Joint Meeting of the RMP Microplastic Workgroup and OPC Microplastic Stakeholders

Wednesday, April 21, 2021
9:00 AM – 3:00 PM
Join Zoom Meeting
https://zoom.us/j/96624872829
Meeting ID: 966 2487 2829

Call-in details:
+1 669 900 6833 US (San Jose)
+1 301 715 8592 US (Washington DC)
+1 312 626 6799 US (Chicago)
Find your local number: https://zoom.us/u/aehtcwIhhA

AGENDA

| 1. | Introductions and Goals for This Meeting (Attachment) | 9:00 |
|    | The goals for this joint RMP/OPC meeting: | Melissa Foley (15 minutes) |
|    | ● Receive OPC experts and stakeholder feedback on the Ocean Protection Council project: **Sources and pathways of microplastics in urban stormwater in California** | |
|    | ● Obtain RMP advisor and RMP stakeholder feedback on future direction of the program | |
|    | ● Obtain recommendations from RMP advisor and RMP stakeholders on RMP special study proposals for 2022 | |
|    | Meeting materials: 2020 RMP MPWG Summary, pages 6 - 13 | |
2. **RMP Item**  
**Discussion: Tire Wear Stormwater Conceptual Model Update**  
The RMP funded development of a microplastics stormwater conceptual model, and the first phase of this conceptual model has been focused on tires. Our literature review identified a few data gaps important for monitoring data interpretation, future RMP monitoring project design, and potentially for agency management decisions.

Desired outcome: Informed workgroup; Feedback from advisor, RMP stakeholders, experts, and broader stakeholder group to guide further work

Meeting Materials: Rubber Conceptual Model Diagram and Mitigation Option Diagram, pages 14 - 15

<table>
<thead>
<tr>
<th>Time</th>
<th>Presenter(s)</th>
<th>Duration</th>
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<tbody>
<tr>
<td>9:15</td>
<td>Kelly Moran</td>
<td>30 minutes</td>
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3. **RMP Item**  
**Information: Tire Wear Debris Collection to Mitigate Pollution**  
Tyre Collective has developed technology to collect tire wear at the point of generation. The technology provides a method to collect tire-wear debris to mitigate emissions. This technology can also be used to collect particles for further characterization and analysis to address microplastic research needs.

Desired outcome: Informed workgroup

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<tr>
<th>Time</th>
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<tbody>
<tr>
<td>9:45</td>
<td>Siobhan Anderson</td>
<td>15 minutes</td>
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4. **OPC Item**  
**Discussion: California Urban Stormwater Conceptual Model, Part 1**  
The OPC funded SFEI to build a conceptual model that synthesizes our current understanding of microplastic sources and pathways to urban stormwater. The goals of this study is to inform research and management recommendations. Draft conceptual models of cigarette filters and fibers will be presented.

Desired outcome: Feedback from advisors, experts, and stakeholders to guide further work

Meeting materials: Cigarette Butts Urban Stormwater Conceptual Model Diagram and text explanation, pages 16 - 20; Fibers Urban Stormwater Conceptual Model Diagram and text explanation, pages 21 - 34

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<thead>
<tr>
<th>Time</th>
<th>Presenter(s)</th>
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<tr>
<td>10:00</td>
<td>Diana Lin Ezra Miller Kelly Moran</td>
<td>50 minutes</td>
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<td></td>
<td></td>
<td>Presentation: 25 min Discussion: 25 min</td>
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5. **Break**  
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<th>Time</th>
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<tr>
<td>10:50</td>
<td>15 minutes</td>
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| 5. | **OPC Item**  
Discussion: California Stormwater Conceptual Model, Part 2  
Draft conceptual model for single-use plastic foodware will be presented.  
Desired outcome: Feedback from advisor, experts, and stakeholders to guide further work  
Meeting materials: Single-Use Plastic Foodware Urban Stormwater Conceptual Model and text explanation, see pages 35 - 47 | 11:05  
Miguel Mendez  
Shelly Moore  
(35 minutes)  
Presentation: 15 min  
Discussion: 20 min |
|---|---|---|
| 6. | **OPC Item**  
Summary: OPC Project Discussion Wrap-up and Next Steps  
Desired outcome: Informed experts and stakeholders on timeline for providing additional comments for OPC report. | 11:40  
Diana Lin  
(5 min) |
| **Lunch Break** | | 11:45  
(60 min) |
| 6. | **RMP Item**  
Information: Update on Ecological Health Effects of Microplastics in Water: Characterizing Current Knowledge and Identifying Research Priorities  
The RMP provided funding to support synthesizing current knowledge about the human and aquatic organism health effects of microplastics in water, identify relevant risk thresholds, and suggest next steps. The webinar series and ongoing workshop is led by SCCWRP and the University of Toronto in coordination with the California Water Resources Control Board and the California Ocean Protection Council. An update on findings from the workshop will be provided.  
Desired Outcome: Informed RMP and broader stakeholder group about ongoing work | 12:45  
Susanne Brander  
(25 minutes)  
Presentation: 15 min  
Discussion: 10 min |
| 7. | **RMP Item**  
Information: Microplastic Risk Assessment for San Francisco Bay  
RMP Microplastic Strategy funding has supported collaboration with Western Washington University researchers to develop a microplastic risk assessment for San Francisco Bay using a Bayesian network relative risk model, which is separately funded through a National Science Foundation grant. The workgroup will review the modeling framework and quantitative results.  
Desired Outcome: Informed RMP stakeholders about risk assessment and data needs. Feedback from RMP stakeholders on priority end points. | 1:10  
Emma Sharpe  
(20 minutes)  
Presentation: 10 min  
Discussion: 10 min |
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<thead>
<tr>
<th></th>
<th>RMP Item</th>
<th>Discussion: Microplastic Workgroup Multi-Year Plan and Future Work</th>
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<tbody>
<tr>
<td>8.</td>
<td>Review of RMP and related activities in Multi-Year Plan</td>
<td>Discuss future direction of the focus area, identifying information needs for stakeholders</td>
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<td></td>
<td>Desired Outcome: Feedback from advisor and RMP stakeholders to guide future work</td>
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<tr>
<td></td>
<td>Meeting materials: MPWG Multi-Year Plan, pages 48 - 49</td>
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<tr>
<th></th>
<th>RMP Item</th>
<th>Discussion: RMP Microplastic Proposals for 2022</th>
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<td>9.</td>
<td>Special study proposals for 2022 will be presented. The workgroup will ask questions, discuss the management needs, and provide feedback.</td>
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<td>2022 Special Study Proposals include:</td>
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<td>RMP Tires Strategy</td>
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<td>Tire Particle/Contaminant Fate and Transport</td>
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<td>Desired outcome: Feedback from advisor and RMP stakeholders on the merits of each proposal and how they can be improved</td>
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<tr>
<td></td>
<td>Meeting materials: MPWG Special Study Proposals, pages 50 - 71</td>
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<tr>
<th></th>
<th>RMP Item</th>
<th>Closed Session - Decision: Recommendations for RMP 2022 Special Studies Funding</th>
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<td>10.</td>
<td>RMP Special Studies are identified and funded through a three-step process. Workgroups recommend studies for funding to the Technical Review Committee (TRC). The TRC weighs input from all the workgroups and then recommends a slate of studies to the Steering Committee (SC). The SC makes the final funding decision.</td>
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<td>For this agenda item, the MPWG is expected to decide (by consensus) on a prioritized list of which studies to recommend to the TRC. To avoid an actual or perceived conflict of interest, the Principal Investigators for proposed special studies leave the room during this agenda item.</td>
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<td>Desired Outcome: Recommendations from MPWG advisor and RMP stakeholders to the TRC regarding which special studies should be funded in 2022 and their order of priority.</td>
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<th></th>
<th>1:30</th>
<th>Diana Lin (30 minutes)</th>
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<td>8.</td>
<td>1:30</td>
<td>Diana Lin (30 minutes)</td>
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<td>9.</td>
<td>2:00</td>
<td>Kelly Moran (30 minutes)</td>
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<td>10.</td>
<td>2:30</td>
<td>Eric Dunlavey (30 minutes)</td>
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<td>Action Description</td>
<td>Time</td>
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<td>11.</td>
<td>Report out on Recommendations</td>
<td>3:00</td>
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<td></td>
<td>Eric Dunlavey (10 minutes)</td>
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<td></td>
<td>Adjourn</td>
<td>3:10</td>
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RMP Microplastic Workgroup Meeting

April 9th, 2020 (remotely held meeting)

Meeting Summary

<table>
<thead>
<tr>
<th>Advisors</th>
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<tbody>
<tr>
<td>Name</td>
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<tr>
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<tr>
<td>Chelsea Rochman</td>
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<tr>
<td>Anna-Marie Cook</td>
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Attendees:

- Adam Wong (SFEI)
- Alexander Black (Virginia Wellington Cabot Foundation)
- Alicia Gilbreath (SFEI)
- Alvina Mehinto (SCCWRP)
- Anne Hsnsen Balis (City of San Jose)
- Artem Dyachenko (EBMUD)
- Ashley LaBass (Bay Planning Coalition)
- Autumn Cleave (SFPUC)
- Barbara Baginska (SFB RWQCB)
- Bryan Frueh (City of San Jose)
- Carolynn Box (5 Gyres)
- Charles Wong (SCCWRP)
- Chris Sommers (BASMAA)
- Cole Burchiel (SF Baykeeper)
- Dane Hardin (Applied Marine Sciences)
- Diana Lin (SFEI)
- Don Yee (SFEI)
- Dawit Tadesse (SWRCB)
- Eric Hansen (Silicon Valley Clean Water)
- Emma Sharpe (Western Washington University)
- Eric Dunlavey (City of San Jose)
- Erika Senyk (Applied Marine Sciences)
- Ezra Miller (SFEI)
- Farid Ramezanzadeh (Hayward)
- Holly Wyer (Ocean Protection Council)
- Jay Davis (SFEI)
- Jaylyn Babitch (San Jose)
- Jeremy Conkle (Texas A&M University Corpus Christi)
- Karin North (City of Palo Alto)
- Kelly Moran (TDC Environmental)

- Kevin Messner (Association of Home Appliance Manufacturers)
- Leah Thornton Hampton (SCCWRP)
- Lester McKee (SFEI)
- Lisa Domotrovitch (SFEI)
- Lorien Fono (BACWA)
- Luisa Valiela (EPA)
- Margaret McCauley (EPA)
- Mary Lou Esparza (CCCSD)
- Maureen Dunn (Chevron)
- Melissa Foley (SFEI)
- Miguel Mendez (SFEI)
- Miriam Diamond (University of Toronto)
- Molly Martin (EPA)
- Nina Buzby (SFEI)
- Rebecca Sutton (SFEI)
- Robert Wilson (City of Petaluma)
- Samantha Harper (SFB RWQCB)
- Scott Coffin (SWRCB)
- Shelly Moore (SCCWRP)
- Shelly Walther (LA County Sanitary District)
- Sherry Lippiat (NOAA)
- Simona Balan (DTSC)
- Simret Yigzaw (City of San Jose)
- Stephanie Hughes (Shell)
- Stephanie Karba (Patagonia)
- Steve Weissberg (SCCWRP)
- Sutapa Ghosal (CDPH)
- Tony Hale (SFEI)
- Tony Luz (Integral Consulting)
- Violet Renich (Orange County Sanitation)
- Wayne Landis (Western Washington University)
1. Introductions and Goals for This Meeting
Melissa Foley began the meeting by conveying a few remote meeting tips and reviewing some of the Zoom platform functionalities. Melissa then reviewed the day’s agenda and introduced the Workgroup’s advisors and invited guests. After a brief roll call, Melissa then gave an overview of the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP), outlining the program objectives and budget allocations related to special studies.

Melissa also communicated the goals for the day, highlighting the role of advisors and stakeholders in providing input on special study proposals, multi-year planning, and the microplastic conceptual model.

2. Discussion: Microplastic Strategy and Collaborations Update
Diana Lin introduced the item by reviewing the past efforts of the Workgroup, in particular the findings and deliverables from the 3-year study supported by the Moore Foundation. She then presented changes to the WG’s multi-year plan (MYP) for the coming year (2021) based on the special study proposals that would be presented in the afternoon; noting that the long-term discussion of the MYP could be held later when there is more clarity on the future of the MPWG.

Going into more detail on outside-RMP work, Diana outlined SFEI’s involvement in efforts to develop a risk assessment framework for microplastics. The Ocean Protection Council is convening a science advisory team (SAT) working group to develop a risk assessment framework for microplastic to inform the OPC’s microplastic strategy. Diana is involved as an external advisor to the SAT working group.

Diana is also working on an upcoming collaboration with Dr. Wayne Landis from Western Washington University (WWU) to develop a microplastic risk assessment. The goal of the collaboration is to generate a San Francisco Bay risk assessment case study using the SF Bay monitoring data with the results from a recently funded NSF grant to Oregon State University (OSU; Principal Investigators Stacey Harper, Susanne Brander, Chris Langdon, Matt Hawkyard) on the toxicity and fate of microplastics. The purpose of the study is to build a structure for understanding the risk probabilities for microplastics, identify the key uncertainties, inform decision makers, and generate peer-reviewed publications. The NSF project will be supporting the team at OSU and WWU, and Diana Lin will be supported by Microplastic Strategy funds. The research will be presented at scientific conferences and published in peer-reviewed journals.

Meeting participants commented that looking for opportunities to leverage larger external efforts is a common and important aspect of effectively utilizing RMP resources. In particular, workgroup members mentioned the importance of outside collaboration related to the need to better understand ecotoxicalogical effects of microplastics.
Meeting participants then provided input on the future of MPWG within the RMP, expressing both support for the work of the MPWG and concern for the RMP’s ability to continue funding the MPWG. Concern stemmed from both the lack of current management applications and the amount of work needed to better understand effects. The MPWG, however, provides a unique regional and pollutant-focused approach that is advantageous to state agencies. Melissa encouraged meeting attendees to reach out to herself and/or Diana with additional comments on the value of the MPWG.

3. Discussion: State Water Board Definition of Microplastics in Drinking Water

Scott Coffin from the State Water Board presented the proposed definition of microplastics in drinking water that was developed as required by Senate Bill 1422. Because of the lack of consensus in existing definitions and diversity in microplastics as a contaminant suite, the State Board developed a definition that follows a categorization framework. Categorizing by state, substance, and size the State Board definition closely follows the European Chemicals Agency’s (ECHA) most recent version of defining microplastics but omits exceptions for biodegradable plastics.

After fully outlining the proposed categorization, Scott noted the opportunity for public comment until April 24th and provided his contact information to anyone with further questions. Meeting participants utilized the Zoom platform chat function to ask a few technical questions and to get more information on how to provide comments on the proposed definition.

4. Information: Stormwater Conceptual Model

Alicia Gilbreath presented on the current status of the stormwater conceptual model development, a special study funded from the previous year’s workgroup meeting. The focus of the conceptual model work was on rubber pieces resulting from tire-wear because they made up the majority of fragments found in Bay Area stormwater samples. Additionally, there is evidence that suggests aqueous leachate from tires may induce acute toxicity to coho salmon.

Alicia conveyed some of the data gaps identified so far, including density data on tire/road wear particles (TRWP), information on tire-derived product usages, and annual distance/area traveled by vehicle type. She posed a few questions to the workgroup members asking for input on any missing aspects and data gap priorities. Meeting participants mentioned a lack of attention to agriculture and interest in synthetic turf usage as potential sources. Additionally the group asked about the timeline for this work, which Alicia and Diana noted would be dependent on whether a second year of funding is approved.
5. Information: The Ecological Impacts of Microplastics in the Environment

Dr. Chelsea Rochman presented data from a literature review and meta-analysis on ecological impacts of macro- and micro-plastics published by her research group recently. The review systematically categorizes reviewed studies based on level of biological organization (e.g., molecules, cell, organ, organism, population, assemblage) and size class of microplastics measured. Findings from the review showed that in recent years the amount of studies detecting an impact is equal to those that did not detect an effect, indicating the complexity of microplastics. Several factors in the study design influence whether an effect from microplastics was measured, including microplastic dose, shape, type, and size, and organism taxa studied, and experimental design.

The review makes a call for more ecologically and environmentally relevant studies, through the use of field studies, and use of environmentally relevant concentrations and sizes. Another identified gap was effects on freshwater organisms; however, Chelsea noted current work on this subject in collaboration with Dr. Miriam Diamond (also of University of Toronto). Wayne Landis commented on the lack of studies on dose response to microplastics and lack of transparency in how studies develop toxicity thresholds which are needed to inform a microplastic risk assessment.

6. Discussion: Microplastic Proposals for 2021

Diana Lin briefly outlined each of the proposed studies to the members of the workgroup, noting the motivation for each study along with the associated budgets and deliverables. After explaining each proposal, meeting participants were given a chance to ask questions and discuss topics with proposal authors prior to the closed session.

The majority of the conversation on the ecotoxicological effects workshop proposal centered on the collaboration with SCCRWP, timing of the effort, and resulting products. Kelly Moran also noted the importance of including exposure routes besides ingestion, such as uptake through the skin or gills of chemicals that leach out of microplastics. When discussing the budget, meeting participants noted the large fraction of funds intended for developing a manuscript. Holly Wyer noted that the workshop would help directly inform the state microplastic strategy being developed by the OPC, highlighting the benefit in having both northern and southern regions of the state represented and the greater applicability of a technical report compared to a journal publication.

Presentation of the stormwater conceptual model proposal did not elicit many questions because it would cover the second year of funding. Barbara Baginska of the Water Board noted that managers would value any findings that inform sample and analysis methods included in final deliverables. There were also no questions resulting from Diana’s presentation proposing the analysis of microplastic in archived sport fish tissue. This study was proposed but not fully
funded at the 2019 MPWG meeting (although sample collection was funded), so the updates mostly provided more details on the number of fish available and associated analytical costs.

After outlining the proposed sediment core study, meeting participants posed a number of technical questions related to methodology and the possible density bias in fragments found in sediment compared to the water column. Chelsea Rochman expressed the value in adding core dating to the study to provide more details on trends. Diana clarified that any engagement with additional outside efforts, such as the risk assessment collaboration with Western Washington University, would be covered by the workgroup’s strategy budget.

7. Closed Session - Decision: Recommendations for 2021 Special Studies Funding

Because Chelsea Rochman would benefit financially from the microplastic in sport fish proposal (as the contract lab), she normally would not participate in the closed session discussions. However, to utilize her expertise, the workgroup members discussed the other three proposals with Chelsea present and had her rank proposals prior to leaving. A Zoom poll was used by the participants to help with ranking proposals given the remote meeting platform. The result of the discussions are shown in the following prioritization table.

<table>
<thead>
<tr>
<th>Study Name</th>
<th>Budget</th>
<th>Modified Budget</th>
<th>Priority</th>
<th>Comments</th>
<th>Worthwhile Study (Y,N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecotoxicological Workshop</td>
<td>$35,950</td>
<td>$18,000</td>
<td>1</td>
<td>only fund workshop and report, reduce manuscript writing budget; important to identify gaps and next steps</td>
<td>Y</td>
</tr>
<tr>
<td>Stormwater Conceptual Model (Year 2)</td>
<td>$30,000</td>
<td>$30,000</td>
<td>3</td>
<td>want to inform modeling and monitoring - would a conceptual model focused on fibers help us with that? broaden fibers beyond stormwater? add tire dust to tire model?</td>
<td>Y</td>
</tr>
<tr>
<td>Microplastic in South Bay Sediment Cores</td>
<td>$50,475</td>
<td>$50,475</td>
<td>4</td>
<td>method development important before proceeding, but methods do exist; trends important for particle types (e.g., tires, current use); baseline for monitoring important; helpful to track source reductions/mitigations on land; adding dating would</td>
<td>Y</td>
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</table>
add a lot to this study; would archiving (freezing) be a possibility?

| Microplastic in Sport Fish | $50,775–92,775 | $51,000 | 2 | better to drop stations than replicates within stations; important to know if it is getting into fish that people eat; difficult to correlate plastic in stomachs with contaminants in tissue that is eaten | Y |
About the RMP

RMP ORIGIN AND PURPOSE

In 1992 the San Francisco Bay Regional Water Board passed Resolution No. 92-043 directing the Executive Officer to send a letter to regulated dischargers requiring them to implement a regional multi-media pollutant monitoring program for water quality (RMP) in San Francisco Bay. The Water Board’s regulatory authority to require such a program comes from California Water Code Sections 13267, 13383, 13268 and 13385. The Water Board offered to suspend some effluent and local receiving water monitoring requirements for individual discharges to provide cost savings to implement baseline portions of the RMP, although they recognized that additional resources would be necessary. The Resolution also included a provision that the requirement for a RMP be included in discharger permits. The RMP began in 1993, and over ensuing years has been a successful and effective partnership of regulatory agencies and the regulated community.

The goal of the RMP is to collect data and communicate information about water quality in San Francisco Bay in support of management decisions.

This goal is achieved through a cooperative effort of a wide range of regulators, dischargers, scientists, and environmental advocates. This collaboration has fostered the development of a multifaceted, sophisticated, and efficient program that has demonstrated the capacity for considerable adaptation in response to changing management priorities and advances in scientific understanding.

RMP PLANNING

This collaboration and adaptation is achieved through the participation of stakeholders and scientists in frequent committee and workgroup meetings (see Organizational Chart, next page).

The annual planning cycle begins with a workshop in October in which the Steering Committee articulates general priorities among the information needs on water quality topics of concern. In the second quarter of the following year the workgroups and strategy teams forward recommendations for study plans to the Technical Review Committee (TRC). At their June meeting, the TRC combines all of this input into a study plan for the following year that is submitted to the Steering Committee. The Steering Committee then considers this recommendation and makes the final decision on the annual workplan.

In order to fulfill the overarching goal of the RMP, the Program has to be forward-thinking and anticipate what decisions are on the horizon, so that when their time comes, the scientific knowledge needed to inform the decisions is at hand. Consequently, each of the workgroups and teams develops five-year plans for studies to address the highest priority management questions for their subject area. Collectively, the efforts of all these groups represent a substantial body of deliberation and planning.

PURPOSE OF THIS DOCUMENT

The purpose of this document is to summarize the key discussion points and outcomes of a workgroup meeting.
Governance Structure for the Regional Monitoring Program for Water Quality in San Francisco Bay

**Steering Committee**

The Steering Committee consists of representatives from discharge groups, water agencies, and federal, state, and local regulatory agencies. The Steering Committee determines the overall budget and allocation of program funds, sets program goals and objectives, and provides direction to the Program from a manager's perspective.

**Technical Review Committee**

- **San Francisco Bay Nutrient Management Strategy Committee**
- **Nutrient Technical Workgroup**

**Workgroups** report to the TEC and address the main technical subject areas covered by the RMP. The Nutrient Technical Workgroup was established as part of the committees tasked with developing a separate Nutrient Management Strategy that makes recommendations to the RMP committees on the use of the RMP funds that support nutrient studies. The workgroups consist of regional and federal staff and scientists recognized as authorities in the field. The workgroups directly guide planning and implementation of special studies.

**RMP Strategic Teams**

- **Small Estuary Planning Strategy Team**
- **IoB Strategy Team**
- **Fishing Strategy Team**

*Currently inactive*
Rubber Stormwater Conceptual Model – Draft

Identifies sources & pathways for tire particles/contaminants to reach the Bay

Tires

- Tire-derived products: Synthetic turf infill; landscape mulch; construction materials; [rubberized asphalt?]; facilities generating & storing these materials
- Non-tire rubber: Shoes, outdoor rubberized paints, rubber-containing outdoor walking surfaces

Air

- Wear and resuspension

Deposition

Pavement*

Impervious Surfaces

Rubber Particles

Wear / decomposition

Pervious Surfaces

Land

Remove street sweeping

Removal

Waste Management

Stormwater runoff

Storm Drains

Urban Waterways

Water

Bay

Leave watershed

*Rubberized asphalt does not contain whole rubber particles.
Theoretical Tire Particle/Contaminant Mitigation Options

Prevention

- Remove toxic ingredients
  - Product reformulation - DTSC Safer Consumer Products Regulations
  - Voluntary tire ingredient review systems (e.g., Green Screen)
  - Voluntary Product Ingredient Controls (OE only) - IMDS/GADSL
  - Eliminate tires/wheels (e.g., hovercraft vehicles)

- Reduce wear debris formation
  - Reduced tire abrasion (wear) rate standard (EU option)
  - Airless tires
  - Tire pressure monitors on vehicles
  - Modify road surfaces to reduce wear
  - Change driver behavior
  - VMT reduction

- Reduce wear debris emissions
  - Install wear debris collection systems on vehicles

- Collect (portion of) wear debris
  - Street sweeping
  - Porous pavement (without recycled tires?)

- Remove wear debris/tire contaminants from runoff
  - Bioretention runoff treatment
  - Runoff infiltration (if determined to be safe)

Remediation

Key:
- Tire Manufacturer Action
- Vehicle Manufacturer Action
- Government Action
- Population-wide Actions
Cigarette Butts

Environmental deterioration (may occur in any compartment)

Cellulose Acetate Fibers

Small fraction may also be from other textiles

Land

Impervious Surfaces → Pervious Surfaces

Storm Drains

Urban Waterways

GSI & trash collectors

Waste Management

Incineration, Landfill

Butt Recycling Projects (e.g., concrete, plastic pellets)

Removal

- street sweeping
- trash clean-ups

smokers’ litter & fiber release

Garbage and ash catchers

Spills

Stormwater runoff

Cigarette Butts Stormwater Conceptual Model - DRAFT
The purpose of this conceptual model is to synthesize and integrate our understanding of the sources and pathways of cigarette butts and associated fiber degradates entering urban stormwater and the environment. This document uses the word “fibers” instead of “microfibers” to avoid inconsistency with the terminology used by some members of the textiles industry. Cigarette butts, fibers, and associated contaminants pose toxicological risk to wildlife species. Cigarette butt leachate contains many toxic contaminants, including heavy metals, and can be acutely toxic to aquatic life (Lee and Lee, 2015; Montalvão et al., 2019; Slaughter et al., 2011). Fibers from cigarette butt filters have received little toxicological study, but may also be a concern, as studies on other types of microplastics frequently report toxic effects (Bucci et al., 2020; Jacob et al., 2020). The conceptual model is meant to inform future research and management recommendations for managing microplastic pollution.

Cigarette butts are one of the most commonly littered items, despite public campaigns against butt litter and municipal ordinances to curb smoking in public spaces. Cigarette butts are the most frequent form of litter found on beaches (Bergmann et al., 2015). Because they seem like they are made of organic materials and should be readily biodegradable, the public still misunderstands their toxicity and persistence (Allen et al., 2017). Butt littering behaviour appears to be the norm among smokers in urban settings, with a clear majority of observed smokers littering their cigarette butts even when bins are readily available (Patel et al., 2013). Out of the approximately 6 trillion cigarettes smoked per year worldwide, 4.5 trillion are littered in the environment (Araújo and Costa, 2019).

The majority of cigarette filters (~90%) are made of cellulose acetate fibers (Abdul Kadir and Sarani, 2015). A single filter is composed of >12,000 fibers of cellulose acetate, and filters fragment and release fibers when released to the environment (Belzagui et al., 2020). Cellulose acetate can be produced with a range of degrees of substitution (how acetylated the cellulose is), depending on the desired properties. The 2.45 substitution of cellulose acetate used in cigarette filters is persistent in the environment. It is not readily biodegraded by organisms that utilize cellulase enzymes due to its additional acetyl groups that require esterases to break down, and it has limited photo degradability in sunlight (Puls et al., 2011; Yadav and Hakkarainen, 2020). Mechanical forces such as being stepped on or driven over can help cigarette butts break down. Even without mechanical means, littered cigarette butts initially decompose fairly quickly, losing about 15% of their mass within the first 30 days, but decompose slowly after that time, with rates depending on environmental factors such as nitrogen availability and microbiome composition (Bonanomi et al., 2020). Without mechanical disturbance or soil, cigarette butts show only minor chemical and morphological changes after several years, while over grassland soil, cigarette butts may be more quickly transformed after de-acetylation.

Due to their ubiquity, cigarette butts are likely the main source of cellulose acetate fibers entering the environment. However, cellulose acetate is not only used in cigarette filters; it also has been and continues to be used in other textile applications such as in diapers, medical gauze, ribbons, apparel linings, and home furnishings, often blended with other fiber materials (Law, 2004). Therefore, the use and improper disposal of these types of textiles may also be a source of cellulose acetate fibers entering the environment.
Cigarette butts are frequently littered onto impervious surfaces such as pavement, where they may be more likely to be subjected to mechanical breakdown forces. Smokers also frequently step on butts to extinguish them, hastening mechanical breakdown. In the San Francisco Bay area, cigarette butts are a frequent litter item in school parking lots (Mock and Hendlin, 2019). Street sweeping may remove cigarette butts and some cellulose acetate fibers, as street sweeping can efficiently remove particles above ~125 μm in size (Selbig and Bannerman, 2007). However, both butts and fibers may be blown or washed off impervious surfaces prior to street sweeping. The ubiquity of cigarette butts found in trash collection surveys conducted on urban roadsides (Moriwaki et al., 2009) and beaches (Allen et al., 2017; Novotny et al., 2009) indicate street sweeping is not a sufficient removal mechanism. Stormwater runoff can transport cigarette butts and cellulose acetate fibers from land into creeks and the ocean.

The distribution of cigarette butt waste in the urban environment is linked to patterns of cigarette sales and consumption (Marah and Novotny, 2011). Stormwater outlets in industrial and mixed commercial/residential areas have been observed to have higher cigarette butt loads than those in residential areas (Weideman et al., 2020). Greened areas also often form sinks for cigarette butts, due to stormwater and wind, as well as from smokers disposing of their butts in clandestine ways in areas "off the beaten [impervious] path" because of negative stigma associated with smoking.

Once in the environment, cigarette butts may be consumed by aquatic animals such as turtles (Macedo et al., 2011), and terrestrial animals such as dogs and cats (Novotny et al., 2011) before they have the chance to degrade. Cellulose acetate fibers may also be ingested by a variety of aquatic animals (Miller et al., 2019; Sutton et al., 2019; Wright et al., 2015). If not consumed, cellulose acetate fibers may be entrapped in sediment or be transported to the open ocean (Sutton et al., 2019).

To combat the problem of cigarette waste, new solutions are being developed for recycling cigarette butts, such as using them as a fiber modifier in concrete (Rahman et al., 2020). Companies such as TerraCycle are also developing ways to recycle cigarette butts into plastic pellets for re-use in other plastic products (Lohan, 2019). Depending on their use and disposal, the products produced from these recycling efforts may also eventually become a source of cellulose acetate entering the environment.

References


**Indoor Fibers**
Indoor fiber-containing goods (e.g., Clothing and other textiles, fiberfill)

**Outdoor Fibers**
Outdoor fiber-containing goods (e.g., carpet, artificial turf, tarps)

**Clothing**
Clothing (when worn outdoors)

**Outdoor industrial fibers**
(e.g., geotextiles, architectural fabric, cordage, packaging; wear from vehicle parts; cutting, decay and demolition of fiber-containing building materials)

**Litter**
(macroplastics, medical masks, losses in waste collection; encampments)

**Waste Management**
(in California)

**Environmental Compartment**

**Key**
- Likely minor pathway
- Likely major pathway

**Fibers Stormwater Conceptual Model - DRAFT**
Text Explanation for Fibers Urban Stormwater Conceptual Model

Background

Fibers from human-created items appear in virtually every environment on Earth. Fibers occur in water and sediment in rivers, estuaries, beaches, and coastal oceans receiving urban runoff and municipal wastewater discharges (Sutton et al. 2019; Browne et al. 2011). Fibers also appear in the open ocean (Barrows et al. 2018), arctic (Athey et al. 2020), deep ocean trenches (Jamieson et al. 2019), and remote mountain wilderness (Brahney et al. 2020; Allen et al. 2019; Napper et al. 2020).

Fibers have a long, narrow thread-like shape, significantly longer in one dimension than in the other two dimensions. Human-made or human-modified polymer fibers < 5 mm in their long dimension would be considered microplastics according to the California definition of microplastics developed for drinking water (California State Water Resources Control Board Resolution 2020-0021). The European Chemicals Agency (ECHA) has proposed to include longer fibers (up to 15 mm) in its microplastics definition (ECHA 2019). Both definitions exclude fibers from unmodified (except by hydrolysis) natural fibers (e.g., unprocessed wool fibers), but include chemically modified natural fibers, like dyed cotton, wool, and rayon (with > 1% synthetic polymer content) because their toxicological properties are likely altered (Hartmann et al. 2019; Coffin 2020). This document uses the word “fibers” instead of “microfibers” to avoid inconsistency with the terminology used by some members of the textiles industry.

Most of California has municipal storm drain systems that are fully separated from municipal wastewater collection systems. Municipal wastewater collection systems flow to municipal wastewater treatment plants that discharge directly to surface water (and not into urban runoff). Except in unusual circumstances (e.g., sewer line overflows), clothing washing and municipal wastewater are not sources of fibers in California urban runoff. This drainage design (which is common in the western USA) stands in contrast to Europe and Asia, where much microplastics research has been conducted in urban watersheds served by combined sewer systems that receive and treat both indoor wastewater and urban runoff.

Investigations of urban stormwater runoff in the San Francisco Bay region found urban runoff microparticle concentrations (1-30 microparticles/L, mean 9) to be significantly higher than wastewater microparticle concentrations (0.008-0.2 microparticles/L, mean 0.06) (Sutton et al. 2019). The study went further to extrapolate loadings from these two pathways from simple models and estimated microplastic loadings from urban stormwater runoff to be up to two orders of magnitude higher than wastewater to the San Francisco Bay (Sutton et al. 2019). Fibers were the most common particle type in wastewater effluent (55%, mean 0.03 fibers/liter) and the second most common particle type in urban runoff (black, rubbery fragments were the most common), composing 39% of all sampled urban runoff microplastics (mean 4 fibers/liter).
A similar, but smaller study in the Toronto (Canada) area found similar microparticle concentrations in urban stormwater runoff (15 ± 8 microparticles/L), with a similar fraction of fibers (41%) (Grbić et al. 2020). Most other studies of microplastics in urban discharges during storm events were in locations served by combined wastewater/stormwater systems (e.g., Luo et al. 2019) or where stormwater contains non-runoff discharges, like industrial wastewater (e.g., Piñon-Colin et al. 2020).

Prior to Sutton et al.’s (2019) finding that urban runoff appears to be the major source of fibers in San Francisco Bay, fibers had generally been assumed to reach surface waters primarily via municipal wastewater effluent (e.g., from washing clothing) (e.g., Gavigan et al. 2020; Browne et al. 2011; Hartline et al. 2016).

While Sutton et al. (2019) assessed only a subset of all collected fibers and could not determine the chemical identity of most urban runoff fibers due to the presence of dyes in the fibers that masked the identifying characteristics of the underlying polymer (i.e., > 50% of fibers were classified as “anthropogenic unknown”), of those that were identifiable, the two most common fibers were polyester (polyethylene terephthalate) and cellulose acetate. The most common identifiable fibers in municipal wastewater effluent (anthropogenic cellulose and cotton) were different than the most common urban runoff fibers, but it is unclear if the difference between urban runoff and wastewater is meaningful given the chemical identity of most fibers was not assessed or could not be identified.

This conceptual model identifies the sources and transport pathways for fibers in urban runoff. This model does not address cellulose acetate from cigarette butts, which is addressed in a separate conceptual model.

The process of developing the model highlighted gaps in available information and identified existing and potential future measures to reduce stormwater fiber loads. An outline of potential control strategies will be provided with the draft report. Those information gaps most relevant to management decisions regarding control measures will be identified in the report’s recommendations.

**Sources of fibers in urban runoff**

**Overview**

Fibers have multiple uses in urban environments. In addition to use in household and industrial textiles (clothing, carpets, upholstery, tarps, awnings, tents, storm drain filter fabric, erosion control blankets, and other geotextiles), fibers fill furniture, toys, diapers, and pillows; compose artificial hair; form cordage (rope, cords, and twine); insulate buildings; and provide structural support for a plethora of outdoor products, such as composite building materials, construction and landscape materials and their transport bags, and vehicle tires.

Fibers occur in diverse urban outdoor surface coverings such as carpet, artificial turf, and landscape fabrics. Cordage has outdoor uses in construction, gardening, and surveying. Non-woven textiles, often found in industrial materials, are also used in surgical masks, an
all-too-common element of outdoor trash during the current pandemic. Fibers may be formed from degradation of larger plastic items in the outdoor environment (Naik et al. 2020).

**Non-Industrial fibers**

Wear, washing, drying, and disposal release fibers from clothing and other non-industrial goods into the environment. For textiles, fiber release rates depend on the nature of the textile product (e.g., filament type; whether it has a mechanically processed surface), manufacturing processes used in its construction (particularly the cutting process), washing conditions, and its age (Y. Cai et al. 2020; De Falco et al. 2020; Almroth et al. 2018; Palacios-Mateo et al. 2021). For other types of common fiber-containing goods that are infrequently washed, such as carpets and fiber fill (e.g., furniture, pillows), fiber releases are likely primarily due to physical contact with the item (abrasion, mechanical degradation, cleaning).

A more limited range of fiber-containing non-industrial goods commonly appear in outdoor urban environments. These include carpet, artificial turf, outdoor furniture, netting, swimming pool and outdoor furniture covers, tarps, tents, and boat and vehicle covers. In those rare urban locations where fishing occurs, fishing gear (ropes, nets, and line) may be used. In areas with unsheltered populations, additional fiber containing non-industrial goods may be located outdoors, such as items that sheltered populations normally use or store indoors (e.g., clothing) and items that are not normally used long-term in urban areas (e.g., tarps, tents). These items can release fibers directly into the outdoor environment, facilitating transfer into urban runoff.

Because most fiber-containing goods are located indoors, most fiber releases likely occur indoors. While most fibers used or released to air indoors will remain indoors, they can be tracked or blown outdoors, or released during material relocation or disposal. Fiber concentrations in air are lower outdoors than indoors (Dris et al. 2017; Liu et al. 2019; Y. Zhang et al. 2020). Ventilation from homes and commercial buildings can be a significant source of particles in outdoor air (Sundt, Schulze, and Syversen 2014; Björklund et al. 2012).

Textiles - and specifically clothing washing - have been a focus of research on environmental fiber releases. In the US, clothing wash water drains into municipal sewer systems or septic tanks, making it unlikely to transfer fibers into stormwater runoff. Fiber losses into the air while wearing garments may rival the losses during washing (De Falco et al. 2020); however, since people spend most of their time indoors (< 10% outdoors according to Klepeis et al. 2001), despite examples of clothing and camping fabric-related fiber emissions at remote locations (e.g., Napper et al. 2020), most of the fiber air emissions from wearing clothing likely remain indoors.

In contrast to clothing washing, clothing drying is a potentially significant source of fibers in urban runoff. In the USA and Canada, dryer use is significantly higher than in other parts of the world (Kapp and Miller 2020). The use of mechanical air dryers with outside ventilation in the USA contrasts with practices in many other parts of the world, where extractive dryers and hanging items to dry are more common (Energy Star 2011). Much of the scientific literature around fibers in the outdoor environment is from areas where outdoor-vented mechanical air dryers are less common than in the USA. Most USA residential and commercial clothing dryers
vent directly to the outdoors without treatment, dispersing fibers not collected in lint traps to the outdoors. Significant quantities of fibers are known to pass through dryer lint filters, as evidenced by the US Federal Emergency Management Agency finding that lint build up in dryer lint traps and exhaust ducting are the primary cause of residential dryer fires (Federal Emergency Management Agency (FEMA) 2012). This outdoor fiber emission source has received surprisingly little investigation. Based on fibers collected in a condensing dryer lint trap, Pirc et al. (2016) estimated that fiber releases during tumble drying of clothing were 3.5 times higher than releases during washing. This study did not measure fibers passing through the lint trap and exhausted to the outdoors. In a small two-dryer study using typical North American mechanical dryers with outdoor exhausts, Kapp and Miller (2020) found that the mass of pink blanket fibers collected outdoors rivaled the amount collected in the two tested dryers’ lint traps.

Industrial Fibers

The diverse industrial uses of fibers may release fibers into the outdoor environment (e.g., air emissions, ground deposition) from manufacturing facilities, product use, and disposal. Unlike clothing, many industrial textiles are non-woven, with different fiber characteristics (Martínez Silva and Nanny 2020). Examples of the long list of industrial and construction uses of fibers (Adanur 2017; Paul 2019) that are notable from the urban runoff perspective include:

- **Geotextiles** - Filtering and other textiles used for construction runoff treatment, silt fences, erosion control, weed control, bank and coastal stabilization, and drainage systems may release fibers when cut, mechanically abraded, or through degradation.

- **Construction and landscaping material packaging** - Fiber-reinforced bags, particularly those used for construction and landscape material and for flood protection (plastic-fiber sand bags), may release fibers when cut open, mechanically abraded, or left outdoors to decay.

- **Ropes, string, and twine** - Construction, landscaping, agriculture, and fishing may release fibers into the environment when cut or during use. Some items may be left to degrade (e.g., in landscaping), from which fibers may be released into runoff. Plastic string used in vegetable production, which is similar to string used in landscaping, might be a significant source of fibers in soil (G. S. Zhang and Liu 2018).

- **Outdoor architectural fabrics** - Roofing, awnings, and temporary fence covers may release fibers through degradation.

- **Vehicle parts** - Parts such as brake pads and belts may release fibers to the air during vehicle operation.

- **Concrete** - Fibers may be added to concrete to address cracking and to improve structural properties, particularly with the newer “foam concrete” technology (Shafei et al. 2021; Amran et al. 2020). In addition to natural fibers, metal, glass, and polymer fibers (e.g., polyester, acrylic, aramid, polyvinyl alcohol, polyethylene, polypropylene, nylon) may be added to concrete. Due to its desirable properties and low cost, polypropylene is
reportedly the most commonly used fiber type (Shafei et al. 2021). Construction operations such as concrete cutting, building demolition, and concrete recycling from building demolition debris could release fibers into outdoor air.

- **Building wraps and insulation** - Modern wood building construction often includes a permeable textiles membrane on the outside of the wood below the building siding. Building insulation may contain various fibers, including recycled textiles (Islam and Bhat 2019). On-site cutting of materials (e.g., cutting window and door openings in building wraps) may release fibers to outdoor air.

**Litter**

**Macroplastics that degrade into fibers** - Depending on the manufacturing processes, macroplastics in the outdoor environment could potentially degrade into fibers. Naik et al. (2020) discovered that nylon and HDPE pellets, which are used in plastic product manufacturing, degraded into microfibers under UV light. This study did not examine end-use products produced with the pellets (Naik et al. 2020).

**Fiber-containing items abandoned outdoors** - Dumping of plush furniture, mattresses, carpet, tarps, and other textiles outdoors may contribute fibers to runoff, particularly if abandoned items are not collected and managed prior to their degradation. Fiber-containing items are often abandoned in areas where unsheltered populations camp (these areas typically lack waste collection services) (Bay Area Stormwater Management Agencies Association 2020). Disposable diapers containing fibers are rare in California litter (Moore 2016; Miller-Cassman et al. 2016; Bay Area Stormwater Management Agencies Association 2020).

**Personal Protective Equipment** - Fibers provide structural support for many medical goods, most of which typically remain indoors. Due to the pandemic, medical masks (e.g., surgical masks) and cleaning wipes composed of nonwoven fibers have popped up as common outdoor litter items (Prata et al. 2020; Wilson 2020; Ammendolia et al. 2021).

**Conceptual model: Sources and Pathways Figure**

As illustrated in the blue sources sections of the conceptual model figure, fibers can be released into the outdoor environment from both indoor and outdoor uses:

1. **Indoors - Transport from indoors to outdoors.** For example, emissions from personal, laundromat, or industrial clothing dryers; industrial facility emissions; carpet fibers tracked outdoors; shaking out rugs outdoors to clean them; fibers in indoor air transferring to the outdoors through open windows and building ventilation exhausts.

2. **Outdoors - Loss of fibers during installation, use, and storage.** For example, fibers lost from clothing while outdoors; wear of tents and tarps; runoff from awnings; wear from walking on outdoor carpet or artificial turf; failure of fiber-containing building materials; driving over fiber-based bags; weather damage to fabric fence coverings; cutting fiber-containing building wraps and insulation; cutting roofing fabric; cutting and installing twine landscaping supports; using storm drain filter fabric.
Fate and Transport

After release to outdoor environments, fibers may deposit on impervious or pervious surfaces, or be washed out of the air by rainfall. Deposited particles - particularly those deposited on impervious surfaces - may be resuspended, redistributed, and modified by vehicles or other human activity, or simply by the motion of the air. Street sweeping, which can efficiently remove particles above ~125 \( \mu \text{m} \) in size (Selbig and Bannerman 2007), may remove larger fibers from gutters and streets. Some fibers may be sequestered in soils and landscape covers.

While in the outdoor urban environment, processes such as photodegradation, hydrolysis, biological degradation, and mechanical degradation can modify fibers (Sait et al. 2021; Sørensen et al. 2021; Zambrano et al. 2019). Degradation rates depend on both the environmental exposure situation and the fiber material (Sait et al. 2021; Zambrano et al. 2019). In addition to releasing fibers and reducing fiber sizes, degradation in the urban environment has potential to release chemical additives within fibers to the environment (Sait et al. 2021; Sørensen et al. 2021).

Due in part to their high surface area to volume ratio, fibers emitted to the outdoor air can transport through the air for long distances, as evidenced by detections in remote global locations (e.g., arctic, mountain wilderness) (Athey et al. 2020; Allen et al. 2019; Brahney et al. 2020). Fibers typically (but not always) dominate microplastic air deposition measurements made using traditional air quality research methods (e.g., elevated passive collection platforms away from known local emissions sources) (Allen et al. 2019; L. Cai et al. 2017; S. L. Wright et al. 2020; Brahney et al. 2020; Dris et al. 2018; Y. Zhang et al. 2020). Available information is insufficient to determine the source of these fibers, though exhaust from clothing dryers seems likely to contribute (Kapp and Miller 2020).

In urban environments, rainfall and runoff wash particles into stormwater collection systems. Washoff from impervious surfaces (streets, sidewalks, roofs) is far more efficient than from pervious surfaces (lawns, gardens, agricultural fields) (Water Environment Federation and American Society of Civil Engineers 1998; Field, Heaney, and Pitt 2000). Biofouling likely plays an important role in the transport and fate of fibers in the environment, in addition to physical factors like wind and water flows (Barrows et al. 2018). In the limited locations where urban runoff receives treatment, fibers may be removed, particularly in systems that filter runoff like bioretention treatment systems (Gilbreath et al. 2019; Smyth et al. 2021). While denser fibers may be temporarily retained in low points in the stormwater collection system under low flow conditions, turbulent flows during larger storm events will likely mobilize these particles and carry them into surface waters (Hoellein et al. 2019).

Waste Management and Reuse

Unwanted fiber-containing products may be disposed with solid waste or reused, such as through clothing resellers and textile recyclers. Some handling and processing of waste and materials for reuse may occur outdoors, but in California, most operations are indoors (e.g., solid waste transfer stations, clothing sorting facilities, clothing resellers) to protect environmental quality or
to protect the quality of the textiles for potential reuse. If landfilled, waste fiber-containing products can degrade to produce fibers.

Fibers may be released into the environment during the waste management process, such as via dispersal of fiber fill material from furniture while awaiting transport to a waste management facility, losses in waste collection (e.g., dumpsters) and transport if not properly covered, emptying vacuum cleaning equipment; building demolition; crushing fiber-containing concrete for recycling; vehicle crushing. As discussed above, improper disposal (litter) also releases fibers into the environment.

A few reuse options for waste fiber products could release fibers into the environment. For example, use of waste carpet to line drainage systems has been proposed (J. Wright 2019).

Within California, once fiber-containing wastes (including biosolids) reach landfills, opportunities for transport of disposed fibers into urban runoff are relatively limited due to California requirements for daily cover of landfilled waste, secondary containment, and leachate collection and treatment systems (California Code of Regulations Titles 14 and 27). Activities at landfills, such as depositing waste in the landfill and compacting waste prior to application of daily cover, could potentially release fibers into the air. Outside of California - particularly in areas with fewer environmental protection regulations, disposal activities can be far less regulated and could be a potentially significant source of fiber emissions to air and to runoff (e.g., Palacios-Mateo et al. 2021).

Assumptions underlying the conceptual model

The conceptual model focuses on potentially significant urban runoff fiber sources and pathways. Examples of excluded potential sources and pathways include:

Indoor fiber uses/wastewater discharges. The conceptual model assumes that municipal urban runoff does not contain meaningful quantities of water that was originally discharged from indoor drains to the municipal wastewater collection (sewer) system. In modern urban construction (which occurs in all portions of California except San Francisco and part of Sacramento), outdoor drains flow through drainage structures like curbs and gutters to separate storm drains that discharge directly to surface water, usually without any treatment. While some cross connections exist - and exfiltration from sewer lines can enter storm drains - these sewage flows typically compose a negligible portion of urban runoff flow in most of California.

Sewer overflows do occur and likely compose an irregular source of fiber discharges to surface water. Sampling locations in the San Francisco Bay regional study avoided areas where sewer overflows commonly occur. Given the extensive separate efforts to control sewer overflows, this source is excluded from the conceptual model.

Agricultural runoff. Agricultural fiber sources, such as textile drainage systems, crop and erosion prevention geotextiles, shade fabric, bird netting, plastic string, and weed prevention, may release fibers when cut, mechanically abraded, or through degradation. Runoff from biosolids

Very limited data are available on fibers in agricultural runoff. The San Francisco Bay watershed investigation did not address runoff from agricultural areas. Grbić et al. (2020) measured runoff from three largely agricultural watersheds near Toronto (Canada), finding microplastic concentrations 13-15 times lower than those in wastewater effluent or urban runoff (Grbić et al. 2020). Agricultural runoff in that study contained an average of < 0.26 fibers per liter. Fiber sources like biosolids and agricultural fabrics may not have been used in these watersheds.

Fiberglass is not included within the definition of microplastic.

Vehicle tires. Fibers in belts are covered by tread. While “bald” tires occur on the road, these are uncommon due to failure risks.

Asphalt. While fibers (like polypropylene and polyester fibers) can be used in asphalt mixes, this use was not reported for California (McDaniel et al. 2015)

Fiber measurement methods

Researchers use differing methods for collecting, identifying, and even defining microplastics, which create inconsistencies in data. Fiber contamination is common in environmental samples (Scopetani et al. 2020). This limits the comparability of data from different locations and studies. The model development process assumes that such differences do not affect the identification of sources and pathways for fiber transport in urban runoff.

References

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Environmental Deterioration (may occur in any section)

Microplastics (MPs)

Single Use Plastic Foodware (SUPF)
Bags, bottles, bowls, caps, cups, cutlery, plates, straws, stirrers, takeout containers, trays, and wrappers

Sources
Urban Commercial and Residential Areas
Grocery Stores, Restaurants, Homes, Parks, Public Areas

Proper disposal

Waste Management
Recycling, Incineration, Landfill

Removal
- Street Sweeping
- Trash Clean-ups

Land

Impervious Surfaces

Pervious Surfaces

Runoff

Storm Drains

Urban Waterways

Spills

Removal
- Trash capture devices
- Trash clean-ups
- GSI

SUPF Stormwater Conceptual Model - DRAFT
Text Explanation for Single-Use Plastic Foodware Urban Stormwater Conceptual Model

Background

“Just one word…Plastics. There is a great future in plastics.” This memorable line of dialogue from the classic 1967 film “The Graduate” encapsulated the optimistic vision of a generation of Americans – the notion that plastics could be key to transforming everyday living, and to creating a hugely profitable industry in the process. What began as a mid-century promise to address the problems of a generation has also produced its own multigenerational legacy of intractable challenges as plastics today are ubiquitous in everyday consumer and industrial products, ranging from product packaging and shopping bags to food containers and medical supplies. The low-cost and versatility of plastic have permitted the rise of single-use plastics (SUPs), which are intended for short-term use and disposal.

In 2017, nearly half of all virgin plastic was converted to products with a lifetime under three years (Geyer, 2020). Plastic packaging, with a typical lifespan of less than six months, constitutes the largest segment of virgin plastic, consuming roughly 36% of the total (Geyer, 2020). By 2030, plastic production is expected to rise by 40% (Geyer, 2020; WWF and Dalberg Advisors, 2019). No estimates have been calculated for the amount of packaging (and other related plastics) that consists of single use plastic foodware (SUPF).

For this conceptual model, SUPF is the primary focus. Here, SUPF are broadly defined as disposable plastic items designed for single use to serve, package, transport, and/or consume prepared food and/or beverages including bags, bottles, bowls, caps, cups, cutlery, plates, straws, stirrers, takeout containers, trays, and wrappers. Our definition includes the proposed revised food packaging definition in California Department of Toxic Substances Control (DTSC) Draft Three Year Priority Product Work Plan (DTSC, 2020); DTSC proposes to define food packaging as “any food contact article that is used to package hot, cold, frozen, or room-temperature food or beverage items and that is available for wholesale to restaurants and grocery stores or for retail sale to consumers.” Food packaging items, including any product designed to facilitate food transport by the consumer, are used widely for food preservation, transport, and delivery to points of retail sale (DTSC, 2020). Our definition for this model expands on DTSC’s definition of food packaging to include items used for food consumption such as utensils, straws, and stirrers. The wide scope of this definition is to ensure inclusion of the variety of plastics items from common sources relating to food that are known to pollute the environment.

Various degradation processes are important to the formation of microplastics from macroplastic sources. In this model, we use the term degradation, as the combination of abiotic (physical and chemical) and biotic processes leading to complete degradation or mineralization of plastics into small molecules like water and carbon dioxide. Deterioration of plastics is an intermediary step in this process where plastic characteristics are changed, including discoloration, surface cracking, and fragmentation into microplastics, but complete mineralization is not yet achieved. The term degradation is used inconsistently in common language and literature to refer to both partial and complete degradation processes. In this model, we will use the term degradation to refer to the complete degradation process (to small molecules), and the term deterioration to refer
to partial or incomplete degradation processes that includes the formation of microplastics. Biodegradation is the action of microorganisms to chemically alter plastic material, contributing to partial or complete environmental degradation. Photooxidation is the abiotic process that deteriorates plastic with an initial exposure of UV rays (i.e., sunlight) that primes the material for oxidation reactions.

It is estimated that around 76% of all plastics have either been sent to a landfill or into the environment (Geyer, 2020). Hence, widespread plastic use has also led to widespread plastic waste in the environment. A significant amount of this waste is inadequately managed (mismanaged) through open dumping, littering, or uncontrolled landfills. It is estimated 42 metric tons (mt) of plastics were openly dumped and littered into the environment worldwide (Geyer et al., 2017; WWF and Dalberg Advisors, 2019). In 2016, roughly three-quarters of the primary plastic produced ended up as waste with more than 40% from plastic packaging waste alone (Geyer et al., 2017; WWF and Dalberg Advisors, 2019). The United States is the largest plastic waste producer in the world with roughly 1.13 to 2.24 mt of mismanaged plastic (Law et al., 2020).

Littered plastic is a significant portion of mismanaged waste globally. Recent studies in international coastal cleanups have consistently shown SUPF such as food wrappers, grocery bags, and plastic bottles among its most collected litter, taking nine of the top ten spots (Munari et al., 2016; Nelms et al., 2017; Ocean Conservancy, 2020). Similar studies of urban pollution have also found varying degrees of plastic pollution (7-20%) with most consisting of SUPF related products (Becherucci and Seco Pon, 2014; Magnusson et al., 2016). A study of litter in urban stormwater in South Africa over twenty years found high levels of plastics by count and mass, especially of SUPF, foamed plastics, and clam shell containers (Ryan et al., 2020; Verster and Bouwman, 2020; Weideman et al., 2020). Regionwide studies in California have shown that plastics are the most common items found in rivers and streams, on land, and in the ocean (BASMAA, 2020; Moore et al., 2016). The amount of area on the ocean floor found to have plastic has increased since 1994 (Moore et al., 2016). A major subcategory of SUPF, single use containers, have not been specifically counted in any of these environments and were not included on data sheets; however, in 2018 it was requested that they be included on the data sheets for the large scale trawl surveys done in Southern California as they were being found more consistently in benthic trawls (Du et al., 2020).

The use of plastics has increased on a worldwide scale over the past century, which has resulted in an increase of plastic debris in our oceans (Andrady, 2011; Eriksen et al., 2014), caused endangerment to wildlife via entanglement and ingestion (Gall and Thompson, 2015; Wilcox et al., 2018), and led to habitat damage (Lusher et al., 2015; Rochman et al., 2013) and significant economic losses (Leggett et al., 2018; Newman et al., 2015). While the increase of macroplastics (particles > 5 mm in size) in the environment has been the subject of decades of environmental research and recent management attention, microplastics (1 μm - 5 mm in size), many formed from the deterioration of macroplastics, are a more recent focus of environmental research. Microplastics deteriorated from larger plastic items are considered secondary microplastics, whereas those originally formed as small pieces, such as microbeads in skin care products, are primary microplastics. Secondary microplastics are thought to be the most abundant in the environment of all microplastics present (Andrady, 2017; Schell et al., 2020). These are a
considerable added hazard and now a focus of increasing concern because of mounting evidence of widespread contamination (Barrows et al., 2018), potential for ingestion, and toxicity of chemical ingredients or transformation products (Coffin et al., 2019; Tian et al., 2020). The potential for bioaccumulation and biomagnification of microplastics and impacts to both marine life and human health (Barboza et al., 2018; Setälä et al., 2014; Teuten et al., 2009) has also increased. Control of land-based sources of plastics is a key component of microplastic management strategies and policies (Cal OPC and NOAA Marine Debris Program, 2018), as much of the plastics found in marine debris appear to be from runoff from rivers and from wastewater effluent (Andrady, 2011; Jambeck et al., 2015; Moore et al., 2016; Schmidt et al., 2017; Talvitie et al., 2017).

Recent investigations in the San Francisco Bay identified urban runoff as a major pathway for microplastics to enter receiving waters. Average concentrations of microplastics in urban runoff from the San Francisco Bay were approximately two orders of magnitude higher than wastewater (Sutton et al., 2019). Fragments were the most common particle type in urban runoff, with nearly half of these particles suspected to be related to tire-wear particles due to their distinctive black and rubbery texture. Other than the suspected tire-wear particles, the most abundant types of plastic polymers that could be identified were polypropylene (PP) and polyethylene (PE), which combined, represented 17% of fragments analyzed via spectroscopy. These common plastics are used in a variety of products not limited to SUPF. We were surprised that expanded polystyrene (EPS) and plastic films commonly used in SUPF did not represent a larger fraction of the microplastics identified in urban stormwater (Sutton et al., 2019). One hypothesis for this is that larger plastic debris may still be trash sized (greater than 5 mm) in the stormwater pathway sampled, and that longer exposure to sunlight and mechanical action may be necessary before such items are transformed to microplastic size.

One of major challenges to addressing microplastic pollution is identifying the product source of microplastics as well as their geographic point of entry into the environment. Data on microplastic characteristics such as polymer composition, color, size, and morphology are commonly collected to provide clues as to their potential sources. To date, there are few studies that are able to directly link microplastics to SUPF. One study in China has inferred the source of microplastics to be SUPF by examining a relatively remote lake, where they found polystyrene (PS) and PE microplastics were predominant, implicating improper disposal (littering) of food packaging and containers from tourism as the likely culprit (Xiong et al., 2018).

Trash on land has recently become a renewed focus of policy throughout the state of California. Current policies include three main areas: 1) product-specific bans addressing known trash sources (e.g., plastic bags); 2) total maximum daily loads (TMDLs); and 3) the Statewide Trash Amendments. While these policies all involve reducing trash on land, they all work in different ways. Bans on specific items include the statewide ban on single-use plastic bags, and local bans throughout the state on specific items such as expanded polystyrene and cigarettes. TMDLs have been passed by regional water quality control boards for many contaminants and specifically concerning trash for at least 15 water bodies. The most well-known TMDL for the Los Angeles River, established in 2001, was one of the nation’s first trash TMDLs (LACRWQCB, 2015, 2007). The goal for 100% trash load reduction mandated by this TMDL was set to be accomplished by September 2016. Many affected jurisdictions have accomplished this using full
trash capture devices or alternative institutional controls such as street sweeping and education. The Statewide Trash Amendments take such TMDLs to a broader level, as jurisdictions throughout the state now must either install full trash capture devices (Track 1) or partial capture devices and institutional controls (Track 2; SWRCB, 2015). This is designed to keep larger trash from flowing into receiving waters from conveyances used to collect or convey stormwater (e.g., storm drains, pipes, ditches), which are owned by a state, city, or other public entity, and are most commonly known as a Municipal Separate Storm Sewer Systems or MS4s.

While the state has controls in place for trash larger than 5 mm, there are no current statewide policies addressing microplastic capture in the environment. However, two state bills, Senate Bills 1263 (2018) and 1422 (2018) have started to address the microplastics problem in California. Senate Bill 1263 requires the Ocean Protection Council to adopt and implement a Statewide Microplastics Strategy related to microplastic materials that pose an emerging concern for ocean health. The second piece of legislation, Senate Bill 1422, requires the California State Water Resources Control Board to both define microplastics in drinking water and develop standardized methods for analyzing microplastics in drinking water. The state has defined ‘Microplastics in Drinking Water’ as solid polymeric materials to which chemical additives or other substances may have been added, which are particles that have at least two dimensions that are greater than 1 and less than 5,000 micrometers (µm) (SWRCB, 2020). Polymers that are derived in nature and have not been chemically modified (other than by hydrolysis) are excluded.

To inform the development of a state microplastics strategy, the conceptual model presented here illustrates the current knowledge of the sources and pathways of SUPF and related microplastics infiltrating the environment from urban runoff. One of the greatest challenges is in linking both macro- and microplastics in the environment to product sources and geographic locations in order to inform management policies that could be directed at reducing pollution. Attempts have been made to determine the pathways of macrodebris (stormwater, littering, wind-blown, homeless encampments, or unknown origin) to rivers and streams, but it is a difficult assessment to make with confidence (BASMAA, 2020; Moore et al., 2020).

The purpose of this conceptual model is to synthesize and integrate our understanding of the contribution of single-use foodware plastics and resulting microplastics entering urban stormwater and the environment. This model focuses on the urban environment in order to inform current research needs and inform actions to reduce land-based SUPF mismanagement. The report will include recommendations for how this model can be used to inform management actions to reduce land-based SUPF and microplastic loads.

**Conceptual Model Description**

There are several different polymer types used to create SUPFs; the most common are high density polyethylene (HDPE), low density polyethylene (LDPE), polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), and expanded polystyrene (EPS) (Singh and Devi, 2019; UNEP, 2018; Verster and Bouwman, 2020). Notably, HDPE, LDPE, PET, and PP constitute the vast majority of packaging plastics, the largest sector of single use plastics (Geyer, 2020). PS and EPS are polymers commonly used for utensils and take-out containers, respectively (Turner, 2020; UNEP, 2018; Wagner, 2020). All of these synthetic polymers are thermoplastics, which are melt processed and theoretically can be recycled, as opposed to
thermoset polymers, which undergo a chemical change and cannot be recycled. Bio-based polymers are less common but have increasing use as an alternative to traditional thermoplastics. Important uses and properties of these polymers are highlighted in Table 1. Additionally, plastic products may be composed of mixtures of polymers, as well as include plastic additives, such as phthalates, bisphenols, flame retardants, and alkylphenols ethoxylates, that can change their properties.

**Table 1. Summary of important characteristics of the polymers most commonly found in single use plastic foodware (SUPFs)**

<table>
<thead>
<tr>
<th>Plastic polymers</th>
<th>Example Uses</th>
<th>Properties</th>
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</thead>
<tbody>
<tr>
<td>High Density Polyethylene (HDPE)</td>
<td>Milk bottles, freezer bags</td>
<td>Typical Density (g/cm$^3$): 0.94-0.97</td>
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<td></td>
<td></td>
<td>UV/Oxidation Resistance: Low</td>
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<tr>
<td></td>
<td></td>
<td>% Crystallinity: 80-90</td>
</tr>
<tr>
<td>Low Density Polyethylene (LDPE)</td>
<td>Bags, containers, plastic film, bottles</td>
<td>Typical Density (g/cm$^3$): 0.89-0.94</td>
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<tr>
<td></td>
<td></td>
<td>UV/Oxidation Resistance: Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Crystallinity: 30-50</td>
</tr>
<tr>
<td>Polyethylene Terephthalate (PET)</td>
<td>Beverage bottles, plastic film, microwaveable packaging</td>
<td>Typical Density (g/cm$^3$): 1.29-1.4</td>
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<tr>
<td></td>
<td></td>
<td>UV/Oxidation Resistance: High</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Crystallinity: 10-30</td>
</tr>
<tr>
<td>Polypropylene (PP)</td>
<td>Microwave dishes, chip bags, bottle caps</td>
<td>Typical Density (g/cm$^3$): 0.85-0.94</td>
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<tr>
<td></td>
<td></td>
<td>UV/Oxidation Resistance: Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Crystallinity: 30-50</td>
</tr>
<tr>
<td>Polystyrene (PS)</td>
<td>Cutlery, plates, cups, lids, bowls, takeout containers, straws</td>
<td>Typical Density (g/cm$^3$): 0.96-1.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UV/Oxidation Resistance: Moderate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Crystallinity: 0</td>
</tr>
<tr>
<td>Expanded Polystyrene (EPS)</td>
<td>Insulated food and beverage packaging such as cups, plates, bowls, trays, and containers</td>
<td>Common Density (g/cm$^3$): 0.015-0.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Crystallinity: 0</td>
</tr>
</tbody>
</table>

Sources: Andrady, 2017; Gomiero et al., 2019; UNEP, 2018; Verster and Bouwman, 2020; WWF and Dalberg Advisors, 2019

The pervasiveness of SUPF in food products, particularly as packaging, indicates use across a wide swath of commercial and institutional organizations. These items are also present in most households, with specific SUPF designed for home use. There may also be unique sources of SUPF depending on the urban area, including warehouses of online vendors for food products and homeless encampments, where disposable use items are common. Overall, likely areas of use and release of SUPF in the urban environment are highlighted below:
Because SUPFs are designed to be easily transported and can be used outdoors (where proper disposal is less convenient), SUPFs are likely to be improperly disposed of directly onto the land and into aquatic environments after their brief usage. This is fairly common in public areas, especially urban areas with higher population densities (Moore et al., 2016). Littering is the primary pathway for SUPFs entering the environment (Law et al., 2020).

SUPF litter in both terrestrial and aquatic environments can deteriorate and form microplastics over time through complex interactions of various chemical and physical processes including mechanical forces, photooxidation, biodegradation, and hydrolysis. SUPF litter on land includes impervious surfaces (i.e., concrete, asphalt) and pervious surfaces (i.e., lawns, porous construction materials). Stormwater runoff can transport SUPF macrodebris and microplastics across impervious surfaces quickly (and pervious surfaces at a much more limited rate) into gutters and storm drains. Urban run-off in California is typically channeled through impervious (piped) storm drain systems into urban creeks and/or larger urban waterways (such as channelized rivers). With a few exceptions (i.e., locations with combined sewer systems and those limited areas where urban stormwater flows through land-based treatment systems), stormwater is directly discharged without treatment to receiving water bodies like creeks, rivers, estuaries, and the ocean. This can lead to faster rates of SUPF and related microplastic entering the environment via this pathway. Aquatic compartments - especially urban waterways and coastal embayments are also vulnerable to receiving litter directly.

As plastics are designed specifically for their stability and durability, their degradation times are very long compared to natural-based organic material. Different conditions in the environment (geography, sunlight availability, temperature, mechanical forces, microbial community, anthropogenic impacts, etc.) along with varying characteristics of plastics create a complex series of interactions that lead to deterioration and degradation. Due to the particular thickness of many SUPF, deterioration to microplastics occurs over long time periods. In comparison, cigarette filters and the fibers within them are designed to break down easily and can form microplastics more quickly.

Across all environments, photooxidation and mechanical action are considered the most important processes of deterioration and degradation of SUPF and related microplastics, though the contributions of biodegradation and hydrolysis are also relevant to consider. Photolysis is particularly efficient when plastics on land surfaces are exposed to the air, especially beach surfaces where high temperatures further increase the rate of deterioration (Andrady, 2017). Plastic is deteriorated by the action of mechanical forces in the environment, including abrasion.
by foot and vehicles, wave action, and turbulence by wind and water. This is relevant in the study of SUPF, especially in stormwater and beaches, as a combination of mechanical forces including wind, water, and anthropogenic forces (humans, vehicles, etc.) can fragment plastics.

Biodegradation occurs throughout the environment and may be enhanced by the formation of biofilms on plastic surfaces, though this may contribute to less surface availability for the action of abiotic processes (Andrady, 2017; Rummel et al., 2017). Plastics with hydrolysable covalent bonds may also break down via hydrolysis when exposed to water. Though biodegradation and hydrolysis in the environment are considered processes too slow to meaningfully degrade plastics, the synergistic effects of these diverse processes contribute to the fragmentation and deterioration of SUPFs (Andrady, 2017).

There are several published methodologies to examine the deterioration and degradation of plastics, but few of these can be translated to generation of microplastics. These methods often rely on important properties of the plastic, highlighted for common polymers in Table 1. Within the literature, analyses can be categorized into assessments of mass loss, chemical changes, and physical changes to the original polymer structure. Mass loss simply uses changes in mass to determine breakdown of a polymer with a focus on surface area, where deterioration takes place (Chamas et al., 2020). This can include partial conversion to small molecules (such as carbon dioxide and water) as well as fragmentation to microplastics. The density, thickness, and morphology of litter, especially in marine environments, are critical factors to understanding the availability of the surface area to deterioration and degradation processes. Most of these polymers have lower densities (Table 1) compared to fresh and marine waters (1 and 1.025 g/cm³ respectively), though this is likely a transient phase as foulants form on the plastic and increase density (Cózar et al., 2014). Additionally, plastic films have a large surface area that allow them to deteriorate more quickly compared to other small particles like fibers and beads.

Assessments of chemical changes often examine the concentrations of specific functional groups in polymers to determine the extent of deterioration and degradation. The specific chemical structure of each polymer highlights the resistance to UV and oxidizability (Table 1). The composition of the plastics is important to understand deterioration rates, though the complexity of plastic mixtures can make understanding these rates more difficult (Andrady, 2017; Li, 2018). SUPFs and microplastics in the environment may also leach plastic additives and/or absorb other contaminants, which further complicate their deterioration and identification. Methods looking at changes in physical properties typically examine the strength of the polymer through thermal and surface analysis. Thermal analysis often involves determining the crystallinity (degree of structural order) of a polymer, with a higher crystallinity indicating greater potential for oxidative deterioration in the environment (Table 1). Although some studies have tried to develop quantitative measures for understanding these phenomena, most are left with wide ranging values that are difficult to compare to each other because metrics and experimental conditions have not yet been standardized across studies. Further, the broad definition of degradation and numerous metrics used make it challenging to extrapolate results to understand the generation of microplastics.

To understand the impacts of different environmental characteristics on deterioration and degradation, their relative importance is qualitatively shown in Table 2. Solar and mechanical forces are the most significant mechanisms with the potential to deteriorate to microplastics and
ultimately degrade. The impacts of exposure to UV light are further amplified by subsequent oxidation and increasing sample temperature. Overall, the land environmental compartment and beaches are the most likely zones for deterioration to occur in the environment. These environments present the greatest likelihood for generation of secondary microplastics through direct photooxidation and various acting mechanical forces. Although microplastics can also form in the marine environment, generally lower temperatures cause much slower rates of abiotic and biotic factors leading to deterioration. Additionally, the lower availability of plastic surface due to foulants (i.e., bacteria and biofilms) and placement in the water column make pathways of deterioration and degradation significantly slower (Andrady, 2017; ter Halle et al., 2016). Stormwater presents a unique interface of both land and marine environments where deterioration can occur at a moderate level, while also transporting SUPF and related microplastics to the environment.

Table 2. Qualitative summary of important characteristics for deterioration and degradation of plastics and microplastics in the environment (adapted from Andrady 2017)

<table>
<thead>
<tr>
<th>Environmental Compartment</th>
<th>Solar (UV)</th>
<th>Sample Temperature</th>
<th>Oxygen Availability</th>
<th>Mechanical Forces</th>
<th>Fouling</th>
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<tbody>
<tr>
<td>Land (General)</td>
<td>High</td>
<td>Very High</td>
<td>Very High</td>
<td>Very High</td>
<td>Low</td>
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<tr>
<td>Beach (Coastal)</td>
<td>High</td>
<td>Very High</td>
<td>Very High</td>
<td>Very High</td>
<td>Low</td>
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<tr>
<td>Surface Water (General)</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Stormwater</td>
<td>High</td>
<td>Moderate</td>
<td>High</td>
<td>Very High</td>
<td>High</td>
</tr>
<tr>
<td>Midwater-deepwater</td>
<td>None</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
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<tr>
<td>Marine Sediment</td>
<td>None</td>
<td>Very Low</td>
<td>Very Low</td>
<td>Low</td>
<td>High</td>
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</tbody>
</table>

Even within proper waste management, there still remain gaps that allow for litter to “spill” back into the environment through transportation of plastic waste, domestic or international, and overall mismanagement of waste for recycling and incineration. In the U.S., plastic waste is estimated to be largely landfilled (81%), where it may take several centuries to degrade (US EPA, 2020). California has a particularly robust management of landfills that limits the potential for losses, exposure, and pollution to the environment. An additional 15% of plastic in the U.S. waste ends up incinerated, which eliminates the material but can contribute to air pollution from the chemicals released and intensive energy required for operation (though some of that energy may be recaptured). Recycling accounts for 9% of plastic waste disposal in the US, though there are no assurances that these materials will ultimately be recycled. Certain plastic waste cannot be recycled due to multiple factors including: chemical contamination, complex polymer mixtures, technical challenges, economic feasibility, lack of market/financial incentive. In addition, plastic waste collected after recycling can be exported internationally, with the US trading nearly 2 million tons in 2016 to countries with lower standards of waste management (Law et al., 2020). When recycled, the plastic produced is of a lower quality and unable to displace products made from virgin plastics (Schell et al., 2020). There are also mechanisms for removal of litter to proper waste management including street sweeping, trash capture devices, and organized trash clean-ups. Currently, there is an insufficient amount of data to fully quantify mismanaged waste in California.
References


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SWRCB, 2020. Definition of “Microplastics in Drinking Water.”

SWRCB, 2015. State Water Resources Control Board Amendment to the water quality control plan for the ocean waters of California to control trash and part 1 trash provisions of the water quality control plan for inland surface waters, enclosed bays, and estuaries of California.


# MULTI-YEAR PLAN FOR MICROPLASTICS

Microplastic studies and monitoring in the RMP from 2016 to 2024. Numbers indicate budget allocations in $1000s. Budgets in parentheses represent funding or in-kind services from external partners. Italicized dollar amounts indicate external funds that are needed but not yet secured. Items included in planning budget are shaded in yellow. Bold boxes indicate multi-year studies.

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<td>(sediment core)</td>
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<td>Stormwater</td>
<td>Moore/TBD</td>
<td></td>
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<tr>
<td>Stormwater Conceptual Model</td>
<td>RMP</td>
<td>OPC</td>
<td>1,3,5</td>
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<tr>
<td>Green stormwater infrastructure:</td>
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<tr>
<td>Evaluating the efficacy of rain</td>
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<tr>
<td>Model transport in Bay &amp; ocean</td>
<td>Moore/External</td>
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<tr>
<td>Evaluate microplastics in biosolids</td>
<td>RMP</td>
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<tr>
<td>Monitoring air deposition</td>
<td>External</td>
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<tr>
<td>Options for source control</td>
<td>Moore Foundation</td>
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<tr>
<td>Characterize microplastic</td>
<td>RMP</td>
<td></td>
<td>1,5</td>
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<td>Synthesis</td>
<td>Moore Foundation</td>
<td></td>
<td>1,3,5</td>
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<tr>
<td>Synthesize findings (e.g., report,</td>
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<td>factsheet, video, symposium</td>
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</tbody>
</table>

| RMP-funded Special Studies Subtotal – MPWG | 25 | 75 | 46 | 30 | 50 | 61.5 | 20 | 75 | 110.5 |
| High Priority Special Studies for RMP Funding |
| RMP-funded Special Studies Subtotal – Other Workgroups | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

- 48 -
<p>| | | | | | | | | | |</p>
<table>
<thead>
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<tbody>
<tr>
<td>RMP Supplemental Environmental Projects Subtotal</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Externally-funded Special Studies Subtotal</td>
<td>0</td>
<td>518</td>
<td>210</td>
<td>340</td>
<td>110</td>
<td>120.5</td>
<td>142</td>
<td>137</td>
<td>176.5</td>
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<tr>
<td>OVERALL TOTAL</td>
<td>25</td>
<td>593</td>
<td>256</td>
<td>370</td>
<td>160</td>
<td>182</td>
<td>162</td>
<td>212</td>
<td>287</td>
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</table>
**Special Study Proposal:**
**RMP Tires Strategy**

Summary: We propose to develop a cross-workgroup strategy for the RMP’s efforts around tire microplastics and tire-related water pollutants. The Tires Conceptual Model project, which was funded in 2020 and is currently underway, is identifying key information gaps around the connections between tires and aquatic habitats. The next step is to establish a short-term RMP strategy and multi-year plan spanning up to 5 years, based on stakeholder needs and the special capabilities of the RMP. This project is being recommended in parallel with other tire and stormwater CECs projects because of the high level of stakeholder interest in tire-related water pollution.

To prepare the strategy, we will identify relevant, specific management policies or decisions that are being evaluated, and priority RMP stakeholder tire-related science information needs that are not being addressed by others. We will then outline and work with experts and RMP stakeholders to refine a set of recommended RMP special studies related to tires for the years 2023-2028. Because tire-wear microplastics release tire-related water pollutants into stormwater, this is a cross-workgroup strategy proposal involving the Microplastics Workgroup (MPWG), the Emerging Contaminants Workgroup (ECWG), and the Sources, Pathways, and Loadings Workgroup (SPLWG). This inter-workgroup strategy will be designed as a short-term companion to the MPWG, ECWG, and SPLWG multi-year plans. Tire-related work that is needed after the 5-year horizon of this strategy would be integrated into future workgroup-specific strategies and multi-year plans. It will address RMP MPWG, ECWG, and SPLWG management questions.

Estimated Cost: $25,500

Oversight Groups: MPWG, ECWG, & SPLWG

Proposed by: Kelly Moran and Rebecca Sutton

Time sensitive: Yes. Responds to high stakeholder interest in tire-related water pollution by identifying the RMP’s role in supporting science-based management actions. Provides information to support DTSC’s science-based Safer Consumer Products regulatory program, which intends to regulate chemicals in tires (a series of decisions are anticipated from 2021-2026).

**PROPOSED DELIVERABLES AND TIMELINE**

<table>
<thead>
<tr>
<th>Deliverable</th>
<th>Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1. Present draft strategy to the MPWG, SPLWG, ECWG and SC</td>
<td>Spring 2022</td>
</tr>
<tr>
<td>Task 2. Semi-Annual updates to STLS</td>
<td>Fall 2021; Spring 2022</td>
</tr>
<tr>
<td>Task 3. Final strategy</td>
<td>October 2022</td>
</tr>
</tbody>
</table>
Background

Every vehicle on the road sheds tiny particles from its rubber tires into the environment. As they disperse into the environment, these microplastic particles convey tire tread ingredients into the air, runoff, and eventually into San Francisco Bay. With funding from the Moore Foundation, the RMP, and other organizations, SFEI found black, rubbery particles in urban stormwater that appeared to be from tires (Sutton et al. 2019). These were the most common microparticles in urban stormwater runoff. Modeling studies indicate tire wear may be one of the top sources of microplastics to the environment globally (Boucher and Friot 2017; Kole et al. 2017; Sieber, Kawecki, and Nowack 2020). Total environmental emissions from tires likely exceed emissions of other well-known pollutant classes like pharmaceuticals and pesticides (Wagner et al. 2018).

Chemicals that leach from tire tread also appear in urban runoff, including in the San Francisco Bay area (Peter et al. 2018; 2020; Z. Tian et al. 2021). One of these chemicals, 6PPD-quinone (a degrade of a tire antioxidant) causes pre-spawn mortality to coho salmon (Tian et al. 2021).

Emerging concerns around exposures to tire particles and tire tread chemical ingredients have fueled intensifying investigations by researchers around the world, who are studying their toxicity, chemistry, and occurrence in organisms and environmental compartments. Non-targeted chemical analysis has identified potentially toxic tire ingredients and degradates in leachates and environmental media (Peter et al. 2018; 2020; Seiwert et al. 2020; Overdahl et al. 2021). Aquatic toxicologists have examined toxicity of leachates (Capoluopo et al. 2020; Gualtieri et al. 2005; Halle et al. 2020; Kolomijeca et al. 2020) and have initiated studies on toxicity of the particles themselves. Environmental monitoring has revealed the presence of tire particles in air, aquatic environments and organisms (Baensch-Baltruschat et al. 2020; Leads and Weinstein 2019; Sutton et al. 2019; Z. Tian et al. 2017). Investigation of potential management measures like runoff treatment and alternatives for toxic ingredients has also begun (e.g., McIntyre et al. 2015; California Department of Toxic Substances Control 2021a; 2021b).

The RMP-funded Tires Conceptual Model project currently underway identified several key data gaps – all related to tire particles and rubbery stormwater particles. The next step is to establish the RMP’s priorities, based on baseline scientific information, stakeholder needs, and the special capabilities of the RMP.

If funded, the proposed Tire Particle/Contaminant Fate and Transport Project will provide key information to focus the development of the Tires Strategy.

This project is specially designed to provide a timely response to high stakeholder interest in tire-related water pollution by working with affected agencies and science experts to define the RMP’s role in supporting science-based management actions for tires. RMP scientists have received inquiries about tires from US EPA, state agencies, regional and local agencies, NGOs, the press, and legislators. The proposal seeks to maximize the RMP’s ability to provide timely support to key efforts, like DTSC’s science-based Safer Consumer Products regulatory program, which has initiated efforts to regulate chemicals in tires to protect
Establishing a special, short-term Tires Strategy will allow the RMP to provide a timely response to stakeholder interest and management agency needs without diverting resources from long-term RMP priorities. Once the strategy is in place, its implementation can be integrated within the existing RMP structure. Determining how to complete the integration of work crossing three RMP workgroups (MPWG, ECWG, and SPLWG) in a cost-effective manner will be crucial to the strategy’s success.

**Study Objectives and Applicable RMP Management Questions**

The goal of this project is to develop a multi-year plan for the RMP’s activities around tire microplastics and tire-related water pollutants.

The objectives of this project are:

1. To identify the specific management policies or decisions regarding tire particles and tire tread chemical ingredients that are anticipated to occur in the next few years.
2. To identify priority RMP stakeholder tire-related science information needs that are not being addressed by others.
3. To outline a list of recommended RMP special studies related to tires for the years 2023-2028, based on addressing scientific information gaps that are within the RMP’s purpose and mission and that not being addressed by others.
4. To vet and refine the five-year plan with RMP science advisors and stakeholders through the RMP workgroup process.

**Table 1. Study objectives and questions relevant to RMP MPWG management questions**

<table>
<thead>
<tr>
<th>Management Question</th>
<th>Study Objective</th>
<th>Example Information Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) How much microplastic pollution is there in the Bay and in the surrounding ocean?</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>2) What are the health risks?</td>
<td>Summary literature review of toxicity data.</td>
<td>Identify tire-related monitoring priorities.</td>
</tr>
<tr>
<td>3) What are the sources, pathways, loadings, and processes leading to microplastic pollution in the Bay?</td>
<td>List of recommended RMP special studies related to tires to address scientific information gaps.</td>
<td>Identify tire-related monitoring (and any modeling support) necessary to improve understanding of pathways, processes, and load estimates for tire microplastics discharged to the Bay in stormwater.</td>
</tr>
<tr>
<td>4) Have the concentrations of microplastics in the Bay increased or decreased?</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
5) Which management actions may be effective in reducing microplastic pollution?

<table>
<thead>
<tr>
<th>Management Question</th>
<th>Study Objective</th>
<th>Example Information Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Which CECs have the potential to adversely impact beneficial uses in San Francisco Bay?</td>
<td>List of recommended RMP special studies related to tires to address scientific information gaps.</td>
<td>Identify tire-related chemical monitoring priorities.</td>
</tr>
<tr>
<td>2) What are the sources, pathways and loadings leading to the presence of individual CECs or groups of CECs in the Bay?</td>
<td>List of recommended RMP special studies related to tires to address scientific information gaps.</td>
<td>Identify tire-related monitoring (and any modeling support) necessary to improve understanding of pathways, processes, and load estimates for tire microplastics discharged to the Bay in stormwater.</td>
</tr>
<tr>
<td>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?</td>
<td>List of recommended RMP special studies related to tires to address scientific information gaps.</td>
<td>Identify any low-cost tire particle and tire tread chemical ingredient characterization necessary to understand their physical, chemical, and biological processes that may affect the transport and fate (e.g., density measurements).</td>
</tr>
<tr>
<td>4) Have the concentrations of individual CECs or groups of CECs increased or decreased?</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>5) Are the concentrations of individual CECs or groups of CECs predicted to increase or decrease in the future?</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>6) What are the effects of management actions?</td>
<td>N/A</td>
<td>N/A</td>
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</table>

Table 2. Study objectives and questions relevant to RMP CEC management questions

<table>
<thead>
<tr>
<th>Management Question</th>
<th>Study Objective</th>
<th>Example Information Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) What are the loads or concentrations of pollutants of concern from small tributaries to the Bay?</td>
<td>List of recommended RMP special studies related to tires to address scientific information gaps.</td>
<td>Identify tire-related monitoring (and any modeling support) necessary to improve understanding of load estimates for tire microplastics discharged to the Bay in stormwater.</td>
</tr>
<tr>
<td>2) Which are the “high-leverage” small tributaries</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 3. Study objectives and questions relevant to RMP SPL management questions
that contribute or potentially contribute most to Bay impairment by pollutants of concern

<table>
<thead>
<tr>
<th>Question</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>3) How are loads or concentrations of pollutants of concern from small tributaries changing on a decadal scale?</td>
<td>N/A</td>
</tr>
<tr>
<td>4) Which sources or watershed source areas provide the greatest opportunities for reductions of pollutants of concern in urban stormwater runoff?</td>
<td>List of recommended RMP special studies related to tires to address scientific information gaps. Identify tire-related monitoring (and any modeling support) necessary to improve understanding of source linkages (e.g., to VMT or land use) and pathways for tire microplastics discharged to the Bay in stormwater.</td>
</tr>
<tr>
<td>5) What are the measured and projected impacts of management action(s) on loads or concentrations of pollutants of concern from the small tributaries, and what management action(s) should be implemented in the region to have the greatest impact?</td>
<td>List of recommended RMP special studies related to tires to address scientific information gaps. Identify studies to inform selection and design of tire-related management actions.</td>
</tr>
</tbody>
</table>

**Approach**

We propose to build a strategy for future RMP work around tire microplastics and tire-related water pollutants. This strategy will build upon the foundation created by the Tires Conceptual Model project that is currently underway. That project is identifying key information gaps around the connections between tires and aquatic habitats. The next step is to establish priorities, based on stakeholder needs and the special capabilities of the RMP. The project will not create new management questions; it will rely on the existing management questions for the RMP's MPWG, ECWG, and SPLWG.

We propose to use a four-step process to develop the RMP Tires Strategy:

1. Engage with relevant management agencies and stakeholders to clarify their tire-related science information needs related to the RMP's function and purpose,
2. Engage with the scientific community to evaluate the extent to which the identified science information needs will be addressed independent of the RMP,
3. Develop a five-year plan outlining the recommended RMP projects related to tires (e.g., monitoring and potentially one or more special studies), and
4. Vet and refine the five-year plan with RMP science advisors and stakeholders through the RMP workgroup process and SC.

The primary effort on the project will be to engage the relevant agencies and stakeholders. From agencies, we will seek to identify a list of specific management policies or decisions
that are anticipated to occur in the next few years and if and whether RMP science would have significant value for their decision-making process. In addition to the Water Boards and urban runoff management agencies (municipalities and Caltrans), agencies that may have an interest in water pollution from vehicle tires include California Department of Toxic Substances Control, California Ocean Protection Council, California Office of Environmental Health Hazard Assessment, US EPA, California Department of Fish & Wildlife, and NOAA Fisheries.

We also intend to engage with others in the scientific community to identify the relevant work they have underway so as to avoid duplication and seek opportunities to leverage RMP resources for any projects recommended to fill key information gaps.

The Tires Strategy will include proposed projects and tasks and projected annual budgets for up to a five-year period starting in 2023. The format will be consistent with other RMP multi-year plans. It will include:

- A list of specific management policies or decisions that are anticipated to occur in the next few years.
- A very brief summary of the latest advances in understanding achieved through the RMP and other programs. This summary will largely be based on the Tires Conceptual Model project, but will add two topics that are beyond the scope of that project: (1) surface water monitoring and (2) aquatic toxicity.
- A list of relevant RMP studies performed within the last five years and studies that are currently underway.
- Brief descriptions of recommended RMP projects.
- Explanation of the rationale for selection of the recommended projects.
- A table summarizing the recommended RMP projects, their timing, and estimated budgets.

The final deliverable will be a brief strategy document accompanying the 5-year budget plan. This inter-workgroup strategy will be designed as a short-term companion to the MPWG, ECWG, and SPLWG multi-year plans. Any tire-related work that is needed after the 5-year horizon of this strategy would be integrated into future workgroup-specific strategies and multi-year plans. A draft of the strategy will be provided for Microplastics, Emerging Contaminants, and Sources Pathways and Loading workgroups, TRC, and SC review. The Small Tributaries Loading Strategy (STLS) Team will be updated on the project twice during the one-year project period.
Budget

The following budget represents estimated costs for this proposed special study (Table 4).

Table 4. Estimated costs.

<table>
<thead>
<tr>
<th>Expense</th>
<th>Estimated Hours</th>
<th>Estimated Cost</th>
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</thead>
<tbody>
<tr>
<td><strong>Labor</strong></td>
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<tr>
<td>Additional Literature Review (Toxicity and monitoring data from elsewhere; topics not included in Tires Conceptual Model project)</td>
<td>18</td>
<td>$3,000</td>
</tr>
<tr>
<td>Strategy Development: Stakeholder and Scientist Engagement; Prepare Draft and Final Strategy</td>
<td>63</td>
<td>$13,000</td>
</tr>
<tr>
<td>Workgroup meetings (MPWG, ECWG, SPLWG) and STLS updates</td>
<td>40</td>
<td>$8,000</td>
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<tr>
<td>Senior Management Review</td>
<td>6</td>
<td>$1,500</td>
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<tr>
<td><strong>Grand Total</strong></td>
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<td><strong>$25,500</strong></td>
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</table>

Budget Justification

**Labor Costs**
Labor will primarily be spent on consulting with management agencies, relevant experts currently working in the field, and RMP stakeholders. While most of the background scientific information will be developed by the RMP’s tires conceptual model project, additional effort will be necessary to identify major findings and gaps in California monitoring data and aquatic toxicity data. Senior managers will help guide the process and review interim products.

Project staff hours reflect the need for teamwork among RMP scientists with expertise in microplastics, CECs and stormwater. As we develop this strategy, we anticipate considerable engagement with regional and state agencies as well as other RMP stormwater, microplastics, and emerging contaminants stakeholders. The budget reflects the need to engage with three RMP workgroups (Microplastics; Emerging Contaminants; and Sources, Pathways, and Loadings) as well as the Small Tributaries Loading Strategy team and the Steering Committee. We also anticipate the need to consult with the RMP’s external experts that support the three workgroups.

**Early Funds Release Request**
If this project is approved, we request early release of funds (by September 2021). This will allow the strategy to inform RMP funding decisions starting in 2022.

**Reporting**

Deliverables will include a) a draft strategy (a brief document), to be presented to the MPWG, SPLWG, and ECWG and SC in spring 2022; b) two verbal updates to STLS (fall 2021; spring 2022); and c) a final strategy document, to be completed by October 31, 2022.

**References**


Special Study Proposal:
Tire Particle/Contaminant Fate and Transport

Summary: The Tires Conceptual Model project, which was funded in 2020 and is currently underway, is identifying several key data gaps crucial to identification and design of management actions. All of these data gaps relate to release of contaminants from tire particles and their fate and transport. This project proposes to fill the highest priority of those data gaps – particle surface area measurements – and to complete related, relatively inexpensive additional tests (morphology, particle size distribution, and density) to support conducting the particle surface area measurements and to inform future monitoring and management efforts.

Results from this project are expected to determine whether tire wear particles that travel primarily through the air (smaller particles) or the particles that fall on or near the road (larger particles) have the greatest overall surface area, and thus the greatest potential to support formation and release of tire-related pollutants like 6PPD-quinone into stormwater and the Bay. This information has tremendous implications for tire-related mitigation strategies. The information will also improve interpretation of tire-related toxicity data from the scientific literature that we would like to use to support the RMP. It will also inform monitoring approaches for tire particles and tire-related contaminants.

The results from this project will have implications for both the proposed Tires Strategy and the proposed Stormwater CECs Monitoring Strategy. This project is being recommended in parallel with the Tires Strategy because it provides foundational information for the strategy, informs and improves science generated by others that we hope to use to support the RMP, and provides information that will be immediately useful to state management agencies addressing (1) pollutants that leach from rubber particles (California Department of Toxic Substances Control [DTSC]) and (2) the particles themselves (California Ocean Protection Council [OPC]).

Because tire-wear microplastics release tire-related water pollutants into stormwater, this is a cross-workgroup strategy proposal involving the Microplastics Workgroup (MPWG), the Emerging Contaminants Workgroup (ECWG), and the Sources, Pathways, and Loadings Workgroup (SPLWG). It will address MPWG, ECWG, and SPLWG management questions.

Estimated Cost: $110,000

Oversight Groups: MPWG, ECWG & SPLWG

Proposed by: Kelly Moran and Rebecca Sutton (SFEI), Jasquelin Peña (UC Davis)

Time sensitive: Yes. Provides information to support upcoming management decisions by DTSC and OPC; informs identification and evaluation of possible mitigation strategies for tire-related stormwater pollutants like 6PPD-quinone; and will inform next steps for the proposed Tires Strategy and Stormwater CECs Monitoring Strategy.
PROPOSED DELIVERABLES AND TIMELINE

<table>
<thead>
<tr>
<th>Deliverable</th>
<th>Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1. Laboratory analysis</td>
<td>Spring 2022</td>
</tr>
<tr>
<td>Task 2. Present update to the MPWG, SPLWG and ECWG</td>
<td>Spring 2022</td>
</tr>
<tr>
<td>Task 3. Semi-Annual updates to STLS</td>
<td>2022</td>
</tr>
<tr>
<td>Task 4. Draft report to the MPWG, SPLWG and ECWG</td>
<td>Summer-Fall 2022</td>
</tr>
<tr>
<td>Task 5. Final report and draft manuscript</td>
<td>December 31, 2022</td>
</tr>
</tbody>
</table>

Background

Every vehicle on the road sheds tiny particles from its rubber tires into the environment. As they disperse into the environment, these microplastic particles convey tire tread ingredients into the air, runoff, and eventually into San Francisco Bay. With funding from the Moore Foundation, the RMP, and other organizations, an SFEI study found black, rubbery particles in urban stormwater (Sutton et al. 2019). These were the most common microparticles in urban stormwater runoff. The source of these particles appears to be tires. Modeling studies indicate tire wear may be one of the top sources of microplastics to the environment globally (Boucher and Friot 2017; Kole et al. 2017; Sieber et al. 2020).

Background

Every vehicle on the road sheds tiny particles from its rubber tires into the environment. As they disperse into the environment, these microplastic particles convey tire tread ingredients into the air, runoff, and eventually into San Francisco Bay. With funding from the Moore Foundation, the RMP, and other organizations, an SFEI study found black, rubbery particles in urban stormwater (Sutton et al. 2019). These were the most common microparticles in urban stormwater runoff. The source of these particles appears to be tires. Modeling studies indicate tire wear may be one of the top sources of microplastics to the environment globally (Boucher and Friot 2017; Kole et al. 2017; Sieber et al. 2020).

Chemicals that leach from tire tread also appear in urban runoff, including in the San Francisco Bay area (Peter et al. 2018; 2020; Tian et al. 2021). One of these chemicals, 6PPD-quinone (a degradate of a tire antioxidant) causes pre-spawn mortality in wild populations of coho salmon (Tian et al. 2021).

The RMP-funded Tires Conceptual Model project currently underway identified several key data gaps crucial to identification and design of management actions. All of these data gaps relate to release of contaminants from tire particles and their fate and transport. This project proposes to fill the highest priority of these data gaps – particle surface area measurements – and to complete related, relatively inexpensive additional tests (morphology, particle size distribution, and density) to support conducting the particle surface area measurements and to inform future monitoring and management efforts.

The proposed project will answer the following critical questions:

1. Which tire wear particles - the ones that travel primarily through the air (smaller particles) or the particles that fall on or near the road (larger particles) - have the greatest overall surface area, and thus the greatest potential to support formation and release of tire-related pollutants like 6PPD-quinone into stormwater and the Bay?
2. What particle size and transport pathway should be prioritized for tire-related mitigation strategies?
3. How does the type of particle used by researchers affect interpretation of tire-related toxicity data from the scientific literature that we would like to use to support the RMP?
4. What is the best approach for sampling tire particles and tire contaminants in RMP monitoring?
The information generated by this project will allow us to identify the transport pathways of greatest importance for water quality, to better understand the potential for chemical ingredients and transformation products like 6PPD-quinone to leach from tires, and to identify the tire wear particle size range of greatest importance from the water quality perspective. It will also allow us to design any future monitoring more accurately and cost-effectively. While this information has fundamental importance and is relatively low cost to obtain, we did not identify any other plans by other scientists to obtain it.

A similar set of measurements undertaken early in the Brake Pad Partnership proved crucial to the design and success of the joint science studies that led to California’s law that nearly phases out copper in vehicle brake pads.

By quickly conducting this study and broadly sharing results, we believe the RMP investment will greatly improve the value of the other work occurring at no cost to the RMP, such as toxicity studies being undertaken at labs around the world. Without this information, we would expect study designs by others may continue to be a bit off-target from the water quality perspective (e.g., using non-representative materials in toxicity tests, focusing on particle sizes that may not be of greatest importance for water quality).

The background below explains the importance of these measurements, starting with background about tire particle sizes.

**Tire wear particle sizes and transport pathways**

Tire wear particles span a broad range of sizes, extending from tiny, primarily air-transported particles small enough to be inhaled (<10 μm) up to particles so large (>100 μm) that they deposit quickly after release. Figures 1 and 2 show tire wear particle size distributions measured (using transmission optical microscopy) in a road simulator laboratory from tires abraded by a rotating asphalt surface (Kreider et al. 2010). Figure 1 shows the tire wear particle size distribution by volume; Figure 2 shows the same distribution as a function of number of particles (irregular lines). While only a few tire wear particle size distributions have been published, multiple researchers have noted bimodal distributions and explored the differences between larger and smaller particles (Wagner et al. 2018).
Figure 1. Tire Wear Particle Size distribution (by volume) from Kreider et al. (2010). Blue lines indicate sieve sizes used in Bay Area microplastics monitoring: 125 μm (stormwater) and 355 μm (surface water). Purple line indicates air quality regulatory threshold (PM10).

Figure 2. Tire wear particle size distribution (by number of particles) from Kreider et al. 2010. Blue lines indicate sieve sizes used in Bay Area microplastics monitoring: 125 μm (stormwater) and 355 μm (surface water). Purple line indicates air quality regulatory threshold (PM10).

Specific Surface Area
Specific surface area (total surface area per unit mass) is a key indicator of potential for release and/or transformation of chemicals contained in environmental particles like tire wear debris. The greater the surface area, the greater the potential for degradate formation and chemical release from the particle.
The few published scanning electron micrograph photos of tire wear debris reveal rough, irregular surfaces, which suggests that these particles may have surface areas much higher than those on tire materials used in various tire leaching and tire toxicity research (e.g., cryomilled particles and ground whole tires used for turf infill). Clarifying these differences would allow us to better interpret information from the literature (particularly toxicity test data).

Management efforts seeking to minimize release of tire-related contaminants will be most effective if they target the particle size fraction containing the majority of the specific surface area.

Another friction-formed material, brake pad wear debris, provides an example of the importance of specific surface area. Due to its micro-roughness, brake pad wear debris has a surface area >150 times greater than most of the powdered reference materials. Hur et al. (2003) found higher copper leaching from brake wear debris containing only 10% copper than any copper-containing reference material (copper oxides, sulfides, or brass). They attributed the higher leaching (despite much lower copper content) to the higher surface area of the wear debris (31 m²/g for wear debris; 0.059-1.4 m²/g for copper-containing reference materials purchased from chemical laboratory suppliers) (Hur et al. 2003).

Surprisingly, tire wear debris specific surface area has not been reported in the literature.

**Morphology**

One line of evidence in identifying tire wear particles – and in beginning to understand their transport in stormwater runoff – involves examining particle morphology. Scanning electron micrograph (SEM) images and tomography are two ways of examining particle morphology. Morphology is a qualitative indicator of specific surface area. Because morphology can relate to the particle formation process, it may not be consistent across all tire wear particle sizes. Morphological differences in tire wear debris, if they occur, can guide the process of selecting sieve sizes to create particle size fractions for specific surface area measurements.

**Density**

Tire wear particle density has been roughly estimated (not based on direct measurements) to be in the range of 1.25-1.8 g/cm³ (Wagner et al. 2018). We were unable to identify published density measurements of tire wear particles (with or without encrustations). Density measurements can inform sampling methods to ensure tire particles are fully recovered and counted. Density will inform conceptual modeling (and possible future numeric modeling) of tire particle transport.

Knowing tire wear particle density and the most environmentally relevant size fraction would allow optimization of any future RMP tire-related monitoring to collect the particles most relevant for water quality.

**Comparison between tire wear particles and substitute laboratory test materials**

Due to the lack of availability of representativesamples of real tire wear particles, scientists have used a variety of substitute materials in studies reported in the scientific literature. Better understanding how real particles compare to these test particles (particularly how their
sizes and surface areas compare) will allow us to better interpret scientific work done by others, particularly aquatic toxicity studies.

**Study Objectives and Applicable RMP Management Questions**

The objectives of this project are:

1. To identify the tire-wear particle size fraction of greatest importance from the water quality perspective, which in turn will identify the tire particle/contaminant transport pathway of greatest importance, thereby focusing consideration of management actions.
2. To better understand the potential for chemical ingredients and degradates to leach from tire-wear particles.
3. To obtain information that will improve interpretation of sometimes conflicting scientific literature around tire particle contaminants, leachates, and aquatic toxicity.
4. To inform design of future tire particle/contaminant-related monitoring and modeling.

**Table 1. Study objectives and questions relevant to RMP MPWG management questions**

<table>
<thead>
<tr>
<th>Management Question</th>
<th>Study Objective</th>
<th>Example Information Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) How much microplastic pollution is there in the Bay and in the surrounding ocean?</td>
<td>To inform design of future tire particle/contaminant-related monitoring and modeling.</td>
<td>Modify sample collection, preparation, and analysis procedures in future microplastics monitoring to maximize recovery of tire particles and allow for more comprehensive assessment of microplastic abundance.</td>
</tr>
<tr>
<td>2) What are the health risks?</td>
<td>To obtain information that will improve interpretation of sometimes conflicting scientific literature around tire particle contaminants, leachates, and aquatic toxicity. To better understand the potential for potentially harmful chemical ingredients and degradates to leach from tire-wear particles.</td>
<td>Inform monitoring data interpretation, particularly how we use tire particle toxicity information in the literature. Improve designs of studies conducted by others (e.g., tire particle toxicity testing), making the data more useful to RMP stakeholders.</td>
</tr>
<tr>
<td>3) What are the sources, pathways, loadings, and processes leading to microplastic pollution in the Bay?</td>
<td>To identify the tire-wear particle size fraction of greatest importance from the water quality perspective, which in turn will identify the tire particle/contaminant transport pathway of greatest importance.</td>
<td>Understand whether tire-wear particles transported by air or those deposited near roads have greater potential to leach contaminants into stormwater.</td>
</tr>
</tbody>
</table>
4) Have the concentrations of microplastics in the Bay increased or decreased?  
N/A  
N/A

5) Which management actions may be effective in reducing microplastic pollution?  
To identify the tire-wear particle size fraction of greatest importance from the water quality perspective, which in turn will identify the tire particle/contaminant transport pathway of greatest importance, thereby focusing consideration of management actions.  
Identify and prioritize potential management actions appropriate for the most important tire particle size fraction.  
Develop improved conceptual models (and inform future numeric models) to predict possible reductions from various management action options.

### Table 2. Study objectives and questions relevant to RMP SPLWG management questions

<table>
<thead>
<tr>
<th>Management Question</th>
<th>Study Objective</th>
<th>Example Information Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) What are the loads or concentrations of pollutants of concern from small tributaries to the Bay?</td>
<td>To inform the design of future tire particle/contaminant-related monitoring and modeling.</td>
<td>Modify sample collection, preparation, and analysis procedures in future microplastics monitoring to maximize recovery of tire particles and allow for more comprehensive assessment of microplastic abundance.</td>
</tr>
<tr>
<td>2) Which are the “high-leverage” small tributaries that contribute or potentially contribute most to Bay impairment by pollutants of concern</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>3) How are loads or concentrations of pollutants of concern from small tributaries changing on a decadal scale?</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>4) Which sources or watershed source areas provide the greatest opportunities for reductions of pollutants of concern in urban stormwater runoff?</td>
<td>To identify the tire-wear particle size fraction of greatest importance from the water quality perspective, which in turn will identify the tire particle/contaminant transport pathway of greatest importance.</td>
<td>Identify and prioritize potential management actions appropriate for the most important tire particle size fraction.</td>
</tr>
<tr>
<td>5) What are the measured and projected impacts of management action(s) on loads or concentrations of pollutants of concern from the small</td>
<td>To identify the tire-wear particle size fraction of greatest importance from the water quality perspective, which in turn will identify the tire particle/contaminant transport pathway of greatest importance.</td>
<td>Identify and prioritize potential management actions appropriate for the most important tire particle size fraction.</td>
</tr>
</tbody>
</table>
Table 3. Study objectives and questions relevant to RMP ECWG management questions

<table>
<thead>
<tr>
<th>Management Question</th>
<th>Study Objective</th>
<th>Example Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Which CECs have the potential to adversely impact beneficial uses in San Francisco Bay?</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>2) What are the sources, pathways and loadings leading to the presence of individual CECs or groups of CECs in the Bay?</td>
<td>To identify the tire-wear particle size fraction of greatest importance from the water quality perspective, which in turn will identify the tire particle/contaminant transport pathway of greatest importance.</td>
<td>Understand whether tire-wear particles transported by air or those deposited near roads have greater potential to leach contaminants into stormwater.</td>
</tr>
<tr>
<td>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?</td>
<td>To better understand the potential for chemical ingredients and degradates to leach from tire-wear particles.</td>
<td>Identify the places in the road area and outdoor environment where tire contaminants are most likely to be released.</td>
</tr>
<tr>
<td>4) Have the concentrations of individual CECs or groups of CECs increased or decreased?</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>5) Are the concentrations of individual CECs or groups of CECs predicted to increase or decrease in the future?</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>6) What are the effects of management actions?</td>
<td>To identify the tire-wear particle size fraction of greatest importance from the water quality perspective, which in turn will identify the tire particle/contaminant transport pathway of greatest importance, thereby focusing consideration of management actions.</td>
<td>Identify and prioritize potential management actions appropriate for the most important tire particle size fraction. Develop improved conceptual models (and inform future numeric models) to predict possible reductions from various management action options.</td>
</tr>
</tbody>
</table>

**Approach**

We propose to:
(1) Examine and compare morphology and specific surface areas of black, rubbery particles collected in stormwater, tire wear debris, and other tire materials that are being used in scientific studies conducted by others.

(2) Determine the size fraction of tire wear debris that accounts for the majority of the specific surface area.

(3) Measure tire particle density.

(4) Use these data and information from the scientific literature to interpret these results.

(5) Share these insights with RMP stakeholders and the scientific community.

The particles we propose to test include:

- Tyre Collective in-laboratory road simulator and test track tire wear particles. The Tyre Collective, a start-up company developing an on-vehicle device to collect tire wear debris, will be generating tire wear particles during its product development process. Their 10% scale laboratory system using a composite formulation of 100% tread material generates wear debris from a sandpaper “road” surface (a debris generation method used by others, e.g., Kreider et al. 2010). The on-road collection system is in development, with the intent of capturing particles from several full-sized vehicle tires on a test track. These systems have the potential to capture a wide range of particle sizes, but neither are designed to provide full or perfect particle size distributions.

- Stormwater black, rubbery particles collected in conjunction with a separate grant-funded study being conducted by SFEI. (Particles from the Sutton et al. 2019 study can only be used for SEMs). These will be separated from non-rubber runoff debris via density separation. We anticipate these particles will be from the larger size fraction of the tire wear particle size distribution.

- Road surface black, rubbery particles to be collected by SFEI as part of this proposed project. The particles are planned to be swept or vacuumed off of pavement on a high-traffic road segment during the dry season (see AP-42; McKenzie et al. 2008). Subsequently, they will be separated from non-rubber road debris via density separation. Due to the collection method, these samples will likely include only the larger particles.

- Laboratory test particles of tires that are commonly used by scientists conducting tire particle toxicity tests. These are anticipated to include lab-generated tire tread particles (potentially from Washington State University and Oregon State University) and artificial turf infill particles (milled whole tires), which we plan to obtain from tire recyclers and/or collect from artificial turf fields.

We propose to work with UC Davis Professor Jasquelin Peña to conduct the following measurements:

- **Specific Surface Area** (SSA) – Brunauer–Emmett–Teller (BET) specific surface area measurements
- **Morphology** – Scanning Electron microscope (SEM) images and tomography
- **Particle Size Distribution** – Inverted phase contrast microscope
- **Density** – Bulk density (mass/volume)
We propose to work with Dr. Jasquelin Peña, Associate Professor in the Department of Civil and Environmental Engineering at U.C. Davis. Professor Peña also has a faculty scientist appointment in the Energy Geosciences Division at the Lawrence Berkeley National Laboratory. She has been working in the field of environmental and molecular geochemistry since 2001. With nearly two decades of experience applying molecular-scale science, environmental mineralogy, and biogeochemistry to investigate interfacial processes, particle structure, and surface reactivity, she has extensive experience in the proposed types of particle characterization measurements. Her laboratory owns or has access on the U.C. Davis campus to the specialized equipment needed for this work, such as the equipment necessary for specific surface area measurements and microscopic imaging.

In the initial phase of the study, we will examine particle morphology and measure particle size distributions. We intend to measure the particle size distribution in each sample via inverted phase contrast microscopy. We plan to use scanning electron microscope images and tomography to look at particle morphology. These relatively inexpensive measurements provide quick insight into the relative surface areas of the different tire particles – as well as the ability to examine the particle to determine if there is a relationship between particle size and morphology. We hypothesize that particles in different size segments are formed by different processes, such that some segments may have larger surface areas as a function of mass than other size segments. We also hypothesize that real tire-wear debris and environmental tire particles have greater specific surface area than the laboratory test particles. The morphology work will address these hypotheses.

Subsequently, based on the preliminary morphology examination and particle size distributions, we plan to divide the tire wear particles (from the Tyre Collective and perhaps from road samples) into size-based fractions to explore surface area as a function of size. We will also measure specific surface area of the particles used in laboratory studies, which will allow us to compare the lab particles to environmental tire particles.

A density-based separation process is currently used to extract tire and other microplastic particles from environmental mixtures. Because tires are denser than most microplastics, this procedure may not collect all tire particles. Surprisingly, the density of tire particles has not been specifically reported in the literature – it is usually listed as a range and often reflects tire material encrusted with road debris (which may also need to be addressed in separation procedures). We plan to measure the density of our various samples; this inexpensive test will inform our future monitoring designs. Density will be a useful input for any future modeling of tire wear particle transport.

We plan to work with Dr. Peña’s lab to prepare a report and short manuscript presenting and interpreting the results. The manuscript would be designed to be a short communication for submission to a quick-publishing journal. To maximize the value of the results, we will also present them at a scientific conference attended by researchers working on tire particle/contaminants fate, transport, and toxicity.
Budget

The following budget represents estimated costs for this proposed special study (Table 4).

Table 4. Estimated costs.

<table>
<thead>
<tr>
<th>Expense</th>
<th>Estimated Hours</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Labor</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Staff</td>
<td>300</td>
<td>$54,000</td>
</tr>
<tr>
<td>Senior Management Review</td>
<td>12</td>
<td>$3,000</td>
</tr>
<tr>
<td><strong>Direct Costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shipping/sample collection</td>
<td></td>
<td>$2,000</td>
</tr>
<tr>
<td>UC Davis (J. Peña Lab)</td>
<td></td>
<td>$51,000</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td></td>
<td>$110,000</td>
</tr>
</tbody>
</table>

Budget Justification

Labor Costs
SFEI labor will primarily be spent on data review and interpretation in the context of the relevant scientific literature; preparing the report and manuscript; obtaining and shipping samples; project management, preparing presentations for the ECWG, SPLWG, and MPWG meetings and a scientific conference; and updates for the STLS. Senior scientists will help guide the process and review interim products. Project staff hours and costs reflect the need for specialized work.

Direct Costs
Most of the UC Davis costs ($41k) are to fund a graduate student to conduct the testing and professor supervision (2 academic quarters); the remaining $10,000 will be used for specialized equipment and supplies (most of this is for the specific surface area measurements). UC Davis labor will primarily be spent on conducting SEM, tomography, BET, particle size and density measurements; sample handling, preparation, separation and storage; analyzing data with computer-based tools; and preparing sections of the report and manuscript. In addition to conducting specialized testing of tire particles, work will include trials of sample preparation methods to address extended de-gassing of rubber particles in preparation for BET measurements.

Early Funds Release Request
If this project is approved, we request early release of funds (by September 2021). This will allow information to be available in time to support upcoming management decisions by DTSC and OPC (multiple decisions anticipated between now and 2025), and to inform the development of the RMP’s proposed Tires Strategy and Stormwater CECs Monitoring Strategy.
Reporting

Deliverables will include a) a progress update presentation, to be presented to the MPWG, SPLWG, and ECWG in spring 2022; b) a draft report to be provided to the MPWG, SPLWG, and ECWG in summer or fall 2022; and c) a final report and draft manuscript (a brief article aimed at a quick-publish journal), to be completed December 31, 2022. The project budget includes quarterly verbal updates to the STLS and a scientific conference presentation to encourage others (whose work will be useful but will not be funded by the RMP) such that they can consider study results when designing future scientific studies.

References


