Contaminants of Emerging Concern in San Francisco Bay: A Strategy for Future Investigations

2023 Revision

Ezra Miller, Miguel Méndez, Diana Lin, Rebecca Sutton

San Francisco Estuary Institute

4/10/2023 - First Draft

SFEI Contribution #XXXX

Suggested Citation:

Miller, E.; Méndez, M.; Lin, D.; Sutton, R.; XXXX. Contaminants of Emerging Concern in San Francisco Bay: A Strategy for Future Investigations, 2023 Revision. SFEI Contribution No.####. San Francisco Estuary Institute, Richmond, CA.

Acknowledgements

XXXXXX

Land acknowledgement text from Alex Tavizon with the CIEA:

The following land acknowledgment evolved out of the collaborative efforts of the original Native Peoples of the San Francisco Bay Region and has been adapted to apply to the broader San Francisco Estuary. While merely a symbolic statement, it is intended to foster a recognition of the tragic history of Native Peoples, to affirm their continued presence and contributions, and to remind non-Natives that the land upon which they live, work, and recreate is stolen from the original stewards of the land.

We acknowledge that the San Francisco Bay is the unceded ancestral homeland of many indigenous people, including the Him-R^n (HIM-rin) Ohlone (oh-LOW-nee) Jalquin (HAWL-keen), Saclan (SAHK-lan) Tribe, the Villages of Lisjan (Lih-SHAWN), the Karkin (CAR-kin), Muwekma (Moo-WECK-mah), Ramaytush (RAH-my-toosh), Tamien (THA-mee-in), and Yokuts (YOH-cuts) Ohlone, Coast and Bay Miwok (MEE-wok), Patwin (PAT-win), and the Amah (AH-mah) Mutsun (MOOT-soon) Tribal Band. The broader San Francisco Estuary is also the homeland of the Plains Miwok, Wappo (WAH-po), Wintun (WIN-tun), and Nisenan (NEE-seh-nahn) people. We recognize that we benefit from living and working in their traditional homeland. We wish to pay our respects by acknowledging the ancestors, elders, and relatives of these Tribal Communities and by affirming their sovereign rights as First Peoples of these Nations.

Please consider that although this statement acknowledges the ancestral and unceded territories of the original Native Peoples of the Estuary, additional steps are required to move towards meaningful restorative justice. This can be working with Estuary Tribes toward ecological restoration and incorporating Traditional Ecological Knowledge, building beneficial and constructive relationships, supporting Tribes in restoring their role as land stewards, and elevating and integrating Native communities in the planning and decision-making for a healthy and resilient Estuary. Tribal communities have been stewarding our natural environment since time immemorial; there is much we need to learn from the Estuary's tribal communities about stewardship.

It is vitally important that we recognize that the land on which we reside is unceded Tribal territory, and also acknowledge and support the Native Peoples who continue to form a crucial part of our Estuary community today.

Table of Contents

Executive Summary

XXXXX

1. Introduction

1.1 The CEC Challenge and San Francisco Bay

Over 350,000 chemicals and mixtures of chemicals have been registered for production and use worldwide (Wang et al., 2020). Globally, chemical production capacity by mass has doubled since 2000, and sales are projected to double again by 2030 compared to 2017(United Nations Environment Programme, 2019). Increases in chemical production and diversification are outpacing other agents of anthropogenic global change such as rising atmospheric CO_2 concentrations, nutrient pollution, habitat destruction, and biodiversity loss (Bernhardt et al., 2017; Persson et al., 2022). Chemical production also results in the unintended production of byproducts, transformation products, and impurities, which may escape scientific and regulatory scrutiny. Overall, annual production and release of anthropogenic chemicals has been suggested to exceed the planetary boundary within which humanity can continue to develop and thrive for generations, as volumes are increasing at a rate that surpasses our overall capacity for assessment and monitoring (Persson et al., 2022).

Within this daunting chemicals management landscape, the challenge for water quality managers and scientists is to protect human and ecological health through effective efforts to address chemical contaminants.

San Francisco Bay, critical habitat for a multitude of estuarine species and a recipient of continuous inputs of chemical pollution from the surrounding urban environment, is a prime example of an ecosystem that merits investigation of the potential impacts of anthropogenic compounds on biota. With a dense urban population of nearly 8 million people, the Bay provides a unique laboratory for study of urban-derived contaminants. Early identification of emerging pollution issues is particularly important in the Bay, because the constrained hydrodynamics of this ecosystem can create a long-term trap for persistent contaminants, with recovery taking decades or longer when contamination is extensive (Klosterhaus et al., 2012).

Only a very small fraction of the large number of chemicals presently or formerly in use is routinely monitored in environments like San Francisco Bay. These generally include legacy contaminants – compounds that tend to meet the criteria of being persistent, bioaccumulative, and toxic – such as polychlorinated biphenyls (PCBs), chlorinated pesticides (e.g., DDT), and other chemicals on the United States Environmental Protection Agency (USEPA) list of 128 regulated priority pollutants. The risks these historically prioritized contaminants pose to ecological and human health are relatively well understood, and monitoring is conducted to support regulatory risk reduction actions.

In contrast, contaminants of emerging concern (CECs) can be broadly defined as synthetic or naturally occurring chemicals that are un- or under-regulated, not commonly monitored in environmental media, and have the potential to enter the environment and cause adverse ecological or human health impacts. Over the last two decades, scientists and government agencies have begun to collect occurrence, fate, and toxicity data for a variety of such chemicals, including per- and polyfluorinated alkyl substances (PFAS), flame retardants, pharmaceuticals, personal care and cleaning product ingredients, current-use pesticides, and tire, paint, and plastic additives. Analytical methods have progressed to the point that it is possible to measure trace quantities (e.g., parts per trillion) of many contaminants in environmental matrices, which has led to frequent detection of a variety of previously unmonitored or unmeasurable chemicals in the environment. Many of these chemicals are considered CECs, often due to their high volume use, potential for toxicity in non-target species, and the increasing number of studies that report their occurrence in the environment.

Determining which of the thousands of CECs pose the greatest threats to the San Francisco Bay ecosystem is a formidable challenge. For most chemicals in use, major information gaps prevent researchers from assessing their potential risks.

- The identities of chemicals used in commercial formulations, their applications, and product-specific uses are often unknown, characterized as confidential business information, or not readily available for other reasons (Z. Wang et al., 2020). Byproducts, impurities, and transformation products associated with chemicals in commerce constitute an even larger data gap (Howard & Muir, 2013).
- Sensitive methods that can reliably measure many chemicals of potential interest at environmentally-relevant concentrations often do not exist. Development of new analytical methods is challenging, so researchers tend to focus their method development efforts on emerging contaminants that are already well-established concerns. Both regulators and regulated communities may be reluctant to rely on exploratory methods that have not been fully and formally standardized, a process that can take many years.
- The potential toxicological impacts of the majority of chemicals in use are largely unknown. Little to no information exists on chronic toxicity for realistic exposures, toxicity to non-target species, or sensitive toxicological endpoints such as behavioral changes that could cause population-level effects. Information is even more limited concerning the impacts of exposure to commonly observed mixtures of contaminants in the environment. Knowledge of toxic modes of action for many CECs is lacking, and details of toxicity studies conducted by chemical manufacturers are often not available for public review. Where there is sufficient information to clearly establish concerns about a specific chemical, manufacturers may replace it with a similar chemical that is relatively data-poor but may also lead to adverse impacts, an unfortunate sequence termed "regrettable substitution."

The combination of such large obstacles and limited resources for generating the needed information makes it difficult for scientists and regulators to prioritize CECs for monitoring and control. For the majority of chemicals in use today, occurrence, persistence, and toxicity data are still needed to establish exposure and risk thresholds that protect the beneficial uses of aquatic ecosystems. In addition, lack of information on sources or uses of different CECs often limits the ability of policymakers to identify and prioritize control measures that effectively prevent pollution.

The San Francisco Bay region has been a leader in addressing these information gaps for CECs. Scientists and water quality managers working to assess and protect San Francisco Bay from pollution have investigated a number of CECs that have the potential to impact the Bay. Bay monitoring data have already informed management measures for a few CECs. Thanks to the region's sustained focus on CECs, San Francisco Bay is one of the most well-studied estuaries for CECs, and has become a hub of CECs science and management.

1.2 Report Objectives

This RMP CEC Strategy document has been revised as part of a continuous effort to refine approaches for supporting the management of CECs in San Francisco Bay. The specific objectives of this report are to:

- Define the management questions that guide RMP studies on CECs (Section 1.3);
- Describe the general approach for identifying and prioritizing CECs with the potential to adversely impact beneficial uses of San Francisco Bay (Section 2.0);
- Outline the current strategy to monitor CECs in the Bay based on the RMP's evaluation of their relative risk (Section 3.0);
- Summarize the process for identifying new CECs suitable for initial study based on novel scientific approaches, current literature, and review of other regional monitoring program lists of prioritized water contaminants (Section 4.0); and,
- Provide recommendations and a multi-year plan for future monitoring and science (Section 5.0).

The Strategy outlined here is part of an iterative process designed to ensure that the RMP remains ahead of the curve regarding CECs, specifically by tracking new information as it becomes available and communicating key findings to RMP stakeholders and the broader community of policymakers.

1.3 RMP CECs Management Questions

The Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) has been monitoring CECs since 2001. In 2006, the RMP established the Emerging Contaminants Workgroup (ECWG), which includes representatives from RMP stakeholder groups, local scientists, and an advisory panel of expert researchers that work together to protect the health of the Bay by addressing the Workgroup's guiding management questions (Section 1.3). The overarching goal of the ECWG is to develop cost-effective CEC identification and monitoring strategies in support of management efforts to minimize impacts to the Bay.

RMP studies are guided by management questions to ensure that all monitoring and science activities support the overarching RMP goal of informing management decisions and protecting water quality in San Francisco Bay. For many years, the CECs focus area was guided by a single management question:

MQ1: Which CECs have the potential to adversely impact beneficial uses in San Francisco Bay?

Management question 1 grounds the RMP's CECs activities within a risk-based approach, which is further refined via the RMP's tiered risk-based framework for CECs (Section 2.2). The tiered risk-based framework suggests specific monitoring strategies as well as management actions for individual contaminants or contaminant classes based on the level of risk posed to the beneficial uses of San Francisco Bay. These beneficial uses include estuarine and wildlife habitat, preservation of rare and endangered species, industrial service supply, navigation, commercial and sport fishing, water contact and noncontact recreation, and fish migration and spawning (California Regional Water Quality Control Board, 2019).

In response to the increasing demand for policy-relevant information about CECs in the region, five new questions were added in 2017, following consultation with ECWG experts and stakeholders; one of these questions has now been revised based on Workgroup recommendations in 2022.

MQ2: What are the sources, pathways, and loadings leading to the presence of individual CECs or groups of CECs in the Bay?

Management question 2 reflects the goal of tracing contaminants back to their sources, providing information to guide pollution prevention activities. A key tool employed by the RMP is the development of conceptual models, which document all relevant uses of an individual CEC or a class of these contaminants, as well as all relevant pathways by which these contaminants make their way to San Francisco Bay. Conceptual models can inform monitoring of CECs in pathways like wastewater and stormwater, and aid in identifying sources. Models and monitoring can provide information regarding the potential impacts of management actions on contaminant loadings discharged via specific pathways.

To address this management question, it is essential for the ECWG and SFEI CECs scientists to coordinate with the RMP's Sources, Pathways, and Loadings Workgroup; and the Bay Area Pollution Prevention Group (BAPPG) of the Bay Area Clean Water Agencies (BACWA).

MQ3: What are the physical, chemical, and biological processes that may affect the transport and fate of individual CECs or groups of CECs in the Bay?

Management question 3 addresses processes occurring within San Francisco Bay that impact the way different CECs behave in the environment. For example, targeted monitoring of contaminants and their likely degradation or transformation products can provide information about contaminant fate and transport that is relevant to management decisions, especially should detected transformation products be significantly more or less toxic to wildlife than the parent compounds. Modeling can be used to inform monitoring design, to determine whether expected processes are sufficient to explain the levels of contaminants observed in Bay matrices, or to identify whether there are gaps in our knowledge about the behavior of specific CECs. For many CECs, multi-media models that can capture the partitioning and movement of contaminants among different matrices will be essential to inform understanding. The RMP has developed a strategy for in-Bay fate modeling that includes consideration of CECs (Jones et al., 2022), and will begin implementing it in 2023, in large part due to expanded resources provided by a recent USEPA Water Quality Improvement Fund grant.

MQ4 (revised, 2023): Have levels of individual CECs or groups of CECs changed over time in the Bay or pathways? What are potential drivers contributing to change?

Management question 4 focuses on historical trends in contaminant levels observed via monitoring. Such temporal trends may be influenced by management actions; independent changes in chemical manufacturing and use, including regrettable substitution; or independent drivers such as changes in climate, population, socio-economic factors, and land and water use. Understanding the likely causes of apparent trends can inform evaluation of the impacts of past management actions, and lead to more effective solutions for pollution problems.

The original 2017 version of this management question was: *Have the concentrations of individual CECs or groups of CECs increased or decreased in the Bay?* In 2022, ECWG experts and stakeholders recommended this management question be expanded to include pathways concentrations and/or loadings discharged to the Bay, and identification of the potential reasons for any noted trend.

Separate studies may be needed to answer the first and second parts of this question. While trying to understanding the drivers of measured changes is important to informing future management actions, it may not always be possible to conclusively link changes in monitoring data with a specific driver when many management actions and human responses are happening at the same time.

MQ5: Are the concentrations of individual CECs or groups of CECs predicted to increase or decrease in the future?

Management question 5 draws on qualitative and quantitative predictions of future pollution, primarily through use of conceptual and numerical models. Factors that may influence predictions include targeted management actions, independent changes in chemical manufacturing and use, population growth, as well as secondary drivers like those described above.

MQ6: What are the effects of management actions?

Management question 6 is written broadly, as management actions can have positive and negative impacts. Studies designed with this question in mind can include temporal trend investigations that encompass periods before and after a management action goes into effect, or comparisons of similar regions employing different types of management of an individual CEC or a class of compounds. Such studies are useful for assessing whether a management action is having the intended effect.

Other responses to this question can encompass reviews of functional substitutes for CECs at the source (e.g., within consumer products) as a means of exploring the potential for a management action to lead to “regrettable substitution,” when a chemical of concern is replaced by another compound with problematic properties. Broad, class-based surveys of contamination are particularly useful for identifying unexpected and potentially negative impacts of management actions.

CALLOUT BOX: The Class-based Approach

A key element of the RMP CEC monitoring and evaluation process is the consideration of individual chemicals as members of broader classes defined by chemical similarities (e.g., bisphenols), or function or use in society (e.g., personal care and cleaning product ingredients). Members of a chemical class may have similar properties with respect to persistence, bioaccumulation, or toxicity. A class-based approach can alert the RMP to potential concerns of a poorly-studied compound that is chemically similar to a well-established toxicant. Members of a use class may be substituted within formulations or products in response to the phase-out or ban of a specific toxic compound; when the data-poor replacement compound turns out to have to pose ecological and/or human health risks, this process is termed “regrettable substitution.” By considering individual chemical contaminants as members of broader classes, we are able to more efficiently evaluate and address potential adverse impacts.

Similar class-based approaches have been adopted by several science and regulatory agencies as a means of systematically evaluating chemicals of concern. In California, efforts that rely on class-based approaches for chemicals monitoring and/or management include the Biomonitoring California program (Biomonitoring California 2021), and the Safer Consumer Products Program within California’s Department of Toxic Substances Control (Bălan et al., 2021). Recently, the State Water Board also recognized the value of the class-based approach for addressing CECs, as documented in commissioned reports (Sutton et al., 2022; Drewes et al., 2023). The RMP strives for harmonization with forward-looking programs like these within the CECs focus area.

In some cases, contaminants may fit the definition of more than one class. For example, bifenthrin is a pyrethroid pesticide, and also can be considered a PFAS. In this situation, the RMP will generally opt to consider the contaminant via the class most relevant to potential management actions.

—END CALLOUT BOX

1.3.1 The RMP Annual Planning and Review Process

The RMP has developed a standardized process for planning and review of CECs activities. The ECWG plays a key oversight role in establishing the RMP's priorities for CECs monitoring and evaluation. Each spring, the ECWG meets to discuss the RMP's strategy and review recent findings. ECWG meetings include several important discussions:

- Strategic future directions for the RMP - Stakeholders and experts consider recommendations from the ECWG science team concerning revised or new strategies and directions for future work. Major elements of CEC Strategy Revisions are developed in collaboration with an ECWG Strategy Subgroup consisting of a subset of ECWG stakeholders and experts. Future implementation of these strategies is outlined via the multi-year plan (MYP; Section 5.1), which is intended to guide monitoring and science activities going forward.

- Status and Trends monitoring data and plans - Status and Trends monitoring is a vital component of the RMP; the goals are to measure contaminant concentrations in the Bay to determine if any contaminants are at levels of concern in some or all regions of the Bay, and if concentrations are changing over time. A recent review of the S&T monitoring design has resulted in refinements that optimize the program for CECs monitoring to inform management decisions (Foley et al., 2023). Among the CECs studied to date by the RMP, PFAS, bisphenols, OPEs, and PBDEs have been added to the RMP S&T monitoring program (Sections 2.3 and 5.2).

- Findings from special studies - Stakeholders and experts review and discuss significant findings from recently completed or ongoing studies of CECs that can be used to inform RMP priorities going forward. In particular, new Bay monitoring data and new toxicity findings in the scientific literature are relevant to prioritization of activities on different CECs through classification within the RMP's tiered risk-based framework (Section 2.2). This risk-based framework guides future monitoring plans for each of the listed contaminants (Section 3), the results of which, in turn, provide key data to update evaluations of potential risk.

- Review and prioritization of special study proposals for the next year- Finally, the ECWG also evaluates special study proposals for the coming year, and provides ranked recommendations for those that should be advanced to the RMP's Technical Review and Steering Committees for consideration. The ECWG also reviews study concepts suitable to be added to a Regional Water Board list of projects for potential funding via Supplemental Environmental Projects.

After the spring workgroup meetings, the RMP Technical Review Committee (TRC) reviews special study proposals from the ECWG and all other workgroups in a summer meeting, and makes recommendations to the RMP Steering Committee (SC) about which studies to fund for the next year. The SC provides ultimate funding decisions as part of its meeting later in the summer.

In the fall, the TRC and SC provide a high level review of all workgroup MYPs as part of a joint meeting. This provides an additional opportunity for these committees to engage with workgroup leads and inform the overall strategy of each RMP focus area. The SC approves all MYPs at its first (January) meeting of the next year.

Throughout the year, the ECWG, TRC, and SC provide peer review of reports and deliverables. In particular, this includes review of documents demonstrating strategic developments on CECs including CEC Strategy Updates and CEC Strategy Revisions (like this one). An Update is a discrete document that focuses on new information and decisions, while a Revision encompasses a comprehensive assessment of the RMP's CECs activities and may outline broad, new directions for future work. CEC Strategy Updates are prepared every one to three years, as needed, while CEC Strategy Revisions are prepared at longer intervals. Also included in every CEC Strategy Update or Revision is an updated MYP.

Under the guidance of this robust planning process, which focuses the RMP's CECs work on the most important, management-relevant scientific information needs, the RMP has generated one of the world's most comprehensive datasets for CECs in an estuarine ecosystem. CECs investigated to date include PFAS, alkylphenols and alkylphenol ethoxylates, bisphenols and other plastic additives, current-use pesticides, pharmaceuticals, personal care and cleaning product ingredients, quaternary ammonium compounds (QACs), roadway and tire-derived contaminants, flame retardants including organophosphate esters (OPEs) and polybrominated diphenyl ethers (PBDEs) and their replacements, and other industrial compounds.

1.3.2 Science to Inform Management

RMP data and communications are specifically designed to inform management decisions. Relevant decision-making bodies and associated management drivers include the following.

- Bay Area Wastewater and Stormwater Agencies – These stakeholders benefit directly from the RMP's focus on CECs. For example, wastewater and stormwater agencies use RMP findings to support voluntary educational efforts to reduce pollution within their service areas. Regionally, RMP CECs activities are an integral part of the San Francisco Estuary Partnership's 2022 Estuary Blueprint (or Comprehensive Conservation and Management Plan; http://www.sfestuary.org/ccmp/).

- San Francisco Bay Regional Water Quality Control Board – The Regional Water Board is leading region-wide efforts to reduce the harmful effects of CECs in the Bay through development of CEC Action Plans. The RMP will provide the scientific support needed to develop and update CEC Action Plans and the related management strategies of local stakeholders.

- California State Water Board – At the statewide level, the Water Board has instituted a CEC Program as part of their water resilience effort to help optimize

California's limited water supply and to protect California aquatic ecosystems (https://www.waterboards.ca.gov/water_issues/programs/cec/). This Program will support statewide source control programs for CECs that are hardest to treat, not regulated and/or routinely monitored, and have not been adequately tested for human or ecological toxicity. The primary objectives of this program include strategically prioritizing, characterizing and, where necessary, regulating CECs to address their statewide emerging public health and water quality concerns. Recent products of the Water Board CEC Program include: 1) a report synthesizing data on the occurrence of key classes of CECs in ambient aquatic ecosystems around the state, and conducting a risk screening exercise similar to that used by the RMP (Sutton et al., 2022); and 2) a report describing the guidance of a science advisory panel concerning the design of CECs monitoring, prioritization, and risk assessment (Drewes et al., 2023).

- California Ocean Protection Council (OPC) – OPC works with partner agencies to provide current data and expert guidance to inform understanding of CECs. For example, OPC co-funded the convening of the science advisory panel on CECs in ambient aquatic ecosystems in California, mentioned above (Drewes et al., 2023). In 2018, OPC provided funding to the Southern California Coastal Water Research Project to screen sediment and fish tissue samples from the Southern California Bight for CECs.

- California Department of Pesticide Regulation (DPR) – Regulations relating to pesticide formulation and application can be a powerful means of preventing environmental contamination. The RMP strives to coordinate its monitoring efforts relating to current-use pesticides with DPR priorities, leveraging available resources to inform statewide pesticide policies. For example, RMP monitoring of influent and effluent from eight Bay municipal wastewater treatment plants for imidacloprid, fipronil, and its degradates, revealed the ubiquity of these contaminants despite treatment, and suggested pet flea control products were a major source (Sadaria et al. 2017). The findings from this study supported the development of DPR's new wastewater surveillance program. DPR's robust monitoring activities in wastewater and in freshwater streams around the state provide considerable data to inform management of conventional current-use pesticides. In collaboration with the California Environmental Protection Agency and the California Department of Food and Agriculture, DPR unveiled a roadmap of ambitious goals and actions to accelerate California's systemwide transition to sustainable pest management and eliminate prioritized high-risk pesticides by 2050 to better protect the health of our communities and environment, while supporting agriculture, food systems and community well-being (Members of the Sustainable Pest Management Work Group and Urban Subgroup, 2023). Of particular relevance to the RMP, this roadmap includes a focus on urban-use pesticides. Meanwhile, the RMP has focused more recent pesticides monitoring efforts on studies that address data gaps regarding antimicrobial active ingredients such as quaternary ammonium compounds (QACs).

- Department of Toxic Substances Control (DTSC) – California is implementing a ground-breaking green chemistry approach to guide chemical and product manufacturers toward safer product design. The DTSC's Safer Consumer Products Regulations, established in 2013, define a process to evaluate whether there are safer alternatives to a chemical of concern in a product, and allow the agency to implement appropriate controls. RMP scientists regularly provide data to the program regarding environmental detections as well as insights on ecological toxicity and chemical source or use information. For example, in 2022, DTSC initiated rulemaking to list motor vehicle tires containing N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD) as a Priority Product under the SCP Regulations based on detections of 6PPD-quinone in RMP monitoring studies (DTSC, 2022). DTSC's priorities for potential future regulation, outlined in triennial workplan documents, inform selection of target analytes for RMP special studies. The RMP's lead scientist on emerging contaminants, Dr. Rebecca Sutton, served on the Green Ribbon Science Panel that advises the agency on implementation of these regulations from 2014 to 2022. Dr. Kelly Moran, a senior scientist within SFEI's CECs team, has been a member of this Panel since 2009, and has served as co-chair since 2014.
- US Environmental Protection Agency (USEPA) – RMP data can also be used to inform federal regulation of industrial chemicals or pesticides. RMP staff seek out opportunities to bring Bay detection information and insights to the attention of the USEPA, for example in the form of comment letters regarding proposed actions such as Significant New Use Rules or pesticide registration review.
- Community-based Organizations (CBOs) – RMP findings may also be useful to community groups seeking to inform themselves about CECs, avoid exposure and impacts, and advocate for better protections from government agencies. A recent example is that of PFAS in sport fish from the Bay, a concern for Bay Area residents who fish frequently for subsistence or cultural purposes.

2. Risk-based Approach to Identify and Prioritize CECs in San Francisco Bay

2.1 Four-element Strategy

The RMP has developed a multi-faceted strategy to direct CEC science in the Bay. Below, we outline the four principal elements within this strategy. Three of these elements are long-standing areas of emphasis for RMP work on CECs, while one is newly elevated based on recent shifts in priorities regarding pathways monitoring.

First, for those CECs known to occur in the Bay, the RMP establishes priorities using a tiered risk-based framework (Section 2.2). This framework guides future monitoring studies for these contaminants, which can occur through Status and Trends monitoring activities or screening and other special studies (Section 2.3). Findings from these studies, in turn, provide key data to update evaluations of potential risk for each contaminant or class (Section 3.0).

Second, and newly defined via this document, the RMP focuses on monitoring and modeling in contaminant pathways, in an effort to begin tracking Bay contaminants back to their sources. In the past, the RMP focused its efforts primarily on ambient Bay monitoring. More recently, the RMP has conducted a number of special studies on CECs in pathways, examining contaminant concentrations in municipal wastewater and urban stormwater, and estimating loads with assistance from the Sources, Pathways, and Loadings Workgroup (SPLWG). The increasing strategic focus on pathways monitoring indicates the need to add a formal element to the RMP's strategy on CECs. As a result of this new focus, BACWA has established a guidance document addressing wastewater monitoring strategy (BACWA 2020), and the RMP is developing a stormwater CECs monitoring strategy integrated with modeling efforts within the SPLWG.

Third, the RMP uses novel approaches to identify additional CECs to examine, including nontargeted analysis and new approach methodologies (NAMs) for hazard assessment. Nontargeted analysis refers to advanced chemical analyses to assess matrices for the presence of unanticipated contaminants that cannot be observed using existing targeted methods (Section 4.1). These techniques typically rely on high resolution mass spectrometry (HRMS) to perform suspect screening, essentially matching unknown sample features to compounds within libraries of spectra, or more advanced nontargeted analysis, which involves determination of the chemical structures of unknown compounds that are not present in libraries. Identification and prioritization of many CECs is hindered by a lack of toxicological data and, therefore, unknown or low-confidence toxicity thresholds. NAMs include in silico and in vitro approaches to predict exposure and hazards of data-poor chemicals, as well as bioassay monitoring of environmental samples to detect possible biological effects that may not be predictable solely from chemical analyses of the samples (Section 4.2).

Fourth, RMP staff review the scientific literature and interact with scientists around the world to evaluate findings from other regional aquatic CEC monitoring programs as a means of identifying new CECs for which no Bay occurrence data yet exist (Sections 4.3-4.4). Initial monitoring to establish the presence of these newly-identified CECs in the Bay may be needed to evaluate the risks they pose. Once Bay data are available, the RMP can place these new CECs within the tiered risk-based framework.

2.2 Tiered Risk-based Framework

For CECs monitored in Bay water, sediment, or biota, a risk-based screening method is used to assign appropriate levels of concern regarding the potential to impact Bay wildlife and people. The categorization of each CEC within the RMP risk-based framework guides future monitoring and management actions (framework in Table 1; CEC tier assignments in Table 2). With this revision of the RMP CEC strategy, we expand the existing framework from four tiers of concern to five, and provide more rigorous, quantitative metrics concerning the risk evaluation process. Key refinements to the RMP framework evolved from a similar risk-screening exercise the Aquatic Science

Center (ASC) performed on behalf of the State Water Board for several classes of CECs (Sutton et al., 2022).

The RMP generally uses a class-based approach for risk evaluation. Evaluating chemical classes within the tiered risk-based framework, rather than individual compounds, provides a means of evaluating and addressing data-poor compounds. Members of a use class might be addressed by a single management action that affects product requirements (e.g., flammability standards that impact use of flame retardants) or disposal practices (e.g., pharmaceutical take-back programs). Substances within a specific chemical or use class may be substituted for one another within products or formulations; in this case, a class-based approach can indicate which compounds may see increasing use as substitutes and, therefore, merit future monitoring.

2.2.1 Risk Quotients

The RMP assigns each CEC or CEC class to a tier in the prioritization framework primarily based on a risk quotient derived from available Bay occurrence data and toxicity information, where sufficient occurrence data are available. A risk quotient is calculated using the 90th percentile concentration of a contaminant in a specific Bay matrix, divided by the best available toxicity threshold for this matrix. The 90th percentile concentration is protective while limiting the influence of outlier measurements.

Risk quotient values for CECs are compared to specified cutoff values to inform placement among four tiers of concern within the risk-based framework: Very High Concern, High Concern, Moderate Concern, and Low Concern (Table 1). Where lack of robust toxicity thresholds, limited occurrence data, and/or insufficient analytical method sensitivity limits the ability to calculate a sound risk quotient, we place contaminants in the Possible Concern tier.

We prioritize data collected within the previous 10 years of monitoring for calculation of the 90th percentile concentration and risk quotient. Our intention is to evaluate the risk associated with current conditions, including the potential effects of recent management actions, which may limit the utility of measurements from more than a decade ago. We also limit calculation of risk quotients when fewer than 10 measurements are available. In particular, we will approach with caution any new classification based on older monitoring data for a contaminant or class in the Very High Concern, High Concern, or Moderate Concern tiers.

Ecological risks are the primary driver of the RMP risk evaluation, with the ecological risk quotient RQ_{eco} defined as:

$$RQ_{eco} = \frac{90th\ percentile\ concentration}{protective\ ecological\ threshold}$$

In general, we use ecosystem-level thresholds derived using either a probabilistic approach and species sensitivity distributions or a deterministic approach applying assessment factors to single species thresholds to account for interspecies differences. Single endpoint thresholds from single species toxicity tests (e.g., ECx, NOEC, LOEC) without assessment factors are not used for the risk screening evaluation. In cases where multiple thresholds are available for a compound, the level of uncertainty in the threshold, transparency in how the threshold was derived, and best professional judgment are used to choose the threshold for risk screening. We give preference to thresholds derived from data from multiple species (and representing multiple trophic levels), chronic exposures (rather than acute), and predominantly experimental data (rather than predicted). We also preferentially use thresholds that have transparent derivation and have been incorporated or adopted in state, federal, or international regulation. All else being equal, we choose the lower threshold to be more protective.

While the thresholds we use are the most robust currently available, we update the risk screening for CECs when new thresholds become available that are more appropriate based on toxicological criteria. Provisional calculation of interim thresholds (e.g., deriving a new PNEC from available single species data) can be performed when this is a high priority for the RMP.

To support the designated beneficial uses of “commercial and sport fishing” and “shellfish harvesting,” we include an evaluation of human health concerns due to sport fish and shellfish consumption in the CEC categorization process. The human health risk quotient RQ_{human} is defined as:

$$RQ_{human} = \frac{90th\ percentile\ concentration}{protective\ consumption\ threshold}$$

We preferentially use consumption thresholds that have been incorporated or adopted in California. When California thresholds are not available, we give preference to consumption thresholds incorporated or adopted in other state, federal, or international regulation. All else being equal, we generally choose the lower threshold to be more protective. However, human consumption thresholds frequently include multiple consumption tiers (e.g., unlimited, one serving per week, one serving per month, etc.) because public health goals must balance the risks of exposure to contaminants with the many known beneficial health effects of consuming fish. Because the Bay's beneficial uses include fishing, but not subsistence fishing, we do not necessarily choose the lowest possible threshold (e.g., unlimited consumption), when a higher threshold (e.g., two meals per week) better reflects San Francisco Bay fish consumption patterns. A 2000 study of seafood consumption patterns in the Bay conducted in collaboration with the Environmental Health Investigations Branch of the California Department of Health Services (SFEI 2000) found that the 90th percentile of fish consumption by Bay Area fishers was seven times per four weeks, or about twice a week. Threshold preference could be adjusted if updated fish consumption rates are determined to be more frequent and/or if subsistence fishing is added as a designated beneficial use.

In many cases, there is insufficient information for calculation of a risk quotient. Sources of uncertainty can include insufficient toxicity data, including lack of thresholds, or inadequate occurrence data. When there is uncertainty in placing a chemical or class in a risk tier, we place these contaminants in the Possible Concern risk tier.

Tier Descriptions

Very High Concern – Occurrence data suggest a very high probability of an adverse impact on San Francisco Bay wildlife or people, with sufficient data indicating occurrence concentrations at least two or more orders of magnitude above ecological risk thresholds (RQ_{eco} well above 100) or one order of magnitude above available human health thresholds for fish consumption (RQ_{human} well above ten).

High Concern – Occurrence data suggest a high probability of an adverse impact on Bay wildlife or people, with sufficient data indicating occurrence concentrations between one and two orders of magnitude above ecological risk thresholds (RQ_{eco} between 10 and 100) and above available human health thresholds for fish consumption, but less than one order of magnitude greater (RQ_{human} between one and ten).

Moderate Concern – Occurrence data suggest a moderate probability of an adverse impact on Bay wildlife or people, with sufficient data indicating occurrence concentrations above ecological risk thresholds, but less than one order of magnitude greater (RQ_{eco} between one and 10) and below available human health thresholds for fish consumption (RQ_{human} less than one).

Low Concern – Occurrence data suggest minimal impact on Bay wildlife or people, with sufficient data indicating occurrence concentrations well below ecological and human health risk thresholds (RQs generally well below one, depending on secondary factors such as trends in use and chemical persistence).

Possible Concern – Lack of robust toxicity thresholds, limited occurrence data, and/or insufficient analytical method sensitivity suggests uncertainty in the level of effect on Bay wildlife or people. Occurrence data for a compound in a matrix are considered limited when fewer than 10 samples are available; this value was selected to limit the impact of a single unusually high or outlier value on calculation of an RQ based on the 90th percentile concentration. Insufficient method sensitivity is indicated when detection or reporting limits of analytical methods for a contaminant are higher than toxicity thresholds, and result in low detection frequencies.

We integrate the class-based approach into the risk screening and tier assignment process in different ways. For structurally similar chemical classes, we apply the class-based approach to guide our overall risk screening classification for all members of the class, typically driven by the highest level of concern identified for an individual compound. In some cases, our risk screening involves the use of read-across methods, where available data of a data-rich substance can be used to predict behavior or toxicity of a chemically similar data-poor substance. Read-across methods are already commonly used in risk assessment. By taking this protective approach to risk-based screening, we attempt to avoid underestimating the risks associated with data-poor compounds, a factor that has led to regrettable substitutions by manufacturers in the past. For use classes, which can encompass compounds with considerable chemical and toxicological diversity, some individual contaminants or subclasses may be categorized in specific tiers separate from the rest.

2.2.2 Approaches to Non-Detects for CECs Data Analysis

The current RMP convention for non-detects (NDs) for legacy contaminants, based on extensive datasets and consideration of the impact of all of the substitution options, is to substitute zero for the concentration of an analyte of interest, resulting in a more conservative set of data, with concentrations of individual compounds or sums of compounds potentially biased towards lower values. The improvement of method detection limits (MDLs), especially for contaminants of emerging concern (CECs), has led to an increasing interest from staff and experts to consider other options for handling of non-detects (and left-censored datasets) for upcoming RMP projects.

Available literature is generally limited and inconclusive on the best approach for the treatment of NDs in environmental data. A few studies have examined the impact of substitution and statistical methods on varying levels of left-censored data to understand which are best to apply (Antweiler 2015; Snelder et al., 2021; Tekindal, Erdogan, and Yavuz, 2015; Hites, 2019; Yee and Wong 2019). In general, substitution tended to fare similarly when frequency of non-detects was low (less than 40%), compared to more advanced methods. At larger censoring rates (usually above ~40%; i.e., detection frequencies below 60%), all methods produced less reliable estimates. Additionally, increasing sample size may improve the reliability of substitution methods, particularly above 70-100 samples.

Our review of the literature highlights a variety of non-detect substitution schemes. Tekindal, Erodogan, and Yavuz (2015) evaluated ND substitution with the MDL and MDL/sqrt(2), alongside other methods, and determined that substitution with MDL/sqrt(2) was among the best of all treatment methods for left-censored data. Antweiler (2015) used the MDL, MDL/2, and MDL*(sqrt(2)/2) in place of NDs. Antweiler found that while the latter substitution showed the overall best treatment across censor percentage, when below 25% censoring, MDL/2 and MDL/sqrt(2) tended to fare similarly. Snelder et al. (2021) specified substitution of MDL/2 for left-censored data in their guidance on trend assessment in environmental data. Hites (2019) explored multiple approaches using a model dataset and found substitution with MDL/2 performed well, even when measurements were 40% non-detect, while expressing caution for any datasets with >20% non-detect.

Within the RMP, Yee and Wong (2019) recently performed an analysis of a heavily left-censored dataset for PCB concentrations from sediment in Dredged Material Management Office (DMMO) studies. A variety of substitution methods were tested within the censored DMMO data set and compared to RMP data with a low censor rate. This study found that the MDL/2 substitution resulted in the most similar distributions between the DMMO and RMP datasets. Calculations using a method explicitly designed to conduct statistical tests of left-censored data (cendiff function from the NADA R-statistical package) further confirmed that ND substitution approaches affect results, particularly when comparing sums of contaminants.

As there is no single, simple answer with respect to the best method to handle non-detects, we suggest a nuanced approach that is informed by our knowledge of chemicals and classes. Moving forward, the following are some potential updates to the current RMP convention on ND substitution.

- Rather than using a single approach, we recommend selecting ND substitution approaches for each class we evaluate. This selection is informed by information on use, environmental distribution, and analysis methods of the overall class, as well as member chemicals and subclasses. While this approach may reduce consistency in ND handling from compound to compound and class to class, we believe it is likely to improve the overall accuracy of our risk evaluations.
- Where substitution is appropriate, we generally recommend replacing NDs with MDL/2. Our review of available studies suggests that this convention performs adequately; this method has an additional advantage of ease of communication to broad audiences. For studies that aggregate data from multiple analytical efforts with inconsistent MDLs (likely due to changes of analytical methods over time), we would replace NDs with MDL/2 specific to the individual analysis. These resulting values can then be used to calculate summary statistics including the sum of total analytes within a particular chemical class.
- We generally do not recommend applying ND substitution schemes where detection frequency is less than 50%. Overall, substitution methods appear to perform well where detection frequencies are at least 60%. Our broad screening studies may include analytes not yet in common use or widely present in the environment, and ND substitution for these measurements could result in concentrations biased towards high values.
- When the choice of substitution scheme may influence the conclusion being drawn, we will perform a sensitivity analysis for ND handling, through comparison of two substitution schemes, replacing NDs first with zero and then with the MDL. This comparison provides a measure of the uncertainty associated with the substitution scheme, and will be particularly useful when summing contaminants within classes. Available monitoring data and detection limits from studies of other locations can be used to inform this interpretation.

We will document decisions about ND handling and associated rationales in future reports and deliverables.

2.2.3 Secondary Factors

While categorization in the tiered risk-based framework is primarily based on the risk quotient, additional characteristics also influence the level of concern associated with each CEC or CEC class. Specific secondary factors that may impact tier assignments for each CEC include persistence in relevant matrices, cumulative impacts, trends in production and use of the chemical, and trends in Bay concentrations over time.

Persistence is a widely recognized hazard criterion in chemical regulations around the world (Cousins et al., 2019; Matthies and Beulke, 2017). The RMP uses established criteria for defining persistence (e.g., ECHA's definition and weight-of-evidence approach for identifying persistence [ECHA, 2017]). Highly persistent contaminants, for example those with half-lives of six months or more across various abiotic matrices (e.g., water, sediment), will accumulate in the environment under a scenario of continuous use. Increasing levels of contamination will lead to an increasing probability of impacts to wildlife or people, many of which may be unanticipated due to limited toxicity information. Once adverse impacts have been observed and relevant management actions implemented, recovery may take decades or longer. Based on these observations, and in particular the likelihood that accumulation of highly persistent contaminants will eventually lead to known and unknown adverse impacts, some have made the argument that high persistence alone is an indicator of risk (Cousins et al., 2019).

For persistent CECs or CEC classes, the RMP may elect to place contaminants in a higher risk tier than would be indicated by the risk quotient alone. In 2020, the RMP used persistence as a rationale to change its approach on PFAS, from a chemical-by-chemical risk evaluation to a class-wide risk evaluation (Miller et al., 2020). An important qualification regarding persistence is that exposure is required to elicit adverse impacts; thus, a contaminant must be both highly persistent and bioavailable to wildlife or people for risk to be present. Biotic metabolism and elimination rates are also important to consider. Persistence combined with slow rates of elimination by biota, especially top predators, is a worst-case situation. In addition, degradates must be evaluated for persistence as well, as in some cases, a degradate may be far more persistent than its parent compound.

Another secondary factor relevant to classification is the potential for cumulative impacts, including additive or synergistic impacts resulting from exposure to contaminant mixtures. For example, co-exposure to multiple endocrine disrupting compounds that trigger similar impacts to an endocrine pathway can result in cumulative (additive or synergistic) impacts to an organism. Cumulative impacts may arise following co-exposure to members of the same class of CECs, or to commonly co-occurring contaminants from different chemical classes with the same mode of action. Greater levels of concern and, therefore, a higher risk tier, may be warranted when cumulative impacts are relevant to the evaluation of a class of CECs. When cumulative impacts are anticipated, a simplistic way to screen for risk is to compare sums of relevant contaminants with the toxicity threshold of the most potent (known) compound in the class; this approach assumes additive impacts and equivalent potency, and thus represents only a gross point of comparison to inform classification in the tiered risk-based framework. This approach is also protective, in that it is more likely to over-estimate rather than under-estimate cumulative mixture effects. Cumulative impacts were relevant to the RMP evaluation of bisphenols, which includes comparison of sums of bisphenols to the best available toxicity threshold for BPA.

Temporal trends in concentrations in Bay matrices, or in chemical production and use, can further inform RMP risk evaluation. When RMP monitoring indicates levels of a CEC or class of CECs in the Bay are declining or increasing over time, this is indicated by [down arrow] and [up arrow] symbols, respectively, in Table 2. Declines may be linked to specific management actions designed to prevent pollution, with continued monitoring appropriate for tracking recovery. For example, PBDE bans and phase-outs have led to declines in contaminant levels in multiple Bay matrices (Sutton et al. 2015a). Continued RMP monitoring of this class of contaminants is still useful to track further declines. In contrast, an increasing trend may warrant classification of a CEC or CEC class in a higher risk tier than might be indicated by the risk quotient alone.

Modified symbols [hollow down arrow] and [hollow up arrow] are used when contaminants are anticipated to be declining or increasing over time based on information other than monitoring data. Contaminants that have not been monitored with sufficient frequency to establish trends may still be expected to decline or increase due to changes in manufacturing and use, or increases in population. Levels of many personal care and cleaning product ingredients in Bay matrices are likely to grow along with our population; while the members of this class for which we have data are generally considered of low concern for the Bay, periodic monitoring may be recommended given this expected trend.

Observed or anticipated trends are particularly useful to inform monitoring recommendations for CECs classified as Low or Possible Concern. In the Low Concern tier, subcategories of contaminants are defined by the following monitoring recommendations: 1) periodic screening - for contaminants that merit periodic monitoring due to potential changes in use (such as those driven by increasing population), or improvements to analytical methods that result in lower detection limits and/or quantification of additional contaminants; 2) transitional - for contaminants of previously elevated concern, like PBDEs, for which monitoring is likely to sunset should concentrations in various matrices decline or remain at low levels; 3) deprioritized - for contaminants we do not currently anticipate monitoring again, as occurrence is well below thresholds and additional information is not needed to inform management.

In the Possible Concern tier, subcategories include: 1) periodic screening - for contaminants that merit periodic monitoring due to current understanding of potential ecotoxicity, or suspected increases in manufacturing and use; 2) deprioritized - for contaminants we do not currently anticipate monitoring again, as additional information is not needed to inform management. In this case, deprioritization may be driven by available method detection or reporting limits that are insufficiently sensitive to quantify current concentrations in the Bay.

Table 1 describes the RMP tiered risk-based framework, including the recommended monitoring and management actions associated with each tier. Table 2 summarizes tier assignments for CECs and CEC classes evaluated in Bay matrices to date. The tier assignments for each CEC in this report are based on available information and will be reviewed regularly as new information on Bay concentrations or potential risks becomes available. A CEC is only assigned to a tier in the framework if it has been analyzed in Bay samples; while predicted occurrence of a CEC based on presence in pathways or in similar settings can inform monitoring priorities, such predictions are not sufficient for classification within the framework.

2.3 Bay Monitoring: Screening Studies and Status and Trends Monitoring

Bay monitoring for CECs can occur via discrete screening studies that indicate a snapshot of occurrence suitable for initial risk evaluation, or sustained Status and Trends (S&T) monitoring that provide a more robust dataset useful for both risk evaluation and observation of temporal trends. Risk screening studies are recommended for new CECs not previously monitored in the Bay, and may also be applied periodically for other CEC classes to examine response to changes in use, or when new analytical methods and new toxicological information become available to improve risk screening evaluations. The RMP S&T Program provides an important platform to monitor CECs in the Bay. The current S&T Program (2022 revision) is specifically tailored to gather monitoring data to address CEC management questions (Foley et al, 2023). The RMP CECs tiered risk-based framework recommends S&T monitoring for CEC classes in the Very High and High Concern risk tier categories; appropriate matrices for monitoring will depend primarily on chemical characteristics and available matrix-specific analytical methods and toxicity thresholds. S&T monitoring may also be considered for Moderate Concern CECs. Screening studies are generally more appropriate for contaminants in other categories.

The 2022 S&T program design for water monitoring includes wet season water monitoring at locations at varying distances from stormwater and wastewater pathways. This allows improved evaluation of potential worst-case impacts to the Bay from CECs transported through wastewater and especially stormwater, which is an important and previously overlooked transport pathway for CECs to the Bay (Overdahl et al., 2021; Sutton et al., 2019; Lindborg et al, in prep, Tian et al., 2021; Shimabuku et al., 2022). Additionally this design allows us to test the conceptual model that CEC concentrations will be highest closest to the pathway inputs to the Bay immediately following a storm event and decrease with increasing distance into the Bay and time since the runoff has occurred. Bay water sites that are near pathway inputs (called “near-field sites”) were selected based on locations downstream of watersheds that include a high proportion of urban land use categories in the lower portion of the watershed because these land uses are hypothesized to include important sources of these CECs. The 2022 design continues to include sampling sites in all Bay subembayments and dry season monitoring to allow for comparison of contaminant concentrations across subembayments and comparison across seasons and years. Dry season monitoring is likely to show the influence of wastewater discharges. At present, CECs included in S&T water monitoring include bisphenols, organophosphate esters, and PFAS; rationales for recommended monitoring for each contaminant class are provided in Section 3.

Sediment monitoring in the S&T program has also been revised to improve evaluation of stormwater and wastewater pathway inputs to the Bay. S&T sediment monitoring now incorporates more robust monitoring in the shallow “margin” areas in the Lower South Bay, South Bay, and Central Bay because these areas are predicted to have the highest concentration of urban runoff-associated CECs, based on our hypothesis that sediment deposition occurs near watershed inputs. Beginning in 2023, sediment sampling will include targeted stations near known stormwater pathway inputs to the Bay; comparison with deep channel sites in the Bay will allow us to evaluate concentration gradients from stormwater and wastewater pathway inputs. Targeted sediment stations also overlap with water and biota monitoring to provide information on bioaccumulation and transport of CECs. Margin sediment sampling will also include randomly selected locations to better characterize the ambient habitat of these shallow areas. Sediment monitoring is planned for every five years. In addition, a robust sample archiving strategy will be implemented to allow for future studies that may require analysis of archived sediment. At present, CECs included in S&T sediment monitoring include bisphenols and PFAS. Monitoring for PBDEs is a short-term priority, with the expectation that declines in key congeners will be observed in response to recent management actions.

S&T monitoring for biota focuses on species most relevant for informing CEC management questions. Therefore the current design includes monitoring for priority CECs in sport fish and bird eggs, and includes pilot studies of prey fish and marine mammals. Sport fish monitoring will be expanded to allow for more robust assessment of spatial patterns and trends. Sport fish monitoring informs Bay fish consumption advisories, and targeted species are selected to be most relevant to informing human health exposure, and include core species the RMP has traditionally monitored to track sport fish trends. Prey fish monitoring is being piloted to allow for comparisons to sediment and sport fish, to assess potential wildlife exposure, and to screen for contaminants that may reach relatively high concentrations in these species. Monitoring in marine mammals is being piloted in the S&T program because marine mammals may accumulate high and potentially deleterious concentrations persistent and bioaccumulative compounds. The primary focus of S&T biota CECs monitoring is PFAS. PBDEs have been a priority for many years, but following effective management actions and observed recovery, the need for S&T monitoring of PBDEs in biota is declining.

While the S&T program is designed for prioritized CECs classes that require more sustained status and trends monitoring across longer temporal periods and greater spatial coverage in the Bay, the program also provides an important platform to conduct screening studies for other CEC classes because the design targets evaluation of worst-case scenario impacts from stormwater and wastewater input pathways. For example, recent S&T monitoring efforts were leveraged to provide samples for analysis of tire and roadway contaminants, quaternary ammonium compounds (QACs), ethoxylated surfactants, and others.

2.4 Sources and Pathways Monitoring and Modeling

RMP science can support CECs management by informing source identification and control strategies. Many individual CECs or CEC classes are present in multiple sources within urban settings. In this context, the term source represents the original product or use from which contaminants are released, such as a consumer product. Pollution prevention via source control is generally considered the most effective and efficient means of addressing environmental contamination. Specific pollution prevention actions will vary depending on the source, and can include product reformulation, chemical or product bans or phase-outs, limits on product use, extended producer responsibility, reduced releases into the environment, and improved disposal options, among others.

The RMP can inform source identification and control actions through pathway monitoring, modeling, and data interpretation that is guided by conceptual models on contaminant sources and transport to the Bay. The Bay receives inputs from a variety of pollution pathways. Major pathways include discharges of municipal wastewater and urban runoff, as well as atmospheric deposition, agricultural runoff, and in-Bay applications (e.g., associated with watercraft, docks, ports). Flows from the Sacramento-San Joaquin Delta are also a major input, and aggregate each of the aforementioned pathways for the broader Central Valley region. Specific contaminant sources may be linked to each pathway; for example, source products designed for down-the-drain disposal are linked to the wastewater pathway. Table 3 provides examples of sources of CECs listed in the tiered risk-based framework, relevant chemical properties, and indicates the observed or expected relevance of each contaminant pathway to the Bay.

The RMP and stakeholder agencies have recently begun to develop and implement a more proactive approach towards wastewater and stormwater pathways monitoring and modeling. In the past, the RMP typically evaluated occurrence of CECs in Bay water, sediment, and biota first; when measurements suggested concern, further work to characterize CECs in relevant pathways might occur to inform potential management actions to reduce contaminant loads into the Bay. Recognizing the unique characteristics of pathways, including higher contaminant concentrations that can enable more reliable and timely observations of temporal trends and the appearance of new contaminants, and the ability to tie contaminants more directly to potential sources, the RMP has pivoted to more diverse, contaminant-specific strategies.

Overall, the emerging RMP approach for municipal wastewater and urban stormwater monitoring and modeling includes: 1) the flexibility to conduct pathways monitoring at earlier stages of contaminant investigation, including preceding or simultaneous with Bay monitoring activities; 2) a focus on modeling to inform monitoring design and to help answer management questions, such as to estimate relative loads from each pathway to indicate which are important contributors to Bay contamination; and 3) an emphasis on evaluating changes over time in pathways concentrations and/or load estimates. While pathway studies are generally funded through Special Study proposals, the need to develop trend data to inform management actions indicates a requirement for sustained coordination with Status and Trends monitoring in the Bay. This emerging pathways approach is responsive to two ECWG Management Questions:

- MQ2: What are the sources, pathways, and loadings leading to the presence of individual CECs in the Bay?
- MQ4: Have levels of individual CECs or groups of CECs changed over time in the Bay or pathways? What are potential drivers contributing to change?

Pathways science requires high levels of engagement with stakeholders representing municipal wastewater and urban stormwater discharges during development of overall monitoring and modeling strategies and approaches; development of specific proposals and study designs; sample collection; data interpretation and modeling; and reporting. In addition to stakeholder engagement within the ECWG, CECs scientists engage with the RMP's Sources, Pathways, and Loadings Workgroup, as well as the Bay Area

Clean Water Agencies (BACWA) and the Bay Area Municipal Stormwater Collaborative (BAMSC). CECs scientists also work with members of state and federal agencies, including California's Department of Pesticide Regulation, Department of Toxic Substances Control, and Water Resources Control Board, as well as the United States Geological Survey and United States Environmental Protection Agency.

BACWA has outlined a collaborative and coordinated approach to working with the RMP to monitor emerging contaminants in municipal wastewater (BACWA 2020). This approach recognizes that taking a regional and collaborative approach to investigating sources and pathways of CECs in wastewater has many advantages compared to individual facility monitoring, including allowing RMP scientists and BACWA members to work together to identify information needs, develop a strategy for sources and pathways investigations that is more scientifically rigorous and more resource efficient, provide centralized and rigorous data quality control led by the RMP science team, and make the information gathered be centrally managed and publicly available. This cooperation is built on the clear communication from regulators that participation in RMP CEC monitoring is part of the joint investigations to understand CECs in municipal wastewater from similar facilities, and results will not be used to justify undue regulatory consequences on individual participating facilities. The information about CECs in wastewater gathered by the RMP is valuable in informing pollution prevention activities led by various RMP stakeholders and beyond, including those led by the BACWA Bay Area Pollution Prevention Group and Department of Toxic Substance Control Safer Consumer Products program. In addition, BACWA has supported state and federal legislation to control products contributing to CECs in the environment.

One of the most important aspects of designing an investigation of priority CECs in municipal wastewater is to select a representative subset of facilities to collect samples. To support this effort, BACWA has compiled information about each member agency that may be important for selecting participants in a given study (BACWA 2020). This includes information characterizing the size of each publicly owned treatment works (POTW), including average daily effluent flows, average dry weather permitted flow, estimated population served, and number of connections. BACWA's white paper also includes a map indicating the location of each facility (which can be categorized by subembayment), and level and type of wastewater treatment including information about the type of secondary treatment, disinfection type, and whether advanced secondary filtration is used. All of these characteristics will need to be updated periodically. Selection of a representative set of POTWs to sample will depend on the specific CEC study objective. For example, a study focused mainly on representing the average concentration of effluent discharge to the Bay may prioritize larger facilities that represent a larger portion of flows to the Bay. A different study design may be needed to understand the range of a particular CEC concentration from different types of POTWs, and may include a more diverse range of facility size, treatment types, geographic locations. Industrial inputs to a specific POTW sewershed may also influence CEC levels. If particular industrial inputs are identified as potential sources of CECs being studied, BACWA and its member agencies can work with RMP scientists to gather information from available sources when needed.

The RMP is currently developing an urban stormwater CECs monitoring approach, with the goal of establishing robust, practical, and cost-effective approaches for stormwater CECs monitoring. A cornerstone of the new stormwater CECs monitoring approach is the integration of modeling and monitoring designs to maximize the value of each sampling event.

Additional contaminant pathways — atmospheric deposition, agricultural discharges, and inputs associated with in-water uses — have not been rigorously examined previously as part of RMP work on CECs. For some CECs, characterization of these pathways may become priorities for the RMP. Should this occur, developing an overall strategy or approach for the relevant pathway is recommended to assure thoughtful study design optimized to address multiple contaminants of interest.

3. CEC Risk Evaluation and Monitoring Recommendations for San Francisco Bay

3.1 Very High Concern

3.2 High Concern

3.2.1 Organophosphate Esters

Definition, Chemical Properties, and Use

Organophosphate esters (OPEs) are organic esters of phosphoric acid, and contain either alkyl chains or aryl groups. More commonly monitored OPEs include chlorinated compounds such as tris(1,3-dichloro-2-propyl) phosphate (TDCIPP) and tris(2-chloroisopropyl) phosphate (TCPP), and non-halogenated compounds such as triphenyl phosphate (TPhP) and tris(2-butoxyethyl) phosphate (TBOEP).

The chemical properties of individual members of the OPE class are highly variable (van der Veen and de Boer, 2012). Several of these compounds are moderately or highly water soluble, and many are semi-volatile (van der Veen and de Boer, 2012). Many OPEs partition to sediment (van der Veen and de Boer, 2012). Occurrence in remote settings suggests long-range transport is taking place, despite early assumptions that OPEs might not be sufficiently persistent to build up in the environment (Blum et al., 2019). Studies of biota indicate organisms can readily metabolize some OPEs; nevertheless, bioaccumulation has been observed in a variety of species, particularly for chlorinated compounds (Greaves and Letcher, 2017; Pantelaki and Voutsa, 2020).

The toxicological concerns of OPEs have been summarized in recent reviews (Blum et al., 2019; Greaves & Letcher, 2017; Patisaul et al., 2021; van der Veen & de Boer, 2012; X. Wang et al., 2020; Yang et al., 2019). Structurally similar to organophosphate pesticides designed to act on the nervous system, the organophosphate esters used as flame retardants and plastic ingredients are also linked to neurological harm, including developmental neurotoxicity. Many of these compounds are recognized as endocrine-disrupting, especially with respect to thyroid function, and can produce a range of other reproductive and developmental effects. Chlorinated OPEs are considered known or suspected carcinogens. Some OPEs demonstrate toxic impacts to aquatic life, often at environmentally relevant levels (e.g., (C. Wang et al., 2020; Zhu et al., 2015) [TDCIPP]).

Organophosphate esters are used as flame retardants and plasticizers in consumer and industrial products including textiles, furniture, electronics, plastics, lubricants, varnishes, and construction materials (Wei et al., 2015). They may also be derived from oxidation of phosphites, commonly used as antioxidants in plastic products (Liu and Mabury, 2018; Venier et al., 2018). The RMP focuses on synthetic OPEs used primarily as flame retardants and plastic additives; naturally derived compounds and synthetic organophosphate esters primarily used as pesticides are not grouped within this contaminant class for risk evaluation and monitoring recommendations. OPEs have been observed in Bay pathways of municipal wastewater and urban stormwater; elsewhere, they have been observed in the air pathway as well (Li et al., 2017; Fu et al., 2021).

Use of OPEs as flame retardants in foam furniture increased dramatically following a California ban and nationwide phase-out of PBDEs (Cooper et al., 2016; Rodgers et al., 2018; Stapleton et al., 2012). More recently, California banned the use of all flame retardants in foam furniture, mattresses, and children’s products, which is expected to lead to declines in this particular use of the compounds.

RMP Monitoring To-Date and Risk Evaluation

Organophosphate ester data are available for multiple Bay matrices and pathways (Table X). The RMP conducted an initial multi-matrix screening study in 2013 and 2014, examining OPEs in Bay water, sediment, bivalves, harbor seal blubber, and in grab samples of municipal wastewater and urban stormwater (Sutton et al., 2019). Bay water concentrations exceeded available toxicity thresholds for TDCIPP and TPhP at some sites, indicating the need for followup water monitoring conducted in 2017 (Shimabuku et al., 2021). An expanded list of OPEs was incorporated into the RMP’s multi-year stormwater screening study, with samples collected from 2019 to 2022 (in prep).

Water and sediment ecotoxicity thresholds are available for some OPEs (Table X). The water threshold for TDCIPP is based on a SSD derived from 23 chronic NOEC and LOEC values representing five species (algae, crustaceans, fish, and invertebrates). The geometric mean was used for the same endpoint and species. The SSD was developed by a log-logistic parametric approach, then the HC5 was estimated from the fitted SSD. The PNEC of 0.00046 µg/L was calculated by dividing the HC5 by a conservative assessment factor of 5. The water threshold of 0.074 µg/L for TPhP is the

Danish environmental quality requirement for surface waters expressed as an annual average (general quality requirement). This is a regulatory value in accordance with the Danish Water Planning Act, BEK no 1625 of 19/12/2017. Sediment PNECs for both compounds were calculated as part of ECHA REACH registration, using an assessment factor of 10 from chronic NOECs. In contrast with TDCIPP and TPhP, very little toxicity testing data is available for TBOEP, meaning its thresholds are based on acute data and large safety factors to account for high uncertainty. Thresholds for TBOEP were derived as part of ECHA REACH registration; the water threshold is based on a 96 hour LC50 for rainbow trout (*Oncorhynchus mykiss*) with an assessment factor of 1000, and the sediment threshold was derived using the equilibrium partitioning method and an assessment factor of 10.

Organophosphate esters are considered a High Concern in the Bay. This evaluation is driven by the risk quotient of TDCIPP in water of 120, meaning the 90th percentile concentration observed in the Bay over recent years has only slightly exceeded a value two orders of magnitude higher than the best available ecotoxicity threshold. Additional risk quotients of note include that of TPhP in water (2.6) and TBOEP in sediment (0.58). Available data are insufficient to indicate changes in OPEs over time, though recent management actions that address some specific uses and compounds could lead to reduced environmental contamination in the future. Secondary factors such as an anticipated decrease in use and environmental occurrence of some OPEs are insufficient to significantly modify this risk evaluation for the Bay.

Current and Upcoming Management Actions

The State of California has taken significant action to reduce use of flame retardants like OPEs in foam furniture. In 2013, California's state flammability standard for foam furniture (TB 117) was updated from an open flame test to a smoldering test for compliance purposes (TB 117-2013), essentially eliminating the need for manufacturers to add chemical flame retardants like organophosphate esters to upholstered furniture. In 2017, DTSC's Safer Consumer Products Program listed children's foam-padded sleeping products with TDCIPP or tris(2-chloroethyl) phosphate (TCEP) as Priority Products. Manufacturers of these products generally elected to eliminate use of these flame retardants rather than complete an alternatives analysis. A subsequent state ban on the manufacture, distribution, and sale of upholstered furniture, mattresses, and children's products containing any flame retardant, effective in 2020, is expected to limit the presence of organophosphate esters in these products in California.

However, it is important to note that organophosphate ester flame retardants are still used in many other products not covered by these management actions. Organophosphate esters also have many other non-flame retardant uses, particularly as plastic ingredients, which have not been addressed at this time.

The USEPA recently issued a regulation on one member of this class, phenol, isopropylated phosphate (3:1) (PIP (3:1); CASRN 68937-41-7), which the agency has determined meets the requirements for expedited action under the Toxic Substances Control Act. The final rule "prohibits the processing and distribution of PIP (3:1), PIP (3:1)-containing products, and PIP (3:1)-containing articles, with specified exclusions;

prohibits or restricts the release of PIP (3:1) to water during manufacturing, processing, distribution, and commercial use; and requires persons manufacturing, processing, and distributing in commerce PIP (3:1) and products containing PIP (3:1) to notify their customers of these prohibitions and restrictions and to keep records" (EPA-HQ-OPPT-2021-0598-0001). The USEPA recently extended the compliance deadline to October 31, 2024, at the request of manufacturers. The 2017 RMP study of Bay water observed one isomer of PIP (3:1), tris(2-isopropylphenyl) phosphate, at low levels (90th percentile concentration 0.0023 µg/L; Shimabuku et al., 2021). The RMP multi-year stormwater screening study, which included an expanded list of nine isopropylated triarylphosphates (ITPs), detected each contaminant with frequencies at or near 100% in samples collected from urban watersheds. The new USEPA regulation is expected to reduce amounts of PIP (3:1) being manufactured, processed, distributed in commerce, used, and disposed, which should lead to lower levels in the environment.

Future Monitoring Strategy

We recommend sustained Status and Trends monitoring in ambient Bay water, as 90th percentile concentrations of some members of this group have exceeded available toxicity thresholds. We do not recommend Status and Trends monitoring of sediment at this time, as there is significant uncertainty associated with the threshold for TBOEP, the only compound for which Bay sediment concentrations are approaching values leading to a risk quotient over one. We also do not recommend monitoring in biota because many OPEs are readily metabolized.

We recommend a special study to assess a broad range of OPEs in wastewater effluent, for comparison with available screening level concentration data in stormwater, as well as potential future monitoring and modeling to obtain first-order loading estimates in stormwater. In the future, we advise development of a synthesis and strategy document that describes available data in the context of a conceptual model on sources and pathways, and charts a course for future RMP activities on this class.

Appendix

Table 1: Tiered Risk Based Framework for RMP
Table 2: Current Status of Classified CECs
Table 3: Pathways Monitoring Matrix of Classified CECs
Table X: OPEs Data, Thresholds, and RQs
Multi-Year Plan

Table 1. Tiered Risk-Based Framework for RMP

	Risk Evaluation	Recommended Monitoring Strategy	Water Quality Management Actions
Very High Concern	Bay occurrence data suggest a **very high probability** of an adverse impact on Bay wildlife or people	Studies to support TMDL or alternative management plan Include in Status and Trends monitoring	303(d) listing* TMDL or alternative management plan* Aggressive control/treatment actions for all controllable sources Track product use and market trends
High Concern	Bay occurrence data suggest a **high probability** of an adverse impact on Bay wildlife or people	Include in Status and Trends monitoring Prioritize special studies on sources, pathways, and loadings to inform potential management actions Consider special studies on fate and/or effects to confirm tier classification	Prioritize action plan/strategy Aggressive pollution prevention Cost-effective control/treatment actions Track product use and market trends
Moderate Concern	Bay occurrence data suggest a **moderate probability** of an adverse impact on Bay wildlife or people	Consider including in Status and Trends monitoring Consider special studies of sources, pathways, and loadings to inform potential management actions Consider special studies on fate and/or effects to confirm tier classification	Action plan/strategy Moderate pollution prevention Cost-effective control/treatment actions Track product use and market trends
Low Concern	Bay occurrence data suggest **minimal impact** on Bay wildlife or people	Periodic screening - Conduct periodic screening level monitoring in water, sediment, or biota; Periodic screening level monitoring in wastewater or stormwater to track trends Transitional - For CECs previously considered moderate concern, maintain Status and Trends monitoring for a limited number of cycles to confirm evaluation, as appropriate Deprioritized - Discontinue monitoring	Low-cost source identification and control Low-level pollution prevention Track product use and market trends
Possible Concern	Uncertainty in measured Bay concentrations or toxicity thresholds suggest **uncertainty** in the level of effect on Bay wildlife or people	Periodic screening - Conduct periodic screening level monitoring in water, sediment, or biota; Periodic screening level monitoring in wastewater or stormwater to track trends; track new information in scientific literature and other sources Deprioritized - Discontinue monitoring	Maintain ongoing effort to identify and prioritize emerging contaminants of potential concern for the Bay Track international and national efforts to identify high priority CECs and their sources Identify and/or develop quantitative chemical and/or biological screening methods

Table 2A. Current status of High-Concern CECs in the tiered risk-based framework for San Francisco Bay.

	Contaminant Class	Trend[1]	Current Bay Data
High Concern	Organophosphate Esters (OPEs)		• Levels of some OPEs in water exceed available toxicity thresholds • Detection of dozens of OPEs in Bay water, sediment, and tissue • Potential for cumulative impacts • Bay wastewater and stormwater are important pathways • High volume and potentially increasing use including as plastic additives and replacements for PBDE flame retardants; a state ban on flame retardants in foam furniture should reduce use in this product category
	Per- and Polyfluoroalkyl Substances (PFAS)	▼ △	• Concentrations in sport fish suggest possible risks to people who frequently eat fish from the Bay • Concentrations in bird eggs are currently in the range of those linked to reproductive effects in wild birds, and have exceeded a PNEC for PFOS • Concentrations in harbor seal serum are comparable to those linked to disruption in gene function in Russian seals • Bird egg and harbor seal serum monitoring suggests declining trend for PFOS, but not other PFAS • Many PFAS are observed in Bay water and sediment • Bay wastewater and stormwater are important pathways • Earlier management actions have focused on PFOS, PFOA, and other long-chain perfluorocarboxylates; many PFAS continue to be used at high volumes • More recent management actions address many important sources including food packaging, personal care products, carpets and rugs, textiles, and fire-fighting foams • Class-wide concerns about persistence, bioaccumulation (some PFAS), and potential cumulative impacts • Toxicity of individual PFAS to aquatic species, beyond a few long-chain compounds like PFOS and PFOA, is not sufficiently characterized

[1]Solid triangles indicate sufficient Bay monitoring data to indicate a temporal trend, while hollow triangles indicate an expected temporal trend based on information other than monitoring data, such as changes in use or new regulations.

Table 2B. Current status of Moderate Concern CECs in the tiered risk-based framework for San Francisco Bay. Rows in blue indicate classes for which the risk tiers may change due to significant projects currently underway and/or the revised classification criteria presented in this draft document.

	Contaminant Class	Trend[1]	Current Bay Data
Moderate Concern	Alkylphenols and Alkylphenol Ethoxylates (APs & APEOs)		• ***Study in progress is expected to inform risk evaluation*** • Previously observed in Bay water, sediment, and tissue (2010 and prior), with concentrations below most toxicity thresholds • Cumulative impacts expected • Bay wastewater and stormwater are important pathways • Previously high volume use in laundry detergent may be decreasing following phase-out and anticipated management actions, though many other uses exist
	Bisphenols	△	• BPA and BPS have been detected in Bay water in the range of BPA aquatic toxicity threshold • BPA and BPF found in Bay sediment with sums above BPA sediment toxicity threshold • Potential for cumulative impacts • Bay wastewater and stormwater are important pathways • Projected increase in production and use worldwide for BPA and alternatives
	Fipronil and Degradates	▽	• Sediment concentrations in the range of toxicity thresholds for degradates • Bay wastewater and stormwater are important pathways • Limited data in marine species • Use has been high in urban areas; lower impact professional application methods have been prescribed via state regulations (2017) and are expected to result in declines
	Imidacloprid	△	• Lower South Bay water concentrations in the range of aquatic toxicity thresholds • Bay wastewater and stormwater are important pathways • Limited data in marine species • Increasing use in urban areas
	Microplastics	△	• Ubiquitous in Bay water, sediment, prey fish, bivalves • High concentrations in stormwater, also observed in wastewater • Uncertainty in toxicity to Bay wildlife; EU considers any discharge to pose a risk (non-threshold contaminant); extremely persistent in environment and difficult to clean up • Increasing plastic use and discharge globally • State and local plastic management actions focus on single-use plastic and packaging, but do not yet address major microplastics sources including tire wear particles and textile fibers

[1]Solid triangles indicate sufficient Bay monitoring data to indicate a temporal trend, while hollow triangles indicate an expected temporal trend based on information other than monitoring data, such as changes in use or new regulations.

Table 2C. Current status of Low Concern CECs in the tiered risk-based framework for San Francisco Bay. Rows in blue indicate classes for which the risk tier may change due to the revised classification criteria presented in this draft document.

	Contaminant Class	Trend[1]	Monitoring Sub-category[2]	Current Bay Data
Low Concern	Hexabromocyclo-dodecane (HBCD)	▽	Deprioritized	• Low concentrations measured in sediment, bird eggs, fish, harbor seals, bivalves • Reduction in use anticipated globally • Clear declines not yet observed in the Bay
	Polybrominated Dibenzo-p-dioxins and Dibenzofurans (PBDD/Fs)	▽	Deprioritized	• Low concentrations • Synthetic sources declining with phase-out of PBDEs • Natural sources not expected to change
	Polybrominated Diphenyl Ethers (PBDEs)	▼	Transitional	• Concentrations in Bay wildlife and sediment have been thoroughly studied and have decreased over time, with the exception of BDE-209 in sediment • Tern egg concentrations are below reproductive toxicity threshold • Sport fish concentrations are below protective human health thresholds for fish consumption • Uncertainty regarding impacts on harbor seals • Penta and Octa commercial mixtures were banned in California in 2004, leading to a nationwide phase-out • Production and use of the last commercial mixture, Deca (the source of BDE-209) was phased out nationwide in 2013; declines are anticipated
	Personal Care and Cleaning Products (10+ monitored e.g., galaxolide and other fragrances)	△	Periodic Screening	• Concentrations generally below toxicity thresholds • Levels expected to increase with population • Many other personal care and cleaning product ingredients have yet to be monitored
	Pharmaceuticals (100+ monitored e.g., ibuprofen, sulfamethoxazole)	△	Periodic Screening	• Previously observed Bay concentrations (2009-2010) generally below toxicity thresholds • Wastewater is the primary pathway; wastewater samples (2016-2017) analyzed for 104 pharmaceuticals suggested seven antibiotics and 10 other compounds might merit followup study in the Bay • Levels expected to increase with population • Various other pharmaceutical analytes have yet to be monitored

Contaminant Class	Trend[1]	Monitoring Sub-category[2]	Current Bay Data
Pyrethroids		Deprioritized	• Detected infrequently and at low levels in open Bay and margin sediment • High Concern in watersheds, as tributary sediment concentrations exceed toxicity thresholds • Lower impact professional application methods have been prescribed via state regulations

[1]Solid triangles indicate sufficient Bay monitoring data to indicate a temporal trend, while hollow triangles indicate an expected temporal trend based on information other than monitoring data, such as changes in use or new regulations.
[2]*Periodic screening* – conduct periodic screening level monitoring in water, sediment, or biota as well as wastewater or stormwater to track trends; *Transitional* – For CECs previously considered moderate concern, maintain S&T monitoring for a limited number of cycles to confirm evaluation, as appropriate; *Deprioritized* – discontinue monitoring.

Table 2D. Current status of Possible Concern CECs in the tiered risk-based framework for San Francisco Bay. Rows in blue indicate classes for which the risk tier may change due to the revised classification criteria presented in this draft document.

	Contaminant Class	Trend[1]	Monitoring Level[2]	Current Bay Data
Possible Concern	4-methylphenol		Deprioritized	• Detected in sediment samples below reporting limits in the South Bay Margins • Uncertainty in available toxicity data
	Alternative Flame Retardants - Hydrophobic Brominated Compounds	△	Periodic Screening	• Detection of several in sediment and tissue • Limited toxicity data for aquatic species • High volume and potentially increasing use as PBDE replacements
	Alternative Flame Retardants - Hydrophobic Chlorinated [Dechlorane] Compounds		Deprioritized	• Detection of Dechlorane Plus and a few related compounds in sediment and tissue • Limited toxicity data for aquatic species • High volume use
	Benzotriazole UV-stabilizers (BZT-UVs)			• Water and sediment concentrations below available toxicity thresholds • Uncertainty in toxicity data • Awaiting stormwater data from multi-year CECs screening study for further classification
	Indole	△	Periodic Screening	• Sediment concentrations in the South Bay Margins at levels exceed an available toxicity threshold • Uncertainty in toxicity to Bay wildlife • Levels may increase with population due to natural sources and consumer products
	Polychlorinated Biphenyl 11 (PCB 11; non Aroclor PCB)		Periodic Screening (via legacy PCB S&T)	• Ubiquitous contaminant and has been detected in Bay water, urban runoff, sediments • Not generally bioaccumulative like the more highly chlorinated PCB congeners (minor congener in prey fish and bivalves) • Uncertainty in toxicity thresholds • Commonly derived from current sources including dyes and pigments • Additional PCBs with non-Aroclor sources that may be appropriate to evaluate include PCB 47, 51, 68, 206, 207, 208, 209

	Contaminant Class	Trend[1]	Monitoring Level[2]	Current Bay Data
Possible Concern	Other Current-Use Pesticides		Periodic Screening	• Concentrations generally below toxicity thresholds • Uncertainty in toxicity to Bay wildlife
	Plastic Additives - Phthalates (e.g., DEHP, BBzP)		Periodic Screening	• Pro bono analysis of water samples (2017) indicates individual phthalates did not exceed available PNECs • Prior analysis (2002-2003) indicates maximum sediment concentrations were in the same range as some PNECs • Potential for cumulative impacts
	Polyhalogenated Carbazoles (PHCZs)		Periodic Screening	• Ubiquitous contaminants detected in Bay sediment, bivalves, fish, birds, and seals • Uncertainty in toxicity thresholds
	Quaternary Ammonium Compounds (QACs)	△	Periodic Screening	• Several detected in Bay sediment; sediment core shows use of some staying roughly the same while others are decreasing over time • Preliminary detections in wastewater; awaiting for data from a long-term pro-bono study • Uncertainty in toxicity to Bay wildlife • Expected to increase with population and response to the COVID-19 outbreak
	Short-chain Chlorinated Paraffins (SCCPs)		Periodic Screening	• Concentrations below toxicity thresholds • Uncertainty in toxicity data • High volume use • Medium- and long-chain versions will be characterized in sediment as part of an ongoing study
	Substituted Diphenylamines (SDPAs)			• Water and sediment concentrations below available toxicity thresholds • Uncertainty in toxicity data • Awaiting stormwater data from multi-year CECs screening study
	Siloxanes			• Detected in bivalves • Uncertainty in bioaccumulation potential • Limited sediment and water toxicity thresholds available • Awaiting pro bono data on sediment and effluent

[1]Solid triangles indicate sufficient Bay monitoring data to indicate a temporal trend, while hollow triangles indicate an expected temporal trend based on information other than monitoring data, such as changes in use or new regulations.
[2]*Periodic screening* – conduct periodic screening level monitoring in water, sediment, or biota as well as wastewater or stormwater to track trends; *Deprioritized* – discontinue monitoring.

Table 3a. Pathways Monitoring Strategy Matrix for High Concern CECs in San Francisco Bay. Pathways: Urban Stormwater, Wastewater, In-Water (e.g., hull paint, dock wood treatments), Atmospheric Deposition (Atmos. Depos.), Agricultural (Ag.) Runoff. Pathways are "Significant" if RMP or other local monitoring data exist; where local data are unavailable, a pathway may be "anticipated to be significant."

				Pathways to the Bay				
	Contaminant Class	**Chemical Properties**	**Notable Sources**	**Urban Stormwater**	**Wastewater**	**In-Water**	**Atmos. Depos.**	**Ag. Runoff**
High Concern	Organophosphate Esters (OPEs)	• Water-soluble • Partition to sediment • Semi-volatile and can be transported long distances • Metabolized; limited bioaccumulation	Used as flame retardants and plastic ingredients for consumer and industrial products incl. furniture, construction materials, textiles, electronics	Significant; ongoing monitoring	Significant; special study recommended	Possible	Possible	Possible; land application of biosolids
High Concern	Per- and Polyfluoroalkyl Substances (PFAS)	• Water-soluble • Partition to sediment • Some are semi-volatile and can be transported long distances • Persistent; precursors degrade to persistent PFAS • Bioaccumulation significant, particularly for long-chain compounds	Used in fire-fighting foams, carpet treatments, grease and water-resistant coatings for clothing and food packaging, processing aids in electronics and polymers, paper manufacturing including toilet paper, cosmetics and personal care products, paints, construction materials, synthetic turf	Significant; ongoing monitoring	Significant; ongoing monitoring	Possible	Possible	Possible; land application of biosolids

Table 3b. Pathways Monitoring Strategy Matrix for Moderate Concern CECs in San Francisco Bay. Pathways: Urban Stormwater, Wastewater, In-Water (e.g., hull paint, dock wood treatments), Atmospheric Deposition (Atmos. Depos.), Agricultural (Ag.) Runoff. Pathways are "Significant" if RMP or other local monitoring data exist; where local data are unavailable, a pathway may be "anticipated to be significant."
Additional contaminant classes will be added in later drafts.

				Pathways to the Bay				
	Contaminant Class	**Chemical Properties**	**Notable Sources**	**Urban Stormwater**	**Wastewater**	**In-Water**	**Atmos. Depos.**	**Ag. Runoff**
Moderate Concern	Bisphenols	• Water-soluble • Partition to sediment • Lower volatility • Metabolized; limited bioaccumulation	Used in polycarbonate plastics, epoxy resins, thermal paper, flame retardants, tires, textiles, paints and coatings	Significant; ongoing monitoring	Significant; recent study in 2020	Possible	Possible	Possible; land application of biosolids

Table X. Key Substances RMP Occurence Data: OPEs

Number of Substances in Class

Number of Substances Monitored by the RMP

Matrix	Water	Sediment	Mussels	Harbor Seal Blubber	Wastewater Effluent	Stormwater Runoff
TCPP	n = 34	n = 10	n = 6	n = 7	n = 3	n = 26
Concentration Range	0.015 - 2.9 μg/L	0.26 - 1.6 μg/kg	<0.15 - 3.6 μg/kg	<1.0 - 8.1 μg/kg ww	2.5 - 3.2 μg/L	0.018 - 1.7 μg/L
90th Percentile	0.26 μg/L	1.2 μg/kg	2.9 μg/kg	7.1 μg/kg ww		1.1 μg/L
Monitoring Data Date Range	2013, 2017	2014	2014	2014	2014	2019 - 2022
Toxicity Threshold	59.2 μg/L (Xing et al. 2019)	292 μg/kg dw (ECHA 2011)	not available	not available	n/a	n/a
RQ	0.0044	0.0041				
TDCIPP						
Concentration Range	0.0028 - 0.45 μg/L	0.73 - 2.0 μg/kg	2.2 - 8.9 μg/kg	<2.5 - 26 μg/kg ww	0.18 - 0.41 μg/L	0.0072 - 9.3 μg/L
90th Percentile	0.055 μg/L	1.4 μg/kg	7.1 μg/kg	22 μg/kg ww		0.32 μg/L
Monitoring Data Date Range	2013, 2017	2014	2014	2014	2014	2019 - 2022
Toxicity Threshold	0.00046 μg/L (Xing et al. 2019)	166 μg/kg dw (ECHA 2011)	not available	not available	n/a	n/a
RQ	120	0.0084				
TPhP						
Concentration Range	<0.0004 - 0.36 μg/L	0.44 - 7.5 μg/kg	<0.40 - 1.6 μg/kg	<1.0 - 24 μg/kg ww	0.027 - 0.13 μg/L	0.0023 - 0.11 μg/L
90th Percentile	0.19 μg/L	5.5 μg/kg	1.5 μg/kg	20 μg/kg ww		0.060 μg/L
Monitoring Data Date Range	2013, 2017	2014	2014	2014	2014	2019 - 2022
Toxicity Threshold	0.074 μg/L (Ministry of Environment and Food of Denmark, 2017)	110 μg/kg dw (ECHA 2011)	not available	not available	n/a	n/a
RQ	2.6	0.05				
TBOEP						
Concentration Range	0.0004 - 1.0 μg/L	0.51 - 4.8 μg/kg	<0.30 - 2.0 μg/kg	<0.25 μg/kg ww	0.029 - 3.6 μg/L	0.024 - 5.9 μg/L
90th Percentile	0.076 μg/L	4.6 μg/kg	1.8 μg/kg			0.91 μg/L
Monitoring Data Date Range	2013, 2017	2014	2014		2014	2019 - 2022
Toxicity Threshold	2.4 μg/L (ECHA 2010)	80 μg/kg dw (ECHA 2010)	not available	not available	n/a	n/a
RQ	0.032	0.58				

EMERGING CONTAMINANTS

Relevant Management Policies and Decisions

Regional Action Plans for emerging contaminants

Early management intervention, including green chemistry and pollution prevention

State and federal pesticide regulatory programs

State Water Board CEC Program

DTSC Safer Consumer Products Program

Recent Noteworthy Findings

In 2022, the RMP launched an effort to review and revise the overall CEC Strategy guiding the program. An early outcome of this revision is a proposal to change the tiered risk-based framework for emerging contaminants, increasing the number of tiers to provide greater ability to distinguish relative risks and communicate RMP monitoring priorities. At present, no CECs would fall into the Very High Concern tier outlined in this revised framework. PFAS and organophosphate esters would be listed as High Concern CECs for the Bay. Moderate Concern CECs include alkylphenols and alkylphenol ethoxylates (surfactants), bisphenols (plastic ingredients), the urban-use pesticides fipronil and imidacloprid, and microplastics (a separate focus area). The multi-year plan for emerging contaminants on the following pages has been reorganized to reflect the proposed revision to the framework.

The RMP continues a major focus on PFAS, widely used fluorine-rich specialty chemicals that are persistent and of high toxicological concern for humans and wildlife. In 2021, the RMP sport fish report indicated concentrations of PFAS, particularly in South Bay fish, exceed thresholds that have been established by other states for the development of consumption advisories. In 2022, RMP stakeholders and scientists participated in a forum with local community groups and tribes to build consensus on next steps to protect fishing communities. Meanwhile, Bay water samples collected in summer 2021 revealed PFAS contamination remains present, with higher levels found in the South and Lower South Bay.

A major RMP effort to screen Bay Area stormwater for CECs is drawing to a close. The fourth and final year of monitoring is complete, and data interpretation is underway. In parallel, we are developing the RMP approach for continued work on CECs in stormwater, and designing and testing new remote sampling equipment.

Priority Questions for the Next Five Years

1. Which CECs have the potential to adversely impact beneficial uses in San Francisco?
2. What are the sources, pathways and loadings leading to the presence of individual CECs or groups of CECs in the Bay?
3. What are the physical, chemical, and biological processes that may affect the transport and fate of individual CECs or groups of CECs in the Bay?
4. Have levels of individual CECs or groups of CECs changed over time in the Bay or pathways? What are potential drivers contributing to change?
5. Are the concentrations of individual CECs or groups of CECs predicted to increase or decrease in the future?
6. What are the effects of management actions?

MULTI-YEAR PLAN FOR EMERGING CONTAMINANTS

Special studies and monitoring in the RMP from 2019 to 2026. Numbers indicate budget allocations in $1000s. Budgets in parentheses represent funding or in-kind services from external sources (e.g., SEP funds). Budgets that are starred represent funding that has been allocated for the given study within other workgroups. Bold boxes indicate multi-year studies. Items shaded in yellow are considered high priority for 2024 funding and beyond. Dollar signs indicate projected future priorities for RMP special studies funding.

Element	Study	Funder	Questions addressed	2019	2020	2021	2022	2023	2024	2025	2026
Strategy	CEC Strategy[1] (no proposal needed after 2020)	RMP	1-6	70	75	60	125	60	62	64	66
	Tires Strategy	RMP	1-6					10	10	10	10
	Stormwater Monitoring Strategy	RMP	1,2				50	55			
STORMWATER MONITORING AND MODELING											
Stormwater	Strategy-driven Stormwater CECs Monitoring and Modeling (multiple contaminant classes)	RMP WQIF	1,2					250 (100)	200 (100)	200 (100)	200
HIGH CONCERN CECs											
PFAS	PFAS: Synthesis and Strategy	RMP	1-6						85		
	Stormwater PFAS[2]	RMP	1,2	33	40	29.6	20				
	PFAS in Ambient Bay Water	RMP	1,4,6			50					
	PFAS in Influent, Effluent, Biosolids; Study TBD, est. value	BACWA	1,2,4,6			(135)	(290)				
	PFAS in Archived Sport Fish	RMP Water Brd	1,4				12.5 (20)	42			
	North Bay Margin Sediment PFAS[3]	SEP	1,2,4,6					(53)			
	Marine Mammals (PFAS and Nonpolar NTA)[4]	RMP S&T	1,4,6					57.75	63.25		
	Bay Water TOP Assay	RMP	1						20	40	40
	PFAS Air Monitoring (~$50-150k)	SEP proposal	1,2								
	Agricultural (Biosolids) PFAS in Water & Sediment of North Bay Margins (~$100-200k)	SEP proposal	1,2,3								

Element	Study	Funder	Questions addressed	2019	2020	2021	2022	2023	2024	2025	2026
	RMP Status and Trends[5]	RMP S&T	1,4	F 9*			E, wet 15.5*	W, S, wet 55.5*	E, F, wet ~35*	W 13*	wet, seals ~25*
	Organophosphate Ester Flame Retardants in Ambient Bay Water	RMP ECCC	1,4								
	Stormwater Organophosphate Ester Flame Retardants[2]	RMP	1,2	33	40	29.6	20				
Organo-phosphate Esters	OPE Wastewater Monitoring	RMP	1,2,4,6						40		
	OPE Air Monitoring (~$50-150k)	SEP proposal	1,2,3,6								
	OPEs: Synthesis and Strategy	RMP	1-6								75
	RMP Status and Trends[5]	RMP S&T	1,4			W 17*	wet 11*	W, wet 28*	wet 11*	W 17*	wet 11*
MODERATE CONCERN CECs											
	Stormwater Ethoxylated Surfactants[2]	RMP	1,2	33	40	29.6	20				
Alkylphenols & Alkylphenol Ethoxylates	Ethoxylated Surfactants in Water, Margin Sediment, Wastewater	RMP	1,2,4	123							
	Followup Study	RMP	1,2,4				30	30			
	Bisphenols in Stormwater[2]	RMP	1,2		21	29.6	20				
	Bisphenols in Wastewater, Sediment	RMP	1,2		72						
Bisphenols	Bisphenols in Biota	RMP	1						80		
	RMP Status and Trends[5]	RMP S&T	1,4			W 13*	wet 8.5*	W, S, wet 47.5*	wet 8.5*	W 13*	wet 8.5*
LOW or POSSIBLE CONCERN CECs											
PBDEs	RMP Status and Trends[5]	RMP S&T	1,3,4	F 24*			E 11.5*	S 20.5*	F 24*		
Plastic Additives	Phthalates and Replacements in Water, Archived Sediment	RMP	1,4							100	
Personal Care & Cleaning	Sunscreens in Wastewater	MMP	1,2		(36.5)						
	QACs in Wastewater	MMP NSF	1,2,4			(58.2) (20)					

Element	Study	Funder	Questions addressed	2019	2020	2021	2022	2023	2024	2025	2026
	QACs & New Concerns in Bay Water, Wastewater[6]	RMP								40	
Pesticides	DPR Priorities in Water & Sediment[5]	RMP USGS	1,2,3								
	Ag Pesticides in Water & Sediment of North Bay Margins (~$100k)	SEP proposal	1,2								
	Antimicrobials in Bay Water, Wastewater[6]	RMP	1,2							30	
Brominated Azo Dyes	Archived Sediment (~$60k)	SEP proposal	1								
Building Materials	Isothiazolinone Biocides and Other Contaminants in Stormwater (~$50k)	U Iowa SEP Proposal	1,2	(2)							
	New concerns	RMP	1								50
Chlorinated Paraffins	Chlorinated Paraffins (medium-long) in Sediment[3]	SEP	1					(53)			
	Chlorinated Paraffins in Ambient Bay and Pathways	RMP	1								120
Vehicles, Roadways (studies also listed in Tires MYP)	Tire, Roadway Contaminants Follow-up from NTA, Stormwater[2]	RMP	1,2	33	40	29.6	20				
	Tire Contaminants Wet Season Water Screen	RMP	1,2				50	40	50		50
	Newly Identified Tire Contaminants (Bay or Stormwater)	RMP	1,2							50	50
	Total Tire Rubber/Tire Chemical Indicators (Stormwater, Bay Wet Season Water, Sediment)	RMP	1,2							25	75
NONTARGETED & OTHER STUDIES											
NTA (including followup targeted studies	Marine Mammals (PFAS and Nonpolar NTA)[4]	RMP S&T	1,4,6					57.75	63.25		
	NTA Data Mining of Water & Sediment Findings	RMP	1,2					45			
	Non-targeted Analysis of Bay Fish	RMP	1						50	50	

Element	Study	Funder	Questions addressed	2019	2020	2021	2022	2023	2024	2025	2026
based on NTA findings)	Follow-up Targeted Study (data mining results)	RMP	1							50	
	Microplastic Additives NTA Study[7]	RMP	1							100	
Other	Toxicology	RMP	1	15		60			60	60	60
RELEVANT STUDIES IN OTHER WORKGROUPS											
Modeling (SPLWG)	Integrated Monitoring and Modeling Strategy - CEC Conceptual Model	RMP	1,2,4			50					
Modeling (SPLWG)	CEC Stormwater Load Modeling Exploration	RMP	2				25				
Strategy (MPWG)	Tires Strategy, Multi-Year Plan	RMP	1,2,3,6				25.5				
Modeling (PCBWG)	In-Bay Fate Model	RMP SEP WQIF				45	75	(408) (350)	(340)	(235)	
RMP-funded Special Studies Subtotal - ECWG				**325**	**328**	**318**	**367.5**	**532**	**657**	**819**	**796**
High Priority Special Studies for Future RMP Funding									**517**	**479**	**516**
RMP Status and Trends Analytical Costs for CECs				**33**	**0**	**30**	**46.5**	**267**	**205**	**43**	**44.5**
RMP-funded Special Studies Subtotal – Other Workgroups				**0**	**0**	**95**	**125.5**	**0**			
MMP & Supplemental Environmental Projects Subtotal				**0**	**36.5**	**58.2**	**0**	**514**			
Pro-Bono & Externally Funded Studies Subtotal				**2**	**0**	**155**	**310**	**450**	**440**	**335**	
OVERALL TOTAL				**360**	**364.5**	**656.2**	**849.5**	**1763**	**1302**	**1197**	**840.5**

1 – The CEC Strategy funds preparation of RMP CEC Strategy Revisions, Updates, and Memos; it also funds literature review, scientific conference attendance, and responses to information requests from RMP stakeholders. A Revision to the CEC Strategy is planned for 2022, resulting in a higher funding request than in the prior years. After 2020, a Special Study proposal is not required for CEC Strategy funding.
2 – The multi-year (2019-2022) stormwater study includes five groups of analytes: PFAS, ethoxylated surfactants, organophosphate esters, bisphenols (added year 2), and targeted stormwater analytes identified via non-targeted analysis. The total projected cost ($586k) is spread across five groups and four years.
3 – A SEP received in 2022 will fund sediment analysis of PFAS and chlorinated paraffins; the $106k budget is split between these classes.
4 – The non-targeted analysis of marine mammal tissues includes investigations of PFAS (targeted and suspect screening) and nonpolar compounds; budgets are split between PFAS and NTA categories.
5 – When a CEC may be included in the the RMP Status and Trends monitoring, there is a code in the cell denoting the matrix for which monitoring is proposed: W = water; S = sediment; B = bivalve; E = eggs; F = fish. Approximate analytical costs are provided to indicate CECs resources provided by Status and Trends monitoring. A review of the Status and Trends design has resulted in expected modifications over future years, with scheduling for some activities uncertain at this time. New codes include “wet,” or pilot wet season water monitoring, and “seals,” indicating potential inclusion of this matrix in future years.
6 – A special study suggested for 2025 could analyze cleaning product ingredients including QACs and other antimicrobials; costs are split among these groups.
7 – A suggested special study that uses non-targeted analysis to identify additives in microplastics is listed as potentially co-funded via both ECWG and MPWG.