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Microplastics from different viewpoints

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MICROPLASTICS REGULATION IN CALIFORNIA: Knowledge Gaps and Challenges for Utilities – Discussions from Workshops with Stakeholders in California

1 Introduction

A growing body of scientific literature reporting potential human health risks caused by microplastics and the presence of microplastics in drinking water sources has gained the attention of the public and policy makers alike. In California, the State Water Resources Control Board (State Water Board), water resources managers, and researchers are engaged in the early phase of a long-term collaborative effort to establish uniform water quality criteria for microplastics in the state. The State of California defines microplastics as follows:

> *"Microplastics in Drinking Water are defined as solid polymeric materials to which chemical additives or other substances may have been added, which are particles which have at least three dimensions that are greater than 1nm and less than 5,000 micrometers (µm). Polymers that are derived in nature that have not been chemically modified (other than by hydrolysis) are excluded."1*

As drinking water utilities across California prepare for regulatory oversight of microplastics in drinking water, industry leaders have articulated an acute need to engage with stakeholders, including utilities, regulators, academic institutions, non-governmental organizations, policymakers, and the public about the state of science and knowledge gaps surrounding microplastics to inform potential policy and regulatory development.

This document summarizes the findings and recommendations that emerged from two workshops held in California that brought diverse stakeholder groups together to discuss the state of the industry, identify knowledge gaps, and contextualize how to prioritize research needs from a utility perspective.

1.1 Target Audience

Utilities, policymakers, agencies, foundations, and other like-minded institutions and entities that can provide funding for the science and those that may be engaged in future policy or regulatory settings.

1.2 Problem Statement

Recent examples of other emerging contaminants have illustrated the importance of engaging the public when developing regulations for a contaminant. The authors assert that during the process of identifying health

[1] https://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/2020/rs2020_0021.pdf

impacts and environmental challenges, and when developing regulations, community-centered public participation is foundational to encourage behavioral changes that minimize environmental and health risks.

The challenges of health and environmental issues are confounded by water stress and the rational need to redefine water resources management approaches locally to leverage the natural and built environment. This approach is fundamentally based on the ethos that once collected and treated all water is equal regardless of its source. Therefore, a broad approach for a wholistic microplastics management strategy should include recommendations that address point- and non-point source control and reduction; treatment efficacy; and what managers and scientists in the water industry need to better understand before regulations are set. These recommendations must be based on sound and repeatable measurements. Recommendations also should include research needs, estimates of environmental and health impacts, new approaches to public outreach and education, and what utilities might do to prepare for future regulations.

1.3 Regulations on Microplastics

Research on the fate and transport of microplastics has revealed that it is abundant in the aquatic environment, including marine and freshwater source waters. It has also been detected in soil and ambient air. Microplastics in the environment can pose environmental and health risks and may impact aquatic and terrestrial food webs. The following sections discuss regulations around the world and in the United States.

Microplastics regulations have been developed in many countries and in various states in the United States. In California, recent legislation requires monitoring microplastics in drinking water sources. Recycled water is unique because its source water includes water from wastewater treatment plants (WWTPs) and, ultimately, which becomes drinking water in potable reuse applications. In California, many utilities provide what are called One Water services, which means both drinking water and water reclamation/reuse, thereby linking concerns about microplastics to water reuse.

1.3.1 Global MP Regulations

During the last two decades, microplastics in the environment have been documented in several scientific publications and regulators have engaged in the issue at different levels.

- As of today, 77 countries limit or ban plastic bags to address secondary microplastics derived from larger plastics and 27 countries have banned or limited the production of specific products and materials, such as straws and polystyrene. To reduce plastic sources, Extended Producer Responsibility (EPR) was developed to make plastic packaging producers and importers responsible for the plastic they produce or import across its entire lifecycle.
- To date, over 70 countries include the EPR for plastic bags to the end-of-life stage and 63 countries mandate EPR for single-use plastics. In March 2022, United Nations Environmental Assembly (UNEA) adopted a resolution titled “End of Plastic Pollution: Towards an international legally binding instrument.” To curb the world’s growing microplastics problem, the international community has agreed on a framework. An intergovernmental negotiating committee (INC) was created to develop a strategy by 2024 (UNEP, 2022).

- In December 2018, the United Nations Environmental Program (UNEP) published the report "Legal Limits on Single-Use Plastics and Microplastics: A Global Review of National Laws and Regulations."
- As of July 2018, 127 countries adopted some form of legislation to reduce plastic bags. As part of the microplastics source reduction strategy, as of July 2018, Canada, France, Italy, Republic of Korea, New Zealand, Sweden, the United Kingdom of Great Britain and Northern Ireland, and the United States of America banned microbeads through national laws or regulations.

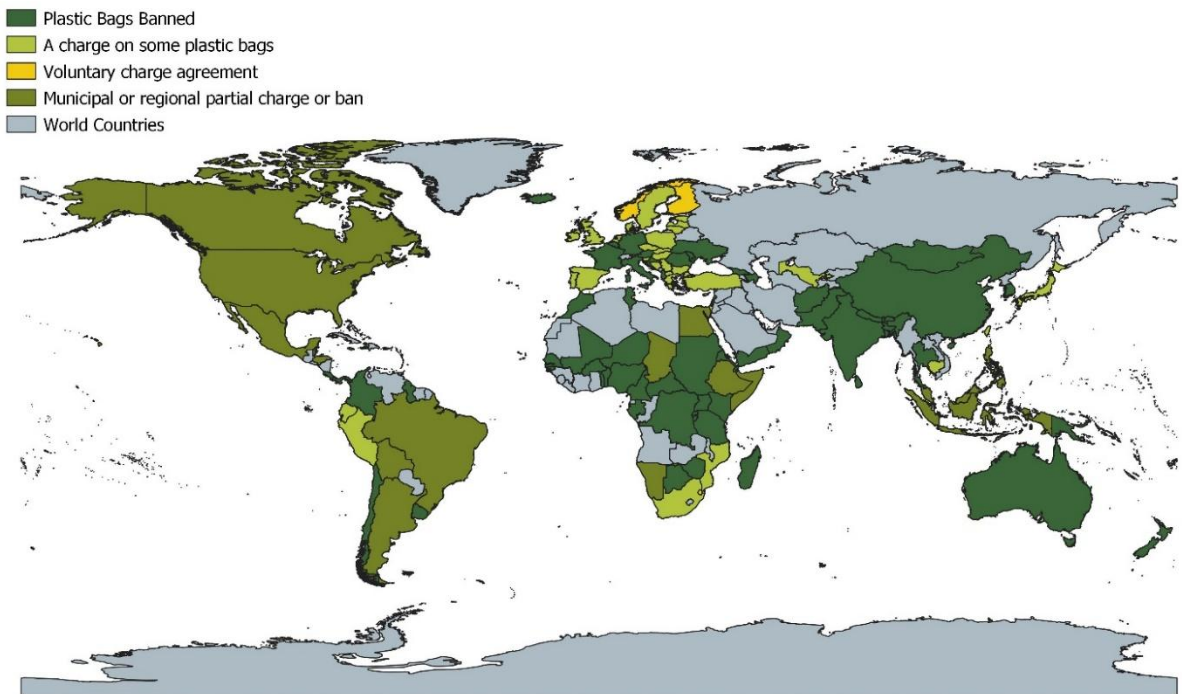

Figure 1- Global Plastic Bag Regulation (Brown and Caldwell 2023)

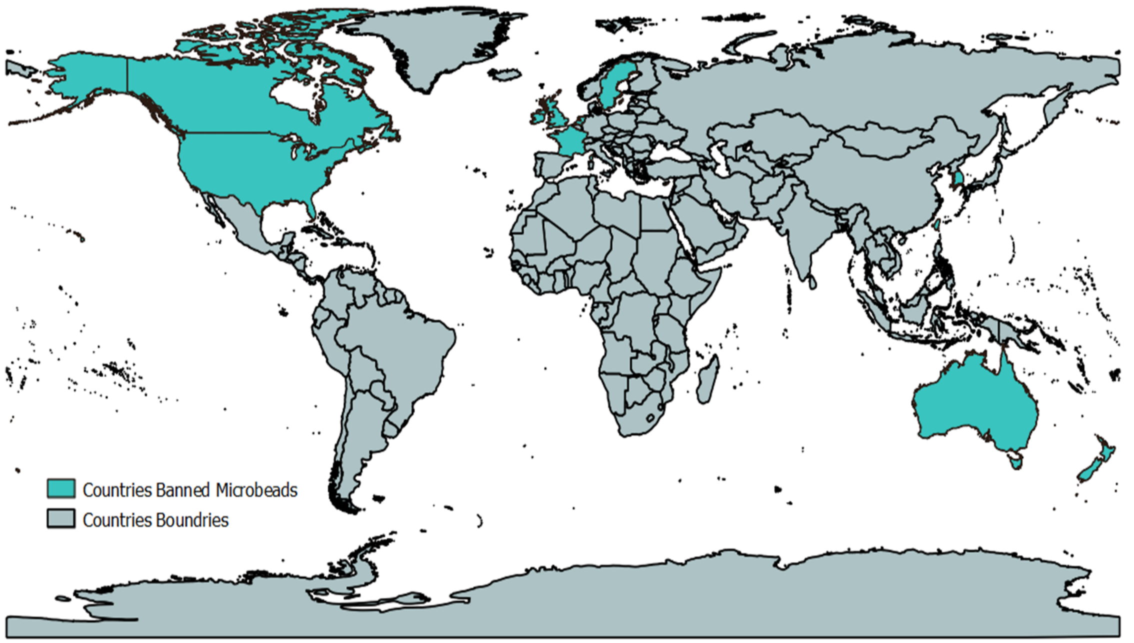

Figure 2- Global Microbead Regulation (Brown and Caldwell 2023)

1.3.2 Microplastics Regulations in the United States

The most recent federal regulation on microplastics was passed in December 2020 with the "Save Our Seas Act" aimed at tackling coastal debris. The regulation includes three titles: Title I: Combating Marine Debris, Title II: Enhanced Global Engagement to Combat Marine Debris, and Title III: Improving Domestic Infrastructures. The goal was to establish domestic and international discussions and initiatives about coastal debris.

The most recent bill passed by California was "Solid Waste: reporting, packaging, and plastic food service ware (SB 54)," which was passed on June 30, 2022. The goal of this bill is to reduce plastic waste by requiring all packaging to be recyclable or compostable by 2032. This legislation also raises $5 million from industry members to shift the plastic pollution burden from consumers to the plastic industry.

As shown in Figure 3, the State of California has passed several bills addressing microplastics in the environment, targeting sources such as microbeads and single-use plastics. While most of these bills prioritized source control, recent legislation has focused on microplastics occurrence.

SB 1422 (2018), signed into law as the the "California Safe Drinking Water: Microplastics" (Act), requires the State Water Board to conduct research, studies, and demonstration programs to ensure provision of a dependable, safe supply of drinking water, which may include improving methods to identify and measure the existence of contaminants in drinking water and to identify the source of the contaminants. The Act also grants the State Water Board the authority to implement regulations that may include monitoring for contaminants and requirements for notifying the public about the quality of the water delivered to customers. The Act also requires the State Water Board to adopt a definition of microplastics in drinking water on or before July 1, 2020; and, on or before July 1, 2021, to adopt a standard methodology for testing drinking water for microplastics and requirements for four years of testing and public reporting of microplastics in drinking water.

SB 1263 (2018) signed into law as the “Statewide Microplastics Strategy” (Strategy) was aimed at developing a greater understanding of the risks associated with microplastics in the marine environment and options to address the issue. The law requires the State of California’s Ocean Council to develop, adopt, and implement a statewide strategy that provides a multi-year roadmap for California to take national and global leadership of microplastics management.

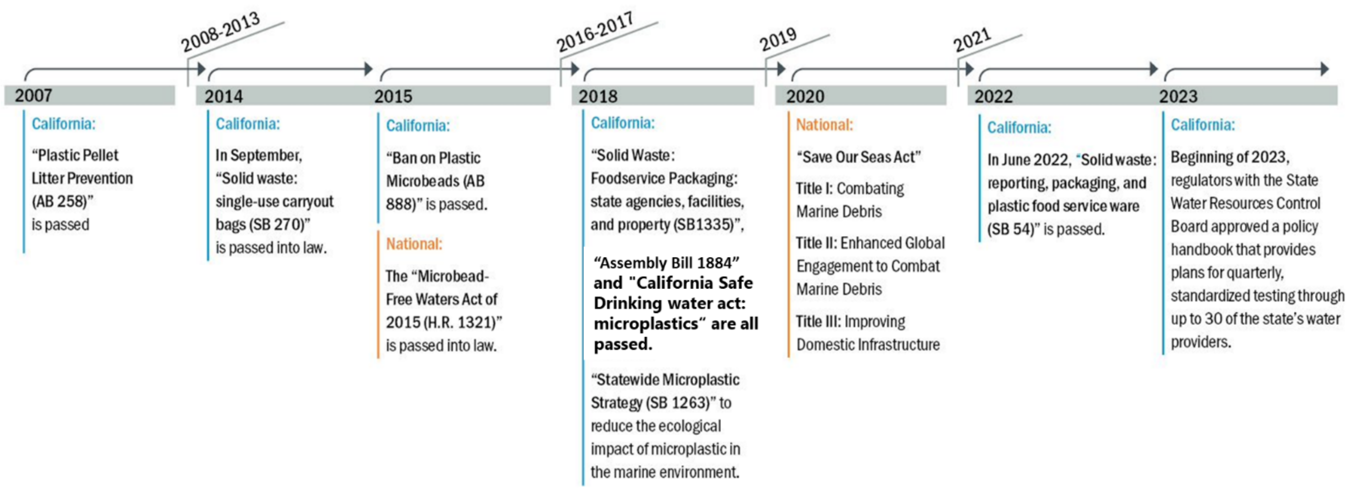

Figure 3- Federal and California State regulations on microplastics (Brown and Caldwell 2023)

1.4 Workshop Overview

Water and wastewater utilities, policymakers, funding agencies, and entities engaged in policymaking and the development of regulations participated in the workshops, in both Northern and Southern California. The workshops discussed the existing knowledge on environmental, ecological, and health risks and the state-of-the-art on microplastics and identified knowledge gaps and future steps in relation to recycled water. A total of 16 utilities shared their experiences which are summarized herein along with the specific needs identified for addressing new microplastics regulations. This document is a compilation of the workshop discussions.

2 Occurrence and Treatment Literature Review

2.1 Microplastics in Reclaimed Water

Treated wastewater effluent serves as the water source for recycled water. Like other contaminants, such as perfluoroalkyl and poly-fluoroalkyl substances (PFAS), wastewater treatment facilities are often the terminal acceptor for microplastics. Previous studies have reported the presence of microplastics in wastewater samples collected from various locations across the globe, including Russia, Sweden, Finland, the United States, the United Kingdom, Netherlands, Germany, Canada, Australia, Italy, Turkey, Denmark, Poland, China, and South Korea (Iyare et al., 2020). A study on the effluent discharge from seven tertiary plants and one secondary plant in southern California was discussed (Carr et al., 2016), recognizing microplastics in discharge from municipal WWTPs. Despite significant microplastics removal at the WWTPs (Wang et al., 2020), studies reported the impact of wastewater effluent discharge on microplastics contamination downstream of the effluent discharge point (Estahbanati, Shirin, 2016). In addition, microplastics were detected in reclaimed water samples (Mengqi Yan, et al., 2022), which highlighted the importance of tracking such contamination across aquatic environments. Results from recent studies that summarize the occurrence of microplastics in San Francisco Bay suggest that microplastics in runoff generated from rain events are approximately two orders of magnitude higher than in treated wastewater effluent (Moran et al., 2021).

2.2 Microplastics Removal during Wastewater Treatment

While WWTPs are not specifically designed to remove microplastics and other contaminants of emerging concern (CECs) (Leslie et al., 2017; Talvitie et al., 2017) Cheng et al., (2021) reviewed microplastics removal during various treatment processes at WWTPs and reported that microplastics removal during preliminary, primary, secondary, and tertiary treatments varies between 6.0 – 58.6%, 19.1 – 99.0%, 66.7 – 92.6%, and 72.7 – 99.9%, respectively.

In drinking water treatment processes, chemically enhanced sedimentation improves microplastics removal. One of the earliest studies, carried out in Finland, reported that a combination of chemically enhanced sedimentation treatment with preliminary treatment results in 50% to 97.9% microplastics removal. Ruan et al., (2019) compared microplastics removal in traditional sedimentation with chemically enhanced sedimentation, and the results indicated the chemically enhanced sedimentation increased microplastics removal to 78.2%, compared with 41.7% microplastics removal in traditional drinking water treatment sedimentation processes.

Secondary treatment typically includes a biological process for removing organic matter and nutrients. In the secondary stage, biofilm can attach to microplastics, resulting in the settling of microplastics in the sedimentation/clarification tank (Cheng et al., 2021). Microplastics removal at a WWTP is dependent on hydraulic retention time (HRT). On one hand, increasing the HRT can increase biofilm attachment to microplastics and increases the possibility of microplastics removal and, on the other hand, increasing the HRT affects the biofilm characteristics and can affect the microplastics attachment to the biofilm adversely. Thus, there is not a clear correlation between retention time and microplastics attachment to the biofilm in secondary wastewater treatment. It is suggested to operate at optimum retention time, depending on different WWTPs, considering physical and chemical characteristics. One research study indicated that operating at the optimum retention time improves biological activity and microplastics removal at the same time (Zöhre & James, 2022). While a few studies have demonstrated the potential biological degradation of microplastics, the details of fate and transport in biological treatment are not clear yet.

Tertiary treatment and disinfection are commonly used as the final treatment steps for non-potable recycled water. Tertiary treatment provides additional microplastics removal opportunities at WWTPs with removal efficiencies ranging from 72.7% to 99.9% (Cheng et al., 2021). Among the tertiary filtration processes, microplastics removal with sand filters and disc filters is variable, while membrane bioreactors (MBR) can achieve up to 99.9% removal when membranes with pore sizes smaller than 0.1 µm are used (Lv et al., 2019). Despite high removal percentages at WWTPs, microplastics, especially smaller fractions, can be present in recycled water. This calls into question the potential contribution of atmospheric deposition past the point of treatment.

Microplastics fragmentation can occur during treatment at different treatment stages through treatment processes. Wu et al., (2022) reported that microplastics are prone to physical, biological, and chemical weathering at WWTPs. In addition to the presence of microplastics in treated effluent, microplastics retained in the sludge from primary and secondary treatment can be a source of microplastics in soil when biosolids are applied on public areas, gardens, landfills, mine rehabilitation sites, or forests.

2.3 Impacts of Microplastics on the Treatment Process

The presence of microplastics in wastewater can affect treatment processes. In secondary treatment, the nitrification process, which relies on symbiotic growth and activities of ammonia-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB), can be inhibited by microplastics (Xiao et al., 2015). In addition, microplastics can negatively impact microbial community composition and floc formation (Meng et al., 2023). Membrane fouling and higher backwash frequency for filters have also been reported due to the presence of microplastics (Cheng et al., 2021). Microplastics can increase disinfectant requirements and decrease UV and chlorine disinfection efficiency in a way that increasing the disinfectant dose may not improve disinfection efficiency at significantly high microplastics concentrations (e.g., > 50 mg/L) (Shen et al., 2021).

The effects of microplastics on biosolids processes have been the subject of several studies. The presence of microplastics can affect hydrolysis and methanogenesis processes in anaerobic digestion and, consequently, can reduce methane yield. Indirect impacts of microplastics in biosolids have been reported to manifest as leaching of toxic chemicals and reactive oxygen species (Manu et al., 2023). The various impacts of treatment processes and potential environmental, ecological, and toxicological risks make microplastics research critical.

3 Methods

3.1 Sample Collection and Quantification Methods

New methods have been developed for microplastics sampling and analysis in recent years. Sample collection methods differ in tools and equipment used, the volume of sample collected, types of filters used, and sample preparation procedures. Dissimilarities also exist in analytical tools and methods used, approaches to quality control (QC), and reported limit of detection between comparable methods. Furthermore, considerable differences exist in the level of quality assurance (QA) deployed in previous studies. These dissimilarities have raised concerns on reproducibility, precision, accuracy, and sensitivity of the methods described (Koelmans et al., 2019). Therefore, it is imperative to develop and describe sample collection and analytical methods that can be broadly and universally applied for identifying and quantifying microplastics with appropriate quality assurance and quality control (QA/QC). In general, the evaluation methods should focus on characterizing microplastics in terms of morphology, size, color, type (chemical makeup), and determining mass and concentration (e.g., number of particles per liter).

The goals for microplastics evaluation can be broadly categorized as qualitative or quantitative goals. Qualitative studies are used to investigate questions for the first time. Novel research develops new techniques or approaches or perhaps adapts or improves existing techniques. In these studies, qualitative outcomes might be new areas of study, promising new sampling techniques, or refinements to existing methods. Quantitative studies are required where discrete or continuous results are compared to one another or to a threshold. Quantitative estimates require significant planning and a higher level of QA than qualitative studies. In the case of microplastics investigations, the goals of individual studies or monitoring programs must be specific to the expected use of the data, the conceptual model of the condition being tested, and the target audience.

3.1.1 Sample Collection

Approaches reported in previous studies for water and wastewater samples include manta net (a modified neuston net) with >300 µm sieve size, grab samples collected with a jar, or in-line filtration. The ASTM method (ASTM D8332-20) recommends using stacked sieves for water and wastewater sample collection. Results from recent studies have indicated that bulk sampling results in reliable and reproducible results compared to net-based methods, especially since spatial and temporal heterogeneity of microplastics can be minimized with larger sample volumes. In-line sampling is preferred when collecting large volumes, which also minimizes potential contamination with airborne microplastics. However, additional resources (labor, time, space, and money) are required when collecting large sample volumes.

The sample collection devices should be free from contamination and should be tested using equipment blanks. Flow-weighted reporting is recommended for quantitative applications in water and wastewater. Recent communication from the State Water Board noted the challenges with stacked sieves and settled on in-line sampling for upcoming drinking water monitoring.

A QA plan is needed for both qualitative and quantitative studies. Selecting the method for sampling, extraction, and analysis also depends on study goals, such as whether the study aims to be novel or must be reproducible. It is important when planning a study, in either context, to have confidence in the results from an instrument to support data interpretation; therefore, QC measures include ensuring that instruments are properly calibrated, evaluating the limit of detection, implementing strict and consistent contamination control, measuring the precision of the analytical results, and measuring the accuracy of polymer matching in both spectroscopic and spectrometric analyses.

ASTM stacked sieves are recommended for wastewater and drinking water. In-line sampling may be preferred in some cases, for example, where large volumes of water are required, and contamination may occur during a sample collection step that can last several minutes or even hours. In open water sampling, samplers may require large volumes. Sampling devices should be free from contamination and should be tested using equipment blanks. Whenever synthetic labware must be employed, selecting fabric colors (pink, for example) can help exclude fiber contamination resulting from the test itself.

3.1.2 Microplastics Characterization

Isolating microplastics by sieving or filtration and purifying through chemical pre-treatment are important first steps in characterizing microplastics. ASTM provides consistent sample preparation methods, which should be non-destructive for quantification studies. Sample preparation methods need to be evaluated with controls as described above. Removing samples from a sieve or petri dish to a slide may generate interferences in counting microplastics. For both analyses, sample preparation is critical. Some sample preparation approaches restrict the use of mass-based approaches (e.g., prepared slides are no longer relevant subsamples for mass quantitation), others of count-based approaches (e.g., particles may break leading to results that are biased high).

Raman spectroscopy, Fourier-transform infrared (FTIR) spectroscopy, and laser direct infrared (LDIR) spectroscopy are useful qualitative methods that produce particle characterization data. When coupled with microscopy, these instruments can provide morphology information such as whether a particle is considered a fiber. In situations requiring microplastics particle count data, these methods should be used only with special attention to counting precision, as any count-based analysis is expected to be highly variable (multiple recounts are required to understand in-sample variability).

Pyrolysis-gas chromatography-mass spectrometry (Py-GCMS) provides mass-based concentration of microplastics polymers per unit volume (or mass) of sample. Py-GCMS requires much less operator time compared to Raman or FTIR spectroscopy. Most mass-based approaches typically sacrifice the particles and, therefore, may not produce particle characteristics data. Preparation and analytical precision of mass-based approaches are more approachable than spectroscopic approaches (for characteristics or count). For this and other reasons, mass-based results are significantly more precise than count results making them well-suited for quantitative studies such as parameterizing the true concentration of microplastics polymers in a sample space.

In general, spectroscopy methods can quantify microplastics as small as 20 µm. The size limitation for Py-GCMS is not known. Recent studies on drinking water that used novel analytical techniques reported that microplastics as small as 1 µm could be quantified (Pivokonsky et al., 2018; Wang et al., 2020). Spectroscopy studies have shown a significant increase in particle counts with the decrease in particle size quantified, raising concerns that previous studies might have underestimated microplastics concentrations. For quantitative analysis, automated counting is advised where total counts are desired. It is possible to provide adequate precision even with manual counting, but only when using rigid replication protocols. In general, to obtain more detailed information about microplastics in water samples, a utility is expected to invest significantly more resources including sampling, analysis, and personnel (Figure 4). Currently, surrogates are not typically employed due to the limited database of resources for microplastics in treatment facilities.

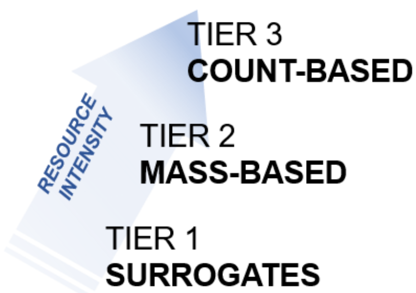

Figure 4 - Increased investment in sampling, analysis, and personnel yields more information about microplastics in water samples.

3.2 Quality Assurance and Quality Control

Sufficient QA/QC is needed for both qualitative and quantitative studies to enhance confidence in the data generated. QA/QC measures for sample collection include consistent methods, tools, and equipment used for sample collection using replicates; consistent sample preparation; negative controls, positive controls, and field blanks; and strict and consistent contamination control. QA/QC measures for sample analysis include ensuring proper equipment calibration, implementing strict and consistent contamination control, verifying equipment performance by using equipment blanks and standard checks, using reference spiked samples, verifying results by using field duplicates, and implementing measures for accurate identification of polymer type.

The Interstate Technology Regulatory Council (ITRC) summarizes QA for microplastics studies and emphasizes that study planning must be based on appropriate study questions. Data quality objectives should be prepared to ensure that selection of a method is compatible with study questions and expected data. Data quality objectives might include polymer type, microplastics size and shape, particle number or polymer mass, and should be specific to study boundaries such as place and time. For monitoring, targeted sample sizes should be defined as well as any inferential goals such as statistical analyses.

3.3 Technical Challenges

Ideal analysis of microplastics would be accurate, fast, and cost-effective, while accurately identifying and quantifying all microplastics in a sample without contamination. Mass- and count-based methods both require assessment of accuracy (e.g., fit to reference spectra and sufficiently random in the sample space). Qualitative studies rely heavily on the accuracy of the method regarding matching spectra. Automated spectral recognition through spectral linear kernel (SRK) was used, for example, to improve consistency of sample identification (Sun, 2022). Both count- and mass-based quantitative studies require measurements of precision, such as relative standard deviation (RSD) or coefficient of variation (CV) for reproducibility. Some techniques may require extended periods of analysis, complicated reporting, reproducibility, repeatability, and relevance of the data.

Another consideration with counting particles is that it is not conservative—the smaller the size of particles, the more particles that will be found, as microplastics tend to break apart in both the treatment and the laboratory environment. With visual methods, such as microscopy, some particles may look similar, further complicating analysis.

A quality management system, such as EPA's Data Quality Objectives approach, is required for any quantitative study. The DQO process is required for EPA-related sampling and is described in Interstate Technology Regulatory Council (ITRC), Standard Methods for Water and Wastewater Analysis and elsewhere. Example DQO requirements include study parameters such as problem formulation, information inputs (such as methods, study boundaries, decision rules, appropriate post-hoc data analysis, hypothesis testing, and decision acceptance criteria.

Data interpretation can be challenging. For example, if microplastics are detected in field blanks, there is no current guidance for managing that data. Environmental and human health risks are not well understood; thus, interpreting collected data without guidance or specific thresholds can be challenging. In lieu of guidance, studies should report QC procedures and precision estimates (such as the CV or RSD) between replicates. Sharing study DQOs will also greatly enhance the relevance of reported data.

4 Outlook/Vision/Opportunities/Solutions

At both workshops, the following three topics were selected for group discussion: (1) Research: industry and academia collaboration on research and funding; (2) Interaction with stakeholders, public perception, and participation; and (3) Technical challenges for utilities.

The following sections summarize discussions of these topics.

4.1 Research: Industry and Academia Collaboration and Funding

The group identified and recommended several potential collaboration and funding opportunities, including the following:

- Establishing open-access funding opportunities.
- Providing research opportunities through Ocean Protection Council proposals.
- Funding research activities through the State Water Board and Water Research Foundation (WRF).
- Developing utility-funded research opportunities for academic centers.
- Using public funding sources to collect data and establish an open data source.

The groups also recommended that the State Water Board should assess the demand for water quality research to track the state of knowledge and take appropriate actions every year.

At the federal level, National Science Foundation (NSF) and United States Environmental Protection Agency (EPA) funding opportunities were recommended as potential research resources. Providing open access to results collected through various studies would help enhance the microplastics knowledgebase and facilitate collaboration between researchers in multiple states.

4.2 Interaction with Stakeholders and Public Perception/Participation

Connectivity to Integrated Regional Water Management (IRWM) approaches were suggested by the participants to identify and implement microplastics management solutions on a regional scale. Regional forums were recommended as another approach for effective interaction among stakeholders and public participation. The groups identified the following as valuable opportunities for public participation, experience sharing, and brainstorming opportunities for collaboration:

- Roundtable discussions at the California Association of Sanitation Agencies (CASA) annual conferences.
- The California Water Environment Association (CWEA) pretreatment conference.
- Town hall meetings with TEDx style presentations.
- Comprehensive and aligned announcements and information sharing from the State Water Board, professional organizations, academia, utilities, and consultants.

- Workshops organized by professional organizations, such as Association of Clean Water Administrators (ACWA), American Water Work Association (AWWA), and California-Nevada (CA-NA) Safe Drinking Water Act (SDWA)

The groups also recommended collaborating with nongovernmental organizations and groups such as the Zero Waste group on topics such as microplastics monitoring, source control, and removal, in their goals to promote public participation and help enhance public perception.

4.3 Technical Challenges for Utilities

As there are several challenges in microplastics sampling, analysis, and data interpretation, technical challenges were included as one of the major topics for group discussion in the workshops. Utility managers may choose to conduct sampling and perhaps monitoring and analysis to ensure that treatment operations continue to meet standards for environmental protection. Sampling and, in some situations, routine monitoring is needed to identify and understand the presence, characteristics, and quantity of microplastics.

One challenge is the transfer of microplastics from one media, for example, raw wastewater samples, into another media, for example, biosolids, in the treatment processes. There is no clear understanding of ecological and health risks caused by microplastics in different matrices. Atmospheric contamination, which is more pronounced in areas near wildfires and heavily urbanized areas, poses a great challenge to ensuring representative sample collection and characterization.

There are many unanswered questions in microplastics pollution risk assessment. The pathways for introducing microplastics into the human body through food webs, ingestion, or inhalation, is poorly understood. The workshop groups highlighted the importance of assessing risk through the entire urban water cycle, including surface water, groundwater, and biosolids when assessing risks associated with recycled water.

The development of standard methods and protocols for sample collection and analysis for each matrix (e.g., water, wastewater, recycled water, soil, or biosolids) was identified as a critical effort for generating reliable data. Data extrapolation was discussed as a substantial data analysis challenge that needs to be addressed. For example, one error in the lab for one sample can be amplified if extrapolated to millions of gallons per day and generalized to represent multiple WWTPs. Also, the bandwidth required for proper sampling, even in the case of analytical work in outside laboratories, is a central question for utilities: what is reasonable to ask, in terms of cost or full-time employees? Emphasis should be placed on defining study questions and selecting compatible methods to resolve those questions.

Non-potable recycled water is often used for irrigating agricultural land, landscapes, golf courses, and parks, or to control construction dust. Despite 80 – 90% removal at a WWTP, microplastics may be present in non-potable recycled water. There are many other potential environmental sources of microplastics including atmospheric deposition. Differentiating microplastics from recycled water versus other sources is a major technical challenge but is critical to managing microplastics and other CECs in water the water supply. Estimating background concentrations (preferably by mass) is critical to understanding any potential additive effects from non-potable recycled water, treated wastewater and treatment residuals (e.g., biosolids).

Potable reuse returns water to an environmental buffer, such as a groundwater aquifer or a reservoir, or directly to a drinking water treatment plant or distribution system. In California, the advanced treatment train used for potable reuse generation must include low-pressure membranes and reverse osmosis. These membrane processes collectively reject microplastics below the smallest size of the detection limit for the current standard methods for drinking water. While purified water from these advanced treatment plants may be relatively free of microplastics, reintroduction in the environmental buffer is a potential concern. Additionally, microplastics in reverse osmosis concentrate will be subsequently discharged to the environment. Therefore, source control and minimization should consider holistic strategies rather than focusing solely on individual sample streams.

Another challenge for utilities in California is the small number of laboratories expected to obtain Environmental Laboratory Accreditation Program (ELAP) certification for microplastics analysis in drinking water, should ELAP accreditation become a requirement for future recycled water testing. It may be preferable for some utilities to prepare for in-house analytical capabilities, which will likely require the maturity of standard operating procedures for and guidance on sampling and analytical methods. ASTM also offers standard practices for collection and preparation of water and wastewater samples.

Lastly, depending on the recycled water application and associated level of treatment - such as secondary disinfected non-potable recycled water versus potable reuse applications that require advanced treatment – the sampling and analytical methods could be for either the wastewater or drinking water methods.

4.4 Source Control/Reduction

Source control was recommended by the workshop participants as the best approach for addressing potential microplastics contamination. Reduction in the production and consumption of plastic products will significantly aid microplastics source control and is the focus of much plastic pollution-related legislation. Microplastics source reduction is also germane to ensuring the quality of recycled water and the managed beneficial reuse of water and wastewater treatment residuals. As recycled water management becomes more prevalent and important in the developed water cycle, effectively maintaining water quality will only be possible through source reduction. Research into common microplastics polymers, morphologies, and other characteristics and quantities should inform source reduction policy and reduction technology.

5 Summary and Conclusions

5.1 Strategies to Prepare or Plan for Microplastics in Recycled Water

While some California drinking water utilities have already begun considerations for microplastics in their traditional supplies, both drinking water utilities and wastewater utilities that supply recycled water may want to consider strategies in preparation for potential future regulations.

- Track microplastics regulations and engage in upstream regulatory or policy development.
- Track microplastics advancements in research, occurrence, treatment technologies.
- Develop inter-utility, intra-utility, and State-level communication and coordination efforts.
- Gain understanding of the multitude and extent of sources of microplastics in the environment and the relative contribution of the wastewater sector, and by extension, the recycled water system.
- Consider participating in research related to microplastics sample collection and analysis and ensure methodologies are well suited for study goals.
- Consider identification of staffing, training, and budgetary needs for sample collection, analysis, and potential treatment upgrades that would need to be incorporated into Capital Improvement Plans in the future.

5.2 Knowledge Gaps

Participants in the workshops identified several knowledge gaps that are needed to better prepare for potential future policies and regulations that may impact recycled water systems.

- Which characteristics will be more important for data collection for recycled water systems? (For example, mass concentration, particle count, polymer type, morphologies [flakes versus fibers], color, and particle size.)
- Little is known about microplastics as vectors for other contaminants, such as PFAS or pathogens. Is it possible to remove microplastics along with other CECs like PFAS and pharmaceuticals with one treatment approach?
- Epidemiological studies on impacts on health and the environment. Little is known about public health risks; more information is needed to be able to understand and interpret microplastics data from a public health perspective.
- Policies need to be constructed based on an understanding of microplastics abundance, transport, and properties. Emphasis should be placed on understanding the relative contribution of recycled water compared to background.
- Address communications gap between academic researchers and utilities.
- Many innovative technologies tested at bench scale do not consider technical feasibility (practicality, infrastructure compatibility, cost assessment, etc.).

- A few studies tested some technically mature technologies for microplastics removal at pilot scale (e.g., AnMBR) and may require further evaluation to understand applicability.
- Regulatory controls require routine measurement with cost-effective and accurate test methods.

6 Contributors

This document is the product of group discussion and its content, in part or in full, is not attributed to the individual contributors.

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