7 DATA GAPS AND FUTURE RESEARCH NEEDS

The science surrounding MP is new and rapidly evolving. Several data gaps and future research needs were identified during the preparation of this guidance and are presented in the following subsections.

7.1 Fate and Transport Data Gaps

Several data gaps were identified related to the movement of MP through the environment.

- Almost all existing studies suggest the need for further research to understand MP in groundwater in one or more areas, such as MP types, abundance, fate and transport mechanisms, retention, and potential impact. A more comprehensive understanding of MP in groundwater would inform decisions regarding the need for MP removal and mitigation from groundwater.
- Additional research is needed to better understand the relationship between sediment characteristics and MP concentrations in different aquatic systems.
- Although there is some understanding of the degradation processes of MP, there is not yet enough information to determine what constitutes “fully degraded” MP when discussing their removal from the environment. It may be possible with further studies to determine from health and environmental effects if the harmful effects of MP could be negated or if there is even a size at which they would not cause a significant negative impact to humans or other organisms, or whether full degradation is required and would potentially consist of reduction to their constituent molecules.
- MP produced during the degradation of plastics has become an issue of increasing concern in recent years because they are more prevalent and may cause potential health risks to the ecosystem and humankind (Zhang, Wang, et al. 2021). However, the formation of MP in the environment under differing conditions is a relatively new field. Additionally, the persistence of MP in the environment is virtually unknown.
- Future research is warranted to develop comprehensive modeling tools that better predict the fate and transport of MP in the environment. Environmental factors (for example, weather, ocean currents), along with physical (shape and size of plastics/MP) and chemical (components of plastics/MP, weathering, degradation) composition, play a significant role in the transport and fate of MP. These factors impact transport mechanisms and deposition in the environment.

7.2 Future Research Needs for Sampling and Analyzing MP

MP analysis is a rapidly changing field. Instrumentation is quickly advancing as manufacturers understand and respond to the need for rapid and inexpensive detection, identification, and quantification of small carbon-based particles.

Needs in terms of sampling and analysis include:

- Standardized MP reference materials with different shapes, sizes, polymers, and morphology. These are necessary so we have universally accepted standards that can be used to quantify the accuracy of extraction and identification methods.
- Guidance for determination of acceptable blank and reference recovery ranges (understanding that different sampling regimes have different DQOs).
- Guidance/acceptance on replicate numbers and replicate variability.
- Affordable instrumentation that allows the rapid detection, identification, and quantification of MP and NP.
- Development of automated systems (for example, machine learning approaches) to decrease identification time and bias.
- Development of methods and instrumentation for NP detection. These very small particles, which may be the most numerous in our environment, are very challenging to extract and identify. Many of the methods outlined here are not effective for NP and much more work needs to be done in this area.

7.3 Data Gaps in Evaluation of Potential Health Risks

There are insufficient data to characterize health risks due to MP ingestion or inhalation at environmentally relevant concentrations.

- As described in Sections 4.5.2 and 4.6.1, the database on health effects of MP is limited to animal studies or occupational studies with extremely high concentrations of MP, and there is insufficient basis to extrapolate results to lower concentrations of MP typically found in the environment.
- Potential effects may vary due to variations in MP physical properties (size, shape, and length), microbial biofilm presence, or chemical properties (type of plastic, and presence of additives or co-contaminants). There is very limited understanding of the role of physical attributes (as opposed to chemical) on adverse impacts of MP in humans (Smith et al. 2018).
- Overall, there is not enough currently available information to assess the implications of exposure to MP from different sources on human health. In Section 4.7.1, the study by Coffin, Bouwmeester, et al. (2022) addressed data limitations and testing goals for characterizing MP in drinking water.
- The ability for various kinds and sizes of MP to accumulate in tissues or specific organs should be assessed. Potential accumulation, and translocation across different tissues in humans, are not well understood (Ribeiro et al. 2020, Smith et al. 2018). Available data suggest that there may be a potential for some of the smaller MP to enter the gastrointestinal tract and translocate to other tissues throughout a mammalian system.
- Some studies of questionable quality or human relevance suggest that uptake of MP at high concentrations may result in adverse effects on the liver or gastrointestinal tract resulting from inflammatory responses. However, the data are not yet sufficient to determine whether and how MP may be of toxicological concern to human health. Existing research results demonstrate that exposure to high concentrations of MP may be toxic to mice and are toxic to various aquatic organisms; however, more data are needed from experimental model systems that are closer to potential human exposure, and with similar human anatomy and cellular processes (Morgan and DeLouise 2020).
- As summarized by WHO (2019), key research needs include studies on the uptake and fate of MP within the mammalian system; the influence of particle size, shape, and chemical composition on uptake, distribution, and potential toxicity; potential for respiratory toxicity; and more research regarding the bioavailability and composition of chemical substances that are associated with MP.

7.4 Data Gaps in Evaluation of Trophic Transfer

- MP with different polymer types, sizes, and shapes must be assessed to determine whether they are transferred into edible tissues of organisms other than the digestive tract, such as fish fillet, and would therefore be available to humans through consumption of these organisms (Ribeiro et al. 2020). Lab experiments should be conducted to quantify exposure, accumulation, translocation, and depuration of MP, with particular interest in edible tissues. Therefore, it is important to monitor MP concentrations in seafood as consumed for risk evaluation, management, and mitigation of MP pollution (Smith et al. 2018), and to assess potential exposure through other food sources through livestock (meats and dairy) and MP uptake through crops.
- There are challenges with assessing uptake and trophic transfer. There is a likely underestimation of measured plastics in tissues due to a lack of analytical capability to measure (particularly in situ) MP and NP (which translocate at higher rates than MP). Studies often report finding single pieces of plastic in a tissue (Rochman 2015).
- Particle surface characteristics could influence ingestion, accumulation, and translocation of MP through the formation of a biological layer of molecules attached to the plastic (Galloway, Cole, and Lewis 2017), or through particle agglomeration.
- The relative importance of MP in sediments/water as vectors for pollutants to animals' tissues should be studied. Investigations should be conducted to investigate whether MP act as a sink of hydrophobic organic compounds in organisms with a high internal concentration of pollutants.

7.5 Data Gaps on Ecological Exposures and Effects

As discussed in Section 4.6.2, further research is needed to identify drivers of toxicity and resulting effects.

- Bucci and Rochman (2022) proposed future work to strengthen understanding of MP toxicity. They proposed conducting testing to further evaluate the particle dimensions (size, shape, polymer, and sorbed environmental contaminants) by testing one dimension at a time while holding the other dimensions constant, evaluating how biofilm can increase the ingestion rate of particles, investigating multiple stressors by evaluating the effects of multiple dimensions together, and assessing how environmental conditions such as pH and temperature can affect toxicity.

- Another data gap is the difference in weathered particles vs. nonweathered particles. Tests might be conducted using weathered manufactured particles or testing extracts from samples collected from effluents, sediments, or water. Many toxicity studies use virgin MP that have not been exposed to weathering, which could affect toxicity. As noted by Coffin, Bouwmeester, et al. (2022), many existing studies are limited to PS spheres, and therefore it would be beneficial to conduct toxicity testing using different polymer types and shapes.
- Standardized toxicity testing and quality assurance/quality control protocols specific to MP would increase consistency and replicability across testing and provide higher quality data.
- A standardized format for analytical results is also needed, as some research data present results in a particle count (that is, number of MP particles per volume of water) versus chemical composition (that is, grams or milligrams).

7.6 Future Research Needs for Mitigating, Abating, and Managing MP

The following research needs are related to mitigation, abatement, and best management practices for MP:

- Further studies are required to develop cost-effective alternatives for plastics and environmentally friendly and economically sound plastic waste valorization methods.
- Although some countries have implemented legislation to reduce plastic consumption and enhance the reuse of plastics, advocating these approaches for all types of plastics is challenging. Moreover, the ability to formulate these policies depends on geographic region and socioeconomic status. Therefore, stringent environmental regulations and the development of appropriate infrastructure and economically sound, environmentally sustainable, and socially acceptable plastic waste management strategies are critical to reduce the threat of MP in the environment.
- There is a need to continue to develop and demonstrate efficacy of innovative and in situ technologies to remediate MP in the environment in all media.
- Better stormwater management systems must be developed to minimize/reduce the amount of plastics entering surface water bodies.
- The incorporation of tertiary treatment in WWTPs and the adoption of membrane filtration in DWTPs, as well as the appropriate selection of coagulants and optimization of water treatment, have been found to further increase the efficiency of MP removal. However, it has not been possible to eliminate MP from the final discharges of water treatment plants and the MP removed in water treatment plants are often returned to the environment through biosolids, disposed membranes, and reject streams containing filtration concentrate. By targeting MP removal from these water treatment wastes, MP can be gradually removed from the environment. No unit processes have been tested at WWTPs specifically for the removal of MP and NP because these technologies are still in the laboratory-scale or preliminary-scale research phase.
- Currently, MP and NP in WWTPs are seen as emerging pollutants; however, studies have depicted particles as a vector in accumulating and transferring various pollutants from the water environment. MP and NP may provide selective adsorption of pollutants through numerous binding mechanisms that have not been well studied. The use, or reuse, of MP- and NP-based adsorbents in WWTPs needs further investigation.
- The applicability of a specific remediation technique to different types of plastics should be tested and documented. Different polymers have demonstrated different resistances to natural degradation. Knowing the feasibility of a specific technique to different plastics is conducive to rational design, improvement, and application of the system.