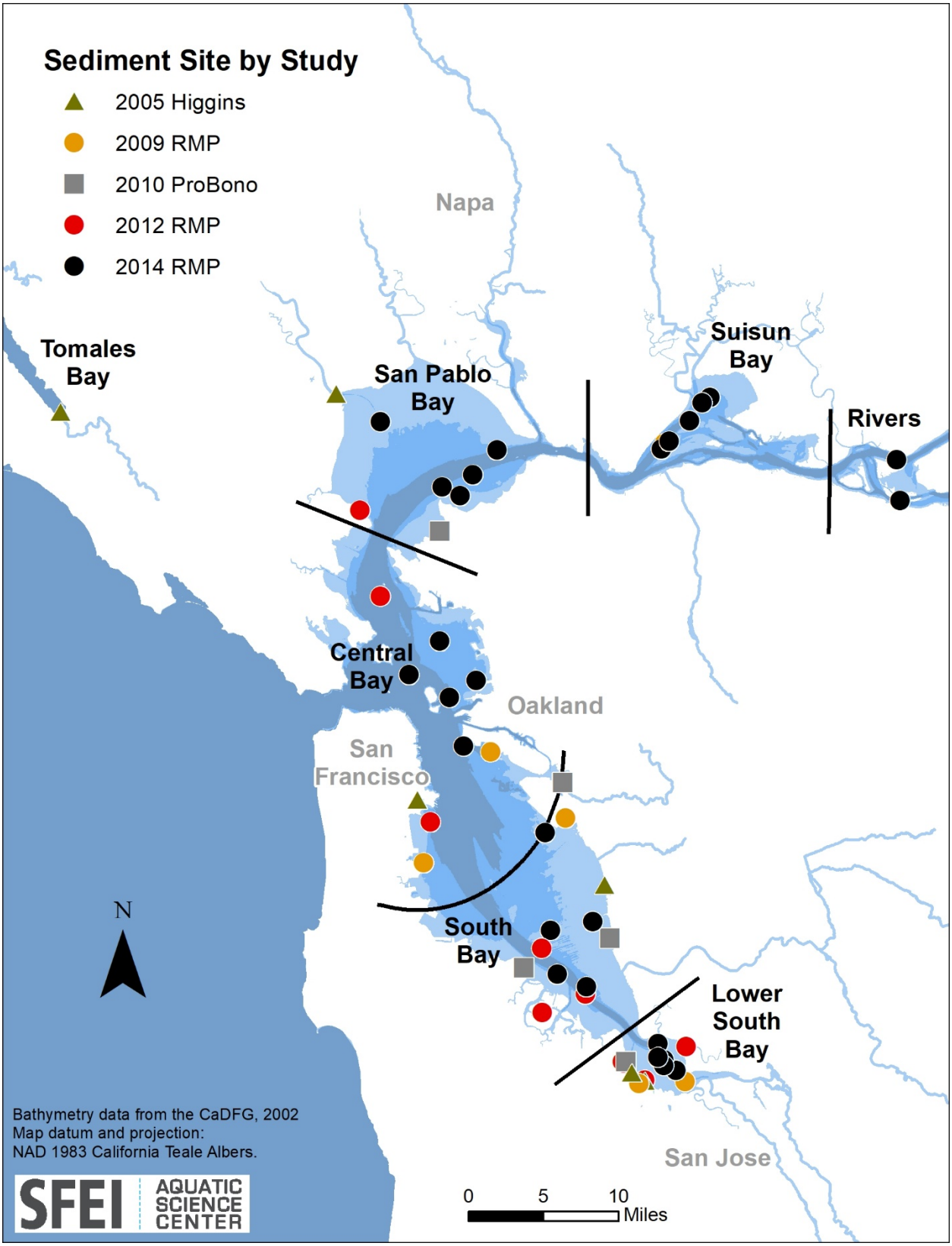

Sediment Site by Study
2005 Higgins
2009 RMP
2010 ProBono
2012 RMP
2014 RMP
Napa
Tomales Bay
San Pablo Bay
Suisun Bay
Rivers
Central Bay
Oakland
San Francisco
South Bay
Lower South Bay
San Jose
N
Bathymetry data from the CaDFG, 2002
Map datum and projection:
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Figure 3 Locations of Sediment Sites Analyzed for PFASs

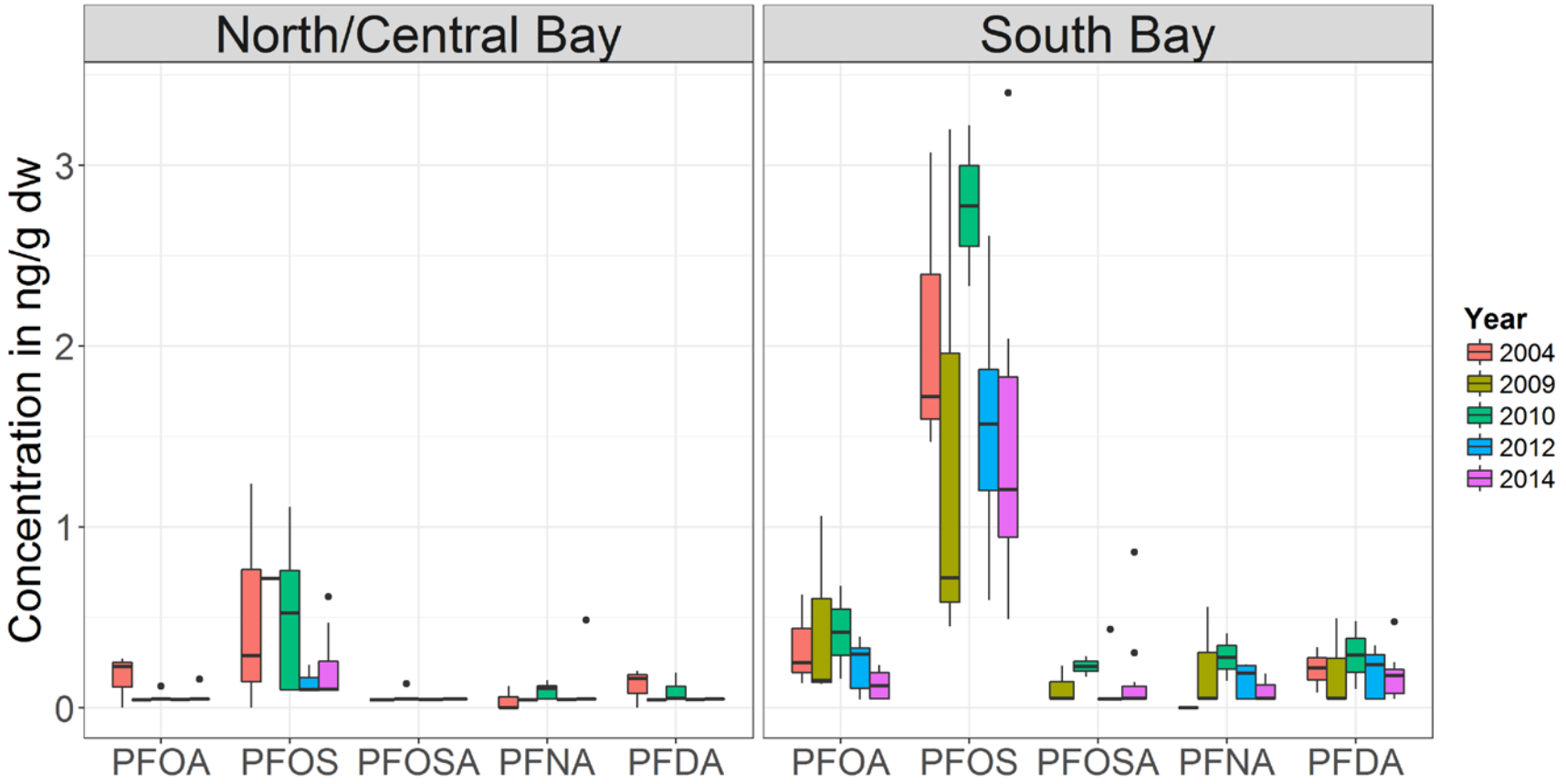

Figure 4 PFAS Concentrations in Sediment. Sediment is segregated by samples collected in the North and Central Bays (n=29) and in the South Bay (n=27). Concentrations are plotted as boxplots, with the box denoting upper and lower quartiles. The horizontal line within the box is the median concentration. Error bars represent the lowest and highest observation within 1.5 interquartile ranges, with observations beyond these limits plotted individually.

2.2 PFASs in San Francisco Bay Bivalves

Living organisms can accumulate some contaminants to levels much greater than those found in ambient water and sediment. Biological monitoring using bivalves has been widely applied by the National Oceanic and Atmospheric Administration (NOAA) and California State Mussel Watch Programs (Phillips 1988; Rasmussen 1994; Kimbrough et al. 2009), among others. Bivalves are exposed to contaminants through their food, by ingesting sediment and assimilating compounds sorbed to particles, and by absorbing dissolved contaminants directly from the water column. Their body burden of contaminants reflects an integration of contamination levels over time. Bivalves also act as transfer vectors of contaminants to higher trophic levels of aquatic food webs.

Bivalves such as clams and mussels can be excellent organisms for monitoring for hydrophobic contaminants because they accumulate chemicals from the ambient environment, have limited mobility, and are fairly resistant to contaminant effects (O'Connor 2002); however, for contaminants like PFASs that bind to proteins rather than lipids, bivalves may be a less robust indicator organism.

The RMP, in collaboration with the Southern California Coastal Water Research Project, deployed caged, transplanted bivalves (*Crassostrea gigas*) from Bodega Head in seven locations in the Bay in 2009 to 2010: Emeryville; San Mateo Bridge; Dumbarton Bridge; Coyote Creek; Yerba Buena; San Pablo Bay and Red Rock in Central Bay. Composites for each site were made consisting of approximately 30 bivalves. In general, PFASs were not detected in these composites, with the exception of two samples: the composite from Dumbarton Bridge contained detectable levels of PFDoDA (0.26 ng/g wet weight (ww)), and the composite near Coyote Creek contained PFOS and PFOSA at 4.4 and 0.85 ng/g ww, respectively (Appendix Table 4).

Resident bivalves (*Geukensia demissa*) were collected at approximately the same time from five Bay margin sites: Richmond Breuner Marsh, San Leandro Bay, Eden Landing, Foster City, and Cooley Landing; these samples were analyzed for 17 PFASs. Consistent with the transplanted bivalve samples, most of these resident bivalve composite samples did not contain detectable concentrations of PFASs. One site in the Lower South Bay (Eden Landing) contained PFASs at relatively high concentrations, 76.3 ng/g (PFOS) and 5.48 ng/g (PFHxS). Sediment collected in the vicinity had low concentrations of PFOS (0.72 ng/g) and no detection of PFHxS. Precursors were generally not detected in any bivalve samples.

Global concentrations of PFASs in bivalves tend to be quite low, less than 10 ng/g ww, consistent with Bay values (Houde et al. 2011). Based on the Bay study and studies elsewhere, bivalves are not recommended as an indicator of the potential for bioaccumulation of PFASs in the Bay food web.

2.3 PFASs in San Francisco Bay Fish

Fish can be sensitive indicators of exposure to aquatic or sediment-bound contaminants. Exposure to contaminants can occur via ingestion, aquatic respiration, and regulation of osmotic pressure. Contaminants may adversely affect fish or higher order predators such as striped bass, sea otters, seals, and humans that consume them.

Concern for impacts to wildlife and human health has led the RMP to monitor both prey fish and sport fish for contaminants such as mercury and PCBs. Some prey fish are known to have fairly high site fidelity and can be indicators of local contamination and food web uptake. An intensive monitoring effort was conducted by the RMP from 2006 through 2013 to evaluate mercury and polychlorinated biphenyls in prey fish. Augmenting this effort, prey fish were collected in Tomales, Central, and South Bays and analyzed for 13 PFASs from 2009 to 2013.

In addition, the RMP collects sport fish at popular recreational sport fishing areas around the Bay to evaluate human exposure. In 2009 and 2014, sport fish from five sites were monitored for 13 PFASs. In 2015, sport fish were monitored for PFASs from one additional site, Artesian Slough, which is located near the outfall of the San Jose-Santa Clara Regional Wastewater Facility.

2.3.1 Prey Fish

In 2009, prey fish were collected from ten intertidal and subtidal sites around the margins of San Francisco Bay, as well as one reference site in Tomales Bay. The collection targeted two species, topsmelt (*Atherinops affinis*) and Mississippi silverside (*Menidia audens*); topsmelt were collected at eight sites, silversides were collected at six sites. Composites for each site consisted of 7 to 15 fish.

A second sampling effort (2012 through 2013) targeted five sites near cormorant nesting sites and seal haul-out sites in Central, South and Lower South Bays (see Sections 2.4 Cormorant eggs and 2.5 Seals for description of sites). Fish were opportunistically collected by California Department of Fish and Wildlife (CADFW) from July 2012 through April 2013. Twenty-four composites consisting of yellowfin gobies (*Acanthogobius flavimanus*), chameleon/cheekspot gobies (*Tridentiger trigonocephalus/Illypnus gilbert*), northern anchovy (*Engraulis mordax*), shiner surfperch (*Cymatogaster aggregate*) and staghorn sculpin (*Leptocottus armatus*) were analyzed for 13 PFASs. Composites were made to have sufficient mass for analyses and varied between one individual to as many as 20 individuals. In addition, two composites of yellowfin goby that were collected in Alviso Slough in 2010 and 2011 by University of California at Davis researchers were also analyzed.

With the exception of anchovy, these prey fish are believed to have high site fidelity, with home ranges of 10 kilometers or less (Melwani et al. 2012). Anchovy migrate into San Francisco Bay in the spring as waters warm and phytoplankton production increases; in the fall, most migrate back to the Pacific Ocean (GoalsProject 2000). In addition, the prey fish that were targeted for this study are likely to be consumed by seals and cormorants (Gibble and Harvey 2015).

PFOS was the major PFAS detected in all prey fish monitored since 2009, both in terms of frequency and concentration (Figure 5, Appendix Table 5). PFOS concentrations in composites ranged from below detection in the Central Bay to 241 ng/g wet weight (ww) in the South Bay. With the exception of Boynton Slough (North Bay), fish from the Central and North Bays tended to have low concentrations of PFOS (1.43 to 13.6 ng/g ww) in contrast to fish from the South Bay, where concentrations of PFOS were much higher (2.63 to 241 ng/g ww). Boynton Slough is located in close proximity to the Fairfield Suisun Wastewater Treatment Plant; the fish from this slough contained 80 ng/g PFOS. As discussed below in Section 4.2, PFOS concentrations in effluent from the Fairfield Suisun Wastewater Treatment Plan are some of the

highest observed in the Bay Area, although the overall flow is relatively low (15 million gallons per day, average dry weather flow). PFOS was not detected in fish from the reference site in Tomales Bay.

Based on a review of the literature, Houde and coauthors (2006) noted that PFOS is the primary PFAS observed in both fresh and saltwater fish. Concentrations of PFOS in other small prey fish monitored elsewhere are comparable to those in the Bay, with average concentrations ranging from 3.1 ng/g for pigfish (*Othropristis chrysoptera*) in Florida to 450 ng/g in slimy sculpin (*Cottus cognatus*) in Lake Ontario (summarized in Sedlak and Grieg 2012).

In San Francisco Bay, staghorn sculpin had the highest geometric mean of PFOS of all species (23.2 ng/g ww) (Sedlak et al. 2017). Sculpin are bottom-dwelling fish, and as such, they may have a higher exposure to PFOS due to PFOS contributions from both the sediment and the water column, relative to more pelagic species. In addition, sculpin may be eating at a higher trophic level than other prey fish. Sculpin consume benthic organisms such as Bay gobies and amphipods, as well as mud crabs and Bay shrimp (GoalsProject 2000). In contrast, topsmelt in the Bay have been reported to feed mainly on plant material (e.g., detritus, diatoms, algae, etc., GoalsProject 2000), although an RMP study evaluating gut contents of topsmelt indicated that their diets were comprised of largely epibenthic invertebrates (e.g., amphipods) (Jahn 2008). Elevated concentrations of PFOS observed in Great Lake sculpin were attributed to the consumption of benthic dwelling shrimp, which have relatively high concentrations given their trophic status (Martin et al. 2004). In another study of Great Lake fish, sculpin were found to have concentrations seven times higher than gobies (i.e., mean of 21 versus 141 ng/g ww (Asher et al. 2012)). Lastly, the sculpin captured in the RMP study were substantially heavier than other prey fish caught (i.e., average weight of sculpin was 28.5 g versus gobies 8.2 g), so it is possible that they were older and therefore exposed longer to PFASs.

PFOSA, a PFOS precursor, was the next most frequently detected compound in San Francisco Bay prey fish. Concentrations of PFOSA ranged from below detection limits to 2.28 ng/g ww. In a Great Lakes study conducted in 2007 to 2008, similar prey fish such as sculpin, alewife, and goby had average PFOSA concentrations of 8.8, 1.7, and 1.5 ng/g ww, respectively (Asher et al. 2012).

Short-chain PFASs were largely not detected in prey fish (Table 5). The absence of short-chain perfluoroalkyl sulfonates and carboxylates is consistent with findings elsewhere and suggests that these compounds do not bioaccumulate in fish (Martin et al. 2003a, b).

Long-chain perfluoroalkyl carboxylates were detected in approximately 70% of the fish in the South Bay. PFDA (0.69- 3.95 ng/g), PFNA (0.51- 10 ng/g) and PFOA (0.51- 7.4 ng/g) were most frequently detected. In contrast, in the North and Central Bays, perfluoroalkyl carboxylates greater than C8 were not detected (with the exception of one detection of PFDoDA in one sample just above the method detection limit).

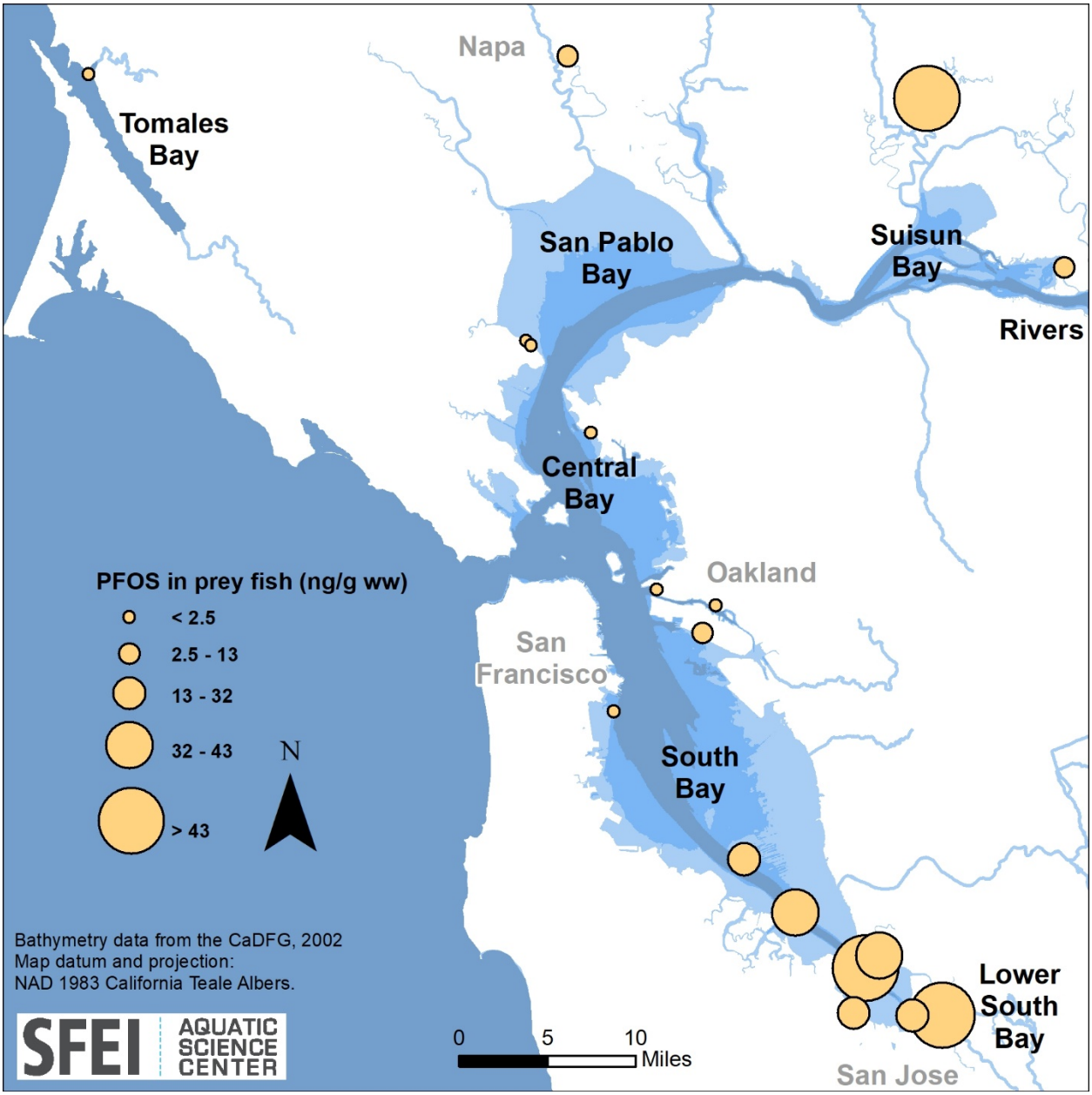

Figure 5 PFOS Concentrations in Prey Fish

2.3.2 Sport Fish

Since 2009, the RMP has monitored sport fish for 13 PFASs at five popular recreational sport fishing locations around the Bay (Figure 6). In 2009, 21 sport fish were caught at five locations: San Pablo Bay, San Francisco Waterfront, Central Bay, Oakland, and South Bay. Sport fish collected included: leopard shark, anchovy, California halibut, striped bass, white sturgeon, shiner perch, and white croaker. In 2014, 12 sport fish were caught from similar locations (Sun et al. 2017). Fewer species were targeted for PFAS analyses: striped bass, white sturgeon, shiner perch, and white croaker. In 2015, five fish (common carp, largemouth bass, and striped bass) were collected in Artesian Slough and analyzed for PFASs. Individual results are presented in the Appendix Table 7.

Similar to prey fish, PFOS is the primary PFAS detected in sport fish (Figure 7), followed by PFOSA. In 2009, PFOS and PFOSA were the only PFASs detected in fish. PFOS was detected in only four of the 21 fish analyzed, with detected values ranging from 7.8 to 18 ww ng/g; PFOSA was detected in two fish, at 2.6 and 4.2 ng/g ww. However, in this early phase of monitoring, the analytical method was still under development.

By 2014, the analytical method had improved, method detection limits had lowered from 4.93 to 0.98 ng/g, and as a result, PFOS was detected with greater frequency, in 9 of the 12 sport fish analyzed, with detected values ranging from 1.85 to 6.96 ng/g ww. PFOSA was detected in 5 of the 12 samples, ranging from 1.2 to 2.88 ng/g ww.

PFOS was detected in all five fish collected in 2015 from a site heavily influenced by wastewater effluent, Artesian Slough, ranging from 2.47 to 17.2 ng/g ww; PFOSA was detected in two fish, 1.98 and 2.06 ng/g ww (Figure 7). In addition, for the first time, there were detections of a number of the long-chain carboxylate compounds such as PFDA, PFUnA, and PFDoDA. This may reflect closer proximity to potential pollution pathways such as wastewater effluent and stormwater runoff. Short-chain compounds were largely not detected in fish from the San Francisco Bay or Artesian Slough.

The PFASs observed and the concentrations detected are typical of concentrations reported in North American waters for similar species of fish (Houde et al. 2006; Houde et al. 2011). In general, PFOS is the primary PFAS observed, with concentrations of PFOA, PFNA, PFDA, PFUnA, PFDoA and the PFOS precursor PFOSA approximately an order of magnitude lower. For example, concentrations of PFOS in trout from the Great Lakes in 2008 ranged from 4.8 in Lake Superior to 121 ng/g ww in Lake Erie (Houde et al. 2011).

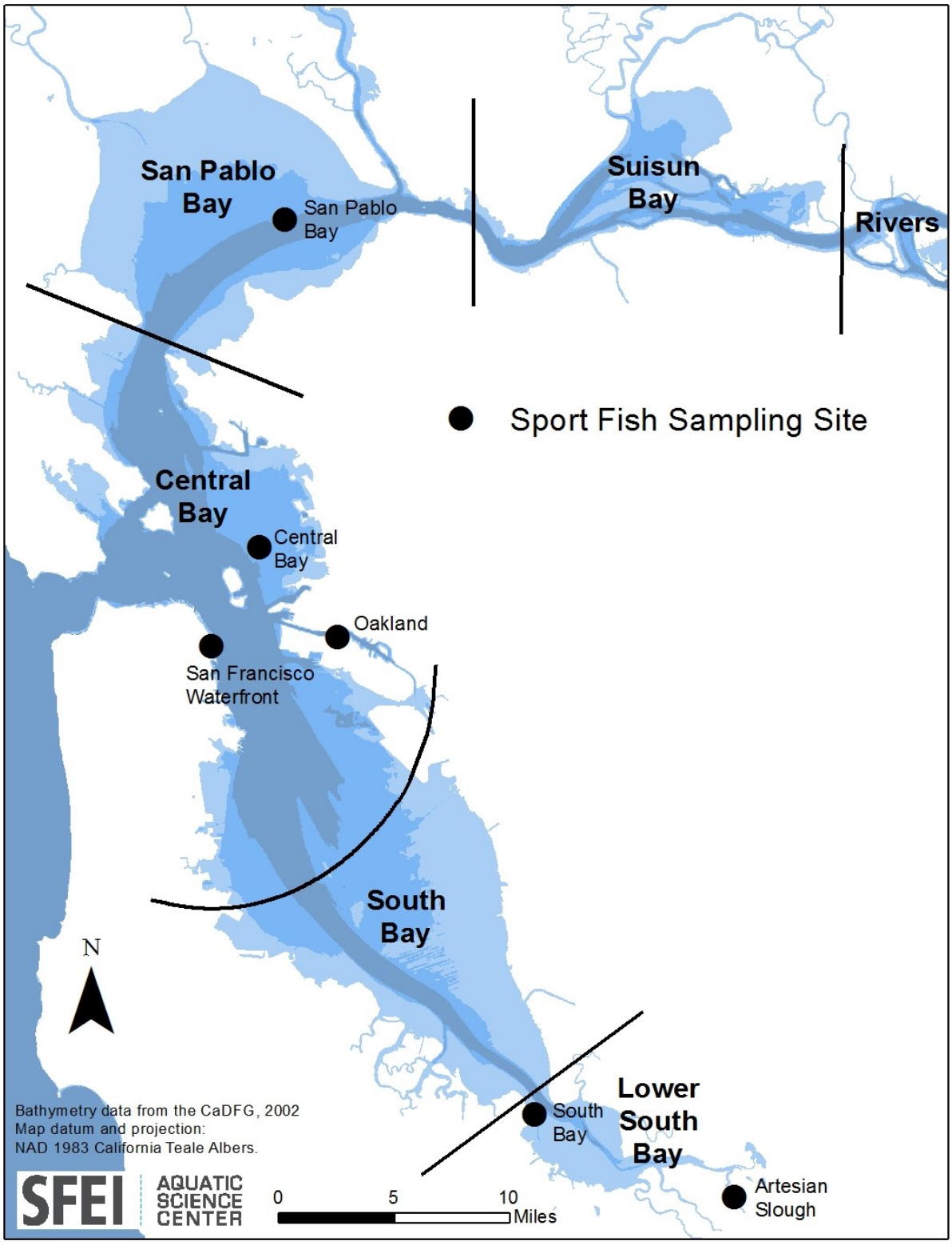

Figure 6 Locations of Sampling Sites for Sport Fish

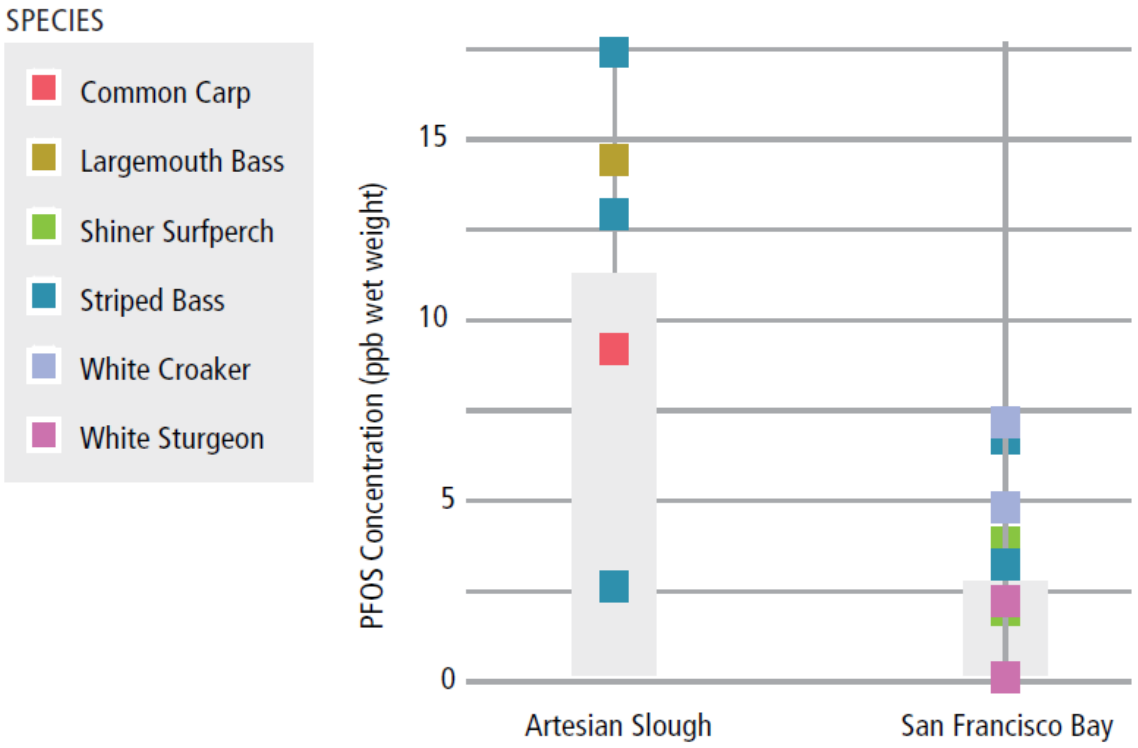

Figure 7 Concentrations of PFOS in Sport Fish. Each point represents an individual fish (carp or bass from Artesian Slough) or composite fish (all other species, including striped bass composites from San Pablo Bay, and Central Bay) samples. Fish that did not contain PFASs above detection limits are not included. The San Francisco Bay fish were collected in 2014; Artesian Slough fish were collected in 2015.

2.4 PFASs in San Francisco Bay Double-crested Cormorant Eggs

The RMP has monitored Double-crested cormorant (*Phalacrocorax auritus*) eggs to assess contaminant exposure from the open water habitats of the Bay. Cormorants are year round avian residents that forage for food in shallow, open waters, close to shore. Their feeding range can be quite large; they are known to forage in an approximately 20-mile radius from their nesting sites (Melwani et al. 2012). As such, they are excellent regional integrators of contaminants. Since 2006, the RMP has monitored cormorant eggs for 13 PFASs from three Bay sites (Figure 8): the Central Bay (at the Richmond Bridge), the South Bay (at Don Edwards Pond or the South Bay Towers), and in the Delta-influenced Suisun Bay (at Wheeler Island). At each site, three composites of seven eggs are collected and analyzed for 13 PFASs including PFOS, PFOA, and a PFOS precursor, PFOSA (Appendix Table 7).

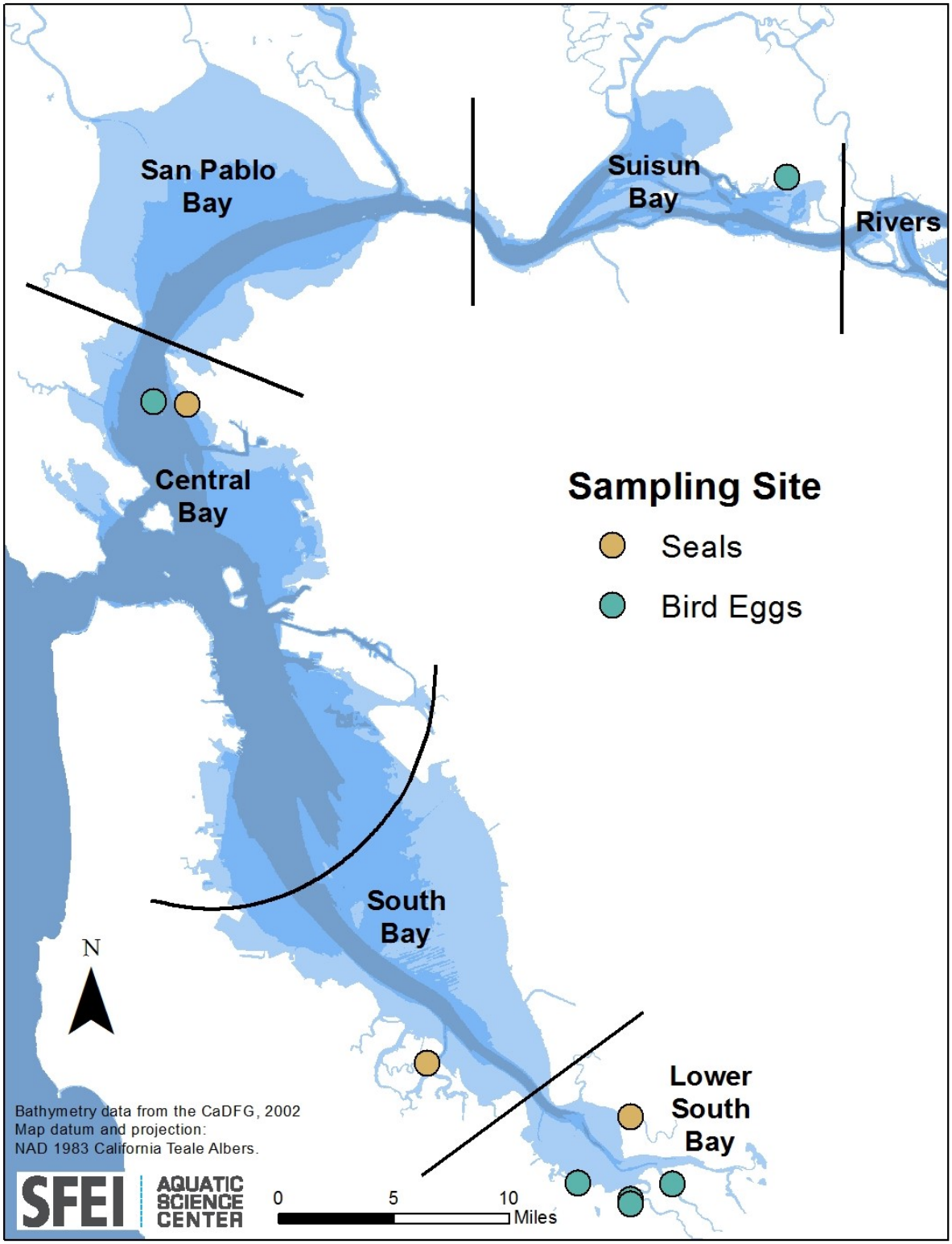

Figure 8 Locations of Bird and Seal Sampling Sites

PFOS is the dominant PFAS identified (Figure 9); the remaining PFASs are an order of magnitude lower. PFOS concentrations are highest in South Bay, followed by Richmond Bridge and then Wheeler Island. Cormorant eggs from the South Bay have had some of the highest concentrations of PFOS observed globally. Given the relatively short half-life of PFOS in birds (two to three weeks, (Houde et al. 2006)), these results suggest on-going exposure to PFOS and/or PFOS precursors.

These spatial patterns persisted in the most recent sampling event in 2016. Concentrations in South Bay eggs ranged from 570 to 654 ng/g ww (median 638); Richmond Bridge eggs from 78 to 152 ng/g ww (median 114); and Wheeler Island from 38 to 88 ng/g ww (median 38). These concentrations are on par with observations from other urban areas (Houde et al. 2006; Houde et al. 2011). For example, PFOS concentrations in cormorant eggs downstream of Hamburg Germany ranged from 100 ng/g to 1,451 ng/g ww with a mean of 540 (Rudel et al. 2011).

Among the perfluoroalkyl carboxylates, PFDA (C10) was detected in the highest concentrations followed by PFNA (C9), PFDoA (C12), and PFUnDA (C11). The South Bay cormorant eggs had higher concentrations of PFOA and PFNA as compared to the other two sites (Figure 9). The specific sources of these contaminants are unknown; however, the presence of long-chain perfluoroalkyl carboxylates may be the result of the degradation of precursors (Letcher et al. 2015). A study of Canadian cormorant eggs indicated higher concentrations of PFOA and PFNA in bird eggs located in urban areas relative to eggs located in remote off-shore locations (Miller et al. 2015).

Short-chain alternatives such as PFBS (C4), PFBA (C4), and PFHxA (C6), were almost exclusively not detected. In general, short-chain PFASs (less than C7) are not observed in bird eggs (Houde et al. 2006; Houde et al. 2011).

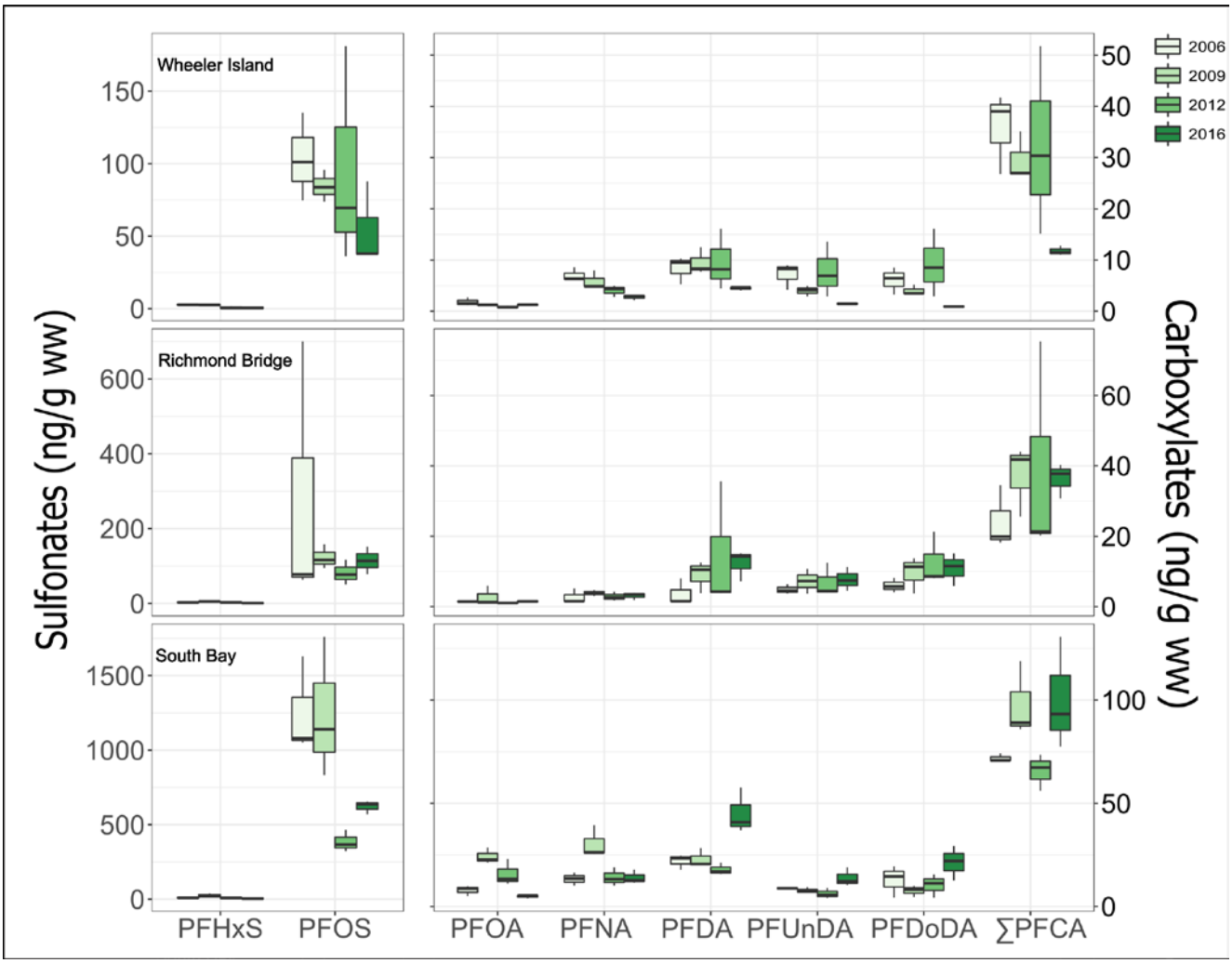

Figure 9 Concentrations of PFASs in Cormorant Eggs
Concentrations of perfluoroalkyl sulfonates (left panels) and perfluoroalkyl carboxylates (right panels) in cormorant eggs collected between 2006-2016: 2006 (light green), 2009 (green), 2012 (darker green) and 2016 (dark green) from Wheeler Island; Castro Rocks; and South Bay. Concentrations are plotted as boxplots, with the box denoting upper and lower quartiles. The horizontal line within the box is the median concentration. Error bars represent the lowest and highest observation within 1.5 interquartile ranges, with observations beyond these limits plotted individually. Sum of perfluoroalkyl carboxylates includes all members (C4 through C12).

2.5 PFASs in San Francisco Bay Harbor Seals

The Pacific harbor seal (*Phoca vitulina richardii*) is a year-round resident of San Francisco Bay and the surrounding coastal waters. Pacific harbor seals are the Bay Area's only resident pinniped, a class consisting of seals, sea lions, and walruses. Seals are primarily observed in the central and southern portions of the Bay, where they forage and haul-out on rocky shoals or mudflats to rest, birth and nurture young pups. Although there are numerous haul-out sites for seals in the Bay, the major sites are located at Castro Rocks below the Richmond Bridge, Yerba Buena Island, and Mowry Slough (Kopec and Harvey 1995). Seals have relatively high site fidelity; while they can forage long distances for food, a tagging study conducted by Nickel and Grigg (2002) observed seals to forage within 20 km of known haul-out sites (in Melwani 2012). Since 2004, the RMP has monitored two of the three major haul-out sites in the Bay, Castro Rocks and Mowry/Corkscrew Slough (Figure 8). A third location in Tomales Bay has been monitored as a reference site.

As apex predators with relatively high site fidelity, Pacific harbor seals are highly desirable biosentinels to monitor for contaminants. Pacific harbor seals are carnivorous opportunists that consume a wide variety of fish including gobies, topsmelt, anchovy, and to a lesser extent shiner surfperch and staghorn sculpin (Gibble and Harvey 2015). Based on correlations between seal fecal scat and fish, harbor seal diets closely parallel the relative distribution of fish available (Gibble and Harvey 2015).

Harbor seals are sampled opportunistically by the RMP, often by leveraging existing scientific collection events or accessing archived biological samples. The RMP has analyzed PFASs in blood from Bay harbor seals from 2004 through 2014 (Appendix Table 8). The RMP has targeted blood because it has been shown that PFASs preferentially accumulate in blood (38%) versus liver (36%) and muscle (13%) (Ahrens et al. 2009b).

PFOS is the dominant PFAS detected in seals (Figure 10 and Appendix Table 8). The highest concentrations are observed in the South Bay. The initial studies of South Bay seals (2004 to 2008) had some of the highest concentrations observed world-wide, with a geometric mean of 906 ng/g ww and a range of 401 to 1,960 ng/g (Sedlak et al. 2017). However, the geometric mean and range of PFOS concentrations observed in South Bay seals in 2014 (184 ng/g, 12.6 to 796 ng/g) are similar to or lower than concentrations observed in other parts of the world. For example, PFOS was detected in blood from stranded seals along the German Bight at average concentrations of 349, range 48 to 887 ng/g (Ahrens et al. 2009b). PFOS concentrations from seals in more remote locations such as Svalbard Norway are lower (e.g., the 2010 average concentration was 48 ng/g ww) (Routti et al. 2016). No difference in PFOS concentrations related to gender has been noted in the studies of Bay seals or in seals elsewhere (Sedlak et al. 2017).

In San Francisco Bay harbor seals, the remaining long-chain perfluoroalkyl carboxylates are typically an order of magnitude lower than PFOS concentrations (Figure 10 and Appendix 8). PFNA and PFDA were the primary perfluoroalkyl carboxylates detected, and they were detected at all sites. Geometric means for PFNA and PFDA from the most recent sampling in the South Bay in 2014 were 20.2 and 9.27 ng/g, respectively (Sedlak et al. 2017). The geometric mean for PFOA was 4.5 ng/g.

Similar patterns of PFOS being much higher than the perfluoroalkyl carboxylates have been observed in seals other regions of the world (Ahrens et al. 2009b; Routti et al. 2016). In seal blood from the German Bight, perfluoroalkyl carboxylates were detected on average at concentrations less than 4.4 ng/g, in contrast to PFOS at 349 ng/g. Similar to San Francisco Bay seals, the primary long-chain perfluoroalkyl carboxylates observed in German Bight seals were PFNA and PFDA, 3.93 and 4.38 ng/g respectively. A recent study of dolphins, seals and porpoises suggests that seals and porpoises have lower concentrations of perfluoroalkyl carboxylates due to higher excretion rates (Galatius et al. 2013).

The exception to this is Tomales Bay seals, where concentrations of PFUnDA (C11) are approximately half the concentration of PFOS in the most recent sampling round. Interestingly, in relatively remote areas such as Antarctica, concentrations of PFUnDA are higher than PFOS; it has been postulated that these carboxylates are present due to the atmospheric transport of precursors to PFUnDA. In a recent study of Antarctic seals (Routti et al. 2015), PFUnDA was ubiquitously identified in seal blood; PFOS on the other hand was only detected in one of the ten seals sampled. Concentrations of PFUnDA were almost three times higher than the PFOS detection (0.16 vs 0.06 ng/mL). The authors hypothesize that the long-range atmospheric transport of fluorotelomer alcohols and the degradation of these compounds to perfluoroalkyl carboxylates may be a significant factor. This is corroborated by the primary detection of the fluorotelomer alcohol, 10:2 FTOH, in Antarctic air mass; 10:2 FTOH is known to degrade to PFUnDA (Routti et al. 2016). The authors also note that direct sources from the McMurdo station may be a factor as well, although concentrations of other PFASs were largely not detected. Given this finding and the relative dearth of sources in Tomales Bay, it is possible that significant concentrations of PFUnDA relative to PFOS maybe the result of atmospheric transport.

The short-chain PFASs are generally not detected in San Francisco Bay seals or in seals elsewhere. Similarly, the precursor PFOSA was not detected in any Bay sample. Recent research suggests that seals can biotransform PFOSA into PFOS (Galatius et al. 2013).

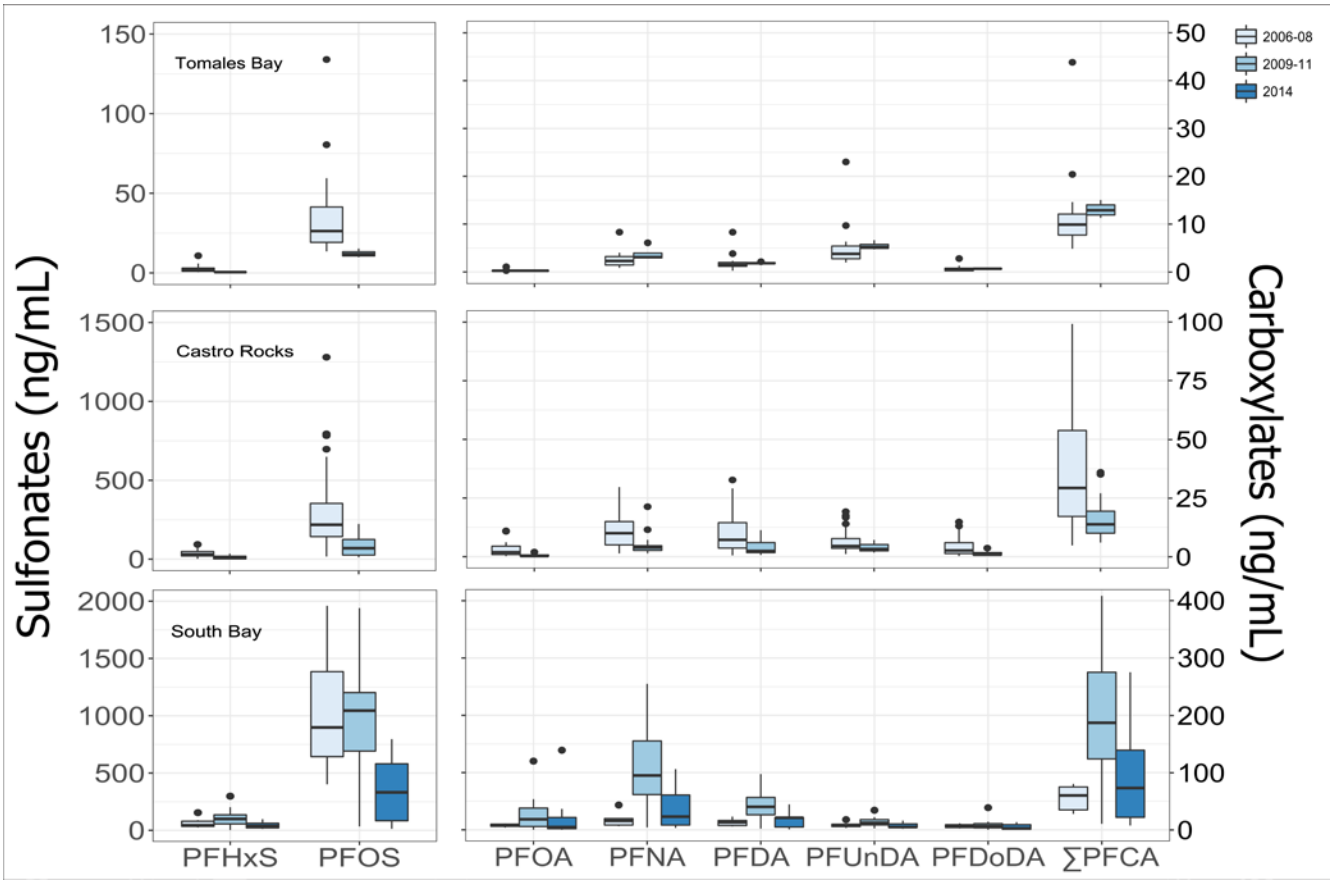

Figure 10 Concentrations of PFASs in San Francisco Bay Seal Blood
Concentration of perfluoroalkyl sulfonates (left panels) and perfluoroalkyl carboxylates (right panels) in seal blood collected between 2004-2008 (light blue), 2009-2011 (blue), and 2014 (dark dark) from South Bay, Castro Rocks, and Tomales Bay. In 2014, samples were only collected from South Bay. Concentrations are plotted as boxplots, with the box denoting upper and lower quartiles. The horizontal line within the box is the median concentration. Error bars represent the lowest and highest observation within 1.5 interquartile ranges, with observations beyond these limits plotted individually. Sum of perfluoroalkyl carboxylates includes C4 through C12.

3.0 PFAS Contamination and Potential Risks

3.1 Risks to Humans: PFAS Levels in Fish Pose Possible Risk for Human Consumption

Fish and seafood consumption is a major pathway for the uptake of PFASs to humans (Haug et al. 2010). California has not established a sport fish human health consumption advisory tissue level for any individual PFASs. The states of Michigan and Minnesota have established consumption guidelines for PFOS based on the frequency of consumption. For individuals consuming fish four times per month, the State of Michigan recommends that fish should not contain more than 38 ng/g ww of PFOS; for eight meals per month, the fish should not exceed 19 ng/g; and for 16 meals per month, no greater than 9 ng/g. The State of Minnesota Department of Public Health has established a fish consumption advisory suggesting unlimited consumption is acceptable for fish containing less than 40 ng/g ww of PFOS.

All sport fish analyzed were below the Minnesota threshold for unlimited fish consumption of 40 ng/g ww, and most were below the Michigan 16 meals per month threshold of 9 ng/g ww. Thirty percent of the fish from the South Bay and southern sloughs exceeded the 9 ng/g ww threshold. None of the sport fish from the Central Bay exceeded this threshold.

This information suggests that frequent consumption of fish from the South Bay may pose a risk for humans.

3.2 Risks to Wildlife

A variety of toxicological impacts for a very limited number of PFASs are reported in the literature for various species under differing laboratory and field conditions. One of the challenges in evaluating the risks associated with these chemicals is that many of the studies reported are undertaken in laboratory settings at very high concentrations that are not representative of environmental conditions. A second challenge is that there are few to no relevant toxicity thresholds available for many Bay species for comparison.

3.2.1 PFASs Are Unlikely to Pose Risks to Bivalves

The lethal concentration for 50 percent of the population (LC_{50}) in a 96-hour test was determined to be 59 mg/L of PFOS for a freshwater mussel (*Unio complanatus*) (Drottar and Krueger 2000). A study of green clams identified genetic damage including fragmentation and breaks of DNA, establishing EC_{50} values (the concentration which induces a response in half the population) based on integrative genotoxicity response of 33 (29-37), 594 (341-1036), 195 (144-265) and 78 (73-84) µg/L for PFOS, PFOA, PFNA, and PFDA, respectively (Liu et al. 2014). These toxicity thresholds are substantially higher than the ambient concentrations observed in San Francisco Bay, which are in the ng/L range.

Based on this limited information, it is unlikely that current levels of PFASs pose a risk to Bay bivalves.

3.2.2 PFASs Are Unlikely to Pose Risks to Fish

At high aqueous concentrations of PFASs (e.g., µg/L, mg/L range), a myriad of deleterious effects to fish have been demonstrated in laboratory settings, including embryo toxicity, cardiac toxicity, delayed hatching, compromised lipid metabolism, increase in malformations such as

abnormal spines and bent tails, and reduced survival (Cui et al. 2017; Sant et al. 2017; Shi et al. 2017). Using USEPA Guidance, Rostkowski et al 2006 calculated a PFOS Secondary Maximum Concentration and a Secondary Continuous Concentration of 8,500 ng/L and 1,200 ng/L for saline waters, representing respectively safe exposure thresholds for aquatic organisms for a one-hour and four-day exposure in a three-year period. Environment Canada also prepared draft Federal Environmental Water Quality Guidelines for PFOS. These guidelines include margins of safety to account for uncertainties associated with the lack of toxicity studies for all species; exceedance of the guidelines does not necessarily mean that adverse effects have occurred. The guideline for effects to aquatic life is 6,000 ng/L (Environment Canada 2013). The European Union (EU) has established a much lower surface water environmental quality standard for the protection of marine pelagic organism of 23 ng/L based on no observable effects concentrations for algae, invertebrates and fish and a safety factor (European Union 2011).

In general, with the exception of one hot spot located in the South Bay near Cooley Landing, these thresholds are substantially higher than the water concentrations observed in the estuary, suggesting fish are unlikely to be experiencing adverse impacts due to PFOS exposure.

3.2.3 PFASs May Pose Risks to Birds

A laboratory study of leghorn chicken eggs reported a lowest observable effects concentration (LOEC) for PFOS of 100 ng/g based on a reduction in hatchability of embryos (Molina et al. 2006). PFOS was injected into the eggs for this study; it is possible that exposure via injection may not exactly mimic the effects of maternally derived exposure. In another laboratory study, a predicted no effects concentration (PNEC) of 1,000 ng/ml for bird eggs was derived based on offspring survival effects in northern Bobwhite quail exposed to PFOS through feed (Newsted et al. 2005). Lastly, field studies have indicated an approximately 50% reduction in hatching success of tree swallows at a PFOS concentration of 500 ng/g ww in egg; a 15% reduction in success was observed at concentrations as low as 148 ng/g (Custer et al. 2014). Environment Canada is one of the few agencies to develop a draft Federal Environmental Water Quality Guideline for bird eggs of 1,900 ng/g ww (Environment Canada 2013). In addition, Environment Canada has developed a Federal Environmental Water Quality guideline for wildlife diet of 8.2 ng/g for birds for PFOS (Environment Canada 2013). Many of the prey fish detected in the Bay exceed this threshold.

The sensitivity of avian species to chemicals can vary widely (e.g., Heinz et al. 2009), but the swallow data suggest that PFOS concentrations in South Bay cormorant eggs are a potential concern. Information on the toxicity of other PFASs is virtually nonexistent. One study indicated that PFOA and PFUnDA had no effect on pipping success at concentrations up to 10,000 ng/g (O'Brien et al. 2009a).

Based on these studies, current PFOS concentrations in the South Bay may pose a risk to birds; the median concentration of PFOS is 638 ng/g which exceeds the 500 ng/g threshold associated with a 50% reduction in hatching success observed by Custer et al (2014). In addition, many of the prey fish exceed the Draft Environmental Water Quality Guideline for avian diets of 8.2 ng/g ww (Environment Canada 2013) suggesting that there may be a potential for adverse effects to birds.

3.2.4 PFASs May Pose Risks to Harbor Seals

There are few guidelines and standards for PFASs that are protective of seals. Environment Canada has developed a Federal Environmental Water Quality guideline for wildlife diet of 4.6 ng/g for mammals for PFOS (Environment Canada 2013). Many of the prey fish that are consumed by Bay seals had concentrations that exceed this threshold, suggesting potential concern.

Very few studies have evaluated the toxicological effects of PFASs on seals. In a study of wild seals (*Pusa sibirica*) from Lake Baikal, Russia (Ishibashi et al. 2008b), perfluoroalkyl acids were found to activate peroxisome proliferator-activated receptors that are important for the regulation of gene functions. Based on laboratory gene assays developed using wild seal livers, the researchers established lowest observable effect concentrations (LOEC) for PFOA, PFNA, PFDA, PFUnDA, and PFOS of 62.5 µM (25.8 ug/g), 125 µM (58 ug/g), 125 µM (64 ug/g), 62.5 µM (35.3 ug/g), and 125 µM (62.5 ug/g). The researchers observed the activation of the peroxisome proliferator receptors in the Baikal seals in the wild that had much lower liver concentrations of PFNA (in the range of 3.3 to 72 ng/g) and PFDA (0.56 to 35 ng/g), suggesting that lower concentrations may have impacts as well (Ishibashi et al. 2008b). It is difficult to compare liver concentrations to blood concentrations; however, the total average PFAS concentrations observed in Baikal seal serum was 14 ng/g and 11 ng/g in male and female seals, respectively and are in the lower range of concentrations detected in Bay seals (Ishibashi et al. 2008a).

In addition, the Lake Baikal seal researchers also attributed a reduction in immune system function of the seals to environmental contaminants including PFASs (Ishibashi et al. 2008a). Suppression of the immune system has been observed in other mammals. Kannan et al. (Kannan et al. 2006) reported a significant correlation between the incidence of disease in California sea otters and PFOS and PFOA concentrations in liver (e.g., <1 to 884 ng/g PFOS and <5 to 147 ng/g PFOA, ww). Guruge et al. (Guruge et al. 2009) observed a significant increase in emaciation and mortality in a study on the effects of PFOS on rat resistance to influenza. In humans, a Norwegian study of 99 children-mother pairs found that prenatal maternal serum PFAS concentrations (e.g., PFNA, PFOA, PFOS and PFHxS) were correlated with decreased vaccine responses and increased frequencies of common cold (PFNA and PFOA) and gastroenteritis (PFHxS and PFOA) (Granum et al. 2013).

Inference from other mammalian systems to seals is challenging given the current state of knowledge; however, in general, there appears to be some similarity in adverse effects observed across different mammalian species. Therefore, in the absence of seal data, it may be informative to briefly note human health effects, as this is one of the most widely studied mammalian systems. Probable links have been identified between PFOA exposure and high cholesterol, ulcerative colitis, thyroid disease, testicular cancer, kidney cancer, and pregnancy-induced hypertension in humans (http://www.c8sciencepanel.org/index.html).

Other human epidemiological studies have identified adverse outcomes associated with exposure to low concentrations of PFOS and PFOA including low birth weights and reduced head circumference. For example, in a paired study evaluating PFOS/PFOA concentrations in maternal serum and birth outcomes, a significant negative correlation was identified for PFOS

and birth weight. Average geometric means in the study of PFOS and PFOA were 4.9 ng/mL and 1.2 ng/mL (Washino et al. 2009). In a Danish Birth Cohort study of 1,400 pregnant women (1969 through 2002), smaller head and abdominal circumferences were observed in the infants born with increasing PFOA concentrations in the mother; the median maternal plasma PFOA concentration was 5.6 ng/mL (Fei et al. 2007).

Based on a recent review of human epidemiological studies of PFOS and PFOA and laboratory studies of mice, Grandjean and colleagues (Grandjean and Clapp 2015) propose benchmark dose levels (BMDL) of 1.3 ng/mL for PFOS and 0.8 ng/mL for PFOA, both in terms of the serum concentration. Benchmark dose is defined as the dose that elicits a response as compared to a background concentration. These benchmark dose levels are significantly below the geometric means observed in 2014 in South Bay seals for both PFOS (184 ng/g) and PFOA (4.5 ng/g), as well as those observed in 2009-2011 in Central Bay seals (56.8 ng/g PFOS and 1.8 ng/g PFOA).

Assuming similar toxicological responses among mammals for PFASs, these findings suggest that adverse effects may be plausible in seals at concentrations currently observed.

3.3 Potential for Risks: Summary

For humans, the evidence to date suggests that current levels of PFOS in fish may pose risks to individuals with a high frequency of consumption of fish from the South Bay and southern sloughs. In these areas, PFOS concentrations in fish may exceed the State of Michigan guideline of 9 ng/g ww for individuals eating 16 meals per month. These guidelines are advisories and are not enforceable regulatory requirements. Fish consumption guidelines have not been established for other PFASs.

For bivalves, evidence to date suggests that risks are unlikely based on existing toxicity data. PFAS concentrations in water that result in impacts to bivalves in laboratories are several orders of magnitude higher than the concentrations observed in the Bay. It should be noted that for many PFASs, there is no toxicological information and a very limited number of PFASs have been analyzed in bivalves.

For fish, evidence to date suggests that risks are unlikely. Studies of fish exposed to PFASs indicate a variety of adverse outcomes at concentrations that are 1,000 times higher than the concentrations observed in the Bay. As noted above, only a small number of PFASs have been the subject of fish toxicity studies.

For birds, evidence to date suggests that PFOS may present a potential risk to birds. Although concentrations of PFOS in cormorant eggs from the most recent sampling event in 2016 are below a PNEC of 1,000 ng/mL, recent field studies of tree swallows suggest that significant decreases in hatching success can occur at concentrations as low as 150 ng/g ww PFOS in eggs. Concentrations in South Bay eggs collected in 2016 exceed this value, suggesting the potential for adverse effects to birds. At the Central Bay and Wheeler site, there were sporadic exceedances of this value.

For harbor seals, inferences based on the evidence to date suggest that PFOS may present a potential risk to seals. Very few studies evaluating the toxicity of PFASs have been conducted

on seals. In one study, there was some indication that low concentrations of PFASs (e.g., less than 100 ng/g in liver) can cause disruption in gene functions. A much wider body of knowledge exists for humans. Low concentrations of PFOS and PFOA (e.g., less 25 ng/mL in blood) has been associated with a myriad of deleterious effects including low birth weights, reduced head circumference, and reduced semen quality. If PFOS and PFOA exhibit similar outcomes across mammalian systems, then it is possible that the concentrations of these contaminants observed in seals could pose a risk.

4.0 PFAS Pathways and Loads to San Francisco Bay

Possible pathways for the introduction of PFASs into the Bay include: wastewater treatment plant (WWTP) effluent; stormwater runoff; riverine discharges; spills and other uncontained releases of materials such as aqueous film-forming foams (AFFF) for fire suppression at military bases, airports, oil refineries and firefighting training sites; seepage of PFAS-contaminated groundwater into the Bay; and atmospheric deposition of volatile perfluoroalkyl acid precursors. Based on a review of the literature (Ahrens et al. 2009a; Houtz and Sedlak 2012; Houtz et al. 2016; Huset et al. 2008; Schultz et al. 2006; Sinclair and Kannan 2006), it is likely that the two major PFAS pathways to the Bay are wastewater effluent and stormwater runoff/riverine discharges.

4.1 Pathways of PFASs to the Bay: Stormwater and Large Tributaries

Stormwater runoff is a significant pathway for the release of PFASs to surface waters (Houtz and Sedlak 2012; Kim and Kannan 2007; Meyer et al. 2011; Muller et al. 2011; Zushi and Masunaga 2009a, b). The sources of the PFASs to stormwater runoff are unclear but may result from the use of PFAS containing products such as car wax or surface treatment materials (Muller et al. 2011).

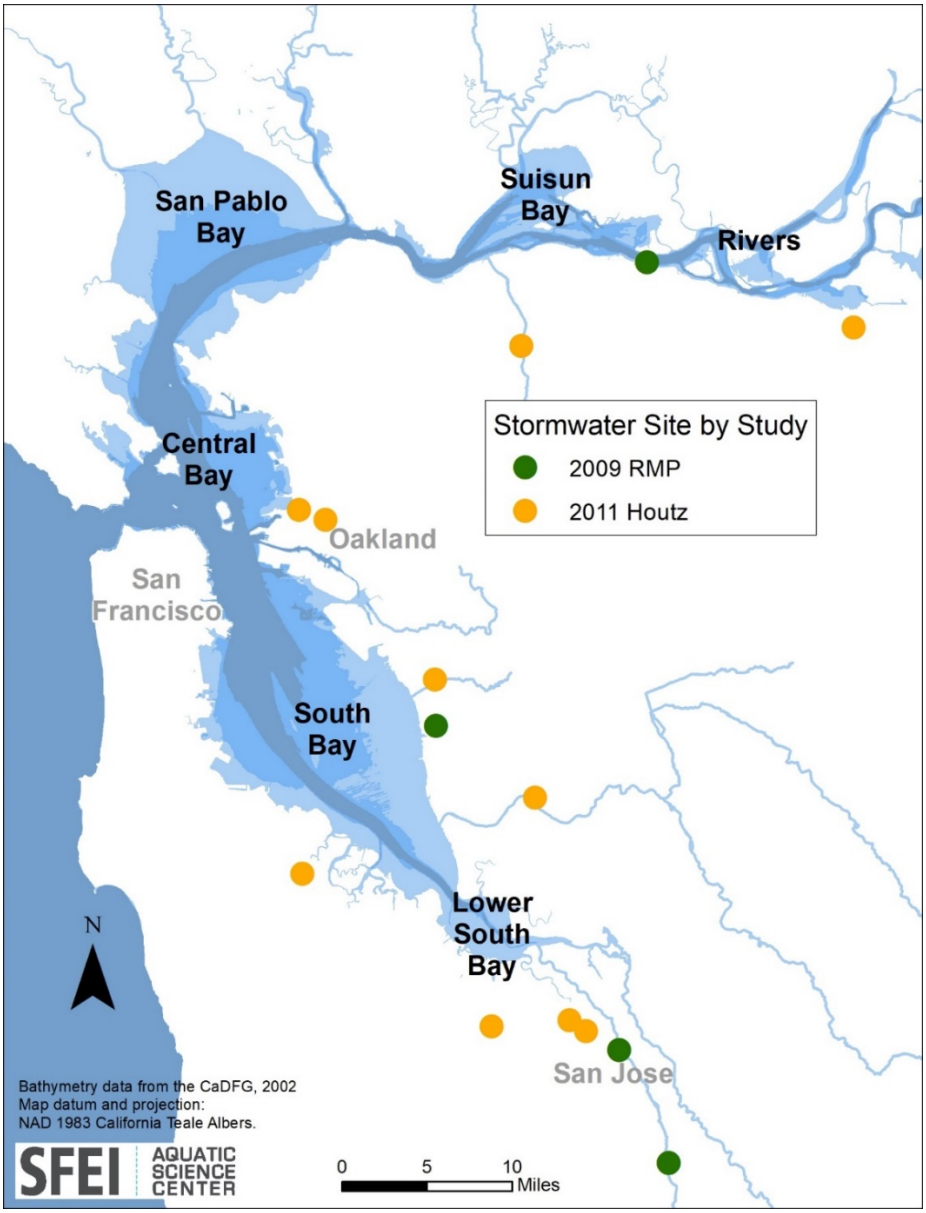

Figure 11 Location of Stormwater Sampling Sites for PFASs

To date, two studies on PFASs in stormwater have been conducted in the Bay Area (Figure 11). The first study was conducted in the winter of 2009/2010 by the RMP, and analyzed seven grab stormwater samples from Hayward (Zone 4 Line A), Guadalupe River, and the confluence of the San Joaquin/Sacramento Rivers (Mallard Island) for 12 perfluoroalkyl acids and one precursor, PFOSA.

Of the PFASs detected in unfiltered stormwater, PFOA was detected at all sites and at the highest concentration (1.5 to 69 ng/L) followed by PFHxA, PFDA, PFHpA, and PFNA (Appendix Table 9a). Concentrations of the remaining PFASs detected were all less than 20 ng/L. PFOS concentrations ranged from 2.1 to 14.2 ng/L. PFOSA was largely not detected. The

short-chain PFOA alternative, PFBA, was detected in concentrations ranging from 1.6 to 17.7 ng/L. The corresponding perfluoroalkyl sulfonate, PFBS, was sporadically detected at low concentrations, < 6.5 ng/L.

PFAS concentrations from an undeveloped upper portion of the Guadalupe watershed (Foxworthy) were lower than samples from the more urbanized and industrialized portion of the watershed (e.g., lower Guadalupe watershed and the small, highly urbanized Hayward watershed). Low concentrations of PFASs were detected at the confluence of the Sacramento and San Joaquin rivers in the Delta, possibly reflecting the influence of large agricultural tracts and undeveloped areas in the watershed; however, the flow from the Delta is quite large and therefore, loads from the Delta may be significant.

The second Bay Area stormwater study was conducted in the winter of 2010/2011 by University of California at Berkeley researchers in collaboration with the RMP. This study analyzed stormwater from ten sites in the Bay Area for perfluoroalkyl carboxylates and sulfonates as well as a number of precursors (Houtz and Sedlak 2012). PFOS, PFOA, and PFHxA were the primary PFASs detected (Appendix Table 9a). PFOS concentrations (2.6 to 26 ng/L) were comparable to PFOA (2.1 to 16 ng/L), followed by PFHxA, 0.9 to 9.7 ng/L (Houtz and Sedlak 2012). Low concentrations of the short-chain PFASs were observed; the study did not measure PFBA. In contrast to the previous RMP study, no significant variation in PFAS distribution by watershed characteristic was observed although some of the highest concentrations were observed in more urbanized areas. Further work is necessary to assess the impact of land use.

Other studies have shown higher PFAS concentrations in urbanized areas. Urban lakes in New York State had higher concentrations of PFOA, PFHpA, PFDA and PFOS compared to rural lakes, and higher concentrations of PFOA were detected in tributaries located in close proximity to parking lots and areas with heavy traffic (Kim and Kannan 2007). In a study of 18 Japanese rivers, Murakami et al. identified a strong correlation between population density and PFOS, PFHpA and PFNA levels (Murakami et al. 2008). A similar association was observed in a study of 59 Canadian rivers (Scott et al. 2009).

In conjunction with direct analysis of PFASs in stormwater, UC Berkeley researchers developed the Total Oxidizable Precursor (TOP) assay to indirectly measure unknown perfluoroalkyl acid precursors in stormwater. The TOP assay rapidly transforms perfluoroalkyl acid precursors to perfluoroalkyl carboxylate products in the presence of hydroxyl radical (Houtz and Sedlak 2012). The TOP assay provides an indication of the overall levels of perfluoroalkyl acid precursors that are present in a matrix and could transform to perfluoroalkyl acids following natural processes in the environment, however it does not predict the rate of transformation or the precise end products of the precursors. Interestingly, after subjecting stormwater samples to the TOP assay, a median increase of 64 percent in perfluoroalkyl carboxylate products was observed, suggesting that there are many unidentified PFASs in stormwater that can degrade to PFOS, PFOA, PFHxA, and PFBA (Houtz and Sedlak 2012).

In addition to stormwater monitoring, Stanford researchers have monitored Upper Silver Creek and Coyote Creek in San Jose, California, during the dry season (May 2006 and June 2007) (Hoehn et al. 2007; Plumlee et al. 2008). PFOS and PFOA were detected in the highest

concentrations, with less frequent detections of PFHxS, PFDA, and some PFOS precursors (Plumlee et al 2008). In the most recent sampling round (June 2007), concentrations of PFOS and PFOA ranged between 4.8 to 56 and 8.0 to 36 ng/L, respectively. Higher concentrations were observed in Upper Silver Creek than Coyote Creek, suggesting that a source of PFASs was located higher in the watershed. Concentrations in these creeks are comparable to stormwater results to date.

Concentrations observed in the Bay Area studies are similar to ambient concentrations observed in the Upper Mississippi River basin (<1 to 125 ng/L PFOA; <1 to 245 ng/L PFOS)(Nakayama et al. 2010), in European rivers (6.5 to 43 ng/L PFOA; 4.7 to 32 ng/L PFOS)(Kwadijk et al. 2010), and in Japan (0.76 to 192 ng/L PFOA; <0.1 to191 ng/L PFOS) (Murakami et al. 2008)). Ten to hundred-fold higher concentrations of PFOS and PFOA have been reported in streams and rivers where spills or direct releases have occurred as a result of the use of AFFF to extinguish fires at airports (Moody et al. 2002) or industrial discharges from the manufacture of fluorochemicals, semiconductor/ electronic equipment, and carpets (Hansen et al. 2002; Konwick et al. 2008; Lin et al. 2009).

Short-chain PFASs (i.e. less than C5) were detected at low concentrations in Bay Area stormwater. In other locations, these short-chain alternatives are being detected more frequently and in some instances at higher concentrations than the long-chain compounds. In a study of 88 sampling sites in the Upper Mississippi River basin, PFBA was the most abundant compound with median concentrations exceeding PFOA (2.7 ng/L vs 2.1 ng/L, respectively) (Nakayama et al. 2010). The widespread detection of PFBA was attributed to its use as a replacement for PFOA; it may also result from the degradation of the hydrofluorocarbons (MacInnis et al. 2017). Similarly, in a study of 21 sites in Holland, the highest detected concentration was a replacement for PFOS, PFBS (C4 sulfonate), at a concentration of 290 ng/L in the Rhein River, which receives industrial and municipal effluents (Kwadijk et al 2010). In San Francisco Bay stormwater, the results of the TOP assay suggest that stormwater contains precursors that are capable of producing PFPeA (C5) upon oxidation (Houtz and Sedlak 2012). PFPeA was produced in the highest concentrations upon oxidation of the stormwater samples in that study, which is typical of the products generated from 6:2 fluorotelomer compounds subjected to TOP assay (Houtz and Sedlak 2012, Houtz et al. 2013).

4.2 Pathways of PFASs to Bay: Wastewater Effluent

Wastewater is a significant pathway for the release of perfluoroalkyl carboxylates and sulfonates and perfluoroalkyl acid precursors to surface waters (Houtz et al. 2016; Schultz et al. 2006; Sinclair and Kannan 2006; Weber et al. 2017). The sources of PFASs to wastewater effluent are likely quite diverse. Consumers are exposed to PFASs through the use of food contact paper, clothing, textiles and carpets that have been treated with PFASs to impart oil and grease repellency as well as stain and water resistance (KEMI 2015). PFASs are also ingredients in cleaning products such as floor waxes and in cosmetics (KEMI 2015). PFOS and PFOA been identified in household dust, indicating a potential exposure pathway for humans and pets as well as a pathway for PFASs to be introduced into effluent (Bjorklund et al. 2009). The use and cleaning of these products release PFASs to domestic wastewater.

In addition, PFASs are widely used in industrial sectors including fluoropolymer production, metal finishing, medical devices manufacturing, photographic and electronic equipment, and oil and mining production. Industrial discharges are hypothesized to be one potential source of PFASs to WWTPs (Boulanger et al. 2005). Facilities that use AFFF for fire suppression may release spent AFFF to WWTPs as a result of routine testing or an incident. This type of release may be episodic.

Effluent from Bay Area WWTPs has been analyzed for 12 PFASs and PFOSA in 2009 (6 plants), 2012 (3 plants) and 2014 (8 plants). In addition to the standard analyte list, the 2012 and 2014 samples were also analyzed for a suite of precursors. 2014 samples were also subjected to the TOP assay to evaluate the presence of unidentified precursors.

The results from the 2009 RMP study were reported in aggregate to maintain the anonymity of the plants participating. In 2012, as part of a *pro bono* RMP study, effluent from the San Jose/Santa Clara Regional Wastewater Facility, City of Palo Alto Wastewater Treatment Plant, and East Bay Dischargers Authority were analyzed by AXYS Analytical (Sedlak et al. 2017). These same facilities plus East Bay Municipal Utilities District, Central Contra Costa Sanitary District, the City of San Mateo Wastewater Treatment Plant, San Francisco Airport and Fairfield Suisun Sewer District were part of a 2014 study led by the Environmental Chemistry Laboratory at the Department of Toxic Substances Control in collaboration with the RMP (Houtz et al. 2016).

PFOS, PFOA and the Perfluoroalkyl Carboxylates

In the 2009 study, the PFAS observed at the highest average concentration observed in effluents was PFOA (32 ng/L), followed by PFOS (24 ng/L), PFHxA (17 ng/L), and PFNA (12 ng/L) (Klosterhaus et al. 2013). In 2012, the highest average concentration was still PFOA (23 ng/L), PFOS (25 ng/L), PFHxA (22 ng/L); however, PFBA (8 ng/L) was detected above PFNA (5 ng/L), possibly reflecting the replacement of long-chain perfluoroalkyl carboxylates with short-chain alternatives. In 2014, an evaluation of six similar WWTPs indicated the highest average was now a short-chain replacement, PFHxA (26 ng/L), followed by PFOA (21 ng/L), PFBA (16 ng/L), PFOS (13 ng/L) and PFPeA (12 ng/L) (Houtz et al. 2016).

Between 2009 and 2014, average concentrations of PFOS and PFOA in effluent declined by 34 and 47 percent, respectively, but the decline in concentration was not statistically significant (Houtz et al. 2016). Other long-chain perfluoroalkyl carboxylates were largely either not detected or detected at relatively low concentrations (< 4 ng/L). Of particular interest was the statistically significant (unpaired t-test, $p<0.05$) increase of several of the short-chain chemicals, specifically PFBA, PFPeA and PFHxA, between the 2009 and 2014 studies; these compounds rose in average concentrations from 150% to 220%.

In the 2014 study, very high concentrations of PFOS, PFPeA, PFHxA, and PFHxS were observed at two WWTPs associated with airports or military bases (i.e., San Francisco Airport Industrial and Fairfield Suisun, which receives approximately 10% of its flow from the nearby Travis Air Force Base). Concentrations of PFOS in San Francisco airport effluent and in Fairfield Suisun effluent were 560 ng/l and 420 ng/L, respectively (Houtz et al. 2016). The researchers hypothesized that the high concentrations of PFOS were due to the use of AFFF, which historically contained PFOS; however, further research at the San Francisco airport

suggests elevated PFAS concentrations at that site may be associated with electroplating operations (Houtz et al. 2016). The airport has taken steps since this study to limit the release of PFASs from the use of firefighting foams (personal commercial with airport environmental team).

Perfluoroalkyl Acid Precursors

Generalization of the fate of precursors in WWTPs is challenging due to the variability of treatment and specific sources in the sewershed (Schultz et al. 2006; Sinclair and Kannan 2006). However, net increases in PFOS, PFOA and other perfluoroalkyl acids during wastewater treatment have provided strong evidence that perfluoroalkyl acid precursors significantly transform to terminal products in these systems (Lee et al. 2010; Schultz et al. 2006; Sinclair and Kannan 2006; Ye et al. 2014). For example, significant increases in PFOA in effluent in a national study of ten wastewater treatment plants were attributed to the transformation of precursors (Schultz et al. 2006b). Increases from 9 to 352% were observed at 7 of the 10 treatment plants. In contrast, at 6 of the 10 plants the concentration of PFOS significantly declined, which was attributed to the adsorption of PFOS to sludge.

The 2012 and 2014 studies detected precursors in effluent, in some instances at elevated concentrations. For example, 6:2 fluorotelomer sulfonate, an ingredient in AFFF, was detected in most of the effluent sampled, and at particularly high concentrations (greater than 200 ng/L) in the effluent from the San Francisco Airport (Houtz et al. 2016).

As part of the 2014 study, Houtz et al. (2016) subjected the effluent from the eight WWTPs to the TOP assay to determine whether the effluent contained unidentified precursors that might be transformed to perfluoroalkyl carboxylates and sulfonates in the environment. On average, the mass concentrations of perfluoroalkyl carboxylates increased 124 percent following the TOP assay (Houtz et al. 2016). The precursors transformed mainly to C6 or shorter compounds, suggesting that few of the precursors are long-chain molecules.

An important finding of the studies of both Bay Area stormwater and wastewater effluent is that a significant portion of the discharges are comprised of unidentified precursors that can transform to perfluoroalkyl carboxylates and sulfonates (Houtz and Sedlak 2012; Houtz et al. 2016). These precursors comprised upwards of 50 percent of the total PFASs identified in San Francisco Bay Area effluent and stormwater.

4.3 Other Pathways to the Bay: Groundwater, Spills and Releases, and Air Deposition

In some areas of the US, contaminated groundwater is a significant source of PFASs to humans and the environment (Moody et al. 2003; Weber et al. 2017). Much of this contamination is associated with the historical use of AFFF at sites where large amounts of petroleum products are used or stored and rapid and effective fire suppression measures are needed. Major users of AFFF include the military (29%), civil aviation (16%), fire departments (14%) and petroleum refineries (39%); in 2004, it was estimated that the total inventory of AFFF maintained on-site was 9.9 million gallons (Darwin 2004). Releases of AFFF may result in contamination of groundwater as a result of the percolation of PFAS contaminated water through soil down to the groundwater where it may be transported subsurface to the San Francisco Bay. Alternatively, spills or releases of AFFF may be transported along the ground surface to streams and rivers that

drain to the Bay. Similarly, leaking landfills and PFAS-contaminated sites have the potential to release PFASs to groundwater if significant quantities of these materials were stored/used and there is a porous conduit through soil to groundwater below.

Very little information exists on the release of PFASs to the Bay from spills and fire-fighting activities, contaminated sites, and landfills. For example, AFFF was used to contain fires associated with the Asiana Airline FL214 crash at SFO in July 2013. Based on discussions with SFO maintenance staff, efforts are made to collect the released AFFF at airports. In addition to airports, several current and former military and landfill sites are located along the shoreline of the Bay. Although military sites and landfills are known sources of PFASs (Backe et al. 2013; Houtz et al. 2013; Moody et al. 2003), the paucity of information on releases from spills, contaminated sites, and former landfills makes it challenging to assess the potential impact of these sites.

To date, two studies have been conducted evaluating PFASs in Bay Area groundwater. Stanford researchers (Plumlee et al. 2008) evaluated 10 PFASs in four groundwater wells (5 to 10 meters in depth) and three shallow push wells (< 1 meter) around Upper Silver Creek in San Jose. PFOS was detected in the highest concentrations, ranging in concentration from 19-192 ng/L in groundwater and 25-58 ng/L in the shallow push wells. PFOA was detected at lower concentrations in the groundwater wells and shallow wells, ranging from below detection limit to 22 and 10 to 28 ng/L, respectively. PFHxS, PFDS, PFDA and two PFOS precursors were detected in the wells at concentrations less than 20 ng/L. The source of the PFAS contamination was not identified, but these results suggest that groundwater may be a potential conduit for PFASs to enter the Bay.

The second study to evaluate PFASs in Bay Area groundwater was conducted by USEPA. Every five years, the USEPA conducts monitoring of drinking water supplies for a limited number of unregulated contaminants (referred to as the UCMR). During the period January 2013 through December 2015, the USEPA monitored drinking water supplies across the country for PFOS, PFOA, PFNA, PFHxS, PFHpA, and PFBS. As part of this study, one groundwater well in Pleasanton, CA was identified as having detectable PFHxS over two different time periods (2013 and 2014), at 32 and 36 ng/L. The depth of the well and the source of the PFHxS is not known. Pleasanton is approximately 20 miles to the east of San Francisco Bay. If the detection of PFHxS is due to a localized source, it is unlikely to have impacted San Francisco Bay.

Nationally, groundwater from contaminated military sites can contain much higher concentrations of PFASs, in the range of 3,000 to 14,600,00 ng/L (Moody et al. 2003; Schultz et al 2004).

In pristine environments, atmospheric deposition is thought to be an important pathway for PFASs into the environment. There are relatively few studies evaluating concentrations of PFASs in rain or other forms of atmospheric deposition; none have been conducted in the San Francisco Bay Area. Some urban areas have shown low PFOA concentrations. For example, rain collected in Albany, New York in 2006 contained a median PFOA concentration of 2.15 ng/L (Kim and Kannan 2007). Based on the limited studies to date, urban areas tend to have much higher concentrations of PFASs than rural areas (Mueller et al. 2011; Scott et al. 2006).

For example, concentrations of PFOA and PFNA in rain collected in the late 1990s in an urban area of Delaware were <0.6 to 89 ng/L and <0.1 to 77 ng/L, respectively (Scott et al. 2006). In addition, short-chain compounds such as PFBA and a number of precursors were also detected.

4.4 Loadings of PFASs to the Bay: Modeling Inputs and Ambient Concentrations

At the request of the ECWG expert panel members, a conservative tracer spreadsheet model to assess the fate of CECs in the Bay was developed (Sutton et al. 2018). This simple spreadsheet model was used as an initial means of assessing whether our current understanding of PFASs captures the majority of PFAS pathways to the Bay, and whether specific pathways or areas of concern might be identified. We selected a geographically explicit model to help us better understand possible sources of the high concentrations of PFOS in biota that reside in the Lower South Bay. The spreadsheet model developed by SFEI staff was our first foray into this arena and we anticipate further refinements. In general, the agreement between modeled and monitored results was good with the exception of the Lower South Bay. Further refinement of input data and the model may be necessary to resolve this discrepancy.

The spreadsheet model is based on the Bay Hydrodynamic Model, which takes stormwater runoff produced by the Bay Area Hydrological Model as inputs. At this time, there is limited documentation for these tools; brief descriptions of both models are provided below.

Bay Area Hydrological Model

The Bay Area Hydrological Model (BAHM) is a continuous simulation model that was developed to estimate flow and pollutant loads from Bay Area watersheds. The model is built upon HSPF (Hydrological Simulation Program--Fortran), a comprehensive package for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants. The model uses continuous rainfall and other meteorologic records to compute streamflow hydrographs and pollutant graphs across multiple pollutant sources, spatial scales, and time steps. Currently, the BAHM divides the entire Bay Area into 63 individual watersheds. The model simulation period is from 1999 to 2016.

The BAHM can be used to estimate stormwater CEC loads from individual watersheds in the region in two ways. One is to simply multiply modeled flow by existing estimates of stormwater CEC concentrations. Another more sophisticated approach is to use the BAHM to directly simulate the fate and transport of CECs in stormwater. Since this is a continuous simulation model, the results of this simulation are time histories of runoff flow rate and CEC concentrations, making it possible to detect interannual variability of CEC loads and how they change over time (trend). More importantly, the results can be fed into the Bay Hydrodynamic Model to simulate the spatial and temporal distributions of CEC concentrations in the Bay. Based on the load estimates, the watersheds that contribute disproportionately high CEC loads can be targeted for monitoring for further investigation. The data gaps identified during model development and implementation can also be used to guide other future monitoring efforts.

Bay Hydrodynamic Model

A three-dimensional hydrodynamic model of the Bay has been developed to support studies of the fate and transport of nutrients, CECs, and other pollutants. This physics-based model incorporates data for tides, Delta outflow, stormwater flows (derived from the BAHM described above), local winds, and regional wastewater and refinery discharges. Further details on the configuration and the water year 2013 validation of the model are available in the Interim Model Validation Report (Holleman et al., 2017).

Conservative Tracer Spreadsheet Model

Due to the complexity of the hydrodynamic model, it is not practical to use it directly for estimating ambient CEC concentrations across many scenarios. The simplified conservative tracer transport model is a distillation of the hydrodynamic output data into a more pragmatic spreadsheet. This spreadsheet is used to relate concentrations in water entering the Bay, whether from stormwater, wastewater or refinery discharges, to estimated ambient concentrations of contaminants in the major subembayments of the Bay. BAHM-derived stormwater input is currently limited to a single contaminant concentration for stormwater; regional variation in stormwater contamination can be added to future iterations of the model. In addition, 42 discharges are individually represented, 37 from wastewater treatment plants and five from refineries. Delta inflows are represented with a single concentration assigned to flows entering the Bay at the confluence of the Sacramento and San Joaquin Rivers.

For the present PFAS application, the hydrodynamic model was run from October 2012 to September 2013. During this period, numerical "dyes" at a nominal unit concentration were added to each discharge mentioned above, and the model predicted concentrations of these dyes throughout the Bay. The water year was divided into consecutive two-month periods, and the dilution of the numerical dyes calculated as an average over each two-month period and spatially averaged over respective sub-embayments. Each two-month period is condensed into a spreadsheet that summarizes the mathematical relationship between concentrations in load streams (i.e., concentration in stormwater and in individual wastewater or refinery discharges) and ambient concentrations in the Bay for each subembayment. This relationship reflects dilution and transport of incoming contaminant mass, assuming no other significant source or loss terms.

Using this spreadsheet requires specifying PFAS concentrations for each of the 37 wastewater discharges, the five refineries, and a representative concentration for stormwater. Note that stormwater concentrations are treated with a single value; available data suggest that there is not great variation in PFAS stormwater concentrations across watersheds in the Bay Area, but the watersheds that have been monitored are limited and may not be representative. The spreadsheet then calculates, for each region of the Bay, the sum of contributions from all inputs, providing a baseline estimate for ambient PFAS concentrations. The regions follow RMP subembayment delineations: Lower South Bay, South Bay, Central Bay, San Pablo Bay, and Suisun Bay.

Model Inputs

The spreadsheet model includes effluent and stormwater concentrations as inputs, and estimates resulting ambient concentrations at the sub-embayment scale. For purposes of determining how

well the model agrees with ambient concentrations monitored in the Bay, we have focused on three PFASs: PFOS, PFOA, and PFHxA. The effluent data were from a 2014 effluent study of eight wastewater treatment plants (Houtz et al. 2014). For the remaining wastewater inputs, the average concentrations from six of the wastewater treatment plants monitored in the 2014 study were used. Two wastewater facilities in the Houtz study had concentrations an order of magnitude higher and were not included in the average. These two facilities were excluded from the average as operations in these watersheds are believed to be somewhat unique (San Francisco Airport (SFO) wastewater treatment plant and the Fairfield Suisun plant, which receives effluent from Travis Air Force base), as discussed previously (Section 4.2 Wastewater). In addition, the flows from these facilities are relatively low (0.6 and 12 million gallons per day), so the overall load to the Bay from these plants is relatively small. The average effluent concentrations for PFOS, PFOA, and PFHxA are 13 (7 to 17 ng/L), 21 (11 to 43 ng/L), and 26 (20 to 33 ng/L), respectively (Houtz et al. 2014). These are unfiltered, total water values.

In absence of data from refineries, the average wastewater effluent concentrations were used. As a first estimate, this is not an unreasonable assumption given that many refineries, fuel depots, and airports have or have had fire-fighting foams that contain PFASs.

For stormwater, the average concentrations from a 2010/2011 study conducted of stormwater from 10 watersheds in the Bay Area were used (Houtz et al. 2012); the concentrations for PFOS, PFOA and PFHxA are 15 (2.6-26 ng/L), 7.3 (2.1-16 ng/L) and 4.5 (0.9 to 9.7 ng/L). These are unfiltered, total water values. These values are from one sampling event of 10 watersheds (Section 4.1 Stormwater) and, therefore, represent a snapshot in time. The uncertainty surrounding these values is likely to be significant.

For Delta flow, the average concentrations of two surface water grab samples collected during one storm event in 2010 were used (PFOS- 1.5, PFOA- 2, and PFHxA -1.8 ng/L). Given the volume of water from the Delta and its influence on the northern bays, it would be prudent to collect more current data, and from multiple events. These samples are also unfiltered, total water values.

Model Results and Discussion

The predicted ambient Bay concentrations from the model were compared to the ambient Bay concentrations monitored in 2009 (Appendix Table 11). Overall, the agreement between modeled and monitored results are generally quite good with the exception of the South and Lower South Bays. Given the uncertainties associated with grab samples from limited stormwater and wastewater events used in the spreadsheet model, this level of discordance might be expected.

However, it is significant that the predicted water concentrations for the Delta and for the Lower South Bay are similar for PFOS (1.4 vs 1.4 ng/L), PFOA (1.8 vs 2.4 ng/L), and PFHxA (1.6 vs 1.6 ng/L); yet the concentrations observed in wildlife in these two areas are significantly different. Concentrations of PFASs are typically an order of magnitude higher in biota from the Lower South Bay vs the Delta. For example, the 2016 median PFOS concentrations in eggs from Wheeler Island are 37.9 ng/g; the 2016 median PFOS concentration in the Lower South

Bay is 639 ng/g. This discrepancy suggests that we may be missing sources or pathways that are significant for biota.

Some of the discrepancy between modeled and observed concentrations may be attributed to limited input data. There is a slight offset for the dates of the effluent collection and Bay water and stormwater monitoring data. Input data for wastewater effluent were from the most recent 2014 sampling event; the ambient Bay data were from a 2009 event, and the stormwater samples were collected in 2009-2010. There is one set of effluent values from 2009; however, this data set is reported as an aggregate (one value) from one set of grab samples. We are concerned that using one value to characterize effluent from 40 plus facilities may not be appropriate. In addition, fewer facilities participated in the 2009 study so the average is not as robust. Lastly, the 2014 study included some of the largest dischargers into the Bay and therefore, better reflects loads into the Bay.

Houtz et al. (2014) observed a decrease in average effluent concentrations for PFOS and PFOA from 2009 to 2014, so ambient Bay concentrations modeled using wastewater inputs from 2014 would be expected to be lower than the measured Bay concentrations; this is generally the case with the exception of the Lower South Bay and South Bay. Houtz et al. (2014) also observed a statistically significant increase in average PFHxA effluent concentrations from 2009 to 2014 (17 ng/L to 26 ng/L) the modeled concentrations using 2014 wastewater data would be expected to be higher than the 2009 monitored ambient Bay concentrations for this contaminant, which is not the case.

Available stormwater input data, obtained during the 2010/2011 wet season, also merit further scrutiny. Data were obtained from an independent study of 10 watersheds, which may not be representative of overall stormwater inputs to the Bay. It is also likely that the simplification of the stormwater inputs in the model using a single concentration for all streams does not reflect the multitude of differing contaminant concentrations from different watersheds through the Bay Area. Given the change in the observed concentrations of PFASs in effluent over time, it is possible that stormwater concentrations and analytes may have changed as well. As noted previously, phase-out of PFOS, PFOA, and long-chain perfluorocarboxylates has led to manufacturing shifts to short-chain perfluorocarboxylates and polyfluoroalkyl substances. While effluent data generally reflect this shift in current uses and sources, it is unknown whether stormwater would also respond as quickly to these changes. Further monitoring of stormwater is suggested to improve the conceptual understanding and predictive modeling of PFASs in the Bay.

In addition to input data, the structural limitation of the spreadsheet model may also contribute to the discrepancy in results. The spreadsheet model has been optimized for pollutants that are persistent and water-soluble. Degradation over time, sorption to sediment, and exchange with the atmosphere are not currently included in the model. The modeled compounds, PFOS, PFOA and PFHxA, do not undergo degradation. However, some of the other model assumptions may be less well-suited to PFASs. Although the model assumes that all contaminants remain dissolved, based on Bay sediment monitoring and independent partitioning studies, we know that PFASs can and do partition to sediments. The partition coefficients vary by compound; for example, based on partition coefficients, PFOA is more likely to partition into water than PFOS (log K_{oc}

2.11 vs. 2.68, Higgins and Luthy 2006). As a result, the model may over-predict the concentrations in the ambient Bay, as the model does not account for partitioning behavior. In addition, some PFASs, such as the fluorotelomer alcohols, are quite volatile and can be transported via the atmosphere, depositing later and transforming to perfluorocarboxylates such as PFOA. This pathway has not been evaluated for the Bay.

The spreadsheet model has other limitations that are less likely to be leading sources of error at this stage. As discussed in Holleman (2017), the hydrodynamic model has less predictive skill and may under represent flushing near the Delta. There is also an assumption in the spreadsheet model that contaminant concentrations do not vary significantly on time scales shorter than the residence time of the various sub-embayments (e.g., up to several months in South Bay). While the two-month analysis periods do reflect seasonal variability in the flows, results related to highly variable incoming concentrations should be interpreted cautiously.

To improve model performance, further refinement of input data and the model are needed. It may be warranted to collect additional stormwater data to provide a more robust characterization of Bay Area watersheds. In addition, several assumptions associated with the model could be improved including: incorporating air deposition, sediment-water partitioning and/or multiple stormwater sources.

5.0 Past and Future Trends in Contamination

5.1 Trends of PFASs in Abiotic Media

While the RMP has monitored Bay sediment, water, stormwater, and wastewater discharges, only wastewater has been monitored with sufficient frequency and consistency to discuss temporal trends.

5.1.1 Wastewater

While effluent data are limited, there is some indication of changes in concentration over time among long-chain PFASs, including PFOS, PFOA, and PFNA, as well as short-chain PFASs including PFBA and PFHxA (Figure 12).

Between 2009 and 2014, average concentrations of PFOS and PFOA in effluent declined by 34% and 47%, respectively (Houtz et al. 2016); these trends were not statistically significant due to the considerable variation observed among plants in 2009. In addition, water restrictions in place during an extended drought period may have resulted in generally higher levels of effluent contaminants in 2014. However, the trends are consistent with production phase-outs and shifts in the market.

During the same period, there was a statistically significant increase in the short-chain perfluorinated carboxylates, specifically PFBA and PFHxA (Houtz et al. 2016). The increase in these C4 and C6 chemicals is attributed to increased production of short chain PFASs, including short chain precursors (Wang et al. 2010).

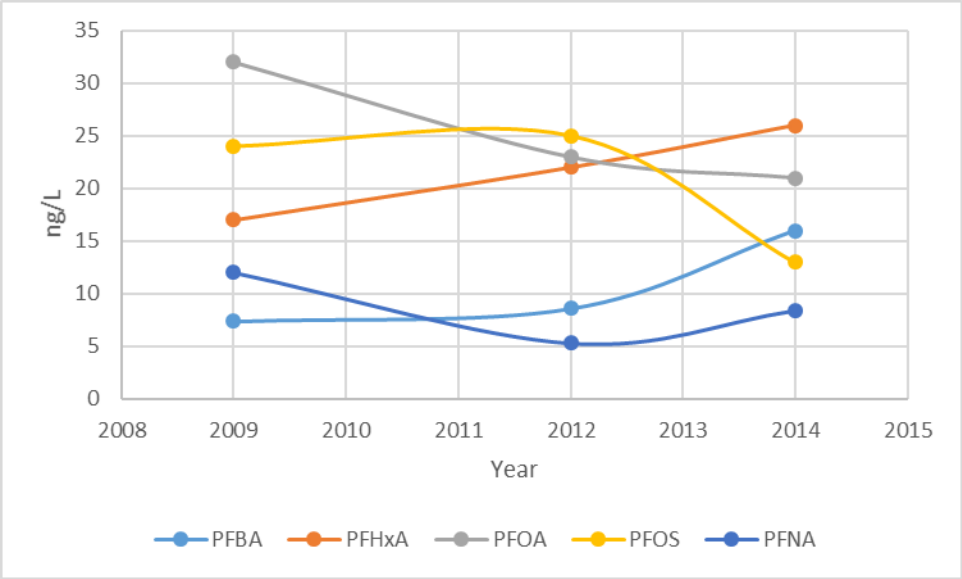

Figure 12 Trends in Averages of Select PFASs in Wastewater Effluent. Six WWTPs were sampled in 2009; three in 2012; six in 2014. Source: Houtz et al. 2016 and Sedlak et al. 2017.

5.2 Trends of PFASs in San Francisco Bay Biota

The monitoring of seal blood and cormorant eggs has been a high priority for the RMP, in part because the concentrations of PFOS in these matrices have been some of the highest observed globally. Sufficient data now exist for these matrices to evaluate temporal trends in contamination.

Monitoring of sport fish has also been a priority due to the potential for human exposure via consumption; however, at present, there are too few data to discern temporal trends.

Concentrations of the perfluoroalkyl carboxylates in cormorant eggs and seals do not show statistically significant trends. The variation observed may be a function of proximity to localized sources with the South Bay generally having the highest concentrations. The South Bay has limited flushing and a wide variety of potential sources such as airports, former military facilities, former landfills, wastewater treatment facilities and urban creeks. In addition, increasing levels of perfluoroalkyl carboxylates in other regions has been attributed to the on-going use of precursors that can degrade to perfluoroalkyl carboxylates (Gauthier and Mabury 2005; Lee et al. 2010; Rankin et al. 2014; Wang et al. 2011).

5.2.1 Declining PFOS Concentrations in Cormorant Eggs

In recent years, a decline in PFOS in South Bay cormorant eggs has been documented. PFOS concentrations in South Bay eggs did not change appreciably between 2006 and 2009 (geometric means of 1230 and 1190 ng/g, respectively, (Sedlak et al. 2017)) (Figure 13). However, in 2012 and 2016, PFOS concentrations in eggs were considerably lower, 381 ng/g and 620 ng/g ww, respectively. Using a one-sided Wilcox rank sum statistical analysis, a comparison of the earlier

sampling periods 2006/2009 to the later sampling periods 2012/2016 was found to be statistically significant ($p<0.01$). Eggs collected from the Richmond Bridge and Wheeler Island sites show no discernible change in PFOS concentration over time.

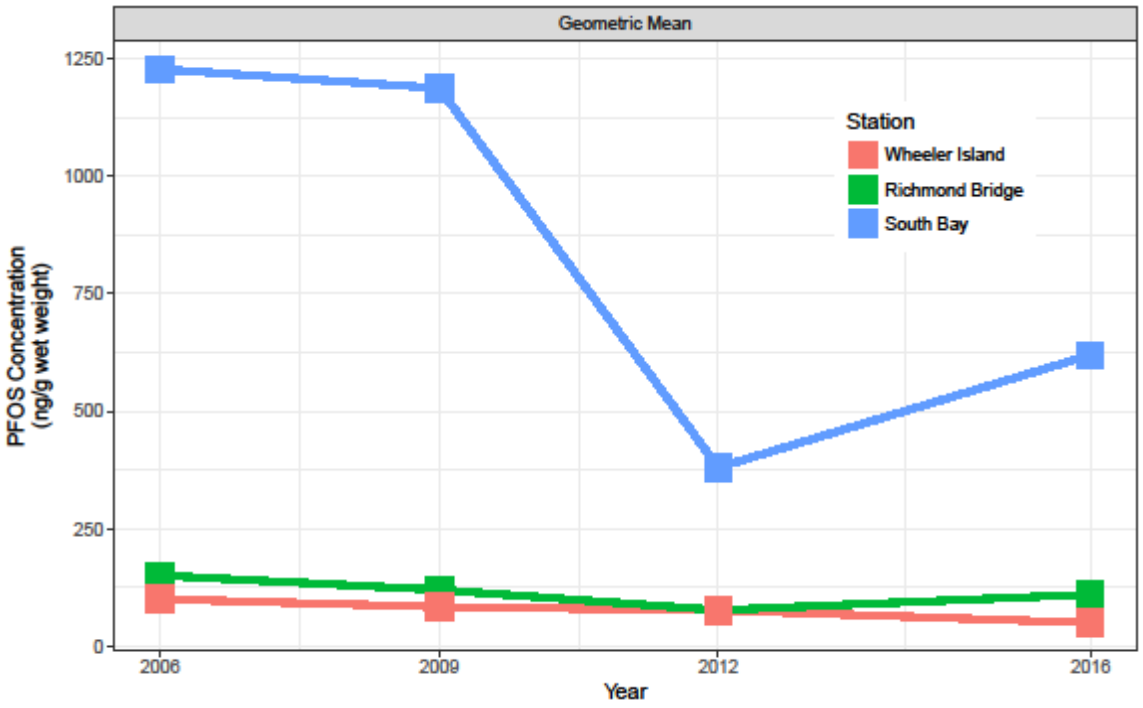

Figure 13 Trends in PFOS Concentrations in Bird Eggs

While the current data suggests a decline in PFOS levels in South Bay bird eggs, it is not uncommon to see interannual variation in contaminants in the Bay food web. Shifts in foraging areas or in prey species availability are two factors that could drive such variation. Of particular interest are the increases in PFOS concentrations in the South Bay and Richmond Bridge eggs from 2012 to 2016. The South Bay and Richmond Bridge sites are in close proximity to a number of potential sources including airports, wastewater treatment plants and significant urban stormwater discharges, all of which are likely to influence biota. It is possible that the recent five-year drought and the initiation of significant water restrictions and water recycling may have enhanced the concentrations of PFOS precursors being discharged into the South Bay and taken up into the food web. As noted above, the concentrations of PFOS in effluent were lower in 2014 as compared to prior years.

In some parts of the world, the decline in PFOS concentrations in eggs has been quite dramatic. For example, Guillemot eggs collected in the Baltic region showed a rapid increase in PFOS from 1968 to 1997 (1,324 ± ng/g ww) followed by a decline in 2003 (614 ng/g ww) (Holmstrom et al. 2005).

In other areas where there were significant industrial sources, the decline occurred more slowly or not at all. An approximately 60% decline in PFOS was observed when comparing Great Blue Heron (*Ardea herodias*) eggs collected near a 3M manufacturing site in St. Paul, Minnesota from 1993 to 2010 to 2011; this decline was attributed to the phase-out of PFOS (Custer et al., 2013). This 3M site has manufactured PFOA, PFOS, PFBS, and other PFASs. No trends were observed in PFOS concentrations in Baltic white-tailed sea eagles (*Haliaeetus albicilla*) from 2000 to 2010, which was attributed to the slow flushing of the Baltic Sea and the potential for on-going inputs (Faxneld et al. 2016).

5.2.2 Declining PFOS Concentrations in Seals

The decline in PFOS in seals has been significant over the last several years. PFOS concentrations declined significantly in the Central Bay seals between samples collected from 2004 to 2008 and those collected from 2009 to 2011 (56.8 to 199 ng/g geometric mean, respectively; Figure 10) (Sedlak et al 2017). In the South Bay, concentrations began to decline in the most recent 2014 sampling event, when they showed a statistically significant decline of over 70%, from 708 ng/g to 184 ng/g (geometric mean, 1-sided Dunn's Test, Bonferroni adjustment for multiple comparisons $p < 0.05$, Sedlak et al. 2017). As noted previously, concentrations of contaminants in Bay biota frequently fluctuate, due to a number of factors. Additional monitoring of seals would be prudent to confirm this possible trend.

PFOS in seals has shown a more rapid decline in other locations globally, which is frequently attributed to the phase-out of PFOS and related compounds in the early 2000s. In the Arctic and Greenland, concentration of PFOS in seals (livers, which accumulate PFASs similarly to blood; Ahrens et al 2009) peaked in 2005 - 2006 period and declined significantly thereafter (Butt et al. 2007; Riget et al. 2013). In Norwegian seals, PFOS concentrations in blood declined from a high in 2004 to the most recent sampling in 2010 (Routti et al. 2016).

It is likely that there is continued exposure to PFOS in the South Bay, due to the longer hydraulic residence time of this embayment, the potential for sediment to serve as an on-going source of both PFOS and its precursors, the continued use of residential, commercial or industrial products that may still contain PFOS or its precursors, and/or as-yet unidentified contaminant sources to the region. While current data suggest concentrations of PFOS in Bay Area apex predators are declining, consistent with trends observed elsewhere, continued monitoring will be essential for assessing these trends.

5.3 Anticipated Future Trends

5.3.1 Continued Detection of Perfluoroalkyl Carboxylates and Sulfonates

PFOS

The major US manufacturer phased out production of PFOS in 2002. Fifteen years later, this persistent contaminant continues to be detected in San Francisco Bay sediment and biota; however, the most recent sampling suggests that the concentrations of PFOS may be declining in seals and bird eggs, particularly in the more contaminated South Bay. Continued monitoring will be necessary to confirm this anticipated trend.

In addition, the most recent wastewater treatment plant effluent sampling in 2014 suggests a decline in PFOS. Stormwater was monitored in the winter of 2010 to 2011, and at that time, concentrations were comparable to wastewater effluent (Houtz et al 2012). Additional stormwater monitoring is needed to evaluate whether similar trends are occurring in stormwater.

A nationwide phase-out of production of a compound of concern is a decisive management action designed to reduce human and environmental exposures. However, a phase-out does not immediately eradicate all sources of contamination. PFOS may be found in products imported from other countries, in older products still in use, in the waste stream, and in large reservoirs such as sediment. It is noteworthy that PFOS continues to be detected in effluent, suggesting either current sources or significant reservoirs of historic material. PFOS, PFOA, and other PFASs continue to be detected in many consumer products currently in use. Food contact paper such as dessert and bakery wrapping paper, fast food wrappers and paperboard has recently been shown to be a surprisingly high source of PFASs (Schaider et al. 2016). PFASs are also present on imported articles such as textiles, outdoor gear, and footwear (Green Peace 2016; van de Veen 2017).

Because a portion of PFOS partitions to sediment, the Bay bottom must be considered an important potential reservoir of this contaminant to the food chain. PFOS precursors, while found at much lower levels in sediment, are expected to degrade to PFOS, acting as a small but continuing source of contamination. Therefore, declines in PFOS are expected to continue in the apex predators, but at a relatively slow pace.

PFOA and Long-chain Perfluoroalkyl Carboxylates

A number of regulatory actions have been undertaken to restrict the use of PFOA and long-chain perfluoroalkyl carboxylates in the US. In 2006, USEPA implemented a voluntary program with the major manufacturers to phase-out PFOA by 2015. Final reports from the program showed that participating US companies met these goals. However, production of PFOA has increased in other countries.

With this regulatory gap, a concern remains that the trend for PFOA and long-chain carboxylates is likely to remain relatively constant. Some studies of these long-chain compounds in humans globally have shown declines (Yeung et al. 2013); others have not shown (Scheringer et al. 2014). We anticipate that it will take at least a decade if not longer to show significant declines in PFOA and the long-chain carboxylates.

Short-chain Perfluoroalkyl Substances

A significant number of short-chain compounds such as PFBS, PFBA, and PFHxA have shown an increase in effluent over time. Based on the substitution of these short-chains and the increased detection of these compounds in effluent, we would expect to see similar increases in stormwater, water and sediment. As shown on Table 1 (Appendix), the elimination half-lives in humans and biota of these compounds are relatively short in comparison to PFOS and PFOA; as a result, they are not detected in biota such as fish, bird eggs, and seals. The lack of bioaccumulation, however, does not mean that these contaminants do not pose a risk.

5.3.2 Expanding Number of Unknown Alternatives

Through regulatory controls and voluntary guidelines, industries in North America and Europe are phasing out the use of C8 chemistry. Very little information is available on the alternatives that are being used (e.g., chemical structure, physical characteristics, toxicity, and production). From the available literature in the public domain, it is believed that manufacturers are primarily switching to two types of alternatives: 1) shorter versions of the long-chain compounds, such as PFBA (C4) or PFBS (C4); or 2) polyfluorinated ethers, which are essentially perfluoroalkyl carboxylates or sulfonates with an oxygen substituted into the chain, such as F-53 (Wang et al 2015).

Given the similarity in structure and preliminary testing conducted to date, researchers believe that these compounds will exhibit similar toxicological responses, physical/chemical characteristics, and environmental persistence as the long-chain compounds they are replacing (Liu et al. 2017; Scheringer et al. 2014; Strynar et al. 2015; Wang et al. 2015). In addition, the short-chain compounds may be less effective in some applications; as a result, it is believed that greater quantities will be needed to provide similar performance to the C8 chemicals (Schering et al 2014).

The short-chain alternatives are typically used to replace the long-chain PFASs used in surface treatments of textiles, leather, and carpets (Wang et al. 2013). While the short-chain compounds are touted as less toxic, there is insufficient information to evaluate whether this is true, particularly for environmental conditions (Wang et al 2015). For example, preliminary toxicity tests suggest that PFHxA is more toxic than PFOA for three aquatic species (Wang et al. 2015). These compounds are more mobile in soil due to lower sorption potential to sediment/particles (Wang et al. 2015), and have shorter break through times through granular activated carbon, one of the more successful removal treatments of PFAS contaminated water. Short-chain PFASs are less bioaccumulative (Wang et al. 2013); however, they are more easily taken up by plants (Blaine et al. 2013).

Perfluorinated and polyfluorinated ethers are believed to be the likely alternatives for the long-chain PFASs used in applications such as the manufacture of fluoropolymers (Strynar et al 2015). GenX and ADONA, polyfluorinated ethers, are used as alternatives to PFOA in the manufacture of fluoropolymers such as polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF). Alternatives to the long-chain perfluoroalkyl sulfonates such as PFOS are perfluoropolyethers such as F-53, and F-53B (Wang et al. 2015); these compounds are used as mist suppressants in metal plating operations, among other applications (Liu et al 2017). The perfluoropolyethers and polyfluorinated ethers are resistant to degradation and classified as persistent (Wang et al. 2015). Of concern is the recent detection of polyfluorinated ethers in the environment, particularly drinking water supplies (Strynar et al. 2012; Sun et al. 2016).

Other alternatives used for surface treatment include polyfluoroalkyl alcohols, polyperfluoroethers, and perfluorohexane sulfonyl fluoride, which readily degrade to PFHxS in the environment (Wang et al. 2013). In addition, manufacturers are substituting the shorter fluorotelomer alcohols such as the 6:2 fluorotelomer alcohols in surface treatment of food

contact materials (Wang et al. 2013). It is well established that fluorotelomer alcohols can degrade to the perfluoroalkyl carboxylates in the environment.

Given the diversity in anticipated alternative chemistries and the lack of public information about the specific compounds used in different applications, it is difficult to predict a suite of essential target analytes *a priori* for future Special Studies. In this situation, two differing analytical methods may be helpful.

First, the TOP assay quantifies concentrations of precursors that may degrade to the more recalcitrant perfluoroalkyl sulfonates and perfluoroalkyl carboxylates. This method has been used effectively to quantify precursors in Bay Area stormwater and wastewater. As described above, a significant portion of the total PFAS present is in the form of unidentified precursors. This method will be useful for evaluating the potential that new alternatives are degrading to the perfluoroalkyl sulfonates and carboxylates. The TOP assay has been developed for commercial application by laboratories such as SGS AXYS Analytical. In addition, several government agencies are using the TOP assay for regulatory purposes. In Australia, the TOP assay is required to certify AFFF foams.

Second, novel non-targeted methods using mass spectrometers and high intensity data analyses have proven useful in identifying a wide range of compounds present in samples. This approach successfully identified 40 new classes of PFASs in groundwater contaminated by AFFF (Barzen-Hanson et al. 2017). In total, 240 individual PFASs were identified in AFFF and AFFF-contaminated groundwater. More relevant to the work proposed here, a study of firefighters in Australia found several new PFOS-like PFASs in human serum (Rotander et al. 2015).

In San Francisco Bay, recommended matrices for the TOP assay and non-targeted analysis include margin sediment and harbor seals. Margin sediment is an appealing matrix for identifying contaminants derived from current uses, as it is located close to sources and pathways and is more likely to be depositional. While PFASs are typically water soluble, they also typically have moderate affinity for particles, such that their presence would be expected in sediment. Harbor seals are apex predators with relatively good site fidelity that provide an integration of risks to high trophic consumers.

6.0 CEC Strategy: Classification of PFASs in the Tiered Risk Framework

The RMP has articulated a strategy for the approach to evaluating and prioritizing chemicals of emerging concern (CECs) to monitor (Sutton et al. 2017). For those chemicals for which monitoring in the Bay has occurred, a risk-based method has been developed for classifying chemicals. These classifications are described briefly below and in more detail in the CEC Strategy document (Sutton et al. 2017):

- High Concern - Bay occurrence data suggests a high probability of moderate or high level effect on Bay wildlife (e.g., frequent detection at concentrations greater than the EC_{10}, the effect concentration where 10% of the population exhibit a response or another effects threshold).

- Moderate Concern – Bay occurrence data suggest a high probability of a low level effect on Bay wildlife (e.g., frequent detection at concentrations greater than the PNEC or NOEC but less than EC_{10} or another low level effects threshold).
- Low Concern – Bay occurrence data suggest a high probability of no effect on Bay wildlife (i.e., Bay concentrations are well below toxicity thresholds and potential toxicity to wildlife is sufficiently characterized).
- Possible Concern – Uncertainty in measured Bay concentrations or toxicity thresholds suggest uncertainty in the level of effect on Bay wildlife.

To date, PFOS has been classified as a moderate concern emerging contaminant based on exceedances of risk thresholds for PFOS in Bay Area bird eggs. The remaining PFASs detected in Bay matrices were classified as possible concerns based on uncertainty associated with toxicity thresholds.

Given the frequent of detection of PFOS together with PFOA and the many deleterious health impacts associated with PFOA, it seems prudent to consider re-classifying PFOA. In addition, given the similar modes of actions of the other long-chain perfluoroalkyl carboxylates and their continued detection in seals and bird eggs, these long-chain compounds should also be reclassified. The similarity of the structures of the short-chain perfluorinated compounds to the long-chain compound suggests that these compounds may have similar toxicological properties; however, there is virtually no environmental toxicity data, resulting in a high degree of uncertainty regarding the classification of the short-chain compounds. An even greater degree of uncertainty exists as to the toxicity of the precursor compounds previously examined in Bay matrices.

6.1 Recommendation for PFOS (maintain as moderate concern)

PFOS levels appear to be declining in seals and bird eggs; nonetheless, we recommend that PFOS remains classified as a moderate concern based on the continued presence of PFOS in South Bay birds above concentrations that have been shown to adversely impact hatching success of tree swallows (*Tachycineta bicolor*). In addition, concentrations in sport fish in the Lower South Bay indicate a possible concern for people eating high fish diets. Furthermore, based on limited studies of Lake Baikal seals and other studies, there is some concern for adverse effects to seals. Lastly, the concentration of PFOS in prey fish exceed Canadian draft guidelines for possible risks to mammals and birds.

6.2 Recommendation for long-chain perfluoroalkyl carboxylates (moderate concern)

The rationale for including PFOA and other long-chain perfluoroalkyl carboxylates as moderate concern emerging contaminants is based on the pervasive detection of these compounds in biota, the knowledge that these compounds do not degrade under environmental conditions, and the identification of adverse responses in other mammalian systems at concentrations observed in Bay seals. In addition, it is noted that the EU and USEPA have targeted the long-chained perfluoroalkyl carboxylates for management actions.

PFOA and long-chain perfluoroalkyl carboxylates (greater than C7) have been detected in Bay Area bird eggs and seals. These compounds are generally an order of magnitude lower than PFOS concentration (Sedlak and Greig 2012; Sedlak et al. 2017). However, unlike PFOS,

concentrations of PFOA, PFNA, PFDA, PFUnDA, and PFDoDA are not showing signs of decline (Sedlak et al. 2017). In addition, in the most recent sport fish sampling (2014), several long-chain PFASs such as PFDA, PFUnDA and PFDoDA were detected for the first time. The continued presence of these long-chain compounds suggests current sources and/or the production from historical long-chain precursors.

Few studies have developed toxicological thresholds that are relevant to Bay species. As described above, Ishibashi and colleagues (2009b) identified the induction of the peroxisome proliferator receptor *in vitro* in seals using high concentrations of PFOA, PFNA, PFDA, PFUnDA and PFOS (µg/g range); the researchers noted that wild seals with much lower concentrations of PFNA (in the range of 3-72 ng/g) and PFDA (0.5 to 35 ng/g) in liver also exhibited induction of the peroxisome proliferator receptor, suggesting that this may occur at environmental concentrations (Ishibashi et al 2009 b). It is difficult to compare liver concentrations to blood concentrations; however, the total average PFAS concentrations observed in Baikal seal serum was 14 ng/g and 11 ng/g in male and female seals, respectively and are in the lower range of concentrations detected in Bay seals.

PFOA has been extensively studied in another mammalian species: humans. In humans, PFOA is associated with a myriad of observed health effects including a reduction in birth weights and suppression of immune responses. These effects are observed at concentrations in blood that are similar to those observed in Bay seals. As described above, Grandjean et al. (2015) suggests a human serum reference dose concentration for PFOA of 0.8 ng/mL, which many Bay seals exceed. Lacking data specific to seals, an argument can be made that toxicity studies on other mammals must be considered as a precautionary means of assessing potential risks.

It should also be noted that PFOA has been classified as a possible human carcinogen (Group 2B) by the International Agency for Research on Cancer, and both PFOS and PFOA are being considered for listing under Proposition 65 based on their reproductive toxicity.

The rationale for including the remaining long-chain perfluoroalkyl carboxylates is based upon studies that suggest that these compounds exhibit similar toxicological endpoints as PFOS and PFOA and are more bioaccumulative. There are very limited studies of the effects of the long-chain perfluoroalkyl carboxylates on wildlife and the results are conflicting. In laboratory studies using high concentrations (µg/L) and model fish, PFNA was found to cause adverse impacts to the fish reproductive systems including reduced egg production and decreased hatching rates (Zhang et al. 2016). In a laboratory egg injection study of chickens evaluating PFOA, PFUDA and a long-chained sulfonate, the researchers concluded that these compounds were unlikely to adversely impact hatching success (O'Brien et al. 2009b).

6.3 Recommendation for other PFASs (possible concern)

For the remaining PFASs observed in the San Francisco Bay Area, there are limited data to evaluate the toxicity of these compounds to Bay biota. The short-chain perfluoroalkyl substances such as PFBS, PFBA, and PFHxA are currently being used as alternatives to PFOS and PFOA; however, there is very little information on their toxicity. Much of this information consists of laboratory studies conducted at high concentrations of species that are not relevant to the Bay. In one study, PFHxA was identified as more toxic than PFOA in three aquatic species

suggesting that these compounds should be classified in the same tier as PFOA (Wang et al 2015).

Based on the Bay Area monitoring that has been conducted to date, it is certainly true that these compounds appear to be less bioaccumulative, with low to non-detect concentrations observed in bird eggs, seals, and fish, despite the significant increases in concentrations of these compounds observed in wastewater effluent over time (Houtz et al. 2016).

At the present time, insufficient information exists to evaluate whether the perfluoroalkyl acid precursors and other PFASs that have been sporadically detected in the Bay present a hazard.

7.0 PFAS Monitoring and Management Strategy

7.1 Monitoring Strategy

Based on the data collected to date, we recommend a three-element monitoring strategy for PFASs that includes: 1) a continuation of Status and Trends monitoring of PFOS and related perfluoroalkyl substances in key matrices; 2) a Special Study that examines margin sediment and harbor seals using non-targeted mass spectrometry and TOP assay methods to identify known and unknown PFASs in the Bay environment; and 3) an analysis of PFASs in stormwater, essential for determining loads and trends.

First, we recommend that the following Status and Trends matrices continue to be monitored for PFOS and PFOA as well as the eleven other PFASs routinely measured simultaneously by many analytical laboratories (at no additional charge): cormorant eggs and sport fish. Bird egg and sport fish monitoring occur every three and five years, respectively as part of the RMP Status and Trends program. The continued monitoring at the current cormorant nesting areas will provide a good representation of spatial distribution. In addition, the repeat sampling every three years at these sites allows for statistical evaluations of trends.

We recommend that three fish species be targeted for PFAS analyses and that sample size of each of these species be increased to provide a more robust data set for statistical analyses. We also recommend that Artesian Slough be included in the sport fish monitoring.

Second, we recommend a special study using advanced techniques including non-targeted and TOP assay methods to identify PFASs not normally monitored via Status and Trends studies. One of the major challenges associated with monitoring this class of compounds is the daunting number of PFASs that are currently in use, of which only a handful are known to the public. The existing RMP suite of PFAS analyses covers some of the short-chain alternatives that are being used (e.g., PFBS, PFBA and PFHxA). However, there are a number of new alternatives identified in the environment, such as GenX, ADONA, and F-53B, which are currently not monitored in the Bay. As shown in Bay Area studies, stormwater and effluent may contain upwards of 50 percent unknown PFASs, which may include these new alternatives and others as-yet unidentified.

Given these challenges, non-targeted and TOP assay methods are recommended. The TOP assay provides information on which precursors are likely to transform over time to the perfluoroalkyl carboxylates (e.g., PFOA, etc.). While it does not identify specific precursors, it permits an assessment of the overall levels of persistent perfluoroalkyl carboxylates and sulfonates that will form in a matrix following complete transformation to terminal products; such information is essential for evaluating the risks to biota.

It is recommended that the TOP assay be coupled with non-targeted methods using high-resolution liquid chromatography quadrupole time-of-flight mass spectrometry (LC-QToF-MS) to identify a much broader suite of PFASs, including potential perfluoroalkyl acid precursors. This approach successfully identified 40 new classes of PFASs in groundwater contaminated by AFFF (Barzen-Hanson et al. 2017). In total, 240 individual PFASs were identified in AFFF and AFFF-contaminated groundwater. More relevant to the work proposed here, a study of firefighters in Australia found several new PFOS-like PFASs in human serum (Rotander et al. 2015). Non-targeted methods will provide a more comprehensive picture of the PFASs present, although for a subset of signals we may be able to identify chemical families or key functional groups but may not be able to identify the exact structures. The advantage of using both techniques is the TOP assay will indicate the quantitative amount of total perfluoroalkyl acid precursors present in a sample while nontargeted analysis will provide confirmation that we are not missing PFASs that may not degrade but are nonetheless of concern.

Two matrices are proposed for study, harbor seals and margin sediment. Harbor seal monitoring will require a special study that involves live capture to monitor the current health of the population. We recommend that the current locations continue to be monitored: South Bay, Central Bay and Tomales. Depending on the findings, it would be particularly valuable to conduct this type of study on a more routine basis to assess trends.

In addition to monitoring biota, it will be important to assess trends in abiotic media. Of particular interest is an evaluation of margin sediments, which typically have the highest contaminant concentrations due to the proximity to sources and are also important habitats for foraging, breeding and nurturing young. With the exception of the most recent sediment sampling conducted in 2014, the sediment sampling conducted to date has consisted largely of a handful of grab sediment samples that have been collected on an infrequent basis.

Should sampling be repeated in future years, comparison of trends observed in sediments and seals will be instructive for seeing the impacts of management actions on PFOS and PFOA, assessing trends in seals and sediments, and ascertaining the reservoirs of PFASs in sediment. In particular, the combination of TOP assay and non-targeted methods can provide information about whether the declines observed in PFOS in biota are consistent across the class of compounds or whether there is merely a substitution from one type of subclass, such as PFOS/PFOA, to another, such as GenX or ADONA.

Third, we recommend a special study of stormwater to assess PFAS presence and trends, ideally using non-targeted and TOP assay methods. In wastewater effluent, a shift in the patterns of PFAS contamination was observed over time, with signs of a decline in PFOS and PFOA concentrations and a statistically significant increase in the concentrations of short-chain

compounds. Previous study suggests that there is a significant percentage of unidentified compounds in stormwater (Houtz and Sedlak 2012); however, we do not know what these contaminants are, nor do we have sufficient data to assess the trends in stormwater. This information will be particularly relevant for calculations of loads to the Bay.

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APPENDIX

Table 1 Half-lives of Select PFASs

	C4		C6		C8			Alternatives		
	PFBA	**PFBS**	**PFHxA**	**PFHxS**	**PFOA**	**PFOS**	**PFOSA**	**GenX**	**ADONA**	**Source**
Humans	75 h			8.5 yrs	3.8 yrs	5.4 yrs				Olsen, Burris, Ehresman Froehlich, EHP 2007 Sept aa(9) 1298-305; Chang SC Toxicol Sci 2008
		25.8 days								Olsen in Polyfluorinated Chemicals and Transformation Products. Thomas P Knepper and Frank T. Lange (editors)
	74.6 hrs									Chang SC Toxicol Sci 2008
Carp						8 days	6.9 days			Cheng et al 2015
Rainbow trout						16.9 days	6.0 days			Brandsma et al . 2011
Monkeys	1.7 days	3.5 - 4 day	0.81-1.45 days	87-141 days	20.9-32.6 days	110-132 days				Summarized in Lau C Toxciol Sci 2007
Rats	1-9 h		1.2-2.4 h		2 h - 6 d	100 d		<12 h		Chang SC Toxicol Sci 2008; Ohmori K Toxicol 2003; Lau C Toxicol Sci 2007; Wang Z Environ Intern 2015 (from European Chemicals Agency Registered Substances)
Mice	3-16 h		<72 h		17 - 19 d			>12 h, <7 d		Chang SC Toxicol Sci 2008; Iwai H Drug Chem Toxicol 2011; Lau C Toxicol Sci 2007; Wang Z Environ Intern 2015 (from European Chemical Agency Registered Substances)
Rabbit					7 h					Lau C Toxicol Sci 2007 (from Hundley 2006)
Dog					8-30 d					Lau C Toxicol Sci 2007 (from Hanhijarvi 1982)

Table 2a. Open water PFAS Concentrations (ng/L)

Year	Station	Group	Region	PFBA		PFBS		PFPA		PFHxA		PFHxS		PFHpA	
				Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2009	Suisun Bay	Ambient	Suisun Bay	-	1	-	2.01	-	1	-	1	-	2.01	-	1
2009	San Pablo Bay	Ambient	San Pablo Bay	-	0.998	-	2	-	0.998	-	0.998	-	2	-	0.998
2009	Central Bay	Ambient	Central Bay	-	0.977	-	1.95	-	0.977	-	0.977	-	1.95	-	0.977
2009	San Leandro Bay	Margins	Central Bay	-	0.974	-	1.95	1.37	0.974	1.82	0.974	2.11	1.95	-	0.974
2009	Eden Landing	Margins	South Bay	2.59	0.995	-	1.99	1.65	0.995	3.14	0.995	2.3	1.99	1.67	0.995
2009	Foster City	Margins	South Bay	-	0.978	-	1.96	-	0.978	2.52	0.978	-	1.96	1.48	0.978
2009	South Bay	Ambient	South Bay	-	0.981	-	1.96	1.34	0.981	1.6	0.981	-	1.96	1.03	0.981
2009	Lower South Bay	Ambient	Lower South Bay	3.02	0.99	-	1.98	2.54	0.99	3.74	0.99	2.65	1.98	2.35	0.99
2009	Cooley Landing	Margins	Cooley Landing	62.2	1.18	7.89	1.97	151	0.987	221	0.987	12.6	1.97	66.8	0.987
2010	Richmond (Breuner Marsh)	Margins	San Pablo Bay	-	0.991	-	1.98	1.04	0.991	1.37	0.991	-	2.02	-	0.991

Year	Station	Group	Region	PFOA		PFOS		PFOSA		PFNA		PFDA		PFUnDA		PFDoDA	
				Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2009	Suisun Bay	Ambient	Suisun Bay	1.38	1	-	2.01	-	1	1.03	1	-	1	-	1	-	1
2009	San Pablo Bay	Ambient	San Pablo Bay	-	0.998	-	2	-	0.998	-	0.998	-	0.998	-	0.998	-	0.998
2009	Central Bay	Ambient	Central Bay	-	0.977	-	1.95	-	0.977	-	0.977	-	0.977	-	0.977	-	0.977
2009	San Leandro Bay	Margins	Central Bay	3.68	0.974	2.37	1.95	-	0.974	-	0.974	-	0.974	-	0.974	-	0.974
2009	Eden Landing	Margins	South Bay	6.76	0.995	6.49	1.99	-	0.995	1.39	0.995	-	0.995	-	0.995	-	0.995
2009	Foster City	Margins	South Bay	4.21	0.978	5.7	1.96	-	0.978	0.995	0.978	-	0.978	-	0.978	-	0.978
2009	South Bay	Ambient	South Bay	2.97	0.981	2.93	1.96	-	0.981	-	0.981	-	0.981	-	0.981	-	0.981
2009	Lower South Bay	Ambient	Lower South Bay	8.62	0.99	6.25	1.98	-	0.99	2.44	0.99	-	0.99	-	0.99	-	0.99
2009	Cooley Landing	Margins	Cooley Landing	75.6	0.987	44.3	1.97	-	0.987	15.1	0.987	11.6	0.987	1.38	0.987	-	0.987
2010	Richmond (Breuner Marsh)	Margins	San Pablo Bay	2.02	0.991	-	1.98	-	0.991	-	0.991	-	0.991	-	0.991	-	0.991

Table 2b. Open water Precursor concentrations (ng/L)

Year	Station	Group	Region	EtFOSA		EtFOSE		MeFOSA		MeFOSE	
				Result	MDL	Result	MDL	Result	MDL	Result	MDL
2009	San Pablo Bay	Ambient	San Pablo Bay	-	0.681	-	0.292	-	3.85	-	1.04
2009	Central Bay	Ambient	Central Bay	-	0.712	-	0.287	-	7.81	-	0.572
2009	San Leandro Bay	Margins	Central Bay	-	1.42	-	0.29	-	10.4	-	1.21
2009	Eden Landing	Margins	South Bay	-	3.62	-	0.429	5.36	4.37	-	1.47
2009	Foster City	Margins	South Bay	-	4.09	-	0.686	-	15.9	-	1.1
2009	South Bay	Ambient	South Bay	-	3.14	-	0.625	-	5.2	-	1.99
2009	Lower South Bay	Ambient	Lower South Bay	-	3.74	-	0.323	-	11.9	-	1.09
2009	Cooley Landing	Margins	Cooley Landing	-	4.22	-	0.461	-	3.68	-	0.921
2010	Richmond (Breuner Marsh)	Margins	San Pablo Bay	-	1.34	-	0.393	-	11.5	-	0.775

Table 3a. Bay Sediment PFAS Concentrations (ng/g dw)

Year	Station[1]	Region	PFBA		PFBS		PFTA		PFPA		PFHxA		PFHxS		PFHpA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2004	Petaluma River	San Pablo Bay	#N/A	#N/A	#N/A	#N/A	-	NR	#N/A	#N/A	#N/A	#N/A	-	NR	#N/A	#N/A
2004	Yosemite Slough	Central Bay	#N/A	#N/A	#N/A	#N/A	0.435	NR	#N/A	#N/A	#N/A	#N/A	-	NR	#N/A	#N/A
2004	Hayward Marsh	South Bay	#N/A	#N/A	#N/A	#N/A	0.309	NR	#N/A	#N/A	#N/A	#N/A	-	NR	#N/A	#N/A
2004	Palo Alto Mudflats	Lower South Bay	#N/A	#N/A	#N/A	#N/A	-	NR	#N/A	#N/A	#N/A	#N/A	-	NR	#N/A	#N/A
2004	San Francisquito Creek	Lower South Bay	#N/A	#N/A	#N/A	#N/A	0.155	NR	#N/A	#N/A	#N/A	#N/A	-	NR	#N/A	#N/A
2004	Lagunitas Creek	Tomales Bay	#N/A	#N/A	#N/A	#N/A	-	NR	#N/A	#N/A	#N/A	#N/A	-	NR	#N/A	#N/A
2009	San Leandro Bay	Central Bay	-	0.0858	-	0.172	#N/A	#N/A	-	0.0858	-	0.0858	-	0.172	-	0.0858
2009	Eden Landing	South Bay	-	0.103	-	0.207	#N/A	#N/A	-	0.103	-	0.103	-	0.207	-	0.103
2009	Foster City	South Bay	-	0.103	-	0.205	#N/A	#N/A	-	0.103	-	0.103	-	0.205	-	0.103
2009	Cooley Landing	Cooley Landing	-	0.095	-	0.19	#N/A	#N/A	-	0.095	0.148	0.095	-	0.19	0.166	0.095
2010	Mothball Fleet	San Pablo Bay	-	0.0991	-	0.198	#N/A	#N/A	-	0.0991	-	0.0991	-	0.198	-	0.0991
2010	Richmond (Breuner Marsh)	San Pablo Bay	-	0.0957	-	0.191	#N/A	#N/A	-	0.0957	-	0.0957	-	0.191	-	0.0957
2010	HORNETFLD	Central Bay	-	0.0983	-	0.197	#N/A	#N/A	-	0.0983	-	0.0983	-	0.197	-	0.0983
2010	Oyster Bay	Central Bay	-	0.103	-	0.207	#N/A	#N/A	-	0.103	-	0.103	-	0.207	-	0.103
2010	Oyster Point	Central Bay	-	0.104	-	0.207	#N/A	#N/A	-	0.104	-	0.104	-	0.207	-	0.104
2010	PALOALTOLANDFILL	South Bay	-	0.11	-	0.22	#N/A	#N/A	-	0.11	-	0.11	-	0.22	-	0.11
2010	Alviso	Alviso	-	0.0999	-	0.2	#N/A	#N/A	-	0.0999	-	0.0999	-	0.2	-	0.0999
2012	Central Bay	Central Bay	-	0.0991	-	0.198	#N/A	#N/A	-	0.0991	-	0.0991	-	0.198	-	0.0991
2012	Central Bay	Central Bay	-	0.0921	-	0.184	#N/A	#N/A	-	0.0921	-	0.0921	-	0.184	-	0.0921
2012	Central Bay	Central Bay	-	0.0941	-	0.188	#N/A	#N/A	-	0.0941	-	0.0941	-	0.188	-	0.101
2012	South Bay	South Bay	-	0.0938	-	0.188	#N/A	#N/A	-	0.0938	-	0.0938	-	0.188	-	0.0938
2012	South Bay	South Bay	-	0.0946	-	0.189	#N/A	#N/A	-	0.0946	-	0.0946	-	0.189	-	0.0946
2012	Alviso	Alviso	-	0.0954	-	0.191	#N/A	#N/A	-	0.0954	-	0.0954	-	0.191	-	0.0954
2012	Corkscrew Slough	Southern Sloughs	-	0.095	-	0.19	#N/A	#N/A	-	0.095	-	0.095	-	0.19	-	0.122
2012	Mowry Slough	Southern Sloughs	-	0.0961	-	0.192	#N/A	#N/A	-	0.0961	-	0.0961	-	0.192	-	0.0961
2012	Cooley Landing	Cooley Landing	-	0.1	-	0.2	#N/A	#N/A	-	0.1	-	0.1	-	0.2	-	0.1

Year	Station[1]	Region	PFBA		PFBS		PFTA		PFPA		PFHxA		PFHxS		PFHpA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2012	Cooley Landing	Cooley Landing	0.126	0.0962	-	0.192	#N/A	#N/A	0.26	0.0962	0.31	0.0962	0.318	0.192	0.286	0.0962
2012	Cooley Landing	Cooley Landing	-	0.0969	-	0.194	#N/A	#N/A	0.103	0.0969	0.102	0.0969	-	0.194	-	0.0969
2012	Cooley Landing	Cooley Landing	-	0.0926	-	0.185	#N/A	#N/A	-	0.0926	-	0.0926	-	0.185	-	0.0926
2014	Sacramento River	Rivers	-	0.0925	-	0.185	#N/A	#N/A	-	0.0925	-	0.0925	-	0.185	-	0.0925
2014	San Joaquin River	Rivers	-	0.146	-	0.187	#N/A	#N/A	-	0.0935	-	0.0935	-	0.187	-	0.0935
2014	Grizzly Bay	Suisun Bay	-	0.0947	-	0.189	#N/A	#N/A	-	0.0947	-	0.0947	-	0.189	-	0.0947
2014	Suisun Bay	Suisun Bay	-	0.0997	-	0.199	#N/A	#N/A	-	0.0997	-	0.0997	-	0.199	-	0.0997
2014	Suisun Bay	Suisun Bay	-	0.095	-	0.19	#N/A	#N/A	-	0.095	-	0.095	-	0.19	-	0.095
2014	Suisun Bay	Suisun Bay	-	0.0988	-	0.198	#N/A	#N/A	-	0.0988	-	0.0988	-	0.198	-	0.0988
2014	Suisun Bay	Suisun Bay	-	0.0993	-	0.199	#N/A	#N/A	-	0.0993	-	0.0993	-	0.199	-	0.0993
2014	Pinole Point	San Pablo Bay	-	0.0962	-	0.192	#N/A	#N/A	-	0.0962	-	0.0962	-	0.192	-	0.0962
2014	San Pablo Bay	San Pablo Bay	-	0.0998	-	0.2	#N/A	#N/A	-	0.0998	-	0.0998	-	0.2	-	0.0998
2014	San Pablo Bay	San Pablo Bay	-	0.0941	-	0.188	#N/A	#N/A	-	0.0941	-	0.0941	-	0.188	-	0.0941
2014	San Pablo Bay	San Pablo Bay	-	0.0929	-	0.186	#N/A	#N/A	-	0.0929	-	0.0929	-	0.186	-	0.0929
2014	San Pablo Bay	San Pablo Bay	-	0.0923	-	0.185	#N/A	#N/A	-	0.0923	-	0.0923	-	0.185	-	0.0923
2014	Central Bay	Central Bay	-	0.11	-	0.203	#N/A	#N/A	-	0.101	-	0.101	-	0.203	-	0.101
2014	Central Bay	Central Bay	-	0.101	-	0.202	#N/A	#N/A	-	0.101	-	0.101	-	0.202	-	0.101
2014	Central Bay	Central Bay	-	0.182	-	0.196	#N/A	#N/A	-	0.098	-	0.098	-	0.196	-	0.098
2014	Central Bay	Central Bay	-	0.121	-	0.201	#N/A	#N/A	-	0.101	-	0.101	-	0.201	-	0.101
2014	Yerba Buena Island	Central Bay	-	0.0992	-	0.198	#N/A	#N/A	-	0.0992	-	0.0992	-	0.198	-	0.0992
2014	Redwood Creek	South Bay	-	0.105	-	0.202	#N/A	#N/A	-	0.101	-	0.101	-	0.202	-	0.101
2014	South Bay	South Bay	-	0.101	-	0.201	#N/A	#N/A	-	0.101	-	0.101	-	0.201	-	0.101
2014	South Bay	South Bay	-	0.0973	-	0.195	#N/A	#N/A	-	0.0973	-	0.0973	-	0.195	-	0.0973
2014	South Bay	South Bay	-	0.132	-	0.203	#N/A	#N/A	-	0.101	-	0.101	-	0.203	-	0.101
2014	South Bay	South Bay	-	0.0977	-	0.187	#N/A	#N/A	-	0.0935	-	0.0935	-	0.187	-	0.0935
2014	Coyote Creek	Lower South Bay	-	0.101	-	0.202	#N/A	#N/A	-	0.101	-	0.101	-	0.202	-	0.101
2014	Lower South Bay	Lower South Bay	-	0.198	-	0.204	#N/A	#N/A	-	0.102	-	0.102	-	0.204	-	0.102

Year	Station[1]	Region	PFBA		PFBS		PFTA		PFPA		PFHxA		PFHxS		PFHpA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2014	Lower South Bay	Lower South Bay	-	0.101	-	0.202	#N/A	#N/A	-	0.101	-	0.101	-	0.202	-	0.101
2014	Lower South Bay	Lower South Bay	-	0.0964	-	0.193	#N/A	#N/A	-	0.0964	-	0.0964	-	0.193	-	0.0964
2014	Lower South Bay	Lower South Bay	-	0.0996	-	0.199	#N/A	#N/A	-	0.0996	-	0.0996	-	0.199	-	0.0996

Year	Station[1]	Region	PFOA		PFOS		PFOSA		PFNA		PFDA		PFUnDA		PFDoDA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2004	Petaluma River	San Pablo Bay	0.229	NR	1.24	NR	#N/A	#N/A	-	NR	0.162	NR	-	NR	-	NR
2004	Yosemite Slough	Central Bay	0.272	NR	0.288	NR	#N/A	#N/A	-	NR	0.203	NR	-	NR	-	NR
2004	Hayward Marsh	South Bay	0.625	NR	1.72	NR	#N/A	#N/A	-	NR	0.335	NR	-	NR	-	NR
2004	Palo Alto Mudflats	Lower South Bay	0.136	NR	1.47	NR	#N/A	#N/A	-	NR	0.084	NR	-	NR	-	NR
2004	San Francisquito Creek	Lower South Bay	0.251	NR	3.07	NR	#N/A	#N/A	-	NR	0.22	NR	-	NR	0.283	NR
2004	Lagunitas Creek	Tomales Bay	-	NR	-	NR	#N/A	#N/A	-	NR	-	NR	-	NR	-	NR
2009	San Leandro Bay	Central Bay	-	0.0858	0.716	0.172	-	0.0858	-	0.0858	-	0.0858	0.165	0.0858	0.134	0.0858
2009	Eden Landing	South Bay	0.15	0.103	0.719	0.207	-	0.103	-	0.103	-	0.103	-	0.103	-	0.103
2009	Foster City	South Bay	0.132	0.103	0.448	0.205	-	0.103	-	0.103	-	0.103	-	0.103	-	0.103
2009	Cooley Landing	Cooley Landing	1.06	0.095	3.2	0.19	0.233	0.095	0.559	0.095	0.495	0.095	0.217	0.095	0.236	0.095
2010	Mothball Fleet	San Pablo Bay	-	0.0991	-	0.198	-	0.0991	-	0.0991	-	0.0991	-	0.0991	-	0.0991
2010	Richmond (Breuner Marsh)	San Pablo Bay	-	0.0957	0.758	0.191	-	0.0957	0.121	0.0957	0.193	0.0957	0.124	0.0957	-	0.0957
2010	HORNETFLD	Central Bay	-	0.0983	-	0.197	-	0.0983	-	0.0983	-	0.0983	-	0.0983	-	0.0983
2010	Oyster Bay	Central Bay	0.12	0.103	1.11	0.207	0.134	0.103	0.152	0.103	0.12	0.103	-	0.103	0.195	0.103
2010	Oyster Point	Central Bay	-	0.104	0.525	0.207	-	0.104	0.106	0.104	-	0.104	-	0.104	0.132	0.104
2010	PALOALTOLANDFILL	South Bay	0.675	0.11	2.33	0.22	0.173	0.11	0.41	0.11	0.477	0.11	0.215	0.11	0.286	0.11
2010	Alviso	Alviso	0.159	0.0999	3.22	0.21	0.285	0.0999	0.148	0.0999	0.104	0.0999	-	0.0999	0.473	0.0999
2012	Central Bay	Central Bay	-	0.0991	-	0.198	-	0.0991	-	0.0991	-	0.0991	-	0.0991	-	0.0991
2012	Central Bay	Central Bay	-	0.0921	-	0.184	-	0.0921	-	0.0921	-	0.0921	-	0.0921	-	0.0921

Year	Station[1]	Region	PFOA		PFOS		PFOSA		PFNA		PFDA		PFUnDA		PFDoDA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2012	Central Bay	Central Bay	-	0.0941	0.237	0.188	-	0.0941	-	0.0941	-	0.0941	-	0.0941	-	0.0941
2012	South Bay	South Bay	0.392	0.0938	1.23	0.188	-	0.0938	0.24	0.0938	0.293	0.0938	-	0.0938	-	0.0938
2012	South Bay	South Bay	-	0.0946	0.603	0.189	-	0.0946	-	0.0946	-	0.0946	-	0.0946	-	0.0946
2012	Alviso	Alviso	-	0.0954	2.61	0.191	0.433	0.0954	-	0.0954	-	0.0954	-	0.0954	-	0.0954
2012	Corkscrew Slough	Southern Sloughs	0.106	0.095	0.595	0.19	-	0.095	-	0.095	-	0.095	-	0.095	-	0.095
2012	Mowry Slough	Southern Sloughs	0.296	0.0961	1.57	0.192	-	0.0961	0.194	0.0961	0.255	0.0961	-	0.0961	-	0.0961
2012	Cooley Landing	Cooley Landing	0.331	0.1	2.12	0.2	-	0.1	0.234	0.1	0.343	0.1	-	0.1	0.157	0.1
2012	Cooley Landing	Cooley Landing	0.385	0.0962	1.66	0.192	-	0.0962	0.192	0.0962	0.213	0.0962	-	0.0962	0.116	0.0962
2012	Cooley Landing	Cooley Landing	0.322	0.0969	1.87	0.194	-	0.0969	0.233	0.0969	0.344	0.0969	-	0.0969	0.134	0.0969
2012	Cooley Landing	Cooley Landing	0.177	0.0926	1.2	0.185	-	0.0926	0.149	0.0926	0.237	0.0926	-	0.0926	0.118	0.0926
2014	Sacramento River	Rivers	-	0.0925	-	0.185	-	0.0925	-	0.0925	-	0.0925	-	0.0925	-	0.0925
2014	San Joaquin River	Rivers	-	0.0935	-	0.232	-	0.0935	-	0.0935	-	0.0935	-	0.0935	-	0.0935
2014	Grizzly Bay	Suisun Bay	-	0.0947	0.411	0.189	-	0.0947	-	0.0947	-	0.0947	-	0.0947	-	0.0947
2014	Suisun Bay	Suisun Bay	-	0.0997	-	0.199	-	0.0997	-	0.0997	-	0.0997	-	0.0997	-	0.0997
2014	Suisun Bay	Suisun Bay	-	0.095	-	0.19	-	0.095	-	0.095	-	0.095	-	0.095	-	0.095
2014	Suisun Bay	Suisun Bay	-	0.0988	0.309	0.198	-	0.0988	-	0.0988	-	0.0988	-	0.0988	-	0.0988
2014	Suisun Bay	Suisun Bay	-	0.0993	-	0.199	-	0.0993	-	0.0993	-	0.0993	-	0.0993	-	0.0993
2014	Pinole Point	San Pablo Bay	-	0.0962	0.47	0.192	-	0.0962	0.486	0.0962	-	0.0962	-	0.0962	-	0.0962
2014	San Pablo Bay	San Pablo Bay	-	0.0998	-	0.2	-	0.0998	-	0.0998	-	0.0998	-	0.0998	-	0.0998
2014	San Pablo Bay	San Pablo Bay	-	0.0941	-	0.188	-	0.0941	-	0.0941	-	0.0941	-	0.0941	-	0.0941
2014	San Pablo Bay	San Pablo Bay	-	0.0929	-	0.186	-	0.0929	-	0.0929	-	0.0929	-	0.0929	-	0.0929
2014	San Pablo Bay	San Pablo Bay	-	0.0923	0.197	0.185	-	0.0923	-	0.0923	-	0.0923	-	0.0923	-	0.0923
2014	Central Bay	Central Bay	-	0.101	0.223	0.203	-	0.101	-	0.101	-	0.101	-	0.101	-	0.101
2014	Central Bay	Central Bay	-	0.101	-	0.202	-	0.101	-	0.101	-	0.101	-	0.101	-	0.101
2014	Central Bay	Central Bay	-	0.098	-	0.196	-	0.098	-	0.098	-	0.098	-	0.098	-	0.098
2014	Central Bay	Central Bay	0.158	0.101	0.613	0.27	-	0.101	-	0.101	-	0.101	-	0.101	-	0.101
2014	Yerba Buena Island	Central Bay	-	0.0992	0.256	0.198	-	0.0992	-	0.0992	-	0.0992	-	0.0992	-	0.0992

Year	Station[1]	Region	PFOA		PFOS		PFOSA		PFNA		PFDA		PFUnDA		PFDoDA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2014	Redwood Creek	South Bay	-	0.101	0.507	0.202	-	0.101	-	0.101	-	0.101	-	0.101	-	0.101
2014	South Bay	South Bay	0.221	0.101	1.26	0.201	-	0.101	0.133	0.101	0.179	0.101	-	0.101	-	0.101
2014	South Bay	South Bay	-	0.0973	0.491	0.195	-	0.0973	-	0.0973	-	0.0973	-	0.0973	-	0.0973
2014	South Bay	South Bay	-	0.101	0.898	0.226	-	0.101	-	0.101	0.175	0.101	-	0.101	-	0.101
2014	South Bay	South Bay	0.235	0.0935	1.61	0.187	-	0.0935	0.19	0.0935	0.475	0.0935	0.115	0.0935	-	0.0935
2014	Coyote Creek	Lower South Bay	0.109	0.101	2.04	0.202	0.304	0.101	-	0.101	0.172	0.101	-	0.101	0.15	0.101
2014	Lower South Bay	Lower South Bay	0.134	0.102	3.4	0.251	0.861	0.102	-	0.102	0.191	0.102	-	0.102	-	0.102
2014	Lower South Bay	Lower South Bay	0.196	0.101	1.15	0.202	-	0.101	0.169	0.101	0.253	0.101	-	0.101	-	0.101
2014	Lower South Bay	Lower South Bay	0.184	0.0964	1.08	0.193	0.143	0.0964	0.107	0.0964	0.217	0.0964	-	0.0964	-	0.0964
2014	Lower South Bay	Lower South Bay	-	0.0996	1.9	0.206	-	0.0996	-	0.0996	-	0.0996	-	0.0996	-	0.0996

1. Sites sampled in 2004 are from Higgins et al. 2005

Table 3b. Sediment Precursor Concentrations

Year	Station[1]	Region	EtFOSA		EtFOSE		EtFOSAA		MeFOSA		MeFOSE		MeFOSAA		FOSAA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2004	Petaluma River	San Pablo Bay	#N/A	#N/A	#N/A	#N/A	0.34	NR	#N/A	#N/A	#N/A	#N/A	0.327	NR	-	NR
2004	Yosemite Slough	Central Bay	#N/A	#N/A	#N/A	#N/A	-	NR	#N/A	#N/A	#N/A	#N/A	-	NR	-	NR
2004	Hayward Marsh	South Bay	#N/A	#N/A	#N/A	#N/A	0.307	NR	#N/A	#N/A	#N/A	#N/A	0.125	NR	-	NR
2004	Palo Alto Mudflats	Lower South Bay	#N/A	#N/A	#N/A	#N/A	0.765	NR	#N/A	#N/A	#N/A	#N/A	0.199	NR	-	NR
2004	San Francisquito Creek	Lower South Bay	#N/A	#N/A	#N/A	#N/A	0.958	NR	#N/A	#N/A	#N/A	#N/A	0.61	NR	0.254	NR
2004	Lagunitas Creek	Tomales Bay	#N/A	#N/A	#N/A	#N/A	-	NR	#N/A	#N/A	#N/A	#N/A	0.199	NR	0.153	NR
2009	San Leandro Bay	Central Bay	-	0.285	-	0.0673	#N/A	#N/A	-	0.312	-	0.111	#N/A	#N/A	#N/A	#N/A
2009	Eden Landing	South Bay	-	0.376	-	0.131	#N/A	#N/A	-	0.115	-	0.234	#N/A	#N/A	#N/A	#N/A
2009	Foster City	South Bay	-	0.153	-	0.0898	#N/A	#N/A	-	0.413	-	0.226	#N/A	#N/A	#N/A	#N/A
2009	Cooley Landing	Cooley Landing	-	0.304	-	0.149	#N/A	#N/A	-	0.333	-	0.371	#N/A	#N/A	#N/A	#N/A
2010	Mothball Fleet	San Pablo Bay	-	0.33	-	0.543	#N/A	#N/A	-	0.562	-	0.748	#N/A	#N/A	#N/A	#N/A

Year	Station[1]	Region	EtFOSA		EtFOSE		EtFOSAA		MeFOSA		MeFOSE		MeFOSAA		FOSAA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2010	Richmond (Breuner Marsh)	San Pablo Bay	-	0.277	-	0.153	#N/A	#N/A	-	0.519	-	0.3	#N/A	#N/A	#N/A	#N/A
2010	HORNETFLD	Central Bay	-	0.197	-	0.506	#N/A	#N/A	-	1.42	-	2.48	#N/A	#N/A	#N/A	#N/A
2010	Oyster Bay	Central Bay	-	0.437	-	1.29	#N/A	#N/A	-	0.617	-	1.6	#N/A	#N/A	#N/A	#N/A
2010	Oyster Point	Central Bay	-	1.6	-	0.491	#N/A	#N/A	-	1.39	-	1.05	#N/A	#N/A	#N/A	#N/A
2010	PALOALTOLANDFILL	South Bay	-	0.256	-	0.367	#N/A	#N/A	-	0.76	-	0.453	#N/A	#N/A	#N/A	#N/A
2010	Alviso	Alviso	-	0.708	-	0.776	#N/A	#N/A	-	1.32	-	1.63	#N/A	#N/A	#N/A	#N/A
2012	Central Bay	Central Bay	#N/A	#N/A	#N/A	#N/A	-	0.355	#N/A	#N/A	#N/A	#N/A	-	0.355	-	0.355
2012	Alviso	Alviso	#N/A	#N/A	#N/A	#N/A	2.57	0.382	#N/A	#N/A	#N/A	#N/A	0.773	0.382	-	0.382
2012	Cooley Landing	Cooley Landing	#N/A	#N/A	#N/A	#N/A	-	0.564	#N/A	#N/A	#N/A	#N/A	-	0.564	-	0.564
2014	Suisun Bay	Suisun Bay	#N/A	#N/A	#N/A	#N/A	-	0.384	#N/A	#N/A	#N/A	#N/A	-	0.384	-	0.384
2014	San Pablo Bay	San Pablo Bay	#N/A	#N/A	#N/A	#N/A	-	0.368	#N/A	#N/A	#N/A	#N/A	-	0.368	-	0.368
2014	Central Bay	Central Bay	#N/A	#N/A	#N/A	#N/A	-	0.362	#N/A	#N/A	#N/A	#N/A	-	0.362	-	0.362
2014	Yerba Buena Island	Central Bay	#N/A	#N/A	#N/A	#N/A	-	0.365	#N/A	#N/A	#N/A	#N/A	-	0.365	-	0.365
2014	Redwood Creek	South Bay	#N/A	#N/A	#N/A	#N/A	-	0.374	#N/A	#N/A	#N/A	#N/A	-	0.374	-	0.374
2014	South Bay	South Bay	#N/A	#N/A	#N/A	#N/A	-	0.355	#N/A	#N/A	#N/A	#N/A	-	0.355	-	0.355
2014	South Bay	South Bay	#N/A	#N/A	#N/A	#N/A	-	0.39	#N/A	#N/A	#N/A	#N/A	-	0.39	-	0.39
2014	Coyote Creek	Lower South Bay	#N/A	#N/A	#N/A	#N/A	0.702	0.372	#N/A	#N/A	#N/A	#N/A	-	0.372	-	0.372
2014	Lower South Bay	Lower South Bay	#N/A	#N/A	#N/A	#N/A	-	0.376	#N/A	#N/A	#N/A	#N/A	-	0.376	-	0.376
2014	Lower South Bay	Lower South Bay	#N/A	#N/A	#N/A	#N/A	0.672	0.367	#N/A	#N/A	#N/A	#N/A	-	0.367	-	0.367

Year	Station[1]	Region	6:2 monoPAP		8:2 monoPAP		6:2 diPAP		8:2 diPAP		4:2 FTS		6:2 FTS		8:2 FTS	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2004	Petaluma River	San Pablo Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2004	Yosemite Slough	Central Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2004	Hayward Marsh	South Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2004	Palo Alto Mudflats	Lower South Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2004	San Francisquito Creek	Lower South Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2004	Lagunitas Creek	Tomales Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2009	San Leandro Bay	Central Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2009	Eden Landing	South Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2009	Foster City	South Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2009	Cooley Landing	Cooley Landing	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	Mothball Fleet	San Pablo Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	Richmond (Breuner Marsh)	San Pablo Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	HORNETFLD	Central Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	Oyster Bay	Central Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	Oyster Point	Central Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	PALOALTOLANDFILL	South Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	Alviso	Alviso	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2012	Central Bay	Central Bay	-	202	-	242	12.5	10.1	77.3	52.5	-	0.734	-	0.745	-	0.752
2012	Alviso	Alviso	-	171	-	1140	9.08	8.55	41.8	16.6	-	0.844	-	0.857	-	0.866
2012	Cooley Landing	Cooley Landing	-	182	-	1340	11.1	9.08	34.5	16.9	-	0.838	-	0.851	-	0.86
2014	Suisun Bay	Suisun Bay	-	206	-	206	-	10.3	-	10.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2014	San Pablo Bay	San Pablo Bay	-	198	-	198	-	9.88	-	9.88	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2014	Central Bay	Central Bay	-	192	-	192	-	9.61	-	9.61	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2014	Yerba Buena Island	Central Bay	-	201	-	257	-	10	-	10	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2014	Redwood Creek	South Bay	-	185	-	185	-	9.25	-	9.25	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

2014	South Bay	South Bay	-	198	-	198	-	9.9	-	9.9	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2014	South Bay	South Bay	-	201	-	201	-	10	-	10	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2014	Coyote Creek	Lower South Bay	-	207	-	207	-	10.3	-	10.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2014	Lower South Bay	Lower South Bay	-	185	-	185	-	9.26	-	9.26	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2014	Lower South Bay	Lower South Bay	-	196	-	196	-	9.8	-	NR	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Year	Station[1]	Region	6:6 PFPi		6:8 PFPi		8:8 PFPi		6:2 FTCA		8:2 FTCA		10:2 FTCA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2004	Petaluma River	San Pablo Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2004	Yosemite Slough	Central Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2004	Hayward Marsh	South Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2004	Palo Alto Mudflats	Lower South Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2004	San Francisquito Creek	Lower South Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2004	Lagunitas Creek	Tomales Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2009	San Leandro Bay	Central Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2009	Eden Landing	South Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2009	Foster City	South Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2009	Cooley Landing	Cooley Landing	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	Mothball Fleet	San Pablo Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	Richmond (Breuner Marsh)	San Pablo Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	HORNETFLD	Central Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	Oyster Bay	Central Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	Oyster Point	Central Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	PALOALTOLANDFILL	South Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	Alviso	Alviso	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2012	Central Bay	Central Bay	-	10.1	-	10.1	-	10.1	-	0.71	-	0.71	-	0.71
2012	Alviso	Alviso	8.75	8.55	-	8.55	-	8.55	-	0.764	-	0.764	-	0.764

Year	Station[1]	Region	6:6 PFPi		6:8 PFPi		8:8 PFPi		6:2 FTCA		8:2 FTCA		10:2 FTCA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2012	Cooley Landing	Cooley Landing	-	9.08	-	9.08	-	9.08	-	1.13	-	1.13	-	1.13
2014	Suisun Bay	Suisun Bay	-	10.3	-	10.3	-	10.3	-	0.768	-	0.768	-	0.768
2014	San Pablo Bay	San Pablo Bay	-	9.88	-	9.88	-	9.88	-	0.736	-	0.736	-	0.736
2014	Central Bay	Central Bay	-	9.61	-	9.61	-	9.61	-	0.725	-	0.725	-	0.725
2014	Yerba Buena Island	Central Bay	-	10	-	10	-	10	-	0.729	-	0.729	-	0.729
2014	Redwood Creek	South Bay	-	9.25	-	9.25	-	9.25	-	0.748	-	0.748	-	0.748
2014	South Bay	South Bay	-	9.9	-	9.9	-	9.9	-	0.711	-	0.711	-	0.711
2014	South Bay	South Bay	-	10	-	10	-	10	-	0.78	-	0.78	-	0.78
2014	Coyote Creek	Lower South Bay	-	10.3	-	10.3	-	10.3	-	0.743	-	0.743	-	0.743
2014	Lower South Bay	Lower South Bay	-	9.26	-	9.26	-	9.26	-	0.752	-	0.752	-	0.752
2014	Lower South Bay	Lower South Bay	-	9.8	-	9.8	-	9.8	-	0.735	-	0.735	-	0.735

Year	Station[1]	Region	6:2 FTuCA		8:2 FTuCA		10:2 FTuCA		PFHxPA		PFOPA		PFDPA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2004	Petaluma River	San Pablo Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2004	Yosemite Slough	Central Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2004	Hayward Marsh	South Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2004	Palo Alto Mudflats	Lower South Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2004	San Francisquito Creek	Lower South Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2004	Lagunitas Creek	Tomales Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2009	San Leandro Bay	Central Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2009	Eden Landing	South Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2009	Foster City	South Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2009	Cooley Landing	Cooley Landing	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	Mothball Fleet	San Pablo Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	Richmond (Breuner Marsh)	San Pablo Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	HORNETFLD	Central Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Year	Station[1]	Region	6:2 FTuCA		8:2 FTuCA		10:2 FTuCA		PFHxPA		PFOPA		PFDPA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2010	Oyster Bay	Central Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	Oyster Point	Central Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	PALOALTOLANDFILL	South Bay	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2010	Alviso	Alviso	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2012	Central Bay	Central Bay	-	0.0888	-	0.0888	-	0.0888	-	101	-	101	-	101
2012	Alviso	Alviso	-	0.0955	-	0.0955	-	0.0955	-	85.5	-	85.5	-	85.5
2012	Cooley Landing	Cooley Landing	-	0.141	-	0.141	-	0.141	-	90.8	-	90.8	-	90.8
2014	Suisun Bay	Suisun Bay	-	0.096	-	0.096	-	0.096	-	103	-	103	-	103
2014	San Pablo Bay	San Pablo Bay	-	0.092	-	0.092	-	0.092	-	98.8	-	98.8	-	98.8
2014	Central Bay	Central Bay	-	0.0906	-	0.0906	-	0.0906	-	96.1	-	96.1	-	96.1
2014	Yerba Buena Island	Central Bay	-	0.0911	-	0.0911	-	0.0911	-	100	-	100	-	100
2014	Redwood Creek	South Bay	-	0.0935	-	0.0935	-	0.0935	-	92.5	-	92.5	-	92.5
2014	South Bay	South Bay	-	0.0889	-	0.0889	-	0.0889	-	99	-	99	-	99
2014	South Bay	South Bay	-	0.0975	-	0.0975	-	0.0975	-	100	-	100	-	100
2014	Coyote Creek	Lower South Bay	-	0.0929	-	0.0929	-	0.0929	-	103	-	103	-	103
2014	Lower South Bay	Lower South Bay	-	0.094	-	0.094	-	0.094	-	92.6	-	92.6	-	92.6
2014	Lower South Bay	Lower South Bay	-	0.0918	-	0.0918	-	0.0918	-	98	-	98	-	98

1. Sites sampled in 2004 are from Higgins et al. 2005

Table 4. Bivalve PFAS Concentrations (ng/g ww)

Year	Station	Region	PFBS		PFPA		PFHxA		PFHxS		PFHpA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2009	San Pablo Bay	North Bay	-	0.17	#N/A	#N/A	-	0.19	-	0.45	-	0.2
2009	Red Rock	Central Bay	-	0.17	#N/A	#N/A	-	0.19	-	0.45	-	0.2
2009	San Francisco Bay - Emeryville	Central Bay	-	0.17	#N/A	#N/A	-	0.19	-	0.45	-	0.2
2009	San Francisco Bay - Yerba Buena	Central Bay	-	0.17	#N/A	#N/A	-	0.19	-	0.45	-	0.2
2009	San Leandro Bay	Central Bay	-	4.63	-	2.31	-	2.31	-	4.63	-	2.31
2009	Cooley Landing	South Bay	-	4.63	-	2.31	-	2.31	-	4.63	-	2.31
2009	Coyote Creek	South Bay	-	0.17	#N/A	#N/A	-	0.19	-	0.45	-	0.2
2009	Eden Landing	South Bay	-	4.98	-	2.49	-	2.49	5.48	4.98	-	2.49
2009	Foster City	South Bay	-	4.9	-	2.45	-	2.45	-	4.9	-	2.45
2009	San Francisco Bay - Dumbarton Bridge	South Bay	-	0.17	#N/A	#N/A	-	0.19	-	0.45	-	0.2
2009	San Francisco Bay - San Mateo Bridge	South Bay	-	0.17	#N/A	#N/A	-	0.19	-	0.45	-	0.2
2009	Bodega Head	Bodega Head	-	0.17	#N/A	#N/A	-	0.19	-	0.45	-	0.2
2010	Richmond (Breuner Marsh)	North Bay	-	4.52	-	2.26	-	2.26	-	4.52	-	2.26

Year	Station	Region	PFOA		PFOS		PFOSA		PFNA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL
2009	San Pablo Bay	North Bay	-	0.2	-	0.2	-	0.17	-	0.21
2009	Red Rock	Central Bay	-	0.2	-	0.2	-	0.17	-	0.21
2009	San Francisco Bay - Emeryville	Central Bay	-	0.2	-	0.2	-	0.17	-	0.21
2009	San Francisco Bay - Yerba Buena	Central Bay	-	0.2	-	0.2	-	0.17	-	0.21
2009	San Leandro Bay	Central Bay	-	2.31	-	4.63	-	2.31	-	2.31
2009	Cooley Landing	South Bay	-	2.31	-	4.63	-	2.31	-	2.31
2009	Coyote Creek	South Bay	-	0.2	4.4	0.2	0.85	0.17	-	0.21
2009	Eden Landing	South Bay	-	2.49	76.3	4.98	-	2.49	-	2.49
2009	Foster City	South Bay	-	2.45	-	4.9	-	2.45	-	2.45
2009	San Francisco Bay - Dumbarton Bridge	South Bay	-	0.2	-	0.2	-	0.17	-	0.21

2009	San Francisco Bay - San Mateo Bridge	South Bay	-	0.2	-	0.2	-	0.17	-	0.21
2009	Boedga Head	Bodega Head	-	0.2	-	0.2	-	0.17	-	0.21
2010	Richmond (Breuner Marsh)	North Bay	-	2.26	-	4.52	-	2.26	-	2.26

Year	Station	Region	PFDA		PFUnDA		PFDoDA	
			Result	MDL	Result	MDL	Result	MDL
2009	San Pablo Bay	North Bay	-	0.16	-	0.19	-	0.22
2009	Red Rock	Central Bay	-	0.16	-	0.19	-	0.22
2009	San Francisco Bay - Emeryville	Central Bay	-	0.16	-	0.19	-	0.22
2009	San Francisco Bay - Yerba Buena	Central Bay	-	0.16	-	0.19	-	0.22
2009	San Leandro Bay	Central Bay	-	2.31	-	2.31	-	2.31
2009	Yerba Buena Island	Central Bay	-	0.16	-	0.19	-	0.22
2009	Cooley Landing	South Bay	-	2.31	-	2.31	-	2.31
2009	Coyote Creek	South Bay	-	0.16	-	0.19	-	0.22
2009	Eden Landing	South Bay	-	2.49	-	2.49	-	2.49
2009	Foster City	South Bay	-	2.45	-	2.45	-	2.45
2009	San Francisco Bay - Dumbarton Bridge	South Bay	-	0.16	-	0.19	0.26	0.22
2009	San Francisco Bay - San Mateo Bridge	South Bay	-	0.16	-	0.19	-	0.22
2009	Boedga Head	Bodega Head	-	0.16	-	0.19	-	0.22
2010	Richmond (Breuner Marsh)	North Bay	-	2.26	-	2.26	-	2.26

Table 5. Preyfish PFAS Concentrations (ng/g ww)

Year	Region	Common Name	PFBA		PFBS		PFPA		PFHxA		PFHxS		PFHpA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2009	Tomales Bay	Topsmelt	-	2.48	-	4.95	-	2.48	-	2.48	-	4.95	-	2.48
2009	North Bay	Mississippi Silverside	-	2.5	-	5	-	2.5	-	2.5	-	5	-	2.5
2009	North Bay	Mississippi Silverside	-	2.49	-	4.98	-	2.49	-	2.49	-	4.98	-	2.49
2009	North Bay	Mississippi Silverside	-	2.45	-	4.9	-	2.45	-	2.45	-	4.9	-	2.45
2009	North Bay	Topsmelt	-	2.44	-	4.88	-	2.44	-	2.44	-	4.88	-	2.44
2009	North Bay	Topsmelt	-	2.49	-	4.98	-	2.49	-	2.49	-	4.98	-	2.49
2009	Central Bay	Mississippi Silverside	-	2.5	-	5	-	2.5	-	2.5	-	5	-	2.5
2009	Central Bay	Topsmelt	-	2.45	-	4.9	-	2.45	-	2.45	-	4.9	-	2.45
2009	Central Bay	Topsmelt	-	2.45	-	4.9	-	2.45	-	2.45	-	4.9	-	2.45
2009	Central Bay	Topsmelt	-	2.45	-	4.9	-	2.45	-	2.45	-	4.9	-	2.45
2009	Central Bay	Topsmelt	-	2.48	-	4.95	-	2.48	-	2.48	-	4.95	-	2.48
2009	South Bay	Mississippi Silverside	-	2.48	-	4.95	-	2.48	-	2.48	-	4.95	-	2.48
2009	South Bay	Topsmelt	-	2.45	-	4.9	-	2.45	-	2.45	7.46	4.9	-	2.45
2009	Alviso	Mississippi Silverside	-	2.46	-	4.93	-	2.46	-	2.46	-	4.93	-	2.46
2010	Alviso	Yellowfin Goby	-	0.485	-	0.971	-	0.485	-	0.485	-	1.43	-	0.485
2011	Alviso	Yellowfin Goby	#N/A	#N/A	-	0.98	-	0.49	-	0.49	-	0.98	-	0.49
2012	Central Bay	Pacific Staghorn Sculpin	-	0.493	-	0.985	#N/A	#N/A	-	0.493	-	1.2	-	0.493
2012	Central Bay	Shiner Surfperch	-	0.493	-	0.985	-	0.493	-	0.493	-	0.985	-	0.493
2012	South Bay	Chameleon Goby	-	0.498	-	0.995	#N/A	#N/A	-	0.498	-	1	-	0.498
2012	South Bay	Cheekspot goby	-	0.495	-	0.99	-	0.495	-	0.495	-	1.62	-	0.495
2012	South Bay	Northern Anchovy	-	0.498	-	0.995	#N/A	#N/A	-	0.498	-	1.57	-	0.498
2012	South Bay	Northern Anchovy	-	0.495	-	0.99	#N/A	#N/A	-	0.495	-	1.98	-	0.495
2012	South Bay	Northern Anchovy	-	0.498	-	0.995	#N/A	#N/A	-	0.498	-	1.06	-	0.498
2012	South Bay	Pacific Staghorn Sculpin	-	0.488	-	0.976	2.13	0.488	-	0.488	2.87	0.976	-	0.488
2012	South Bay	Yellowfin Goby	-	0.49	-	0.98	#N/A	#N/A	-	0.49	-	0.98	-	0.49
2013	Central Bay	Northern Anchovy	-	0.483	-	0.966	-	0.483	-	0.483	-	0.966	-	0.483

Year	Region	Common Name	PFBA		PFBS		PFPA		PFHxA		PFHxS		PFHpA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2013	Central Bay	Shiner Surfperch	-	0.488	-	0.976	1.46	0.488	-	0.488	-	0.976	-	0.488
2013	South Bay	Cheekspot goby	-	0.835	-	1	-	0.5	-	0.5	-	1.49	-	0.5
2013	South Bay	Cheekspot goby	-	0.498	-	0.995	#N/A	#N/A	-	0.498	-	3.78	-	0.498
2013	South Bay	Northern Anchovy	-	0.5	-	1	#N/A	#N/A	-	0.5	-	1.39	-	0.5
2013	South Bay	Pacific Staghorn Sculpin	-	0.498	-	0.995	#N/A	#N/A	-	0.498	1.83	0.995	-	0.498
2013	South Bay	Pacific Staghorn Sculpin	-	0.493	-	0.985	-	0.493	-	0.493	1.65	0.985	-	0.493
2013	South Bay	Pacific Staghorn Sculpin	-	0.495	-	0.99	#N/A	#N/A	-	0.495	9.82	0.99	-	0.495
2013	South Bay	Pacific Staghorn Sculpin	-	0.495	-	0.99	#N/A	#N/A	-	0.495	-	0.99	-	0.495
2013	South Bay	Shiner Surfperch	-	0.951	-	0.995	#N/A	#N/A	-	0.498	-	1.04	-	0.498
2013	South Bay	Shiner Surfperch	-	0.965	-	0.98	2.01	0.49	-	0.49	-	0.98	-	0.49
2013	South Bay	Shiner Surfperch	-	0.495	-	0.99	#N/A	#N/A	-	0.495	1.67	0.99	-	0.495
2013	South Bay	Shiner Surfperch	-	0.79	-	0.985	#N/A	#N/A	-	0.493	-	2.54	-	0.493
2013	South Bay	Yellowfin Goby	-	0.49	-	0.98	-	0.49	-	0.49	1.07	0.98	-	0.49
2013	South Bay	Yellowfin Goby	-	0.495	-	0.99	#N/A	#N/A	-	0.495	1.33	1.06	-	0.495

Year	Region	Common Name	PFOA		PFOS		PFOSA		PFNA		PFDA		PFUnDA		PFDoDA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2009	Tomales Bay	Topsmelt	-	2.48	-	4.95	-	2.48	-	2.48	-	2.48	-	2.48	-	2.48
2009	North Bay	Mississippi Silverside	-	2.5	9.08	5	-	2.5	-	2.5	-	2.5	-	2.5	-	2.5
2009	North Bay	Mississippi Silverside	-	2.49	80	4.98	-	2.49	-	2.49	-	2.49	-	2.49	-	2.49
2009	North Bay	Mississippi Silverside	-	2.45	8.76	4.9	-	2.45	-	2.45	-	2.45	-	2.45	-	2.45
2009	North Bay	Topsmelt	-	2.44	5.7	4.88	-	2.44	-	2.44	-	2.44	-	2.44	-	2.44
2009	North Bay	Topsmelt	-	2.49	-	4.98	-	2.49	-	2.49	-	2.49	-	2.49	-	2.49
2009	Central Bay	Mississippi Silverside	-	2.5	12.4	5	-	2.5	-	2.5	-	2.5	-	2.5	-	2.5
2009	Central Bay	Topsmelt	-	2.45	-	4.9	-	2.45	-	2.45	-	2.45	-	2.45	-	2.45

Year	Region	Common Name	PFOA		PFOS		PFOSA		PFNA		PFDA		PFUnDA		PFDoDA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2009	Central Bay	Topsmelt	-	2.45	-	4.9	-	2.45	-	2.45	-	2.45	-	2.45	-	2.45
2009	Central Bay	Topsmelt	-	2.45	-	4.9	-	2.45	-	2.45	-	2.45	-	2.45	-	2.45
2009	Central Bay	Topsmelt	-	2.48	13.6	4.95	-	2.48	-	2.48	-	2.48	-	2.48	-	2.48
2009	South Bay	Mississippi Silverside	-	2.48	28.2	4.95	9.58	2.48	-	2.48	3.4	2.48	-	2.48	-	2.48
2009	South Bay	Topsmelt	-	2.45	41.7	4.9	-	2.45	-	2.45	-	2.45	-	2.45	-	2.45
2009	Alviso	Mississippi Silverside	-	2.46	60.2	4.93	4.31	2.46	-	2.46	-	2.46	-	2.46	-	2.46
2010	Alviso	Yellowfin Goby	0.617	0.485	23.9	0.971	-	0.583	1.3	0.485	2.79	0.485	2.26	0.485	2.49	0.485
2011	Alviso	Yellowfin Goby	1.32	0.496	24.4	0.98	-	0.588	1.64	0.49	2.07	0.49	1	0.49	1.56	0.49
2012	Central Bay	Pacific Staghorn Sculpin	-	0.493	-	1.32	2.44	0.591	-	0.493	-	0.493	-	0.493	-	0.493
2012	Central Bay	Shiner Surfperch	-	0.493	2.42	0.985	-	0.591	-	0.493	-	0.493	-	0.493	0.573	0.493
2012	South Bay	Chameleon Goby	0.512	0.498	4.17	1.02	2.78	0.597	0.649	0.498	-	0.498	-	0.498	-	0.498
2012	South Bay	Cheekspot goby	-	0.495	9.04	0.99	1.8	0.594	0.632	0.495	0.856	0.495	-	0.495	0.565	0.495
2012	South Bay	Northern Anchovy	-	0.498	10.1	0.995	2.37	0.597	-	0.498	0.686	0.498	-	0.498	0.604	0.498
2012	South Bay	Northern Anchovy	-	0.495	11.1	0.99	2.78	0.594	0.509	0.495	0.797	0.495	-	0.495	0.918	0.495
2012	South Bay	Northern Anchovy	-	0.498	3.04	0.995	2.68	0.597	-	0.498	-	0.498	-	0.498	-	0.498
2012	South Bay	Pacific Staghorn Sculpin	5.56	3.89	67.3	0.976	2.59	0.585	6.56	0.488	1.89	0.488	-	0.488	-	0.488
2012	South Bay	Yellowfin Goby	-	0.49	5.05	0.98	-	0.588	0.632	0.49	-	0.49	-	0.49	-	0.49
2013	Central Bay	Northern Anchovy	-	0.483	2.57	0.966	2.8	0.58	-	0.628	-	0.483	-	0.483	-	0.483
2013	Central Bay	Shiner Surfperch	-	0.488	1.43	0.976	-	0.585	-	0.488	-	0.488	-	0.488	-	0.488
2013	South Bay	Cheekspot goby	-	0.5	16.4	2.3	1.08	0.6	-	0.5	1.39	0.5	1.05	0.5	1.27	0.5
2013	South Bay	Cheekspot goby	-	0.498	10.1	0.995	1.68	0.597	-	0.498	2.13	0.498	0.944	0.498	1.33	0.498
2013	South Bay	Northern Anchovy	-	0.5	20.5	1	4.51	0.6	2.3	0.5	0.718	0.5	-	0.5	-	0.5
2013	South Bay	Pacific Staghorn Sculpin	-	0.498	95.8	0.995	15.9	0.597	2.84	0.498	3.12	0.498	1.01	0.498	1.3	0.498
2013	South Bay	Pacific Staghorn Sculpin	0.915	0.77	58.4	0.985	6.75	0.591	2.04	0.493	1.13	0.493	-	0.493	1.08	0.493
2013	South Bay	Pacific Staghorn Sculpin	14.8	10	241	0.99	8.19	0.594	10	0.495	3.95	0.495	0.999	0.495	0.932	0.495
2013	South Bay	Pacific Staghorn Sculpin	-	0.706	2.63	0.99	2.17	0.594	-	0.495	-	0.495	-	0.495	-	0.495
2013	South Bay	Shiner Surfperch	-	0.498	21.2	0.995	4	0.597	-	0.498	1.58	0.498	1.19	0.498	2.38	0.498

Year	Region	Common Name	PFOA		PFOS		PFOSA		PFNA		PFDA		PFUnDA		PFDoDA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2013	South Bay	Shiner Surfperch	0.79	0.49	12.7	0.98	2.16	0.588	1.6	0.49	0.773	0.49	-	0.49	0.971	0.49
2013	South Bay	Shiner Surfperch	3.45	1.31	29.9	0.99	1.5	0.594	2.27	0.495	1.02	0.495	-	0.495	0.784	0.495
2013	South Bay	Shiner Surfperch	-	0.493	10.3	0.985	5.51	0.591	-	0.493	-	0.493	0.628	0.493	1.64	0.493
2013	South Bay	Yellowfin Goby	-	0.49	18.7	0.98	-	0.588	0.656	0.49	1.09	0.49	0.666	0.49	1.29	0.49
2013	South Bay	Yellowfin Goby	7.44	5.76	28.9	0.99	0.638	0.594	3.43	0.495	0.764	0.495	-	0.495	-	0.495

Table 6. Sportfish PFAS Concentrations (ng/g ww)

Year	Region	Common Name	PFHxS		PFOS		PFBA		PFPA		PFHxA		PFHpA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2009	San Pablo Bay	California Halibut	-	4.93	-	4.93	-	2.46	-	2.46	-	2.46	-	2.46
2009	San Pablo Bay	Leopard shark	-	4.85	-	4.85	-	2.43	-	2.43	-	2.43	-	2.43
2009	San Pablo Bay	Shiner Surfperch	-	4.98	-	4.98	-	2.49	-	2.49	-	2.49	-	2.49
2009	San Pablo Bay	Striped Bass	-	4.9	-	4.9	-	2.45	-	2.45	-	2.45	-	2.45
2009	San Pablo Bay	Striped Bass	-	5	-	5	-	2.5	-	2.5	-	2.5	-	2.5
2009	San Pablo Bay	White Sturgeon	-	4.83	-	4.83	-	2.42	-	2.42	-	2.42	-	2.42
2009	Central Bay	California Halibut	-	4.98	-	4.98	-	2.49	-	2.49	-	2.49	-	2.49
2009	Central Bay	California Halibut	-	4.69	-	4.69	-	2.35	-	2.35	-	2.35	-	2.35
2009	Central Bay	Leopard shark	-	5	-	5	-	2.5	-	2.5	-	2.5	-	2.5
2009	Central Bay	Northern Anchovy	-	4.93	-	4.93	-	2.46	-	2.46	-	2.46	-	2.46
2009	Central Bay	Shiner Surfperch	-	4.93	-	4.93	-	2.46	-	2.46	-	2.46	-	2.46
2009	Central Bay	Striped Bass	-	4.98	-	4.98	-	2.49	-	2.49	-	2.49	-	2.49
2009	Central Bay	White Croaker	-	4.98	-	4.98	-	2.49	-	2.49	-	2.49	-	2.49
2009	Central Bay	White Croaker	-	4.98	-	4.98	-	2.49	-	2.49	-	2.49	-	2.49
2009	South Bay	Leopard shark	-	5	18	5	-	2.5	-	2.5	-	2.5	-	2.5
2009	South Bay	Northern Anchovy	-	5	5.56	5	-	2.5	-	2.5	-	2.5	-	2.5
2009	South Bay	Northern Anchovy	-	4.9	7.77	4.9	-	2.45	-	2.45	-	2.45	-	2.45
2009	South Bay	Shiner Surfperch	-	5	-	5	-	2.5	-	2.5	-	2.5	-	2.5
2009	South Bay	White Croaker	-	4.93	-	4.93	-	2.46	-	2.46	-	2.46	-	2.46
2009	South Bay	White Sturgeon	-	4.93	9.64	4.93	-	2.46	-	2.46	-	2.46	-	2.46
2009	South Bay	White Sturgeon	-	4.9	-	4.9	-	2.45	-	2.45	-	2.45	-	2.45
2014	San Pablo Bay	Striped Bass	-	0.995	6.63	0.995	-	0.498	-	0.498	-	0.498	-	0.498
2014	San Pablo Bay	White Sturgeon	-	1	-	1	-	0.5	-	0.5	-	0.5	-	0.5
2014	Central Bay	Shiner Surfperch	-	1	1.85	1	-	0.5	-	0.5	-	0.5	-	0.5
2014	Central Bay	Shiner Surfperch	-	0.995	-	0.995	-	0.498	-	0.498	-	0.498	-	0.498
2014	Central Bay	Striped Bass	-	0.995	-	0.995	-	0.498	-	0.498	-	0.498	-	0.498

2014	Central Bay	Striped Bass	-	1	3.16	1	-	0.5	-	0.5	-	0.5	-	0.5
2014	Central Bay	White Croaker	-	1	4.68	1	-	0.5	-	0.5	-	0.5	-	0.5
2014	Central Bay	White Croaker	-	1	1.98	1	-	1.5	0.723	0.5	-	0.5	-	0.5
2014	Central Bay	White Sturgeon	-	0.995	-	0.995	-	0.498	-	0.498	-	0.498	-	0.498
2014	South Bay	Shiner Surfperch	-	0.995	3.72	0.995	-	0.498	-	0.498	-	0.498	-	0.498
2014	South Bay	White Croaker	-	1	6.96	1	-	0.5	-	0.5	-	0.5	-	0.5
2014	South Bay	White Sturgeon	-	0.995	2	0.995	-	0.498	-	0.498	-	0.498	-	0.498
2015	Artesian Slough	Common Carp	-	1.01	8.98	1.01	-	0.503	-	0.503	-	0.503	-	0.503
2015	Artesian Slough	Largemouth Bass	-	0.98	14.2	0.98	-	0.49	-	0.49	-	0.49	-	0.49
2015	Artesian Slough	Striped Bass	-	1	17.2	1	-	0.5	-	0.5	-	0.5	-	0.5
2015	Artesian Slough	Striped Bass	-	0.985	12.7	0.985	-	0.493	-	0.493	-	0.493	-	0.493
2015	Artesian Slough	Striped Bass	-	0.995	2.47	0.995	-	0.498	-	0.528	-	0.498	-	0.498

Year	Region	Common Name	PFOA		PFNA		PFDA		PFUnDA		PFDoDA		∑PFCA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2009	San Pablo Bay	California Halibut	-	2.46	-	2.46	-	2.46	-	2.46	-	2.46	11.07	22.14
2009	San Pablo Bay	Leopard shark	-	2.43	-	2.43	-	2.43	-	2.43	-	2.43	10.935	21.87
2009	San Pablo Bay	Shiner Surfperch	-	2.49	-	2.49	-	2.49	-	2.49	-	2.49	11.205	22.41
2009	San Pablo Bay	Striped Bass	-	2.45	-	2.45	-	2.45	-	2.45	-	2.45	11.025	22.05
2009	San Pablo Bay	Striped Bass	-	2.5	-	2.5	-	2.5	-	2.5	-	2.5	11.25	22.5
2009	San Pablo Bay	White Sturgeon	-	2.42	-	2.42	-	2.42	-	2.42	-	2.42	10.89	21.78
2009	Central Bay	California Halibut	-	2.49	-	2.49	-	2.49	-	2.49	-	2.49	11.205	22.41
2009	Central Bay	California Halibut	-	2.35	-	2.35	-	2.35	-	2.35	-	2.35	10.575	21.15
2009	Central Bay	Leopard shark	-	2.5	-	2.5	-	2.5	-	2.5	-	2.5	11.25	22.5
2009	Central Bay	Northern Anchovy	-	2.46	-	2.46	-	2.46	-	2.46	-	2.46	11.07	22.14
2009	Central Bay	Shiner Surfperch	-	2.46	-	2.46	-	2.46	-	2.46	-	2.46	11.07	22.14
2009	Central Bay	Striped Bass	-	2.49	-	2.49	-	2.49	-	2.49	-	2.49	11.205	22.41
2009	Central Bay	White Croaker	-	2.49	-	2.49	-	2.49	-	2.49	-	2.49	11.205	22.41
2009	Central Bay	White Croaker	-	2.49	-	2.49	-	2.49	-	2.49	-	2.49	11.205	22.41

2009	South Bay	Leopard shark	-	2.5	-	2.5	-	2.5	-	2.5	-	2.5	11.25	22.5
2009	South Bay	Northern Anchovy	-	2.5	-	2.5	-	2.5	-	2.5	-	2.5	11.25	22.5
2009	South Bay	Northern Anchovy	-	2.45	-	2.45	-	2.45	-	2.45	-	2.45	11.025	22.05
2009	South Bay	Shiner Surfperch	-	2.5	-	2.5	-	2.5	-	2.5	-	2.5	11.25	22.5
2009	South Bay	White Croaker	-	2.46	-	2.46	-	2.46	-	2.46	-	2.46	11.07	22.14
2009	South Bay	White Sturgeon	-	2.46	-	2.46	-	2.46	-	2.46	-	2.46	11.07	22.14
2009	South Bay	White Sturgeon	-	2.45	-	2.45	-	2.45	-	2.45	-	2.45	11.025	22.05
2014	San Pablo Bay	Striped Bass	-	0.498	-	0.498	-	0.498	-	0.498	-	0.498	2.241	4.482
2014	San Pablo Bay	White Sturgeon	-	0.5	-	0.5	-	0.5	-	0.5	-	0.5	2.25	4.5
2014	Central Bay	Shiner Surfperch	-	0.5	-	0.5	-	0.5	-	0.5	-	0.5	2.25	4.5
2014	Central Bay	Shiner Surfperch	-	0.498	-	0.498	-	0.498	-	0.498	-	0.498	2.241	4.482
2014	Central Bay	Striped Bass	-	0.498	-	0.498	-	0.498	-	0.498	-	0.498	2.241	4.482
2014	Central Bay	Striped Bass	-	0.5	-	0.5	-	0.5	-	0.5	-	0.5	2.25	4.5
2014	Central Bay	White Croaker	-	0.5	-	0.5	-	0.5	-	0.5	0.669	0.5	2.669	4.5
2014	Central Bay	White Croaker	-	0.5	-	0.5	-	0.5	-	0.5	-	0.5	3.223	5.5
2014	Central Bay	White Sturgeon	-	0.498	-	0.498	-	0.498	-	0.498	-	0.498	2.241	4.482
2014	South Bay	Shiner Surfperch	-	0.498	-	0.498	-	0.498	-	0.498	-	0.498	2.241	4.482
2014	South Bay	White Croaker	-	0.5	-	0.5	0.638	0.5	-	0.5	-	0.5	2.638	4.5
2014	South Bay	White Sturgeon	-	0.498	-	0.498	-	0.498	-	0.498	-	0.498	2.241	4.482
2015	Artesian Slough	Common Carp	-	0.503	-	0.503	4.56	0.503	2.23	0.503	4.17	0.503	12.469	4.527
2015	Artesian Slough	Largemouth Bass	-	0.499	-	0.49	2.5	0.49	1.41	0.49	2.08	0.49	7.4645	4.419
2015	Artesian Slough	Striped Bass	-	0.5	-	0.5	1.98	0.5	0.624	0.5	0.599	0.5	4.703	4.5
2015	Artesian Slough	Striped Bass	-	0.493	-	0.493	1.55	0.493	-	0.493	0.952	0.493	4.2275	4.437
2015	Artesian Slough	Striped Bass	-	0.498	-	0.498	-	0.635	-	0.498	-	0.498	2.3245	4.649

Table 7. Bird Egg PFAS Concentrations (ng/g ww)

Year	Station	Acronym	Detects	Min	1st Q	Median	3rd Q	Max
2006	Richmond Bridge	PFBA	(0/3)	1.38	1.38	1.39	1.44	1.5
2006	Richmond Bridge	PFPA	(0/3)	1.38	1.38	1.39	1.44	1.5
2006	Richmond Bridge	PFHxA	(0/3)	1.38	1.38	1.39	1.44	1.5
2006	Richmond Bridge	PFHxS	(0/3)	2.75	2.76	2.78	2.89	3
2006	Richmond Bridge	PFHpA	(0/3)	1.38	1.38	1.39	1.44	1.5
2006	Richmond Bridge	PFOA	(0/3)	1.38	1.38	1.39	1.44	1.5
2006	Richmond Bridge	PFOS	(3/3)	63	70.4	77.7	389	700
2006	Richmond Bridge	PFOSA	(0/3)	1.38	1.38	1.39	1.44	1.5
2006	Richmond Bridge	PFNA	(1/3)	1.39	1.44	1.5	3.34	5.19
2006	Richmond Bridge	PFDA	(1/3)	1.39	1.44	1.5	4.73	7.97
2006	Richmond Bridge	PFUnDA	(3/3)	3.66	4.07	4.47	5.43	6.38
2006	Richmond Bridge	PFDoDA	(3/3)	4.06	4.88	5.69	6.92	8.14
2006	Richmond Bridge	∑PFCA	(3/3)	18.2	19	19.9	27.2	34.6
2006	South Bay	PFBA	(1/3)	1.34	1.69	2.05	2.61	3.17
2006	South Bay	PFPA	(0/3)	1.32	1.33	1.34	1.69	2.05
2006	South Bay	PFHxA	(0/3)	1.32	1.33	1.34	1.69	2.05
2006	South Bay	PFHxS	(3/3)	8.77	8.87	8.96	11.2	13.4
2006	South Bay	PFHpA	(0/3)	1.32	1.33	1.34	1.69	2.05
2006	South Bay	PFOA	(3/3)	5.14	6.92	8.69	9.3	9.9
2006	South Bay	PFOS	(3/3)	1050	1070	1080	1360	1630
2006	South Bay	PFOSA	(0/3)	1.32	1.33	1.34	1.69	2.05
2006	South Bay	PFNA	(3/3)	10.1	11.9	13.6	15	16.4
2006	South Bay	PFDA	(3/3)	17.9	20.7	23.4	24.1	24.7
2006	South Bay	PFUnDA	(3/3)	8.54	8.7	8.85	9.1	9.35
2006	South Bay	PFDoDA	(3/3)	4.4	9.5	14.6	17.1	19.5
2006	South Bay	∑PFCA	(3/3)	70.8	70.8	70.8	72.5	74.1
2006	Wheeler Island	PFBA	(0/3)	1.22	1.25	1.28	1.41	1.54

Year	Station	Acronym	Detects	Min	1st Q	Median	3rd Q	Max
2006	Wheeler Island	PFPA	(0/3)	1.22	1.25	1.28	1.41	1.54
2006	Wheeler Island	PFHxA	(0/3)	1.22	1.25	1.28	1.41	1.54
2006	Wheeler Island	PFHxS	(0/3)	2.44	2.5	2.55	2.81	3.07
2006	Wheeler Island	PFHpA	(0/3)	1.22	1.25	1.28	1.41	1.54
2006	Wheeler Island	PFOA	(1/3)	1.22	1.38	1.54	2.12	2.7
2006	Wheeler Island	PFOS	(3/3)	74.5	87.8	101	118	135
2006	Wheeler Island	PFOSA	(0/3)	1.22	1.25	1.28	1.41	1.54
2006	Wheeler Island	PFNA	(3/3)	6.19	6.26	6.33	7.46	8.59
2006	Wheeler Island	PFDA	(3/3)	5.25	7.38	9.5	9.9	10.3
2006	Wheeler Island	PFUnDA	(3/3)	4.22	6.25	8.27	8.62	8.96
2006	Wheeler Island	PFDoDA	(3/3)	3.29	4.87	6.44	7.49	8.54
2006	Wheeler Island	∑PFCA	(3/3)	26.8	32.9	39	40.3	41.7
2009	Richmond Bridge	PFBA	(0/3)	1.21	1.22	1.23	1.24	1.24
2009	Richmond Bridge	PFPA	(0/3)	1.21	1.22	1.23	1.24	1.24
2009	Richmond Bridge	PFHxA	(0/3)	1.21	1.22	1.23	1.24	1.24
2009	Richmond Bridge	PFHxS	(2/3)	2.42	3.84	5.26	5.45	5.63
2009	Richmond Bridge	PFHpA	(0/3)	1.21	1.22	1.23	1.24	1.24
2009	Richmond Bridge	PFOA	(1/3)	1.23	1.24	1.24	3.58	5.92
2009	Richmond Bridge	PFOS	(3/3)	94.7	105	116	137	158
2009	Richmond Bridge	PFOSA	(0/3)	1.21	1.22	1.23	1.24	1.24
2009	Richmond Bridge	PFNA	(3/3)	2.94	3.38	3.81	4.25	4.68
2009	Richmond Bridge	PFDA	(3/3)	3.73	7.12	10.5	11.5	12.5
2009	Richmond Bridge	PFUnDA	(3/3)	3.61	5.41	7.21	8.96	10.7
2009	Richmond Bridge	PFDoDA	(3/3)	3.67	7.49	11.3	12.5	13.7
2009	Richmond Bridge	∑PFCA	(3/3)	25.6	33.7	41.8	42.9	44
2009	South Bay	PFBA	(0/3)	1.19	1.19	1.2	1.21	1.21
2009	South Bay	PFPA	(0/3)	1.19	1.19	1.2	1.21	1.21
2009	South Bay	PFHxA	(0/3)	1.19	1.19	1.2	1.21	1.21
2009	South Bay	PFHxS	(3/3)	14.9	17.8	20.6	30.4	40.1

Year	Station	Acronym	Detects	Min	1st Q	Median	3rd Q	Max
2009	South Bay	PFHpA	(0/3)	1.19	1.19	1.2	1.21	1.21
2009	South Bay	PFOA	(3/3)	21.3	22.1	22.8	25.8	28.7
2009	South Bay	PFOS	(3/3)	833	987	1140	1450	1760
2009	South Bay	PFOSA	(1/3)	1.19	1.2	1.21	2.17	3.13
2009	South Bay	PFNA	(3/3)	25.7	26	26.3	32.9	39.5
2009	South Bay	PFDA	(3/3)	19.9	20.3	20.6	24.5	28.3
2009	South Bay	PFUnDA	(3/3)	6.74	7.05	7.36	8.39	9.42
2009	South Bay	PFDoDA	(3/3)	4.64	6.47	8.3	9.15	10
2009	South Bay	∑PFCA	(3/3)	85.9	87.5	89.1	104	119
2009	Wheeler Island	PFBA	(0/3)	1.21	1.22	1.23	1.24	1.24
2009	Wheeler Island	PFPA	(0/3)	1.21	1.22	1.23	1.24	1.24
2009	Wheeler Island	PFHxA	(0/3)	1.21	1.22	1.23	1.24	1.24
2009	Wheeler Island	PFHxS	(0/3)	2.42	2.44	2.47	2.47	2.48
2009	Wheeler Island	PFHpA	(0/3)	1.21	1.22	1.23	1.24	1.24
2009	Wheeler Island	PFOA	(0/3)	1.21	1.22	1.23	1.24	1.24
2009	Wheeler Island	PFOS	(3/3)	73.8	78.8	83.7	89.7	95.7
2009	Wheeler Island	PFOSA	(0/3)	1.21	1.22	1.23	1.24	1.24
2009	Wheeler Island	PFNA	(3/3)	4.85	4.87	4.89	6.43	7.96
2009	Wheeler Island	PFDA	(3/3)	7.73	8.03	8.32	10.4	12.5
2009	Wheeler Island	PFUnDA	(3/3)	2.92	3.53	4.14	4.55	4.95
2009	Wheeler Island	PFDoDA	(3/3)	3.45	3.48	3.51	4.35	5.19
2009	Wheeler Island	∑PFCA	(3/3)	26.7	26.8	27	31	35.1
2012	Richmond Bridge	PFBA	(0/3)	0.242	0.243	0.244	0.256	0.267
2012	Richmond Bridge	PFPA	(0/3)	0.242	0.243	0.244	0.249	0.254
2012	Richmond Bridge	PFHxA	(0/3)	0.242	0.243	0.244	0.249	0.254
2012	Richmond Bridge	PFHxS	(3/3)	1.7	2.3	2.89	3.08	3.27
2012	Richmond Bridge	PFHpA	(0/3)	0.242	0.243	0.244	0.249	0.254
2012	Richmond Bridge	PFOA	(3/3)	0.923	0.962	1	1.14	1.28
2012	Richmond Bridge	PFOS	(3/3)	50.9	63.9	76.8	96.9	117

Year	Station	Acronym	Detects	Min	1st Q	Median	3rd Q	Max
2012	Richmond Bridge	PFOSA	(0/3)	0.29	0.291	0.293	0.299	0.305
2012	Richmond Bridge	PFNA	(3/3)	1.71	2.14	2.57	3.39	4.2
2012	Richmond Bridge	PFDA	(3/3)	3.79	4.01	4.23	19.9	35.6
2012	Richmond Bridge	PFUnDA	(3/3)	3.99	4.19	4.39	8.4	12.4
2012	Richmond Bridge	PFDoDA	(3/3)	8.02	8.32	8.61	14.9	21.2
2012	Richmond Bridge	∑PFCA	(3/3)	20.2	20.8	21.3	48.3	75.4
2012	South Bay	PFBA	(0/3)	0.236	0.239	0.243	0.246	0.249
2012	South Bay	PFPA	(0/3)	0.236	0.239	0.243	0.246	0.249
2012	South Bay	PFHxA	(0/3)	0.236	0.239	0.243	0.246	0.249
2012	South Bay	PFHxS	(3/3)	6.03	7.22	8.4	11.1	13.7
2012	South Bay	PFHpA	(0/3)	0.236	0.239	0.243	0.246	0.249
2012	South Bay	PFOA	(3/3)	11.1	12.3	13.4	18.2	23
2012	South Bay	PFOS	(3/3)	323	345	366	416	466
2012	South Bay	PFOSA	(0/3)	0.283	0.287	0.292	0.295	0.299
2012	South Bay	PFNA	(3/3)	10.1	11.7	13.3	16.2	19.1
2012	South Bay	PFDA	(3/3)	15.8	16.4	16.9	19.1	21.3
2012	South Bay	PFUnDA	(3/3)	4.08	4.92	5.76	7.41	9.05
2012	South Bay	PFDoDA	(3/3)	4.33	7.82	11.3	13.4	15.5
2012	South Bay	∑PFCA	(3/3)	56.1	61.7	67.3	70.4	73.5
2012	Wheeler Island	PFBA	(0/3)	0.243	0.243	0.244	0.25	0.255
2012	Wheeler Island	PFPA	(0/3)	0.243	0.243	0.244	0.25	0.255
2012	Wheeler Island	PFHxA	(0/3)	0.243	0.243	0.244	0.25	0.255
2012	Wheeler Island	PFHxS	(1/3)	0.486	0.498	0.51	1.02	1.53
2012	Wheeler Island	PFHpA	(0/3)	0.243	0.243	0.244	0.25	0.255
2012	Wheeler Island	PFOA	(3/3)	0.654	0.715	0.775	0.928	1.08
2012	Wheeler Island	PFOS	(3/3)	36.1	52.8	69.4	125	181
2012	Wheeler Island	PFOSA	(0/3)	0.292	0.292	0.293	0.299	0.306
2012	Wheeler Island	PFNA	(3/3)	2.76	3.54	4.32	4.64	4.96
2012	Wheeler Island	PFDA	(3/3)	4.46	6.32	8.18	12.1	16.1

Year	Station	Acronym	Detects	Min	1st Q	Median	3rd Q	Max
2012	Wheeler Island	PFUnDA	(3/3)	2.93	4.92	6.91	10.3	13.6
2012	Wheeler Island	PFDoDA	(3/3)	2.95	5.73	8.51	12.3	16.1
2012	Wheeler Island	∑PFCA	(3/3)	15.2	22.8	30.4	41.1	51.8
2016	Richmond Bridge	PFBA	(0/3)	0.242	0.245	0.248	0.249	0.25
2016	Richmond Bridge	PFPA	(0/3)	0.263	0.275	0.287	0.409	0.53
2016	Richmond Bridge	PFHxA	(0/3)	0.242	0.245	0.248	0.249	0.25
2016	Richmond Bridge	PFHxS	(1/3)	0.483	0.644	0.805	1	1.2
2016	Richmond Bridge	PFHpA	(0/3)	0.242	0.245	0.248	0.249	0.25
2016	Richmond Bridge	PFOA	(3/3)	1.16	1.3	1.44	1.57	1.69
2016	Richmond Bridge	PFOS	(3/3)	77.9	96	114	133	152
2016	Richmond Bridge	PFOSA	(1/3)	0.297	0.299	0.3	0.82	1.34
2016	Richmond Bridge	PFNA	(3/3)	1.85	2.63	3.4	3.62	3.83
2016	Richmond Bridge	PFDA	(3/3)	7.17	10.7	14.3	14.7	15.1
2016	Richmond Bridge	PFUnDA	(3/3)	4.51	5.96	7.41	9.31	11.2
2016	Richmond Bridge	PFDoDA	(3/3)	5.84	8.67	11.5	13.3	15.1
2016	Richmond Bridge	∑PFCA	(3/3)	30.8	34.3	37.7	39	40.3
2016	South Bay	PFBA	(0/3)	0.252	0.252	0.252	0.252	0.253
2016	South Bay	PFPA	(0/3)	0.252	0.252	0.252	0.252	0.253
2016	South Bay	PFHxA	(0/3)	0.252	0.252	0.252	0.252	0.253
2016	South Bay	PFHxS	(3/3)	4.3	4.41	4.52	4.57	4.61
2016	South Bay	PFHpA	(0/3)	0.252	0.252	0.252	0.252	0.253
2016	South Bay	PFOA	(3/3)	3.88	4.62	5.36	5.44	5.52
2016	South Bay	PFOS	(3/3)	570	604	638	646	654
2016	South Bay	PFOSA	(2/3)	0.302	0.463	0.625	0.908	1.19
2016	South Bay	PFNA	(3/3)	11.7	12.2	12.7	15.4	18
2016	South Bay	PFDA	(3/3)	36.9	38.9	40.8	49.3	57.7
2016	South Bay	PFUnDA	(3/3)	10.3	11.3	12.3	15.7	19.1
2016	South Bay	PFDoDA	(3/3)	12.7	17.4	22.1	25.7	29.3
2016	South Bay	∑PFCA	(3/3)	77.5	85.4	93.3	112	131

Year	Station	Acronym	Detects	Min	1st Q	Median	3rd Q	Max
2016	Wheeler Island	PFBA	(0/2)	0.249	0.25	0.252	0.253	0.254
2016	Wheeler Island	PFPA	(0/3)	0.249	0.25	0.252	0.253	0.254
2016	Wheeler Island	PFHxA	(0/3)	0.249	0.25	0.252	0.253	0.254
2016	Wheeler Island	PFHxS	(0/3)	0.498	0.504	0.51	0.618	0.725
2016	Wheeler Island	PFHpA	(0/3)	0.249	0.25	0.252	0.253	0.254
2016	Wheeler Island	PFOA	(3/3)	1.06	1.16	1.26	1.31	1.35
2016	Wheeler Island	PFOS	(3/3)	37.8	37.9	37.9	62.8	87.7
2016	Wheeler Island	PFOSA	(0/3)	0.299	0.302	0.305	0.328	0.352
2016	Wheeler Island	PFNA	(3/3)	2.16	2.58	2.99	3.07	3.14
2016	Wheeler Island	PFDA	(3/3)	4.02	4.35	4.67	4.67	4.67
2016	Wheeler Island	PFUnDA	(3/3)	1.34	1.41	1.48	1.56	1.64
2016	Wheeler Island	PFDoDA	(3/3)	0.752	0.844	0.935	1.03	1.12
2016	Wheeler Island	∑PFCA	(3/3)	11.1	11.3	11.5	12.1	12.8

Table 8. Harbor seal PFAS Concentrations (ng/g)

Year	Station	Acronym	Detects	Min	1st Q	Median	3rd Q	Max	Average MDL
2006-08	Tomales Bay	PFBA	(0/21)	0.25	0.25	0.25	0.254	0.356	0.527
2006-08	Tomales Bay	PFBS	(0/21)	0.499	0.5	0.5	0.505	0.66	1.03
2006-08	Tomales Bay	PFPA	(0/21)	0.25	0.25	0.25	0.253	0.329	0.517
2006-08	Tomales Bay	PFHxA	(0/21)	0.25	0.25	0.275	0.329	0.9	0.662
2006-08	Tomales Bay	PFHxS	(16/21)	0.5	1.04	1.91	3.04	10.8	1.03
2006-08	Tomales Bay	PFHpA	(0/21)	0.25	0.25	0.25	0.253	0.329	0.517
2006-08	Tomales Bay	PFOA	(1/21)	0.25	0.25	0.25	0.254	1.07	0.517
2006-08	Tomales Bay	PFOS	(21/21)	13.5	19.2	26.3	41.4	134	1.03
2006-08	Tomales Bay	PFOSA	(0/21)	0.25	0.25	0.25	0.253	0.329	0.517
2006-08	Tomales Bay	PFNA	(21/21)	0.84	1.44	2.29	3.22	8.31	0.517
2006-08	Tomales Bay	PFDA	(20/21)	0.25	1.18	1.53	1.99	8.31	0.517
2006-08	Tomales Bay	PFUnDA	(21/21)	1.97	2.75	3.79	5.41	23	0.518
2006-08	Tomales Bay	PFDoDA	(14/21)	0.25	0.25	0.607	0.775	2.8	0.517
2006-08	Castro Rocks	PFBA	(1/34)	0.243	0.25	0.25	0.254	0.562	0.524
2006-08	Castro Rocks	PFBS	(0/34)	0.486	0.5	0.505	0.7	2.5	1.5
2006-08	Castro Rocks	PFPA	(0/34)	0.243	0.25	0.25	0.254	0.38	0.524
2006-08	Castro Rocks	PFHxA	(0/34)	0.2	0.25	0.263	0.452	0.79	0.753
2006-08	Castro Rocks	PFHxS	(34/34)	1.6	20.2	30	48.2	93.2	1.67
2006-08	Castro Rocks	PFHpA	(10/34)	0.243	0.25	0.251	0.762	3.36	0.524
2006-08	Castro Rocks	PFOA	(30/34)	0.25	0.914	1.88	4.48	11	0.527
2006-08	Castro Rocks	PFOS	(34/34)	16.5	143	218	353	1280	2.2
2006-08	Castro Rocks	PFOSA	(0/34)	0.2	0.25	0.25	0.256	1.25	0.603
2006-08	Castro Rocks	PFNA	(34/34)	1.38	5.02	10	15	29.7	0.515
2006-08	Castro Rocks	PFDA	(34/34)	0.53	3.65	7.19	14.5	32.7	0.524
2006-08	Castro Rocks	PFUnDA	(34/34)	1.11	3.54	4.54	7.72	19.2	0.524
2006-08	Castro Rocks	PFDoDA	(31/34)	0.25	1.35	2.63	5.98	14.8	0.524
2004	Southern Sloughs	PFBA	(0/6)	0.25	0.25	0.25	0.25	0.25	0.5

Year	Station	Acronym	Detects	Min	1st Q	Median	3rd Q	Max	Average MDL
2004	Southern Sloughs	PFBS	(0/6)	0.5	0.5	0.5	0.5	0.5	1
2004	Southern Sloughs	PFPA	(0/6)	0.25	0.25	0.25	0.25	0.25	0.5
2004	Southern Sloughs	PFHxA	(0/6)	0.25	0.25	0.25	0.25	0.486	0.579
2004	Southern Sloughs	PFHxS	(6/6)	24.4	34.6	43.6	79.1	154	1.66
2004	Southern Sloughs	PFHpA	(3/6)	0.25	0.25	0.443	0.718	1.34	0.5
2004	Southern Sloughs	PFOA	(6/6)	3.91	6.11	7.77	9.96	11.3	0.504
2004	Southern Sloughs	PFOS	(6/6)	401	643	898	1390	1960	11.3
2004	Southern Sloughs	PFOSA	(0/6)	0.25	0.25	0.25	0.25	0.25	0.5
2004	Southern Sloughs	PFNA	(6/6)	6.35	8.35	15.7	19.7	43.3	0.5
2004	Southern Sloughs	PFDA	(6/6)	5.93	7.52	13.2	16.3	23.1	0.5
2004	Southern Sloughs	PFUnDA	(6/6)	3.25	5.7	8.15	9.84	17.8	0.606
2004	Southern Sloughs	PFDoDA	(6/6)	2.34	4.02	6.76	8.93	11.5	0.5
2009-11	Tomales Bay	PFBA	(0/4)	0.25	0.25	0.25	0.25	0.25	0.5
2009-11	Tomales Bay	PFBS	(0/4)	0.5	0.5	0.5	0.5	0.5	1
2009-11	Tomales Bay	PFPA	(0/4)	0.25	0.25	0.25	0.25	0.25	0.5
2009-11	Tomales Bay	PFHxA	(0/4)	0.25	0.25	0.25	0.25	0.25	0.5
2009-11	Tomales Bay	PFHxS	(0/4)	0.5	0.5	0.5	0.5	0.5	1
2009-11	Tomales Bay	PFHpA	(0/4)	0.25	0.25	0.25	0.25	0.25	0.5
2009-11	Tomales Bay	PFOA	(0/4)	0.25	0.25	0.25	0.25	0.25	0.5
2009-11	Tomales Bay	PFOS	(4/4)	9.89	10.6	11.8	13.3	15.3	1
2009-11	Tomales Bay	PFOSA	(0/4)	0.25	0.25	0.25	0.25	0.25	0.5
2009-11	Tomales Bay	PFNA	(4/4)	2.88	2.94	3.1	3.95	6.09	0.5
2009-11	Tomales Bay	PFDA	(4/4)	1.72	1.78	1.82	1.92	2.14	0.5
2009-11	Tomales Bay	PFUnDA	(4/4)	4.72	4.93	5.23	5.75	6.65	0.5
2009-11	Tomales Bay	PFDoDA	(4/4)	0.561	0.619	0.667	0.706	0.737	0.5
2009-11	Castro Rocks	PFBA	(0/13)	0.25	0.25	0.25	0.278	0.357	0.541
2009-11	Castro Rocks	PFBS	(0/13)	0.5	0.5	0.5	0.555	0.715	1.08
2009-11	Castro Rocks	PFPA	(0/13)	0.25	0.25	0.25	0.278	0.357	0.541
2009-11	Castro Rocks	PFHxA	(0/13)	0.25	0.25	0.25	0.278	0.357	0.541

Year	Station	Acronym	Detects	Min	1st Q	Median	3rd Q	Max	Average MDL
2009-11	Castro Rocks	PFHxS	(12/13)	0.58	1.84	6.88	18.4	35.1	1.08
2009-11	Castro Rocks	PFHpA	(0/13)	0.25	0.25	0.25	0.278	0.357	0.541
2009-11	Castro Rocks	PFOA	(4/13)	0.25	0.25	0.278	0.751	1.95	0.541
2009-11	Castro Rocks	PFOS	(13/13)	12.2	25.7	69.4	125	223	1.08
2009-11	Castro Rocks	PFOSA	(0/13)	0.25	0.25	0.25	0.278	0.357	0.541
2009-11	Castro Rocks	PFNA	(13/13)	1.39	2.68	3.87	4.68	21.3	0.541
2009-11	Castro Rocks	PFDA	(13/13)	0.706	1.72	2.43	6.02	11.3	0.541
2009-11	Castro Rocks	PFUnDA	(13/13)	1.71	2.48	3.26	5.18	7.14	0.541
2009-11	Castro Rocks	PFDoDA	(10/13)	0.278	0.696	0.856	1.76	3.65	0.541
2009-11	Southern Sloughs	PFBA	(0/20)	0.25	0.25	0.25	0.292	0.329	0.54
2009-11	Southern Sloughs	PFBS	(0/20)	0.5	0.5	0.5	0.584	0.66	1.08
2009-11	Southern Sloughs	PFPA	(0/20)	0.25	0.25	0.25	0.292	0.329	0.54
2009-11	Southern Sloughs	PFHxA	(0/20)	0.25	0.25	0.25	0.292	0.329	0.54
2009-11	Southern Sloughs	PFHxS	(20/20)	2.49	55.8	99.3	135	298	1.08
2009-11	Southern Sloughs	PFHpA	(2/20)	0.25	0.25	0.269	0.299	0.803	0.54
2009-11	Southern Sloughs	PFOA	(18/20)	0.25	5.77	18.5	38	120	0.54
2009-11	Southern Sloughs	PFOS	(20/20)	34	692	1050	1200	1940	2.37
2009-11	Southern Sloughs	PFOSA	(0/20)	0.25	0.25	0.25	0.292	0.329	0.54
2009-11	Southern Sloughs	PFNA	(20/20)	4.33	61.5	95	155	694	0.601
2009-11	Southern Sloughs	PFDA	(20/20)	2.05	26.3	40.3	56.6	97.4	0.54
2009-11	Southern Sloughs	PFUnDA	(20/20)	2.63	8.54	12.3	17.8	34.2	0.54
2009-11	Southern Sloughs	PFDoDA	(19/20)	0.25	3.46	6.55	10.8	38.7	0.54
2014	Southern Sloughs	PFBA	(0/7)	0.241	0.248	0.25	0.25	0.255	0.497
2014	Southern Sloughs	PFBS	(0/7)	0.481	0.496	0.5	0.5	0.52	0.998
2014	Southern Sloughs	PFPA	(0/7)	0.241	0.248	0.25	0.25	0.255	0.497
2014	Southern Sloughs	PFHxA	(0/7)	0.241	0.248	0.25	0.25	0.255	0.497
2014	Southern Sloughs	PFHxS	(7/7)	11.8	20.9	37.7	61.5	97.2	0.995
2014	Southern Sloughs	PFHpA	(1/7)	0.241	0.248	0.25	0.25	0.792	0.497
2014	Southern Sloughs	PFOA	(5/7)	0.246	2.04	4.78	21.6	139	2.51

Year	Station	Acronym	Detects	Min	1st Q	Median	3rd Q	Max	Average MDL
2014	Southern Sloughs	PFOS	(7/7)	12.6	83.7	331	581	796	1.28
2014	Southern Sloughs	PFOSA	(0/7)	0.241	0.248	0.25	0.25	0.255	0.497
2014	Southern Sloughs	PFNA	(7/7)	3.34	8.32	23.1	60.9	106	0.497
2014	Southern Sloughs	PFDA	(7/7)	0.829	4.97	21	21.5	44.5	0.497
2014	Southern Sloughs	PFUnDA	(7/7)	1.86	4.24	4.89	10.4	16.2	0.497
2014	Southern Sloughs	PFDoDA	(6/7)	0.246	1.15	2.57	8.95	13.6	0.497

Table 9a. Stormwater PFAS Concentrations (ng/L)

Year	Station	Study[1]	PFBA		PFBS		PFPA		PFHxA		PFHxS		PFHpA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2009	Hayward Zone 4 Line A	RMP	16.6	15.1	6.49	2.73	-	5.85	23.7	3.93	10.2	2.03	22.3	4.35
2009	Guadalupe River -Rising	RMP	17.7	4.48	3.7	2.03	6.5	4.69	31.7	2.33	9.66	2.32	25.6	4.64
2009	Guadalupe River -Peak	RMP	5.51	1.58	-	2.01	1.22	1.01	5.3	1.01	3.94	2.01	6.57	1.07
2010	Mallard Island – Rising	RMP	1.55	1	-	1	-	1	1.86	0.99	-	2.01	-	1
2010	Mallard Island- Peak	RMP	-	1	-	1	-	0.99	1.7	0.99	-	1.99	-	0.99
2010	Guadalupe River Foxworthy - Rising	RMP	3.87	0.99	-	0.99	1.65	0.99	3.7	1.02	-	1.98	2.76	0.99
2010	Guadalupe River Foxworthy - Peak	RMP	4.29	11.02	-	2.05	3.26	1.02	3.93	18	2.17	2.05	2.75	1.02
2010	Belmont Creek	Houtz and Sedlak 2012	#N/A	#N/A	-	6	3.3	1	6.6	1	2.5	1	4.6	1
2010	Belmont Creek	Houtz and Sedlak 2012	#N/A	#N/A	-	6	2.7	1	8.2	1	4.7	1	5.4	1
2010	Belmont Creek	Houtz and Sedlak 2012	#N/A	#N/A	3.6	1	4.2	1	9.7	1	6.5	1	5.7	1
2010	Calabazas Creek	Houtz and Sedlak 2012	#N/A	#N/A	2.6	1	3.7	1	6.9	1	1.2	1	3.5	1
2010	Calabazas Creek	Houtz and Sedlak 2012	#N/A	#N/A	6	1	-	4	4.4	1	1.1	1	2.2	1
2010	Calabazas Creek	Houtz and Sedlak 2012	#N/A	#N/A	2.2	1	1.4	1	3.3	1	1	1	1.8	1
2010	Calabazas Creek	Houtz and Sedlak 2012	#N/A	#N/A	-	6	-	4	3	1	2.6	1	1.5	1

Year	Station	Study[1]	PFBA		PFBS		PFPA		PFHxA		PFHxS		PFHpA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2010	Ettie Street Pump Station	Houtz and Sedlak 2012	#N/A	#N/A	2.7	1	1.7	1	4.3	1	1.9	1	2.3	1
2010	Ettie Street Pump Station	Houtz and Sedlak 2012	#N/A	#N/A	2.4	1	6.8	1	4.5	1	2.7	1	2.4	1
2010	Ettie Street Pump Station	Houtz and Sedlak 2012	#N/A	#N/A	3.4	1	7.6	1	4.8	1	3.7	1	2.9	1
2010	Glen Echo Creek	Houtz and Sedlak 2012	#N/A	#N/A	-	6	2.9	1	6	1	1.8	1	2.9	1
2010	Glen Echo Creek	Houtz and Sedlak 2012	#N/A	#N/A	4.3	1	9.5	1	6.2	1	3.3	1	2.8	1
2010	Lower Marsh Creek	Houtz and Sedlak 2012	#N/A	#N/A	-	6	-	4	3.3	1	0.3	1	0.9	1
2010	Lower Marsh Creek	Houtz and Sedlak 2012	#N/A	#N/A	-	6	2	1	2	1	0.6	1	1	1
2010	Lower Marsh Creek	Houtz and Sedlak 2012	#N/A	#N/A	-	6	0.8	1	0.9	1	-	2	1.4	1
2010	San Lorenzo Creek	Houtz and Sedlak 2012	#N/A	#N/A	-	6	1.4	1	7.7	1	3.7	1	4.2	1
2010	San Lorenzo Creek	Houtz and Sedlak 2012	#N/A	#N/A	4.8	1	1	1	5.7	1	2.4	1	2.9	1
2010	San Lorenzo Creek	Houtz and Sedlak 2012	#N/A	#N/A	-	6	2.5	1	4.5	1	1.7	1	2.5	1

Year	Station	Study[1]	PFBA		PFBS		PFPA		PFHxA		PFHxS		PFHpA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2010	San Lorenzo Creek	Houtz and Sedlak 2012	#N/A	#N/A	4.8	1	6.6	1	5.1	1	2.2	1	2.8	1
2010	San Lorenzo Creek	Houtz and Sedlak 2012	#N/A	#N/A	5.6	1	7.2	1	6	1	2.4	1	3.5	1
2010	San Tomas Creek	Houtz and Sedlak 2012	#N/A	#N/A	-	6	6.3	1	4.5	1	1.4	1	1.5	1
2010	San Tomas Creek	Houtz and Sedlak 2012	#N/A	#N/A	-	6	3.7	1	4.3	1	1.1	1	1.6	1
2010	San Tomas Creek	Houtz and Sedlak 2012	#N/A	#N/A	3.1	1	1.1	1	5.6	1	1.5	1	2.8	1
2010	San Tomas Creek	Houtz and Sedlak 2012	#N/A	#N/A	4.5	1	3.1	1	4	1	1.4	1	2	1
2010	Stevens Creek	Houtz and Sedlak 2012	#N/A	#N/A	-	6	1.1	1	2.6	1	1.5	1	1.2	1
2010	Stevens Creek	Houtz and Sedlak 2012	#N/A	#N/A	-	6	1.9	1	2.9	1	1	1	1.3	1
2010	Walnut Creek	Houtz and Sedlak 2012	#N/A	#N/A	10.6	1	4.3	1	6.6	1	3.8	1	3.7	1
2010	Walnut Creek	Houtz and Sedlak 2012	#N/A	#N/A	11	1	4.8	1	8.7	1	2.2	1	2.9	1
2010	Walnut Creek	Houtz and Sedlak 2012	#N/A	#N/A	-	6	1.1	1	5	1	2.4	1	3.1	1

Year	Station	Study[1]	PFBA		PFBS		PFPA		PFHxA		PFHxS		PFHpA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2010	Walnut Creek	Houtz and Sedlak 2012	#N/A	#N/A	-	6	1.1	1	4	1	2.6	1	3.9	1
2010	Zone 5 Line M (Union City)	Houtz and Sedlak 2012	#N/A	#N/A	-	6	3	1	6.4	1	1	1	3	1
2010	Zone 5 Line M (Union City)	Houtz and Sedlak 2012	#N/A	#N/A	3.5	1	3.3	1	3.7	1	1.5	1	2.2	1
2010	Zone 5 Line M (Union City)	Houtz and Sedlak 2012	#N/A	#N/A	-	6	1.7	1	3.9	1	1.7	1	2.3	1

Year	Station	Region	PFOA		PFOS		PFOSA		PFNA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL
2009	Hayward Zone 4 Line A	RMP	69	2.76	5.77	2.02	-	1.01	23.5	4.24
2009	Guadalupe River -Rising	RMP	66	1.02	14.2	2.03	1.09	1.02	19	2.21
2009	Guadalupe River -Peak	RMP	16.6	1.01	13.7	2.01	-	1.01	5.77	1.29
2010	Mallard Island – Rising	RMP	2.39	1	-	2.01	-	1	1.14	1
2010	Mallard Island- Peak	RMP	1.53	0.99	2.06	1.99	-	0.99	-	0.99
2010	Guadalupe River Foxworthy - Rising	RMP	7.57	0.99	4.55	1.98	-	0.99	1.9	0.99
2010	Guadalupe River Foxworthy - Peak	RMP	5.75	1.02	4.76	2.05	-	1.02	1.5	1.02
2010	Belmont Creek	Houtz and Sedlak 2012	11	1	19	1	1.1	1	2	1
2010	Belmont Creek	Houtz and Sedlak 2012	12.1	1	17.4	1	0.5	1	2.3	1

Year	Station	Region	PFOA		PFOS		PFOSA		PFNA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL
2010	Belmont Creek	Houtz and Sedlak 2012	15.7	1	22.6	1	0.6	1	2.8	1
2010	Calabazas Creek	Houtz and Sedlak 2012	10.8	1	16.7	1	1.7	1	3.6	1
2010	Calabazas Creek	Houtz and Sedlak 2012	6	1	10.6	1	0.4	1	1.3	1
2010	Calabazas Creek	Houtz and Sedlak 2012	4.8	1	9	1	0.4	1	1.2	1
2010	Calabazas Creek	Houtz and Sedlak 2012	4.7	1	11.4	1	0.6	1	0.8	1
2010	Ettie Street Pump Station	Houtz and Sedlak 2012	5.1	1	14.6	1	0.8	1	2.2	1
2010	Ettie Street Pump Station	Houtz and Sedlak 2012	6.5	1	14.4	1	1	1	2	1
2010	Ettie Street Pump Station	Houtz and Sedlak 2012	8.4	1	16.8	1	1.3	1	2.2	1
2010	Glen Echo Creek	Houtz and Sedlak 2012	8.3	1	14.7	1	0.5	1	2.4	1
2010	Glen Echo Creek	Houtz and Sedlak 2012	9.3	1	25.3	1	0.2	1	2	1
2010	Lower Marsh Creek	Houtz and Sedlak 2012	4	1	3.6	1	-	2	0.8	1

Year	Station	Region	PFOA		PFOS		PFOSA		PFNA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL
2010	Lower Marsh Creek	Houtz and Sedlak 2012	4	1	5.7	1	0.7	1	0.9	1
2010	Lower Marsh Creek	Houtz and Sedlak 2012	2.3	1	2.6	1	0.2	1	0.4	1
2010	San Lorenzo Creek	Houtz and Sedlak 2012	11	1	26.3	1	1.1	1	3	1
2010	San Lorenzo Creek	Houtz and Sedlak 2012	9	1	18.3	1	1.1	1	2.2	1
2010	San Lorenzo Creek	Houtz and Sedlak 2012	11	1	14.3	1	0.5	1	1.9	1
2010	San Lorenzo Creek	Houtz and Sedlak 2012	7.6	1	16.9	1	0.7	1	1.5	1
2010	San Lorenzo Creek	Houtz and Sedlak 2012	8.9	1	19.2	1	0.5	1	1.4	1
2010	San Tomas Creek	Houtz and Sedlak 2012	6.5	1	10.7	1	1.6	1	1.9	1
2010	San Tomas Creek	Houtz and Sedlak 2012	7	1	10.3	1	0.7	1	1.5	1
2010	San Tomas Creek	Houtz and Sedlak 2012	7.9	1	18.6	1	0.3	1	1.2	1
2010	San Tomas Creek	Houtz and Sedlak 2012	5.8	1	14.6	1	0.4	1	0.8	1
2010	Stevens Creek	Houtz Sites	3.9	1	5.4	1	1.1	1	1	1

Year	Station	Region	PFOA		PFOS		PFOSA		PFNA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL
2010	Stevens Creek	Houtz and Sedlak 2012	3.1	1	3.8	1	-	2	0.3	1
2010	Walnut Creek	Houtz and Sedlak 2012	9.1	1	20.8	1	0.5	1	3.8	1
2010	Walnut Creek	Houtz and Sedlak 2012	6.7	1	10.3	1	0.5	1	1.8	1
2010	Walnut Creek	Houtz and Sedlak 2012	8.8	1	15.3	1	-	2	1.5	1
2010	Walnut Creek	Houtz and Sedlak 2012	3.8	1	7.3	1	-	2	0.3	1
2010	Zone 5 Line M (Union City)	Houtz and Sedlak 2012	10.7	1	17.7	1	1.8	1	2.6	1
2010	Zone 5 Line M (Union City)	Houtz and Sedlak 2012	7.3	1	11.1	1	-	2	2.1	1
2010	Zone 5 Line M (Union City)	Houtz and Sedlak 2012	5.6	1	9.7	1	0.5	1	1.4	1

Year	Station	Region	PFDA		PFDS		PFUnDA		PFDoDA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL
2009	Hayward Zone 4 Line A	RMP	21.4	1.08	#N/A	#N/A	4.73	1.01	1.23	1.01
2009	Guadalupe River -Rising	RMP	29.1	1.02	#N/A	#N/A	4.16	1.02	1.66	1.02
2009	Guadalupe River -Peak	RMP	6.7	1.01	#N/A	#N/A	1.38	1.01	-	1.01
2010	Mallard Island – Rising	RMP	-	1	#N/A	#N/A	-	1	-	1
2010	Mallard Island- Peak	RMP	-	0.99	#N/A	#N/A	-	0.99	-	0.99

Year	Station	Region	PFDA		PFDS		PFUnDA		PFDoDA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL
2010	Guadalupe River Foxworthy - Rising	RMP	1.38	0.99	#N/A	#N/A	-	0.99	-	0.99
2010	Guadalupe River Foxworthy - Peak	RMP	-	1.02	#N/A	#N/A	-	1.02	-	1.02
2010	Belmont Creek	Houtz Sites	3.2	1	-	2	0.5	1	0.9	1
2010	Belmont Creek	Houtz Sites	2.2	1	-	2	0.5	1	-	2
2010	Belmont Creek	Houtz Sites	2.8	1	-	2	-	4	0.2	1
2010	Calabazas Creek	Houtz Sites	3.7	1	-	2	0.6	1	0.7	1
2010	Calabazas Creek	Houtz Sites	1.2	1	-	2	-	4	-	2
2010	Calabazas Creek	Houtz Sites	1.3	1	-	2	-	4	-	2
2010	Calabazas Creek	Houtz Sites	0.6	1	-	2	-	4	-	2
2010	Ettie Street Pump Station	Houtz Sites	1.7	1	0.4	1	1.1	1	0.5	1
2010	Ettie Street Pump Station	Houtz Sites	1.7	1	0.6	1	0.6	1	0.5	1
2010	Ettie Street Pump Station	Houtz Sites	1.9	1	0.6	1	0.9	1	0.4	1
2010	Glen Echo Creek	Houtz Sites	3	1	0.4	1	0.7	1	0.7	1
2010	Glen Echo Creek	Houtz Sites	2.4	1	0.7	1	-	4	0.4	1
2010	Lower Marsh Creek	Houtz Sites	0.8	1	-	2	-	4	-	2
2010	Lower Marsh Creek	Houtz Sites	1.7	1	-	2	-	4	-	2
2010	Lower Marsh Creek	Houtz Sites	-	2	-	2	-	4	-	2
2010	San Lorenzo Creek	Houtz Sites	2	1	-	2	-	4	-	2
2010	San Lorenzo Creek	Houtz Sites	1.6	1	-	2	-	4	0.2	1
2010	San Lorenzo Creek	Houtz Sites	1.7	1	-	2	0.8	1	-	2
2010	San Lorenzo Creek	Houtz Sites	1.3	1	-	2	-	4	0.2	1
2010	San Lorenzo Creek	Houtz Sites	1.6	1	-	2	-	4	0.3	1
2010	San Tomas Creek	Houtz Sites	3.3	1	-	2	0.5	1	0.5	1
2010	San Tomas Creek	Houtz Sites	2.5	1	0.4	1	1	1	0.4	1
2010	San Tomas Creek	Houtz Sites	1.5	1	-	2	-	4	-	2
2010	San Tomas Creek	Houtz Sites	1.1	1	-	2	-	4	0.3	1

Year	Station	Region	PFDA		PFDS		PFUnDA		PFDoDA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL
2010	Stevens Creek	Houtz Sites	1.2	1	-	2	-	4	-	2
2010	Stevens Creek	Houtz Sites	0.2	1	-	2	-	4	-	2
2010	Walnut Creek	Houtz Sites	1.6	1	-	2	-	4	0.6	1
2010	Walnut Creek	Houtz Sites	1.6	1	-	2	-	4	0.3	1
2010	Walnut Creek	Houtz Sites	2.1	1	-	2	-	4	1.9	1
2010	Walnut Creek	Houtz Sites	-	2	-	2	-	4	-	2
2010	Zone 5 Line M (Union City)	Houtz Sites	4	1	0.4	1	0.9	1	0.8	1
2010	Zone 5 Line M (Union City)	Houtz Sites	1.8	1	0.4	1	-	4	1	1
2010	Zone 5 Line M (Union City)	Houtz Sites	1.2	1	-	2	-	4	0.7	1

[1]Houtz E and D Sedlak. 2012. Oxidative conversion as a means of detecting precursors to perfluoroalkyl acids in urban runoff. Environmental Science and Technology. Only one sample was collected from each site; however, it was run in triplicate.

Table 9b. Stormwater Precursor Concentrations (ng/L)

Year	Station	Region	EtFOSA		EtFOSE		EtFOSAA		MeFOSA		MeFOSE		MeFOSAA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2009	Hayward Zone 4 Line A	Central Bay	-	55	-	11	#N/A	#N/A	-	33	-	38	#N/A	#N/A
2009	Guadalupe River	South Bay	-	53	-	12	#N/A	#N/A	-	31	-	28	#N/A	#N/A
2010	Mallard Island	North Bay	-	21	-	5	#N/A	#N/A	-	40	#N/A	#N/A	#N/A	#N/A
2010	Mallard Island	North Bay	-	13	-	3	#N/A	#N/A	-	25	#N/A	#N/A	#N/A	#N/A
2010	Guadalupe River Foxworthy	South Bay	-	44	-	9	#N/A	#N/A	-	47	#N/A	#N/A	#N/A	#N/A
2010	Guadalupe River Foxworthy	South Bay	-	27	-	7	#N/A	#N/A	-	46	#N/A	#N/A	#N/A	#N/A
2010	Belmont Creek	Houtz Sites	#N/A	#N/A	-	2	0.4	1	#N/A	####	#N/A	#N/A	0.9	1
2010	Belmont Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	Belmont Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	Calabazas Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	Calabazas Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	Calabazas Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	Calabazas Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	Ettie Street Pump Station	Houtz Sites	#N/A	#N/A	-	2	1.3	1	#N/A	####	#N/A	#N/A	0.1	1
2010	Ettie Street Pump Station	Houtz Sites	#N/A	#N/A	-	2	0.4	1	#N/A	####	#N/A	#N/A	0.4	1
2010	Ettie Street Pump Station	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	1	1
2010	Glen Echo Creek	Houtz Sites	#N/A	#N/A	-	2	1.4	1	#N/A	####	#N/A	#N/A	-	2
2010	Glen Echo Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	Lower Marsh Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	Lower Marsh Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	Lower Marsh Creek	Houtz Sites	#N/A	#N/A	-	2	0.3	1	#N/A	####	#N/A	#N/A	-	2
2010	San Lorenzo Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	San Lorenzo Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	0.5	1
2010	San Lorenzo Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	San Lorenzo Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	San Lorenzo Creek	Houtz Sites	#N/A	#N/A	-	2	0.5	1	#N/A	####	#N/A	#N/A	-	2

Year	Station	Region	EtFOSA		EtFOSE		EtFOSAA		MeFOSA		MeFOSE		MeFOSAA	
			Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2010	San Tomas Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	San Tomas Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	San Tomas Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	San Tomas Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	Stevens Creek	Houtz Sites	#N/A	#N/A	-	2	0.4	1	#N/A	####	#N/A	#N/A	0.5	1
2010	Stevens Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	Walnut Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	0.2	1
2010	Walnut Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	Walnut Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	Walnut Creek	Houtz Sites	#N/A	#N/A	-	2	-	2	#N/A	####	#N/A	#N/A	-	2
2010	Zone 5 Line M (Union City)	Houtz Sites	#N/A	#N/A	-	2	0.2	1	#N/A	####	#N/A	#N/A	-	2
2010	Zone 5 Line M (Union City)	Houtz Sites	#N/A	#N/A	-	2	0.4	1	#N/A	####	#N/A	#N/A	-	2
2010	Zone 5 Line M (Union City)	Houtz Sites	#N/A	#N/A	-	2	0.3	1	#N/A	####	#N/A	#N/A	-	2

Year	Station	Region	6:2 FTS		8:2 FTS	
			Result	MDL	Result	MDL
2009	Hayward Zone 4 Line A	Central Bay	#N/A	#N/A	#N/A	#N/A
2009	Guadalupe River	South Bay	#N/A	#N/A	#N/A	#N/A
2010	Mallard Island	North Bay	#N/A	#N/A	#N/A	#N/A
2010	Mallard Island	North Bay	#N/A	#N/A	#N/A	#N/A
2010	Guadalupe River Foxworthy	South Bay	#N/A	#N/A	#N/A	#N/A
2010	Guadalupe River Foxworthy	South Bay	#N/A	#N/A	#N/A	#N/A
2010	Belmont Creek	Houtz Sites	-	2	-	2
2010	Belmont Creek	Houtz Sites	-	2	-	2
2010	Belmont Creek	Houtz Sites	-	2	-	2
2010	Calabazas Creek	Houtz Sites	-	2	-	2
2010	Calabazas Creek	Houtz Sites	-	2	-	2

2010	Calabazas Creek	Houtz Sites	-	2	-	2
2010	Calabazas Creek	Houtz Sites	-	2	-	2
2010	Ettie Street Pump Station	Houtz Sites	4.1	1	0.7	1
2010	Ettie Street Pump Station	Houtz Sites	0.9	1	-	2
2010	Ettie Street Pump Station	Houtz Sites	0.9	1	-	2
2010	Glen Echo Creek	Houtz Sites	0.9	1	-	2
2010	Glen Echo Creek	Houtz Sites	0.6	1	-	2
2010	Lower Marsh Creek	Houtz Sites	-	2	-	2
2010	Lower Marsh Creek	Houtz Sites	-	2	-	2
2010	Lower Marsh Creek	Houtz Sites	-	2	-	2
2010	San Lorenzo Creek	Houtz Sites	-	2	-	2
2010	San Lorenzo Creek	Houtz Sites	-	2	-	2
2010	San Lorenzo Creek	Houtz Sites	-	2	-	2
2010	San Lorenzo Creek	Houtz Sites	-	2	-	2
2010	San Lorenzo Creek	Houtz Sites	-	2	-	2
2010	San Tomas Creek	Houtz Sites	-	2	-	2
2010	San Tomas Creek	Houtz Sites	-	2	-	2
2010	San Tomas Creek	Houtz Sites	-	2	-	2
2010	San Tomas Creek	Houtz Sites	-	2	-	2
2010	Stevens Creek	Houtz Sites	-	2	-	2
2010	Stevens Creek	Houtz Sites	-	2	-	2
2010	Walnut Creek	Houtz Sites	-	2	-	2
2010	Walnut Creek	Houtz Sites	-	2	-	2
2010	Walnut Creek	Houtz Sites	-	2	-	2
2010	Walnut Creek	Houtz Sites	-	2	-	2
2010	Zone 5 Line M (Union City)	Houtz Sites	-	2	-	2
2010	Zone 5 Line M (Union City)	Houtz Sites	-	2	-	2
2010	Zone 5 Line M (Union City)	Houtz Sites	-	2	-	2

Table 10a. Effluent PFAS Concentrations (ng/L)

Dataset	Acronym	Detects	Min	1st Q	Median	3rd Q	Max	Average MDL
RMP 2009	PFBA	(6/6)	2.56	3.57	7.18	9.39	14.9	1.15
RMP 2009	PFBS	(3/6)	0.985	0.996	3.19	8.15	17.6	2
RMP 2009	PFPA	(5/6)	1.63	2.59	3.36	5.93	21.9	1.38
RMP 2009	PFHxA	(6/6)	11.2	14.7	16.5	17.7	23.1	1.17
RMP 2009	PFHxS	(5/6)	1.74	2.7	3.63	4.24	16.6	2.25
RMP 2009	PFHpA	(6/6)	3.98	4.44	5.25	5.9	7.12	1.05
RMP 2009	PFOA	(6/6)	10	14	23.8	29.5	91	1
RMP 2009	PFOS	(6/6)	2.76	4.18	5.36	33.6	81.2	2
RMP 2009	PFOSA	(1/6)	0.493	0.494	0.499	0.508	1.15	1
RMP 2009	PFNA	(6/6)	6.26	6.95	10.7	13.8	20.8	1
RMP 2009	PFDA	(5/6)	0.51	2.61	3.73	5.28	5.96	1
RMP 2009	PFUnDA	(0/6)	0.493	0.494	0.499	0.508	0.51	1
RMP 2009	PFDoDA	(0/6)	0.493	0.494	0.499	0.508	0.51	1
RMP 2012 Pro Bono	PFBA	(27/27)	4.57	7.27	8.44	10	11.5	1.48
RMP 2012 Pro Bono	PFBS	(0/27)	1.01	1.1	1.11	1.13	2.66	2.44
RMP 2012 Pro Bono	PFPA	(27/27)	1.67	2.61	3.99	4.39	21.8	1.32
RMP 2012 Pro Bono	PFHxA	(27/27)	13.8	15.2	19.8	29.7	35.4	1.1
RMP 2012 Pro Bono	PFHxS	(20/27)	1.03	1.71	3.94	6.46	8.33	2.2
RMP 2012 Pro Bono	PFHpA	(27/27)	2.52	3.52	4.11	4.59	6.6	1.1
RMP 2012 Pro Bono	PFOA	(27/27)	7.66	8.76	15.5	39.5	42.1	1.1
RMP 2012 Pro Bono	PFOS	(27/27)	4.7	12.6	15.9	41	49.7	2.43
RMP 2012 Pro Bono	PFOSA	(1/27)	0.505	0.55	0.555	0.555	1.09	1.1
RMP 2012 Pro Bono	PFNA	(27/27)	3.74	4.61	5.61	5.87	6.73	1.1
RMP 2012 Pro Bono	PFDA	(27/27)	1.25	1.67	2.54	2.87	3.84	1.1
RMP 2012 Pro Bono	PFUnDA	(0/27)	0.505	0.55	0.555	0.555	0.57	1.1
RMP 2012 Pro Bono	PFDoDA	(0/27)	0.505	0.55	0.555	0.555	0.57	1.1

Dataset	Acronym	Detects	Min	1st Q	Median	3rd Q	Max	Average MDL
Houtz 2014 Sites	PFBA	(10/10)	8.15	14.3	19.2	24.5	156	#N/A
Houtz 2014 Sites	PFBS	(10/10)	1.43	2.27	3.62	5.35	54.8	#N/A
Houtz 2014 Sites	PFPA	(10/10)	4.4	7.36	14.8	32.6	620	#N/A
Houtz 2014 Sites	PFHxA	(10/10)	20.5	23.4	25.9	32.6	530	#N/A
Houtz 2014 Sites	PFHxS	(10/10)	3.96	4.62	5.79	26.7	364	#N/A
Houtz 2014 Sites	PFHpA	(10/10)	2.54	3.45	5.59	8.72	223	#N/A
Houtz 2014 Sites	PFOA	(10/10)	11	13.5	32	62	94.5	#N/A
Houtz 2014 Sites	PFOS	(10/10)	7.23	11.3	17.8	408	635	#N/A
Houtz 2014 Sites	PFNA	(10/10)	4.64	7.43	10.9	18.5	41.6	#N/A
Houtz 2014 Sites	PFDA	(10/10)	1.9	2.7	3.95	9.82	136	#N/A
Houtz 2014 Sites	PFDS	(10/10)	0.0186	0.0407	0.0932	0.693	7.63	#N/A
Houtz 2014 Sites	PFUnDA	(10/10)	0.344	0.503	0.722	1.57	8.81	#N/A
Houtz 2014 Sites	PFDoDA	(10/10)	0	0.427	0.558	0.841	2.13	#N/A

Table 10b. Effluent Precursor Concentrations (ng/L)

Dataset	Acronym	Detects	Min	1st Q	Median	3rd Q	Max	Average MDL
RMP 2009	EtFOSA	(0/6)	0.357	1.06	1.19	1.74	2.41	2.7
RMP 2009	EtFOSE	(0/5)	0.169	0.173	0.178	0.265	0.313	0.439
RMP 2009	MeFOSA	(0/6)	1.01	1.85	2.52	4.11	4.95	5.76
RMP 2009	MeFOSE	(0/5)	0.259	0.371	0.489	0.5	0.605	0.889
RMP 2012 Pro Bono	EtFOSAA	(0/4)	2.01	2.02	2.02	2.03	2.03	4.04
RMP 2012 Pro Bono	MeFOSAA	(0/4)	2.01	2.02	2.02	2.03	2.03	4.04
RMP 2012 Pro Bono	FOSAA	(0/4)	2.01	2.02	2.02	2.03	2.03	4.04
RMP 2012 Pro Bono	6:2 monoPAP	(0/3)	39.5	39.7	39.9	40.2	40.4	79.9
RMP 2012 Pro Bono	8:2 monoPAP	(0/3)	39.5	39.7	39.9	40.2	40.4	79.9
RMP 2012 Pro Bono	6:2 diPAP	(0/3)	1.98	1.99	2	2.01	2.02	3.99
RMP 2012 Pro Bono	8:2 diPAP	(0/3)	1.98	1.99	2	2.01	2.02	3.99
RMP 2012 Pro Bono	4:2 FTS	(0/27)	3.86	4.49	4.6	4.65	4.71	9.02
RMP 2012 Pro Bono	6:2 FTS	(0/27)	3.92	4.56	4.67	4.72	4.78	9.16
RMP 2012 Pro Bono	8:2 FTS	(0/27)	3.96	4.61	4.72	4.77	4.83	9.26
RMP 2012 Pro Bono	6:6 PFPi	(0/3)	1.98	1.99	2	2.01	2.02	3.99
RMP 2012 Pro Bono	6:8 PFPi	(0/3)	1.98	1.99	2	2.01	2.02	3.99
RMP 2012 Pro Bono	8:8 PFPi	(0/3)	1.98	1.99	2	2.01	2.02	3.99
RMP 2012 Pro Bono	6:2 FTCA	(0/4)	4.01	4.03	4.04	4.05	4.07	8.08
RMP 2012 Pro Bono	8:2 FTCA	(0/4)	4.01	4.03	4.04	4.05	4.07	8.08
RMP 2012 Pro Bono	10:2 FTCA	(0/4)	4.01	4.03	4.04	4.05	4.07	8.08
RMP 2012 Pro Bono	6:2 FTuCA	(1/4)	0.5	0.504	0.508	0.81	1.71	1.01
RMP 2012 Pro Bono	8:2 FTuCA	(0/4)	0.5	0.504	0.505	0.506	0.51	1.01
RMP 2012 Pro Bono	10:2 FTuCA	(0/4)	0.5	0.504	0.505	0.506	0.51	1.01
RMP 2012 Pro Bono	PFHxPA	(0/3)	19.8	19.9	20	20.1	20.2	39.9
RMP 2012 Pro Bono	PFOPA	(0/3)	19.8	19.9	20	20.1	20.2	39.9
RMP 2012 Pro Bono	PFDPA	(0/3)	19.8	19.9	20	20.1	20.2	39.9
Houtz 2014 Sites	EtFOSAA	(10/10)	0.411	1.07	1.47	1.92	46.8	#N/A

Dataset	Acronym	Detects	Min	1st Q	Median	3rd Q	Max	Average MDL
Houtz 2014 Sites	MeFOSAA	(10/10)	0.0816	1.01	2.08	3.67	34.9	#N/A
Houtz 2014 Sites	4:2 FTS	(10/10)	0	0.0142	0.0187	0.0406	1.55	#N/A
Houtz 2014 Sites	6:2 FTS	(10/10)	2.23	3.01	3.59	17.2	443	#N/A
Houtz 2014 Sites	8:2 FTS	(10/10)	0.105	0.632	0.978	17.9	51.4	#N/A
Houtz 2014 Sites	PFHxPA	(10/10)	0.467	1.1	1.46	2.97	17.5	#N/A
Houtz 2014 Sites	PFOPA	(10/10)	0.33	0.651	0.97	1.39	9.93	#N/A

Table 11 Comparison of Model versus Monitored Concentrations for Water in Bay Area Subembayments (ng/L total water)

Chemical	Method	Riverine Inputs from Delta	Suisun Bay	San Pablo Bay	Central Bay	South Bay	Lower South Bay
PFHxA	Model	1.6	1.2	0.43	0.30	0.65	1.6
	Monitored (2009)	1.8	<1.0	<1.0	<1.0	1.6	3.74
PFOS	Model	1.4	2.0	0.41	0.25	0.51	1.4
	Monitored (2009)	1.5	<2.0	<2	<1.95	2.93	6.25
PFOA	Model	1.8	1.3	0.46	0.31	0.73	2.4
	Monitored (2009)	2.0	1.38	<1.0	<1.0	2.97	8.62