

Toxics in Aquatic Life Implementation Strategy Research Agenda Update 2024/2025

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1. INTRODUCTION

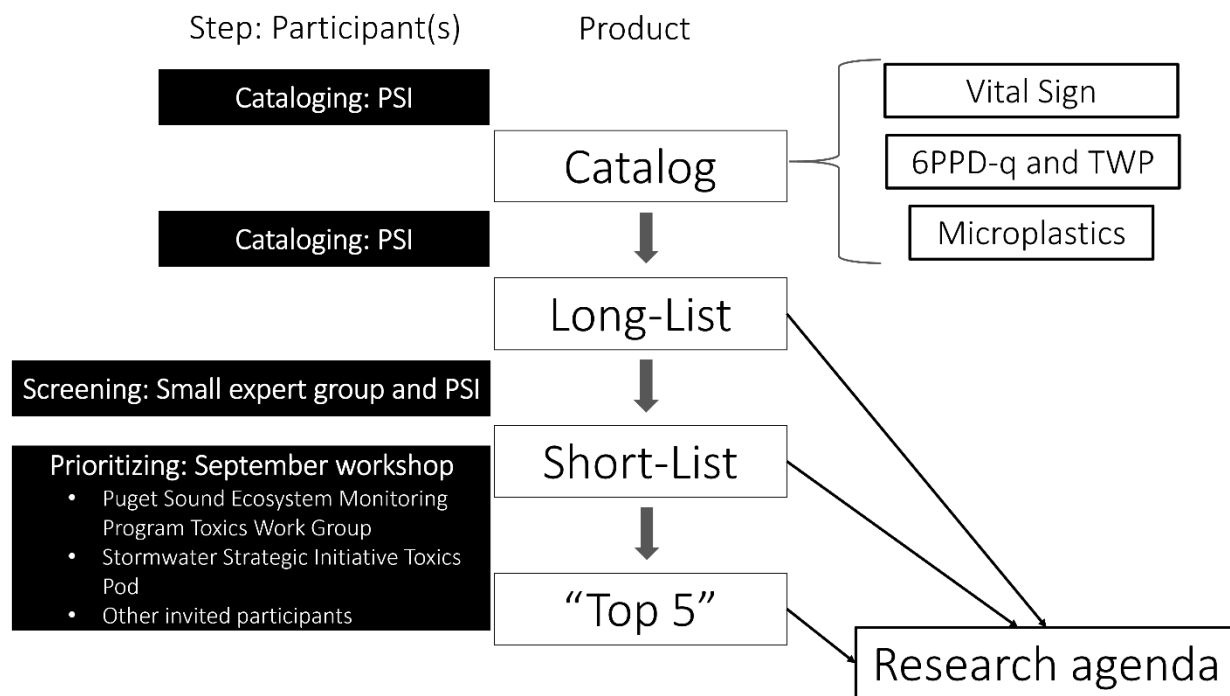
In 2019, the University of Washington Puget Sound Institute (PSI) supported development of a research and monitoring agenda to address key uncertainties in the [Toxics in Aquatic Life \(TIAL\) Implementation Strategy](#) (formerly Toxics in Fish (TIF)), a recovery plan in the Puget Sound National Estuary Program which aims to decrease chemical contamination in fish, as measured by the [Puget Sound TIAL Vital Sign indicators](#). PSI asked regional toxics experts to identify priority knowledge gaps based on the extent to which they were barriers to management, planning, and activities for the Implementation Strategy. The resulting uncertainties comprised a regional research agenda on chemical pollution in Puget Sound (described in Chapter 7 of the [TIAL Implementation Strategy](#)).

PSI documented the 2019 toxics research agenda in its [Grand Uncertainties Matrix \(GUM\)](#), a database of regional research priorities for Implementation Strategies. In 2024, PSI and the Stormwater Strategic Initiative team recognized a need to update the toxics research agenda given research progress and new research questions from the preceding five years. This report describes the development of an updated toxics-related research agenda, in coordination and engagement with toxics experts. The research agenda includes 17 top research priorities about topics such as biomarkers for chemical exposure monitoring, tire chemical effects on organisms (ITRC, 2024), and microplastics distribution.

2. METHODOLOGY

PSI generally utilized a multi-step process ([Figure 1](#)): PSI cataloged toxics uncertainties from various sources, PSI and regional experts screened (some) uncertainties for relevance to the Implementation Strategy, and PSI asked additional experts and stakeholders to prioritize uncertainties based on importance to the Implementation Strategy. As described below, these steps varied for three topical lists of uncertainties related to microplastics, 6PPD-Q and tire wear particles, and the TIAL Vital Sign.

Figure 1. Research agenda development process (TWP = tire wear particles)



2.1 CATALOGING

PSI iteratively collated scientific toxics uncertainties from workshop documents and other sources ([Table 1](#)) and reviewed the resulting list. PSI organized uncertainties by topic and combined similar or replicate uncertainties. PSI also developed (with input from the experts in [Table 2](#)) research themes that characterize uncertainties from the 2019 research agenda and the new catalog.

Table 1. Sources of potential new uncertainties cataloged

Source	Source Type	Source Date
Where the rubber meets the road: Emerging environmental impacts of tire wear particles and their chemical cocktails (Mayer et al., 2024)	Pre-proof journal article	2024
Conversation with Rhea Smith (Ecology) (R. Smith, personal communication, March 15, 2024)	Conversation with expert	2024
Stormwater Strategic Initiative (SIL) Toxics Pod 2024 Investment Recommendations (D. Bilhimer, personal communication, July 22, 2024)	Government/stakeholder spreadsheet	2024
Conversation with Maggie Taylor (Nooksack Indian Tribe) (M. Taylor, personal communication, July 23, 2024)	Conversation with expert	2024
Seattle Aquarium Microplastics and Marine Debris Workshop (Discussion of uPlastics in the Environment and Protocols for uPlastic ID (Q&A), 2023)	Workshop document	2023
Focus on: Monitoring 6PPD-q in the environment (Flores, 2023) (PSI reviewed this source but did not identify any uncertainties from this source for the catalog.)	Report	2023
What We Know: 6PPD and 6PPD-quinone (Interstate Technology Regulatory Council, 2023)	Report	2023
PNAMP Fish Monitoring Work Group Tech Talk by Nat Scholz: An update on NOAA-F stormwater science in Puget Sound (Pacific Northwest Aquatic Monitoring Partnership, 2023)	Research talk	2023
Salish Sea Marine Survival Project Transboundary Workshop 2023 (Salish Sea Marine Survival Project, 2023)	Workshop document	2023
6PPD Washington State interagency webinar follow-up (State of Washington Department of Ecology et al., n.d.)	Report	2023
Collaborative Innovation Forum: Functional Substitutes to 6PPD in Tires Meeting Report (Sustainable Chemistry Catalyst (University of Massachusetts Lowell), 2023)	Meeting report	2023
NWIFC 2023 Annual Report (Treaty Tribes in Western Washington, 2023)	Report	2023

Source	Source Type	Source Date
Stormwater Strategic Initiative Lead Fall 2023 Wastewater Treatment and Onsite Sewage Systems Workshops (F. Bothfeld, personal communication, January 29, 2024)	Workshop document	2023
6PPD Alternatives Assessment Hazard Criteria (Washington State Department of Ecology, 2023a) (PSI reviewed this source but did not identify any uncertainties from this source for the catalog.)	Report	2023
Focus on: Reducing Sources of 6PPD (Washington State Department of Ecology, 2023b)	Report	2023
Responsiveness Summary: 6PPD Hazard Criteria (Washington State Department of Ecology, 2023c)	Report	2023
Quality Assurance Project Plan: Monitoring of tire contaminants in coho salmon watersheds (Smith, 2023)	Report	2023
Focus on: Best Management Practices for 6PPD-q (Water Quality Program, 2023) (PSI reviewed this source but did not identify any uncertainties from this source for the catalog.)	Report	2023
6PPD in Road Runoff Assessment and Mitigation Strategies (Environmental Assessment Program & Water Quality Program, 2022)	Report	2022
Stormwater Treatment of Tire Contaminants Best Management Practices (BMP) Effectiveness (Navickis-Brasch et al., 2022)	Report	2022
Puget Sound Federal Task Force Action Plan 2022-2026 (Puget Sound Federal Task Force, 2022)	Report	2022
Stormwater Strategic Initiative Lead 2021 Toxics Workshops (Stormwater Strategic Initiative (2021a) and documents contained therein (e.g., Day, 2021; Harper, 2021; King-Heiden, 2021; Kolodziej & McIntyre, 2021; McIntyre & Kolodziej, n.d.; Senter, 2021; Stormwater Strategic Initiative 2021b; 2021c; 2021d; West, 2021); Toxics in Aquatic Life – Key Messages 2021.04.26_FINAL document (internal SIL file) (C. A. James, personal communication, October 3, 2023))	Workshop documents	2021

Source	Source Type	Source Date
Hazardous Waste and Toxics Reduction Program Technical Memo (Washington State Department of Ecology & Manahan, 2021)	Report	2021
2020 State of Our Watersheds (Treaty Tribes in Western Washington, 2020)	Report	2020
2019 Tribal Habitat Strategy (<i>gʷəḏʔadad</i>) (Northwest Indian Fisheries Commission, 2019)	Report	2019
Recommended Priorities for Salmon Recovery and the Chinook Implementation Strategy (Tribes, 2017)	Report	2017

Table 2. Toxics experts involved in cataloging (theme development) and screening steps

Name	Affiliation
Dustin Bilhimer	Stormwater Strategic Initiative Lead, Washington Department of Ecology
Jenée Colton	King County
Louisa Harding	Washington Department of Fish and Wildlife
William Hobbs	Washington Department of Ecology
Andy James (member of PSI research agenda development team)	University of Washington Tacoma
Ani Jayakaran	Washington State University
Sandra O'Neill	Washington Department of Fish and Wildlife

PSI then divided the catalog into three lists: 6PPD-Q, microplastics, and Vital Sign (all other uncertainties relevant to the TIAL Implementation Strategy). TIAL Implementation Strategy uncertainties were previously identified and prioritized before the discovery of 6PPD-Q was published (Tian et al., 2021). PSI separated 6PPD-Q uncertainties in this 2024/2025 effort because of the high quantity of uncertainties and research about 6PPD-Q, and given other existing efforts to prioritize 6PPD-Q research (including ITRC (2024)). PSI separated microplastics uncertainties in order to draw upon unique expertise specific to microplastics. Though microplastics are absent from the [TIAL Implementation Strategy](#), the Stormwater Strategic Initiative considers microplastics to be CECs and relevant to the Implementation

Strategy (D. Bilhimer, personal communication, June 17, 2024).¹ PSI undertook the remainder of the cataloging process, and screening and prioritization, slightly differently for the three lists.

2.1.1 VITAL SIGN

To organize related Vital Sign uncertainties and assess relevance, PSI categorized uncertainties by research themes, strategies from the TIAL Implementation Strategy, and Puget Sound Ecosystem Monitoring Program (PSEMP) Key Messages² about the TIAL Vital Signs.

PSI iteratively reviewed and refined the Vital Signs catalog to produce a consolidated long-list. Rationales for omitting an uncertainty from the long-list included:

- Already in GUM
- PSI merged uncertainty with similar uncertainties in catalog
- Unrelated to toxics
- Irrelevant to TIAL Implementation Strategy (e.g., uncertainties about contaminants or media that are not the focus of the Implementation Strategy)
- Not a specific uncertainty (e.g., uncertainties that lacked specificity)
- Answer is known
- Not an uncertainty (e.g., statements that are, or recommend, actions rather than research)
- Scientifically irrelevant (i.e., uncertainties that were contradictory (D. Bilhimer, personal communication, July 22, 2024) or that proposed methods mismatched to the topic

¹ The 2019 TIAL research agenda (documented in the [GUM](#)) included one microplastics-related uncertainty that was presented in the Starter Package of the [TIAL Implementation Strategy](#) development process.

² See the [Toxics in Aquatic Life Vital Sign](#) for more information and the public 2021 key messages; PSI used draft updated key messages for the present work (C. A. James, personal communication, April 22, 2024).

(Stormwater Strategic Initiative, 2021b). In both of these cases, elements of the excluded uncertainties were also covered by other uncertainties.)

2.1.2 6PPD-Q

PSI cross-referenced the 6PPD-Q catalog with uncertainties in a preliminary version of the [2024 Interstate Technology & Regulatory Council report](#) describing the current scientific understanding about 6PPD/6PPD-Q (with a national lens) (ITRC, 2024), to explore the possibility of using the report as a vetted list of 6PPD-Q uncertainties.

2.1.3 MICROPLASTICS

PSI cross-referenced the microplastics catalog with information in a [2024 presentation by Elise Granek](#) (2024) and two recent microplastics reports (Iwanowicz et al., 2024; Paterson et al., 2024). PSI also identified uncertainties from Granek (2024) and Paterson et al. (2024) and categories of uncertainties from Iwanowicz et al. (2024) that were not in the microplastics catalog.

PSI developed the following microplastics research themes based on uncertainties from Granek (2024), Iwanowicz et al. (2024), Paterson et al. (2024), and the microplastics catalog:

- Field methods and protocols
- Analysis methods and protocols
- Microplastics levels (various media)
- Fate, pathways, and sources
- Ecotoxicity
- Dynamics between microplastics and CECs
- Management effectiveness
- Regulation options and necessary data

- Alternatives
- Other
- Particle and chemical characterization
- Interactions with organisms
- Transport (Environmental Protection Agency, 2024)

PSI assigned one or two of the above themes to each uncertainty in the microplastics catalog. After developing the research themes PSI did not further use the microplastics catalog, instead choosing to source microplastics uncertainties directly from experts (described below).

2.2 SCREENING

2.2.1 VITAL SIGN

PSI convened experts ([Table 2](#)) on August 20, 2024 to produce a short-list of critical Vital Sign uncertainties by screening the Vital Sign long-list for relevance to the TIAL Implementation Strategy. Experts applied a 1-3-5 ranking to the long-list uncertainties based on their relevance to the TIAL Implementation Strategy: 5 = critical, 3 = could help management, 1 = not relevant.³

PSI synthesized rankings and input and used the following principles to identify uncertainties for the short-list:

- Add to short-list:
 - Uncertainties that received all or majority 5s
 - Uncertainties the expert group agreed to include

³ In some cases, experts used rankings of 2 or 4 instead of the 1, 3, or 5 ranking options.

- Omit from short-list:
 - Uncertainties that received all 1s, blanks, and/or question marks⁴
 - Uncertainties the expert group agreed not to include
 - Uncertainties that received no 5s

Twenty-four uncertainties did not meet these principles, so PSI discussed them internally and decided on short-list uncertainties based on expert discussion, overall rankings, expert notes, and/or PSI's professional judgement. PSI edited some uncertainties and amended some of the initial short-list allocations that had been originally decided using the above principles. PSI assigned one uncertainty⁵ directly to the research agenda (top priority) because more than one research effort currently addresses it.

PSI sent screening results to the expert group to invite questions or further discussion. Before prioritization, PSI slightly edited some uncertainties and added the seven 2019 top toxics research priorities to the short-list so new uncertainties could be prioritized relative to the previous top priorities.

2.2.2 6PPD-Q

Instead of using the 6PPD-Q catalog, PSI adapted the uncertainties from the preliminary version of ITRC (2024) by combining related uncertainties and editing some uncertainties to produce the 6PPD-Q short-list. Given the numerous expert contributors to ITRC (2024), PSI considered these uncertainties adequately screened and not requiring additional review before prioritization.

⁴ Some screening experts did not rank all uncertainties.

⁵ Uncertainty: "Where are the geographic priorities for stormwater retrofits necessary to intercept road-derived toxics (6ppd, PAHs, etc.) to protect salmonid populations in Puget Sound (i.e. coho and chinook), especially important prey populations for SRKW?" (GUM ID TIF 65 in [Appendix Table A1](#))

2.2.3 MICROPLASTICS

PSI consulted microplastics experts directly to produce a top 5 list of microplastics research and monitoring priorities (described below), so PSI did not screen microplastics uncertainties.

2.3 PRIORITIZATION

2.3.1 VITAL SIGN AND 6PPD-Q

At an in-person workshop on September 12, 2024, PSI solicited feedback on and prioritization of the Vital Sign and 6PPD-Q short-lists from 36⁶ toxics experts, including members of the PSEMP Toxics Work Group and the Stormwater Strategic Initiative Toxics Pod.

In the first prioritization session participants discussed, provided feedback on, and prioritized uncertainties on the Vital Sign short-list in four self-selected stations (each with identical lists). Participants suggested additional uncertainties, and prioritized uncertainties by voting for five uncertainties they thought most important in response to the following questions:

- Which of the following questions/uncertainties are critical to the implementation of the Toxics in Fish strategies? Which are barriers?
Critical = gap in knowledge inhibits our ability to plan or implement
- Does this lack of knowledge (research need) prevent management and regulatory action to protect aquatic life and consumers from toxics?

Participants could vote for suggested modifications to uncertainties.

In the second session, participants discussed, provided feedback on, and prioritized uncertainties on the 6PPD-Q short-list using a similar approach to the Vital Signs session. Participants worked in three self-selected stations and could concurrently provide feedback on microplastics uncertainties (see below) in a fourth station.

⁶ This includes three toxics experts who were discussion facilitators at workshop stations but also engaged in the activity.

After the workshop, PSI transcribed and reviewed comments, votes, and participant-suggested new uncertainties. PSI edited some uncertainties in response to feedback and for clarity (which involved combining or dividing some uncertainties). In general, PSI did not incorporate suggested edits if they: would result in a duplicative uncertainty, were irrelevant to the Implementation Strategy, or would change the focus of an existing uncertainty. PSI summarized comments from participants in notes (see [Appendix Table A1](#), [Appendix Table A2](#), and [Appendix Table A3](#)). Where applicable, in notes PSI also described the focus needed for an uncertainty to be relevant to the TIAL Implementation Strategy (e.g., species remit, human health (see below), etc.). PSI also summarized screening expert feedback in notes for Vital Sign uncertainties.

PSI added participant-suggested uncertainties to the Vital Sign or 6PPD-Q research agendas unless the uncertainties:

- Were duplicative (including with 2019 research agenda);
- Already have known answers ([Appendix Table A4](#)); or
- Were outside the scope of the TIAL Implementation Strategy ([Appendix Table A4](#)).

In some cases, PSI described participant-suggested uncertainties in summary notes for related uncertainties instead of adding to the research agenda.

For merged uncertainties, PSI combined votes from the separate uncertainties. For votes cast on comments, PSI added these to the other votes cast on the uncertainty even if the comments suggested edits (unless comments led to the addition of a separate new uncertainty, or comment votes applied to multiple uncertainties; for the latter, PSI split and distributed the votes which occasionally produced non-integer vote totals). PSI allocated the following priority levels to Vital Sign and 6PPD-Q short-list uncertainties (separately):

- Top = five (6PPD-Q) or six (Vital Sign) uncertainties with the most votes
- High = uncertainties with the next four (6PPD-Q) or six (Vital Sign) most votes after the top priorities. Top and high priority uncertainties comprised a top 9 or top 12 priority list for 6PPD-Q and Vital Sign, respectively.

- Medium = uncertainties with three or more votes and not in the top 9 (6PPD-Q)/top 12 (Vital Sign)
- Low = uncertainties with two or fewer votes

To the Vital Signs research agenda PSI also added long-list uncertainties not on the Vital Signs short-list (based on screening). PSI assigned them medium (if they received at least one 5 ranking during screening) or low (remaining uncertainties) priority. PSI minorly edited some long-list uncertainties for clarity.

2.3.2 MICROPLASTICS

PSI convened four microplastics experts ([Table 3](#)) on August 28, 2024 and asked them to share what they thought are important microplastics research topics for Puget Sound. PSI used the following modified subset of the microplastics research themes (from Granek (2024), Iwanowicz et al. (2024), Paterson et al. (2024), and the microplastics catalog) to prompt discussion:

- Sampling and analytical methods and protocols
- Fate, pathways, and sources
- Ecotoxicity (including particulates and plastic-associated contaminants)
- Management effectiveness
- Regulation options and necessary data
- Safer/green alternatives for additives
- Other

Experts generated a list of uncertainties about microplastics and then voted for the three uncertainties they thought were most important using the [EasyRetro platform](https://easyretro.io/) (<https://easyretro.io/>) and provided additional feedback.

Table 3. Microplastics experts involved in identifying microplastics research priorities for Puget Sound

Name	Affiliation
Elise Granek	Portland State University
Julie Masura	University of Washington Tacoma
Ezra Miller	San Francisco Estuary Institute
Andrew Spanjer	United States Geological Survey

The five uncertainties with the most votes were also the only ones that received any votes, providing a clear top 5 list of microplastics priorities. PSI requested feedback on this top 5 at the prioritization workshop on September 12, 2024. Workshop participants also suggested additional uncertainties.

PSI transcribed and reviewed comments, votes⁷, and participant-suggested new uncertainties from the September workshop using the same process as for Vital Sign/6PPD-Q. PSI ultimately did not edit the top 5 microplastics uncertainties based on workshop feedback.

PSI added to the microplastics research agenda the top 5 uncertainties, other uncertainties generated by microplastics experts in the August meeting (except for those that were actions or value questions rather than uncertainties), and workshop participant-suggested new uncertainties. PSI allocated the following priority levels to microplastics uncertainties:

⁷ PSI did not ask September workshop participants to cast votes on microplastics uncertainties, but some participants cast votes nonetheless. PSI did not consider September workshop votes when allocating priority levels to any microplastics uncertainties.

- Top = five uncertainties that received the most votes from the microplastics experts in the August meeting (top 5)
- High = two additional uncertainties identified by the microplastics expert group in the August meeting
- No priority = uncertainties suggested by participants in the September workshop (since these were not officially voted upon for prioritization)

2.3.3 HUMAN HEALTH

September workshop participants suggested modifying several Vital Sign and 6PPD-Q uncertainties to include human health impacts from, or exposure to, toxic contaminants. PSI did not edit uncertainties to incorporate human health topics outside the scope of the TIAL Implementation Strategy (which covers impacts on humans solely through consumption of aquatic species), but lists the pertinent uncertainties in [Appendix Table A5](#) for reference. A few 6PPD-Q uncertainties (also listed in [Appendix Table A5](#)) cover human health topics outside the scope of the Implementation Strategy and are retained in the research agenda because PSI did not remove these uncertainties before the September workshop.

2.3.4 CROSS-TOPIC PRIORITIZATION

To quickly capture expert opinion on relative prioritization among the three uncertainty list topics, PSI also asked September workshop participants: If you have \$100 to spend across vital signs uncertainties, 6ppd-q, and microplastics, how would you spend it? PSI transcribed responses and identified the median hypothetical value allocated to each topic.

3. RESULTS

The full lists of uncertainties in the research agenda, including votes and feedback from workshop participants, are provided in [Appendix Table A1](#), [Appendix Table A2](#), and [Appendix Table A3](#). In addition, the final research agenda as well as the full catalog, long-list, and short-

lists are available in the [2025 TIAL Research Agenda spreadsheet](#) for access using Microsoft Excel (link directly downloads Microsoft Excel file).

3.1 VITAL SIGN

The Vital Sign catalog contained 145 uncertainties, the long-list contained 59, and the short-list contained 27 (34 including the seven 2019 top priorities).

The final Vital Sign research agenda consists of 71 uncertainties: 33 from the short-list, six from the September workshop, and 32 others from the long-list. Seven uncertainties are top Vital Sign priorities ([Table 4](#)), six uncertainties are high, 21 are medium, and 37 are low priorities ([Appendix Table A1](#)).

Table 4. Top 7 priority TIAL Vital Sign uncertainties

What biomarkers (cellular, molecular, genetic) can be used to monitor effects of chemical exposure in various organisms (fish, shellfish, etc.)?
What is the cumulative impact of toxics, mixtures, and other stressors (e.g., temperature, pathogens) on species, including salmon?
Are biosolids a significant source of CECs, including PFAS, to the surface water/ground water/Puget Sound?
What are the priority compounds in stormwater? (top priority uncertainty from 2019)
What are the primary loading pathways for toxic contaminants, including CECs, to "enter the Sound (e.g., runoff/CSOs vs. post-processing sewage [outfalls])" (Stormwater Strategic Initiative, 2021b, p. 1)
What are the cumulative effects of pharmaceuticals, CECs, and legacy contaminants (PCBs, PAHs, PBDEs, etc.) exposures on species in Puget Sound? (top priority uncertainty from 2019)
Where are the geographic priorities for stormwater retrofits necessary to intercept road-derived toxics (6ppd, PAHs, etc.) to protect salmonid populations in Puget Sound (i.e. coho and chinook), especially important prey populations for SRKW?

3.2 6PPD-Q

The 6PPD-Q short-list contained 22 uncertainties adapted from ITRC (2024).

The final 6PPD-Q research agenda consists of 26 uncertainties: 21 from the short-list and five from the September workshop ([Appendix Table A2](#)). Two uncertainties from the workshop may have been suggested as microplastics uncertainties instead ([Appendix Table A2](#)).

Five uncertainties are top priorities ([Table 5](#)), four uncertainties are high, seven are medium, and ten are low priorities ([Appendix Table A2](#)).

Table 5. Top 5 priority 6PPD-Q uncertainties (adapted from ITRC (2024))

Investigate sublethal impacts of tire-related chemicals to both acutely-affected and tolerant species, and implications for survival.
Identify additional product sources of 6PPD, 6PPD-q, and other PPDs (e.g., tire reefs, crumb-rubber, indoor mats, etc.). Study the toxicity, degradation products, and occurrence of other PPDs.
Identify safe alternatives to 6PPD (either within the PPD chemical family or non-PPD alternatives) that provide required antiozonant, antioxidant, and anti-fatigue protection to tires. What are the toxicity, transformation products, and environmental trade-offs of these alternatives?
Investigate toxicity of 6PPD-Q in various species, and across trophic levels, including microbial communities, algae, aquatic plants, terrestrial organisms (e.g., amphibians, reptiles, birds), mammals, and humans.
What is the effectiveness of stormwater control measures (SCMs) such as street sweeping, catchment/management, biochar-enhanced SCMs, and permeable pavement, across various land uses at reducing 6PPD-q loadings? Does air transport impact effectiveness?

3.3 MICROPLASTICS

The microplastics catalog contained 102 uncertainties.

The final microplastics research agenda consists of 11 uncertainties: five top priorities ([Table 6](#)), two high priorities, and four new uncertainties not assigned a priority level ([Appendix Table A3](#)).

Table 6. Top 5 priority microplastics uncertainties

What is the relative distribution of microplastic sources (e.g., fishing gear, clothes, etc.) and the primary pathways (e.g., stormwater, aerial deposition, in water activity, etc.) of microplastics in Puget Sound?
What is the distribution of microplastics among different matrices (e.g., sediment, fish, water) in Puget Sound?
Develop/adopt a standard analytical method/protocol for microplastics in Washington State, including a focus on tire wear particles.
What is the toxicology of microplastic fibers across a range of types, sizes, and species?
How effective are stormwater BMPs (e.g., trash capture devices) at removing microplastics?

3.4 CROSS-TOPIC PRIORITIZATION

29 participants submitted responses to the \$100 question for prioritization among the three research topics. Based on the 22 participant responses which contained a numerical value for at least one of the topics, the median hypothetical amounts allocated to each topic were \$70 for Vital Sign (range \$0-100), \$20 for 6PPD-Q (range \$0-50), and \$10 for microplastics (range \$0-50) (all numbers rounded to the nearest \$10).

4. DISCUSSION

4.1 UPDATED RESEARCH AGENDA

The research and monitoring priorities for the TIAL Vital Sign, 6PPD-Q, and microplastics comprise an update to a regional toxics research agenda for Puget Sound. This research agenda builds on ITRC (2024) by prioritizing among numerous 6PPD-Q uncertainties identified in that national work. Top 6PPD-Q priorities include research on environmental impacts, alternative chemicals, sources, and stormwater best management practices (BMPs) (Navickis-Brasch et al., 2022). The microplastics research agenda highlights the need for fundamental research on this topic in Puget Sound to establish suitable analytical methods, understand how microplastics affect organisms, and learn where microplastics are found and originate in Puget Sound. Participating experts indicated that microplastics merit some attention in Puget Sound,

comprising a smaller proportion (~10% of overall funding) than Vital Sign and/or 6PPD-Q research.

The Vital Sign research agenda captures mostly new priorities, including new questions about pathways, sources, priority sites, the combination of chemical and non-chemical stressors, and the use of biomarkers in monitoring. Of the seven top toxics research priorities from 2019, two were top priorities again ([Table 4](#)), and the rest were deprioritized (two to high, one to medium, and two to low priority). Notably, one 2019 top uncertainty deprioritized to low priority (“Which CECs should be prioritized?”) was addressed in a recent regional study on CEC prioritization (James et al., 2023). In contrast, participants reiterated the top priority of a similar 2019 uncertainty about chemical prioritization for stormwater specifically; one workshop participant noted the uncertainty is answered but may need to be studied on an ongoing basis.

An important consideration in the prioritization of the toxics research agenda is that most new Vital Signs and 6PPD-Q uncertainties suggested by workshop participants (10 out of 11) are low priorities. These results may be due to the workshop format; since suggestions and voting occurred in stations, all participant-suggested new uncertainties were not reviewed and voted upon by all participants like the short-list uncertainties were.

4.2 NEXT STEPS

Workshop participants commented that answers may be known for at least one Vital Sign uncertainty in each priority level. The 6PPD-Q research agenda received far fewer comments about uncertainties being answered, and workshop participants pointed to existing research for two microplastics uncertainties. A future review of the scientific literature may determine if, and to what extent, uncertainties have been addressed. Participants also suggested research ideas for at least one Vital Sign uncertainty in each priority level, which can aid in the next step to resolve uncertainties: scoping into research projects.

PSI plans to communicate this research agenda to the Stormwater Strategic Initiative to inform their upcoming funding decisions related to the TIAL Implementation Strategy. PSI will add the 2025 research agenda ([Appendix Table A1](#), [Appendix Table A2](#), and [Appendix Table A3](#)) to the

[GUM](#), to accompany the 2019 research agenda. PSI will update the priority level of 2019 top priority uncertainties in the GUM. PSI also intends to communicate the research agenda to the broader Puget Sound science and recovery community to inform other research funding opportunities.

5. REFERENCES

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APPENDIX

[Appendix Table A1](#) contains the final Vital Sign research agenda, which is comprised of uncertainties from the long-list and from expert suggestions at the September 2024 workshop. These final uncertainties include edits based on feedback from screening experts and September 2024 workshop participants. Prioritization is based on expert group screening (August 2024) and expert voting at the September 2024 workshop. PSI edited some uncertainties, so the final version of the uncertainty (Uncertainty column) may differ from the original uncertainty/uncertainties as stated in the source(s).

Appendix Table A1. Puget Sound Toxics Vital Sign Research Agenda

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
What biomarkers (cellular, molecular, genetic) can be used to monitor effects of chemical exposure in various organisms (fish, shellfish, etc.)?	TIF 61	Prioritization workshop participants (September 2024) suggested employing transcriptomics or other non-targeted approaches, asked whether effects are incorporated into existing mussel monitoring, and expressed interest in the development of biomarkers or toxicity thresholds specifically for shellfish to support the caged mussels indicator. Workshop participants also suggested investigating biomarkers in humans. Humans are not added to the uncertainty text because uncertainties should be focused on the TIAL Implementation Strategy which addresses human health exclusively via consumption of aquatic life.	16	Top	Pacific Northwest Aquatic Monitoring Partnership (2023)	9/12/2024 Toxics Workshop

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
What is the cumulative impact of toxics, mixtures, and other stressors (e.g., temperature, pathogens) on species, including salmon?	TIF 62	A prioritization workshop participant (September 2024) noted connections with uncertainty TIF 92 and possibly TIF 15. In addition, workshop participants noted the importance of studying salmon habitat stressors, environmental impacts, and temperature (though there was uncertainty about how exactly to deal with temperature change). Workshop participants noted that toxicity should be studied in organisms under stress, and that location will matter for the answer to this uncertainty. Screening experts (August 2024) expressed interest in dividing the original long-list uncertainty into two: relative impacts (comparison between stressors) and cumulative impacts (combination of stressors, which matters more). Experts also pointed to the Salish Sea Survival synthesis (Salish Sea Marine Survival Project, 2023?) as a source of information and pointed out the relevance of WET testing for chemical combinations. PSI will soon summarize this research (and how it addresses the uncertainty) in a GUM Research Note.	10	Top	Pacific Northwest Aquatic Monitoring Partnership (2023); Puget Sound Federal Task Force (2022); Salish Sea Marine Survival Project (2023); Tribes (2017)	9/12/2024 Toxics Workshop
Are biosolids a significant source of CECs, including PFAS, to the surface water/ground water/Puget Sound?	TIF 63	A prioritization workshop participant (September 2024) noted this uncertainty is connected to uncertainty TIF 76. A workshop participant expressed interest in whether biosolids are a source of legacy contaminants. Screening experts (August 2024) specified the need for research on biosolid pathways and CEC groundwater fate.	10	Top	Stormwater Strategic Initiative Lead Fall 2023 Wastewater Treatment and Onsite Sewage Systems Workshops (F. Bothfeld, personal communication, January 29, 2024)	9/12/2024 Toxics Workshop

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
What are the priority compounds in stormwater? (2019 top priority uncertainty)	TIF 17	Prioritization workshop participants (September 2024) noted that this uncertainty has been answered and suggested noting the need to conduct ongoing work to update prioritization. Workshop participants suggested adding text about contaminant concentration and flow; this is not added to the uncertainty because concentration measurements are already implied in the uncertainty as written and flow is addressed in uncertainty TIF 64 about pathways. Workshop participants suggested connections with uncertainties TIF 93, TIF 64, TIF 37, TIF 24, and TIF 26.	9	Top	GUM (Starter Package)	9/12/2024 Toxics Workshop
What are the primary loading pathways for toxic contaminants, including CECs, to "enter the Sound (e.g., runoff/CSOs vs. post-processing sewage [outfalls])" (Stormwater Strategic Initiative, 2021b, p. 1)	TIF 64	A prioritization workshop participant (September 2024) noted that uncertainties TIF 64 and TIF 24 are comparable; TIF 24 is now edited to focus on sources rather than pathways. In addition, workshop participants suggested specific pathways: wastewater, commercial, consumer products, industry, open ocean, and stormwater. For the latter pathway, an Ecology study is cited (no details on which one); PSI will soon summarize this research (and how it addresses the uncertainty) in a GUM Research Note. Workshop participants also asked specifically about pathways for microplastics, suggested improving estimates of loading in Puget Sound, and suggested using effects-based monitoring of pathways as part of research on hotspots. Screening experts (August 2024) disagreed internally on the extent to which this uncertainty has been answered for different groups of contaminants.	8	Top	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b; 2021c); Tribes (2017)	9/12/2024 Toxics Workshop

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
What are the cumulative effects of pharmaceuticals, CECs, and legacy contaminants (PCBs, PAHs, PBDEs, etc.) exposures on species in Puget Sound? (2019 top priority uncertainty)	TIF 15	Prioritization workshop participants (September 2024) suggested using effects-based monitoring and expertise from modelers to answer this uncertainty, and suggested studying humans. Humans are not added to the uncertainty text because uncertainties should be focused on the TIAL Implementation Strategy which addresses human health exclusively via consumption of aquatic life. Participants expressed that this uncertainty is more unknown for non-fish species. Participants also suggested possible connections with uncertainties TIF 92 and TIF 62.	8	Top	GUM (Starter Package)	9/12/2024 Toxics Workshop
Where are the geographic priorities for stormwater retrofits necessary to intercept road-derived toxics (6ppd, PAHs, etc.) to protect salmonid populations in Puget Sound (i.e. coho and chinook), especially important prey populations for SRKW?	TIF 65	Screening experts (August 2024) noted that this uncertainty is currently being studied, and expressed that research on this uncertainty should continue.	n/a	Top	Stormwater SIL Toxics Pod 2024 Investment Recommendations (D. Bilhimer, personal communication, July 22, 2024)	8/2024 Screening

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
What are the impacts on human health (i.e. poor health, disease) of contaminants of emerging concern through consumption?	TIF 66	Prioritization workshop participants (September 2024) suggested studying epidemiological impacts. Workshop participants also suggested expanding the uncertainty to address additional human exposure pathways, OneHealth, additional species such as southern resident killer whales, and legacy contaminants, and noted that understanding CEC impacts would be even harder for humans than for fish yet such work could motivate increased concern from the public about toxic pollution. Additional human exposure pathways and OneHealth are not added to the uncertainty text because uncertainties should be focused on the TIAL Implementation Strategy which addresses human health exclusively via consumption of aquatic life. Screening experts (August 2024) indicated the need for effects thresholds/benchmarks for aquatic species and humans.	7	High	Stormwater SIL Toxics Pod 2024 Investment Recommendations (D. Bilhimer, personal communication, July 22, 2024)	9/12/2024 Toxics Workshop

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
What is the effectiveness of advanced wastewater treatment types at removing CECs and what are the co-benefits/costs of nutrient (N or P specifically) removal technologies for treatment of toxics?	TIF 67	Prioritization workshop participants (September 2024) noted connections among uncertainties #19, #20, #21, and #22 (workshop IDs); #19 and #22 (workshop IDs) are now merged into TIF 67, and #20 and #21 (workshop IDs) are now merged into TIF 68. Participants also asked for specificity about the definition of cost and expressed that there is some knowledge about effectiveness. For this uncertainty, cost is defined as the expense of treating wastewater. Screening experts (August 2024) noted that data does exist to address the first part of this uncertainty, though the uncertainty still warrants further research. They also expressed that there may be some existing information about the second part of this uncertainty. In follow-up consultation with a small expert group following the September workshop, they expressed that the costs and benefits of nutrient removal technologies may be known. In particular, one expressed that this is not an uncertainty for marine systems and nitrogen (but that it may be unknown for freshwater). PSI will soon summarize relevant research (and how it addresses the uncertainty) in a GUM Research Note.	6.5	High	Stormwater SIL Toxics Pod 2024 Investment Recommendations (D. Bilhimer, personal communication, July 22, 2024); Stormwater Strategic Initiative Lead Fall 2023 Wastewater Treatment and Onsite Sewage Systems Workshops (F. Bothfeld, personal communication, January 29, 2024); 2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b)	9/12/2024 Toxics Workshop

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
What are the costs and comparative benefits of removing CECs and other priority toxics through wastewater treatment as opposed to upstream source control? How effective are upstream source control measures for municipal wastewater, and how can these be more effective?	TIF 68	Prioritization workshop participants (September 2024) noted connections among uncertainties #19, #20, #21, and #22 (workshop IDs); #19 and #22 (workshop IDs) are now merged into TIF 67, and #20 and #21 (workshop IDs) are now merged into TIF 68. A workshop participant noted that this uncertainty may be answered, and asked about talking to economists. For the first question in this uncertainty, screening experts (August 2024) noted the management relevance and also noted the connection with the other uncertainty on this list about reducing PBDEs.	6.5	High	Stormwater SIL Toxics Pod 2024 Investment Recommendations (D. Bilhimer, personal communication, July 22, 2024); Stormwater Strategic Initiative Lead Fall 2023 Wastewater Treatment and Onsite Sewage Systems Workshops (F. Bothfeld, personal communication, January 29, 2024)	9/12/2024 Toxics Workshop
Is stormwater treatment effective in removing all chemicals of concern? Which chemicals of concern are removed? (2019 top priority uncertainty)	TIF 26	Some prioritization workshop participants (September 2024) noted that this uncertainty may already be answered or at least there is existing research; an example is a set of demonstration projects from the Puget Sound Federal Leadership Task Force studying 6PPD-Q on impervious surfaces. PSI will soon summarize this research (and how it addresses the uncertainty) in a GUM Research Note. Workshop participants also suggested answering this uncertainty using an ambient monitoring program or an inventory of treatments and their locations.	6	High	GUM (HSS)	9/12/2024 Toxics Workshop

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
To what extent may stormwater runoff impact the effectiveness of "ongoing and future physical habitat restoration projects (e.g., culvert replacements)" (Puget Sound Federal Task Force, 2022, p. 44)?	TIF 69	Prioritization workshop participants (September 2024) expressed that salmon and stormwater management need to be integrated and that stormwater issues are not included in process of developing fish passage projects; a workshop participant indicated that the uncertainty is answered but the issue is connecting water quality research with DOT work. A workshop participant suggested using BACI studies and working to locate ecological traps in order to address this uncertainty. A screening expert (August 2024) noted that this uncertainty has been a question for a while and needs to be answered; they also said the answer to this uncertainty will depend on location.	6	High	Puget Sound Federal Task Force (2022)	9/12/2024 Toxics Workshop
What are the primary and local sources/loadings to Puget Sound that can be addressed with focused cleanup or management programs? (2019 top priority uncertainty)	TIF 24	A prioritization workshop participant (September 2024) noted that uncertainties TIF 64 and TIF 24 are comparable; TIF 24 is now edited to focus on sources rather than pathways. Workshop participants also noted: that this uncertainty (on the GUM already) continues to be an uncertainty; the need to address this uncertainty by watersheds; the importance of source control; and that comprehensive loading data should inform which pathways/sources are managed. They also suggested using effects-based monitoring of places as part of research on hotspots, and expressed interest in understanding the contribution of landfill and septic sources and how "macrotrash" affects organisms in Puget Sound.	6	High	GUM (Starter Package)	9/12/2024 Toxics Workshop
Develop and implement screening-level toxicity tests for CECs for stormwater.	TIF 70	It is unclear how the toxicity tests called for in this uncertainty would be different from existing toxicity tests. A prioritization workshop participant (September 2024) noted a need for more WET testing for particular chemicals and effluents/pathways.	5	Medium	Puget Sound Federal Task Force (2022)	9/12/2024 Toxics Workshop

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
Can green stormwater infrastructure treat air and water?	TIF 71	Prioritization workshop participants (September 2024) indicated interest in studying this uncertainty specifically for PFAS and 6PPD-Q. For 6PPD-Q, this could be relevant for informing the level of concern about 6PPD-Q in other parts of the country. Workshop participants also indicated that this uncertainty is answered and pointed to several areas of research: EPA studies of 6PPD-Q air deposition and human health, and Wooster (Jennifer Faust) research on air deposition for PFAS. PSI will soon summarize this research (and how it addresses the uncertainty) in a GUM Research Note.	5	Medium	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b)	9/12/2024 Toxics Workshop
What are the current industry fee structures for toxic chemicals and how could EJ/HEAL Act requirements affect fee spending?	TIF 72	Prioritization workshop participants (September 2024) suggested reviewing HST from MTCA and noted that location- and population-specific information is necessary to answer this uncertainty.	5	Medium	Stormwater SIL Toxics Pod 2024 Investment Recommendations (D. Bilhimer, personal communication, July 22, 2024)	9/12/2024 Toxics Workshop
More Integrated Watershed Monitoring, incorporating habitat assessment (physical), ecosystem toxicology (chemical water/sediment), and biota toxicology (solid biota)	TIF 73		5	Medium	9/12/2024 Toxics Workshop	9/12/2024 Toxics Workshop
What are the effects/increased risk of contaminant-related immunosuppression on Puget Sound species?	TIF 74	A prioritization workshop participant (September 2024) noted that 'omics research on this topic would increase available data but would complicate the issue.	4	Medium	Puget Sound Federal Task Force (2022)	9/12/2024 Toxics Workshop

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
Is air deposition an important pathway for transporting contaminants to stormwater?	TIF 75	Prioritization workshop participants (September 2024) indicated interest in studying this uncertainty specifically for PFAS and 6PPD-Q. For 6PPD-Q, this could be relevant for informing the level of concern about 6PPD-Q in other parts of the country; for PFAS there was also interest in research on air deposition generally (not limited to stormwater). Research on air deposition in receiving waters is relevant to understanding air transport of chemicals. Workshop participants also indicated that this uncertainty is answered and pointed to several areas of research: EPA studies of 6PPD-Q air deposition and human health, and Wooster (Jennifer Faust) research on air deposition for PFAS. PSI will soon summarize this research (and how it addresses the uncertainty) in a GUM Research Note. Screening experts (August 2024) noted the SIL-relevance of this uncertainty.	4	Medium	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b)	9/12/2024 Toxics Workshop
What is the range of options for the removal of PFAS from wastewater, activated sludge, and biosolids to reduce land application of PFAS and how big of a problem is that for any receiving water or groundwater?	TIF 76	A prioritization workshop participant (September 2024) noted that this uncertainty (TIF 76) is comparable to TIF 63. Workshop participants suggested specifically addressing removal by incineration, asking whether that creates issues via air transport and asking about the toxicity of degradation products. Workshop participants also suggested considering information from Maine on this topic. PSI will soon summarize this research (and how it addresses the uncertainty) in a GUM Research Note.	4	Medium	Stormwater SIL Toxics Pod 2024 Investment Recommendations (D. Bilhimer, personal communication, July 22, 2024)	9/12/2024 Toxics Workshop

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
"Establish toxicity benchmarks for" Puget Sound species "through the integration of New Approach Methods" (Puget Sound Federal Task Force, 2022, p. 64)	TIF 77	There is already a technical framework for setting toxicity benchmarks. However, there remains a need to create a framework for creating benchmarks that can inform regulation. Prioritization workshop participants (September 2024) noted a need for more WET testing for particular chemicals and effluents/pathways, and noted that this uncertainty is not closely related to management.	3	Medium	Puget Sound Federal Task Force (2022)	9/12/2024 Toxics Workshop
What is the effectiveness of pollution prevention programs? (2019 top priority uncertainty)	TIF 4	Prioritization workshop participants (September 2024) suggested using an ambient monitoring program to answer this uncertainty, suggested using specific monitoring data on toxics exposures and health metrics, and pointed to relevant findings about this uncertainty from the PPRC. PSI will soon summarize this work (and how it addresses the uncertainty) in a GUM Research Note.	3	Medium	GUM (HSS)	9/12/2024 Toxics Workshop
What design factors and best practices impact green stormwater effectiveness, implementation, and ease of maintenance?	TIF 78	A prioritization workshop participant (September 2024) noted that this uncertainty may already be answered and that the issue is money for maintenance and monitoring. A workshop participant noted an issue with the capacity for GSI assessment and the availability of training programs; a workshop participant responded that training programs are available.	3	Medium	Puget Sound Federal Task Force (2022)	9/12/2024 Toxics Workshop
"Develop new decision support and modeling tools to characterize stormwater risks more precisely to ESA-listed marine mammals, rockfish, salmon, and steelhead in Puget Sound" (Puget Sound Federal Task Force, 2022, p. 44)	TIF 79	During screening (August 2024), PSI felt this uncertainty is connected to TIF 100.	n/a	Medium	Puget Sound Federal Task Force (2022)	8/2024 Screening

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
What CECs and other toxic chemicals are in WWTP effluent?	TIF 80	Screening experts (August 2024) noted that data does exist to address this uncertainty, though the uncertainty still warrants further research.	n/a	Medium	Stormwater Strategic Initiative Lead Fall 2023 Wastewater Treatment and Onsite Sewage Systems Workshops (F. Bothfeld, personal communication, January 29, 2024)	8/2024 Screening
Research emerging technologies to foster a sustainable market for biosolids and nutrient recovery, identifying and addressing profitability barriers.	TIF 81	Screening experts (August 2024) felt more biosolids research is needed before the pursuit of potential market (recommended editing uncertainty).	n/a	Medium	Stormwater Strategic Initiative Lead Fall 2023 Wastewater Treatment and Onsite Sewage Systems Workshops (F. Bothfeld, personal communication, January 29, 2024)	8/2024 Screening
What is the effectiveness of green stormwater infrastructure, including bioinfiltration and swales? What is the "cost and feasibility" of widespread implementation of green stormwater infrastructure? (Puget Sound Federal Task Force, 2022, p. 46)	TIF 82	Screening experts (August 2024) noted that there is knowledge and ongoing research addressing this question. The more unknown aspect of this uncertainty is how implementation impacts GSI effectiveness.	n/a	Medium	Stormwater SIL Toxics Pod 2024 Investment Recommendations (D. Bilhimer, personal communication, July 22, 2024); Pacific Northwest Aquatic Monitoring Partnership (2023); Puget Sound Federal Task Force (2022); Treaty Tribes in Western Washington (2020); Treaty Tribes in Western Washington (2023)	8/2024 Screening

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
What is the effectiveness of bioretention treatment of stormwater? What is the relative importance of specific mechanisms of bioretention? What "factors [impact the] efficacy" of specific bioretention mechanisms? (McIntyre et al., 2022, p. 7)	TIF 83	Screening experts (August 2024) indicated that there is ongoing research addressing this question. They also de-emphasized the mechanisms aspect of this uncertainty.	n/a	Medium	McIntyre et al. (2022) (in Environmental Assessment Program and Water Quality Program (2022)); Puget Sound Federal Task Force (2022)	8/2024 Screening
What sources of toxic exposure from indoor air pose the greatest risk for human health?	TIF 84	Screening experts (August 2024) noted that this uncertainty didn't connect to the SIL.	n/a	Medium	Stormwater SIL Toxics Pod 2024 Investment Recommendations (D. Bilhimer, personal communication, July 22, 2024)	8/2024 Screening
What treatment plants are sources of CECs in Puget Sound?	TIF 85	Screening experts (August 2024) suggested editing this uncertainty to ask about relative loadings (prioritization) among treatment plants.	n/a	Medium	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b)	8/2024 Screening
What is the primary source of PBDEs to Puget Sound?	TIF 86	Screening experts (August 2024) thought this uncertainty is not sufficiently specific.	n/a	Medium	2021 Stormwater SIL Toxics Workshops (Toxics in Aquatic Life – Key Messages 2021.04.26_FINAL document (internal SIL file) (C. A. James, personal communication, October 3, 2023))	8/2024 Screening
What explains the observed difference in PBDE contamination in natural and hatchery juvenile Chinook in Sandie O'Neill's work?	TIF 87	Screening expert (August 2024) is named specifically in this uncertainty; they suspect patterns are due to distributions and behavior of these populations. They expressed that this uncertainty is not as important as others.	n/a	Medium	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b; 2021c)	8/2024 Screening

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
What is causing the long term trends in PCBs, PBDEs, and EDCs from TBIOS monitoring results (including West et al. (2017))?	TIF 88	Screening experts (August 2024) suspect that the answer to this uncertainty is management and reduced chemical input.	n/a	Medium	2021 Stormwater SIL Toxics Workshops (West, 2021)	8/2024 Screening
What are the specific health risks from consumer products that inadvertently contain PCBs?	TIF 89	Screening experts (August 2024) expressed relevance of this uncertainty to TSCA and interest in discussion about this uncertainty for that reason. Screening experts also anticipated low exposure concentrations.	n/a	Medium	Stormwater SIL Toxics Pod 2024 Investment Recommendations (D. Bilhimer, personal communication, July 22, 2024)	8/2024 Screening
Which CECs should be prioritized? (2019 top priority uncertainty)	TIF 37	Prioritization workshop participants (September 2024) noted that this uncertainty has been answered (citing a UW research study, presumably James et al. (2023)), suggested noting the need to conduct ongoing work to update prioritization, and suggested prioritizing PFAS (particularly AFFF compounds). PSI will soon summarize the UW research study (James et al., 2023) and others (and how they address the uncertainty) in a Research Brief accessible via the GUM.	2	Low	GUM (IDT Meeting #1; Cascadia notes)	9/12/2024 Toxics Workshop
What is the water quality of groundwater in industrialized areas?	TIF 90	Prioritization workshop participants (September 2024) noted there is available data to answer this uncertainty, and expressed interest in groundwater quality in proximity to landfills.	2	Low	2021 Stormwater SIL Toxics Workshops (Senter, 2021)	9/12/2024 Toxics Workshop

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
What is the effectiveness of education and training campaigns for stormwater management? (2019 top priority uncertainty)	TIF 25	Prioritization workshop participants (September 2024) asked how to measure this uncertainty, expressed support for education and outreach programs, suggested coming up with specific pollution reduction actions that can be asked of the general public, and shared the following resources for behavior change information: Zero Waste Washington, King County, cbsm.com, and prisma.org. PSI will soon summarize this work (and how it addresses the uncertainty) in a GUM Research Note.	2	Low	GUM (IDT Meeting #1; Cascadia notes)	9/12/2024 Toxics Workshop
How to insulate public agencies from risk related to innovation?	TIF 91		2	Low	9/12/2024 Toxics Workshop	9/12/2024 Toxics Workshop
Do degradation products of mixtures increase overall toxicity to species?	TIF 92	Prioritization workshop participants (September 2024) noted connections with uncertainty TIF 62 and possibly TIF 15. In addition, a workshop participant noted that this uncertainty is known for PFAS (degradation products do increase toxicity).	1	Low	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b)	9/12/2024 Toxics Workshop
What is the fate and transport and occurrence of stormwater chemicals other than 6PPD-Q?	TIF 93	A prioritization workshop participant (September 2024) suggested broadening the uncertainty beyond stormwater; the uncertainty is not edited in this way, because stormwater was a central focus of the original uncertainty. A workshop participant also suggested adding 6PPD-Q, but 6PPD-Q fate and transport is already addressed in separate 6PPD-Q uncertainties.	1	Low	Puget Sound Federal Task Force (2022)	9/12/2024 Toxics Workshop

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
What places have the potential for groundwater recharge? To what extent is chemical loading a barrier to implementing reclaimed water?	TIF 94	Prioritization workshop participants (September 2024) expressed interest in understanding impacts of septic system and landfill sources, pointed to research by Lisa Rozmyn at WSU (for the second question), and asked about the spatial resolution of the answer to this uncertainty. PSI will soon summarize this research (and how it addresses the uncertainty) in a GUM Research Note. Screening experts (August 2024) noted that this uncertainty was interesting.	1	Low	Stormwater Strategic Initiative Lead Fall 2023 Wastewater Treatment and Onsite Sewage Systems Workshops (F. Bothfeld, personal communication, January 29, 2024)	9/12/2024 Toxics Workshop
Are building materials a significant source of contaminants to the environment?	TIF 95	Prioritization workshop participants (September 2024) noted that this uncertainty is answered, and pointed to existing work generally (including Ecology PCB report (Washington State Department of Ecology, 2024), Habitable (https://habitablefuture.org/about/), and potentially other resources) and current knowledge about PFAS in concrete. PSI will soon summarize this work (and how it addresses the uncertainty) in a GUM Research Note. Screening experts (August 2024) expressed the need to study the pathway of contamination from building materials, and asked for clarity on whether this uncertainty would address old or new building materials.	1	Low	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b)	9/12/2024 Toxics Workshop
What is the best way to reduce specific sources of PBDEs?	TIF 96	A prioritization workshop participant (September 2024) noted that PBDEs are being added to select WWTP permits by Ecology. Screening experts (August 2024) expressed interest in looking specifically at sources relevant to the Snohomish/Everett.	1	Low	Stormwater SIL Toxics Pod 2024 Investment Recommendations (D. Bilhimer, personal communication, July 22, 2024)	9/12/2024 Toxics Workshop
"What can regulators do to reduce sources of PFASs to" ground water? (Stormwater Strategic Initiative, 2021d, p. 2)	TIF 97	A prioritization workshop participant (September 2024) suggested that an answer to this uncertainty may be to reduce fluorine-based foams at military/airport locations.	1	Low	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021d)	9/12/2024 Toxics Workshop

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
Which toxics in whole plastics pose the greatest biotic and human risks?	TIF 98	For TIAL Implementation Strategy purposes, impacts to humans should be considered only in relation to consumption of aquatic life.	1	Low	9/12/2024 Toxics Workshop	9/12/2024 Toxics Workshop
Are phthalates occurring at levels that affect organisms in Puget Sound?	TIF 99	Prioritization workshop participants (September 2024) noted that the answer to this question may be no, or that impacts may be minimal, and that metabolites should be the focus of research. Screening experts (August 2024) indicated that further research is needed on toxicity, and that freshwater is not of concern.	0	Low	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b)	9/12/2024 Toxics Workshop
What are cumulative impacts of chemicals in stormwater runoff on Puget Sound species (including "keystone" species and plankton)?	TIF 100	Prioritization workshop participants (September 2024) noted specific interest in understanding cumulative impacts on humans. Humans are not added to the uncertainty text because uncertainties should be focused on the TIAL Implementation Strategy which addresses human health exclusively via consumption of aquatic life. Screening experts (August 2024) thought this uncertainty is not sufficiently specific (before "cumulative" or other elements were added).	0	Low	McIntyre et al. (2022) (in Environmental Assessment Program and Water Quality Program (2022)); Northwest Indian Fisheries Commission (2019); Pacific Northwest Aquatic Monitoring Partnership (2023); Puget Sound Federal Task Force (2022)	9/12/2024 Toxics Workshop
Do dioxins/furans impact Puget Sound species or their consumers?	TIF 101		0	Low	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021d)	9/12/2024 Toxics Workshop
What are the most timely, feasible, and effective whole watersheds to restore, to reduce toxics impacts to both humans and aquatic life?	TIF 102	Prioritization workshop participant (September 2024) expressed that the first question in this uncertainty is linked to fish and human co-benefits. For TIAL Implementation Strategy purposes, impacts to humans should be considered only in relation to consumption of aquatic life.	0	Low	9/12/2024 Toxics Workshop	9/12/2024 Toxics Workshop
What is the benefit of requiring stormwater discharge monitoring of organic contaminants?	TIF 103		0	Low	9/12/2024 Toxics Workshop	9/12/2024 Toxics Workshop

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
Are WQS stringent enough for Puget Sound species?	TIF 104		0	Low	9/12/2024 Toxics Workshop	9/12/2024 Toxics Workshop
What are the effects of bioaccumulative compounds on other species (in addition to indicator species)? What is the "distribution of contaminants"? (Stormwater Strategic Initiative, 2021d, p. 10)	TIF 105		n/a	Low	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021d)	8/2024 Screening
What are the impacts of pesticides/neonicotinoids on Puget Sound species and food webs?	TIF 106		n/a	Low	2021 Stormwater SIL Toxics Workshops (King-Heiden, 2021; Stormwater Strategic Initiative, 2021b; 2021c)	8/2024 Screening
To what extent do recycled products contain CECs? What degradation chemicals are produced from CECs?	TIF 107		n/a	Low	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021d)	8/2024 Screening
To what extent do CECs accumulate in nearshore aquatic vegetation? Does proximity to WWTP outfalls affect the concentrations bioaccumulated?	TIF 108	Screening expert (August 2024) questioned the value of answering this uncertainty, given existing mussel monitoring.	n/a	Low	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b)	8/2024 Screening
"Is fish Cmax consistent in zooplankton?" (Stormwater Strategic Initiative, 2021b, p. 9)	TIF 109		n/a	Low	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b)	8/2024 Screening
What heart functions can demonstrate impacts of chemical contamination?	TIF 110	Screening experts (August 2024) thought this uncertainty is too specific.	n/a	Low	Pacific Northwest Aquatic Monitoring Partnership (2023)	8/2024 Screening

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
“Are neonicotinoids frequently applied with adjuvants? Do you monitor and/or evaluate mixture effects of these pesticides with adjuvant chemicals?” (Stormwater Strategic Initiative, 2021b, p. 17)	TIF 111	Screening experts (August 2024) indicated that neonicotinoids might not be of great concern/presence in Puget Sound (compared to freshwater), and expressed interest in research specifically about imidacloprid.	n/a	Low	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b)	8/2024 Screening
“As LC50 values for Daphnia are considerably higher for imidacloprid than other aquatic invertebrates (e.g., Ephemeroptera) how would this potentially impact the interpretation of your results of mixture impacts on mortality and reproduction?” (Stormwater Strategic Initiative, 2021b, p. 17)	TIF 112	Screening experts (August 2024) indicated that this uncertainty is about the species used for toxicity testing.	n/a	Low	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b)	8/2024 Screening
Are clothes a source of flame retardants to the environment?	TIF 113	Screening experts (August 2024) pointed to Ecology study on this topic (Wong, 2022).	n/a	Low	2023 SEAQ Microplastics and Marine Debris Workshop (Discussion of uPlastics in the Environment and Protocols for uPlastic ID (Q&A), 2023)	8/2024 Screening
Are electronic waste products a source of flame retardants to the environment? What are the options for addressing "products/existing stockpiles" containing flame retardants (based on how long they persist)? (Discussion of uPlastics in the Environment and Protocols for uPlastic ID (Q&A), 2023, p. 1)	TIF 114	Screening experts (August 2024) thought this uncertainty is not sufficiently specific.	n/a	Low	2023 SEAQ Microplastics and Marine Debris Workshop (Discussion of uPlastics in the Environment and Protocols for uPlastic ID (Q&A), 2023)	8/2024 Screening
What is the effectiveness of stormwater permits?	TIF 115	Screening experts (August 2024) noted that SAM addresses this, but additional work could be done.	n/a	Low	Northwest Indian Fisheries Commission (2019)	8/2024 Screening

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
"What proportion of juvenile outmigrant Chinook are going out to the Sound via the Lower Mainstem vs the Distributary Channels?" (Stormwater Strategic Initiative, 2021b, p. 14)	TIF 116	Screening experts (August 2024) suggested that this uncertainty might relate to another strategy. They indicated that there is less of a need to study this uncertainty.	n/a	Low	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b)	8/2024 Screening
"Why [are] PCBs in sole tissue...increasing over time?" (Stormwater Strategic Initiative, 2021b, p. 2)	TIF 117		n/a	Low	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b)	8/2024 Screening
"How much "human wellness" source control" would "it take to have a meaningful impact" on CECs "through wastewater and the food web?" (Stormwater Strategic Initiative, 2021b, p. 9)	TIF 118		n/a	Low	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b)	8/2024 Screening
What are the costs/benefits and return on investment for replacing consumer products containing toxics with non-toxic alternatives (swap-out programs) and what is the long-term effectiveness of those programs?	TIF 119	Some screening experts (August 2024) thought this uncertainty is not sufficiently specific. Others indicated that it could be informative to engage economists on this uncertainty. Screening experts also indicated interest in determining the necessary metrics for evaluating swap-out program effectiveness, and expressed the expectation this uncertainty will be chemical-specific.	n/a	Low	Stormwater SIL Toxics Pod 2024 Investment Recommendations (D. Bilhimer, personal communication, July 22, 2024)	8/2024 Screening
To what extent is grey water discharge a source of CECs?	TIF 120	Screening experts (August 2024) clarified that "grey water" refers to boat waste. Screening experts indicated that other types of "grey water" would not be included here. Some screening experts thought this uncertainty is worth exploring, and some screening experts suggested that this potential contaminant source would be relatively minimal.	n/a	Low	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b)	8/2024 Screening

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source(s)	Prioritization Source
“Some of the newly added impairments are from sampling results for samples taken 20 to 30 years ago, we are bought in to quarterly sampling for these impairments even though our sampling never even detects them. How will these old ones ever go away?” (Stormwater Strategic Initiative, 2021b, p. 12)	TIF 121	Screening experts (August 2024) did not think this uncertainty is a research question.	n/a	Low	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b)	8/2024 Screening
What are the barriers to behavior change in Puget Sound?	TIF 122	A screening expert (August 2024) said that this uncertainty is interesting, and noted that this uncertainty connects to another uncertainty on this list.	n/a	Low	Stormwater SIL Toxics Pod 2024 Investment Recommendations (D. Bilhimer, personal communication, July 22, 2024)	8/2024 Screening
What toxics issues can effectively use social marketing approaches?	TIF 123		n/a	Low	Stormwater SIL Toxics Pod 2024 Investment Recommendations (D. Bilhimer, personal communication, July 22, 2024)	8/2024 Screening
What are the economic impacts, costs, and risks due to one or more classes of priority toxics?	TIF 124	A screening expert (August 2024) noted this uncertainty could be important for policy.	n/a	Low	Stormwater SIL Toxics Pod 2024 Investment Recommendations (D. Bilhimer, personal communication, July 22, 2024)	8/2024 Screening

[Appendix Table A2](#) contains the final 6PPD-Q research agenda, which is comprised of uncertainties adapted from ITRC (2024) and uncertainties suggested by experts in the September 2024 workshop. These final uncertainties include edits based on feedback from September 2024 workshop participants. Prioritization is based on expert voting at the September 2024 workshop. PSI edited some uncertainties, so the final version of the uncertainty (Uncertainty column) may differ from the original uncertainty/uncertainties as stated in the source(s).

Appendix Table A2. Puget Sound 6PPD-Q Research Agenda

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source	Prioritization Source
Investigate sublethal impacts of tire-related chemicals to both acutely-affected and tolerant species, and implications for survival.	TIF 125	A prioritization workshop participant (September 2024) noted connections between uncertainties TIF 138, TIF 128, and TIF 125.	16	Top	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop
Identify additional product sources of 6PPD, 6PPD-q, and other PPDs (e.g., tire reefs, crumb-rubber, indoor mats, etc.). Study the toxicity, degradation products, and occurrence of other PPDs.	TIF 126	A prioritization workshop participant (September 2024) noted that this uncertainty (TIF 126) is connected to uncertainty TIF 133. A workshop participant indicated that understanding this uncertainty would help ESA consultations.	10	Top	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop
Identify safe alternatives to 6PPD (either within the PPD chemical family or non-PPD alternatives) that provide required antiozonant, antioxidant, and anti-fatigue protection to tires. What are the toxicity, transformation products, and environmental trade-offs of these alternatives?	TIF 127	Prioritization workshop participants (September 2024) noted that there is a large amount of existing research internationally. PSI will soon summarize this research (and how it addresses the uncertainty) in a GUM Research Note. Workshop participants also noted that this uncertainty is not relevant to PSEMP and asked whether it would be feasible to secure funding that could be used as an incentive for industry.	9	Top	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source	Prioritization Source
Investigate toxicity of 6PPD-Q in various species, and across trophic levels, including microbial communities, algae, aquatic plants, terrestrial organisms (e.g., amphibians, reptiles, birds), mammals, and humans.	TIF 128	A prioritization workshop participant (September 2024) noted connections between uncertainties TIF 138, TIF 128, and TIF 125. Workshop participants noted that existing research on toxicity in humans specifically is preliminary, but that more research in this area would be useful for garnering management/policy action more rapidly. For TIAL Implementation Strategy purposes, research on this uncertainty should focus on species in Puget Sound, and impacts to humans should be considered only in relation to consumption of aquatic life.	9	Top	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop
What is the effectiveness of stormwater control measures (SCMs) such as street sweeping, catchment/management, biochar-enhanced SCMs, and permeable pavement, across various land uses at reducing 6PPD-q loadings? Does air transport impact effectiveness?	TIF 129	Prioritization workshop participants (September 2024) highlighted the relevance of BMP effectiveness research and expressed interest in understanding ways to minimize runoff (and loading) upstream using rain gardens, green infrastructure, and other measures.	8.5	Top	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop
Characterize the occurrence and persistence of 6PPD-q in all environmental media, including indoor dust, pore water in sediment, snow, food (e.g., crops, seafood), and drinking water. Characterize ecological and human exposure from 6PPD used in rubber products other than tires and the relative importance of different exposure routes to humans. Measure impacts to multiple organs and organ systems.	TIF 130	Prioritization workshop participants (September 2024) noted connections between uncertainties #55 and #39 (workshop IDs), TIF 134, TIF 132, and TIF 144; the present uncertainty (TIF 130) combines #55 and #39 (workshop IDs). A workshop participant also asked about broadening this uncertainty to address the organism scale (human and animal); this is already addressed by TIF 128. For TIAL Implementation Strategy purposes, research should focus on media relevant for Vital Sign indicator species (caged mussels, Chinook salmon, Pacific herring, and English sole). Research on human exposure should focus only on the pathway of consumption of aquatic life.	8	High	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop
Characterize the capacity of road design, including roadside barriers and vegetation, to reduce the transport of 6PPD and 6PPD-q.	TIF 131	A prioritization workshop participant (September 2024) noted that there is a large amount of existing research about this uncertainty. PSI will soon summarize this research (and how it addresses the uncertainty) in a GUM Research Note.	7	High	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source	Prioritization Source
Conduct biomonitoring on 6PPD and 6PPD-q in people (e.g., in urine, serum, organs).	TIF 132	Prioritization workshop participants (September 2024) noted connections to uncertainties TIF 130 and TIF 144. A workshop participant noted that 6PPD-Q might not bioaccumulate as much as 6PPD, so DOH would like to understand 6PPD. For TIAL Implementation Strategy purposes, impacts to humans should be considered only in relation to consumption of aquatic life. PSI will periodically review the research status of this and other uncertainties and will note existing or completed projects that increase understanding about the uncertainties.	7	High	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop
Investigate bioaccumulation of 6PPD, 6PPD-q, and other tire-related chemicals in organisms, particularly in edible tissues, including uptake and biomagnification through the food web.	TIF 133	A prioritization workshop participant (September 2024) noted that this uncertainty (TIF 133) is connected to uncertainty TIF 126. A workshop participant expressed interest in understanding the flux of 6PPD/6PPD-Q from the aquatic to terrestrial ecosystem through the following trophic relationships: riparian spiders → birds / → amphibians. For TIAL Implementation Strategy purposes, research on this uncertainty should focus on species in Puget Sound.	6	High	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop
Determine the fate (e.g., persistence and half-life) of 6PPD and 6PPD-q in the environment and understand how it varies with different environmental conditions.	TIF 134	Prioritization workshop participants (September 2024) noted connections to uncertainties TIF 135, TIF 136, and TIF 130. The only other specific comment on this uncertainty from workshop participants is now being addressed through a new uncertainty (TIF 147).	5	Medium	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop
Develop modeling that predicts where 6PPD-q will partition in the environment, with focused sampling.	TIF 135	A prioritization workshop participant (September 2024) noted the need to address hotspots. Workshop participants noted connections among uncertainties TIF 134, TIF 135, and TIF 136.	5	Medium	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop
Characterize transport pathways (including air deposition) of TRWP, 6PPD, and degradation products including 6PPD-Q.	TIF 136	Prioritization workshop participants (September 2024) noted connections among uncertainties TIF 134, TIF 135, and TIF 136.	5	Medium	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source	Prioritization Source
Determine which policies may reduce 6PPD-q exposures (e.g., road design, stormwater permitting).	TIF 137	A prioritization workshop participant (September 2024) noted that uncertainty TIF 137 needs to be addressed after TIF 131 (there is a need to understand effectiveness of road design before studying policy).	4	Medium	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop
Understand the mechanism of toxicity of 6PPD-q, including responses from the same species with different life histories (e.g., migratory vs. non-migratory, fresh water vs. anadromous).	TIF 138	A prioritization workshop participant (September 2024) noted connections among uncertainties TIF 138, TIF 128, and TIF 125.	4	Medium	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop
Identify other transformation and degradation products of 6PPD and 6PPD-q.	TIF 139		3	Medium	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop
Investigate leaching rates of 6PPD and 6PPD-q from tire and road wear particles (TRWP) and whole tires.	TIF 140	A prioritization workshop participant (September 2024) noted connections between uncertainties TIF 140 and TIF 146.	3	Medium	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop
Identify the fate of 6PPD and 6PPD-q in infiltration-based stormwater control measures and their impact on groundwater.	TIF 141	A prioritization workshop participant (September 2024) highlighted the relevance of BMP effectiveness research.	1.5	Low	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop
Determine size fractions of TRWP containing 6PPD and 6PPD-q and analyze how these change under different tire, road, or other environmental conditions.	TIF 142		1	Low	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop
What facilities (e.g., combined sewer systems, decant facilities, tire makers) are pathways for 6PPD/6PPD-Q?	TIF 143		1	Low	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop
Investigate disproportionate impacts from 6PPD-q to different groups of people, including overburdened communities, and characterize exposure factors in overburdened communities that may lead to increased exposure.	TIF 144	Prioritization workshop participants (September 2024) noted connections among uncertainties TIF 130, TIF 132, and TIF 144. For TIAL Implementation Strategy purposes, impacts to humans should be considered only in relation to consumption of aquatic life.	1	Low	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop

Uncertainty	GUM ID	Notes	9/12/2024 Total Votes	Priority Level	Uncertainty Source	Prioritization Source
Create methods for measuring other tire wear chemicals in tissues.	TIF 145		1	Low	9/12/2024 Toxics Workshop	9/12/2024 Toxics Workshop
Characterize factors (e.g., temperature, concentration of ozone in air, and presence of other oxidants) that influence the reaction of 6PPD into 6PPD-q and the formation of 6PPD-q in tires and TRWP in the environment.	TIF 146	A prioritization workshop participant (September 2024) noted connections between uncertainties TIF 140 and TIF 146.	0	Low	Adapted from ITRC (2024)	9/12/2024 Toxics Workshop
Do stormwater management projects (such as stormwater ponds, bioswales, etc.) negatively impact species who use them?	TIF 147	A prioritization workshop participant (September 2024) also expressed interest in how green infrastructure affects the fate of 6PPD/6PPD-Q in the terrestrial food web.	0	Low	9/12/2024 Toxics Workshop	9/12/2024 Toxics Workshop
How to reduce road miles driven and road run off?	TIF 148	In follow-up consultation with a small expert group following the September 2024 workshop, one pointed to relevant Climate Change and Energy initiatives. They also suggested using the King County Don't Wait to Inflate model instead. PSI will soon summarize this research (and how it addresses the uncertainty) in a GUM Research Note.	0	Low	9/12/2024 Toxics Workshop	9/12/2024 Toxics Workshop
Are tire wear particles and microplastics continued sources of toxics?	TIF 149	It is possible that this question was suggested as a microplastics uncertainty rather than a 6PPD-Q uncertainty.	0	Low	9/12/2024 Toxics Workshop	9/12/2024 Toxics Workshop
Tire wear particles are considered micro and nanoplastics. What are the environmentally relevant concentrations of TRWP, TWPs?	TIF 150	It is possible that this question was suggested as a microplastics uncertainty rather than a 6PPD-Q uncertainty.	0	Low	9/12/2024 Toxics Workshop	9/12/2024 Toxics Workshop

[Appendix Table A3](#) contains the final microplastics research agenda, which is comprised of uncertainties identified by microplastics experts (in August 2024 meeting) and uncertainties suggested by experts at the September 2024 workshop. Prioritization is based on votes by microplastics experts in the August 2024 meeting. PSI did not ask September workshop participants to cast votes on microplastics uncertainties, but some did and those votes are presented in the table (9/12/2024 Total Votes column). PSI did not use these workshop votes to inform the allocation of priority levels to microplastics uncertainties.

Appendix Table A3. Puget Sound Microplastics Research Agenda

Uncertainty	GUM ID	Notes	8/28/2024 Votes	9/12/2024 Total Votes	Source of Uncertainty (and Prioritization)	Priority Level
What is the relative distribution of microplastic sources (e.g., fishing gear, clothes, etc.) and the primary pathways (e.g., stormwater, aerial deposition, in water activity, etc.) of microplastics in Puget Sound?	TIF 151		3	0	8/28/2024 Microplastics meeting	Top
What is the distribution of microplastics among different matrices (e.g., sediment, fish, water) in Puget Sound?	TIF 152	A prioritization workshop participant (September 2024) suggested that research on uncertainties TIF 153 and TIF 154 should take place before research on this uncertainty (TIF 152).	3	0	8/28/2024 Microplastics meeting	Top
Develop/adopt a standard analytical method/protocol for microplastics in Washington State, including a focus on tire wear particles.	TIF 153		2	2	8/28/2024 Microplastics meeting	Top
What is the toxicology of microplastic fibers across a range of types, sizes, and species?	TIF 154	Prioritization workshop participants (September 2024) indicated the importance of focusing on benthic species. For TIAL Implementation Strategy purposes, research on this uncertainty should focus on species in Puget Sound. A workshop participant pointed to OSU and USGS for work related to this uncertainty. PSI will soon summarize this research (and how it addresses the uncertainty) in a GUM Research Note.	1	5	8/28/2024 Microplastics meeting	Top

Uncertainty	GUM ID	Notes	8/28/2024 Votes	9/12/2024 Total Votes	Source of Uncertainty (and Prioritization)	Priority Level
How effective are stormwater BMPs (e.g., trash capture devices) at removing microplastics?	TIF 155	Prioritization workshop participants (September 2024) expressed expectation that microplastics are comparable to TSS, so this isn't an uncertainty; indicated that the answer to this uncertainty varies; and pointed to OSU (Brander and Harper) and EPA Trash Free Waters as relevant resources. PSI will soon summarize this work (and how it addresses the uncertainty) in a GUM Research Note.	1	0	8/28/2024 Microplastics meeting	Top
What are non-regrettable substitutions for plastics, particularly plasticizers?	TIF 156		0	n/a	8/28/2024 Microplastics meeting	High
What is the ecotoxicity of microplastics (of various types, features, etc.) that are found in the environment?	TIF 157		0	n/a	8/28/2024 Microplastics meeting	High
How can plastic use be reduced (e.g., via single-use bag bans, changes to food and packaging, reducing consumption, etc.)?	TIF 158	A prioritization workshop participant (September 2024) noted the importance of "environmentally preferable purchasing" and "pollution prevention".	n/a	4	9/12/2024 Toxics Workshop	No priority
To what extent does PFAS connect/bind to microplastics?	TIF 159	A prioritization workshop participant (September 2024) noted that this uncertainty was interesting.	n/a	2	9/12/2024 Toxics Workshop	No priority
What types of plastics are more likely to become nanoplastics?	TIF 160		n/a	0	9/12/2024 Toxics Workshop	No priority
How effective is wastewater treatment at removing microplastics?	TIF 161		n/a	0	9/12/2024 Toxics Workshop	No priority

[Appendix Table A4](#) contains uncertainties that were suggested by experts in the September 2024 workshop and which are not included in the toxics research agenda either because they do not align with the scope of the TIAL Implementation Strategy or because they are not unknowns. Some other participant-suggested uncertainties were not added to the research agenda and are not listed in this table; these uncertainties were either duplicates with other uncertainties (including those in the 2019 research agenda), or were related enough to other uncertainties that PSI incorporated them into the summary notes for those uncertainties.

Appendix Table A4. Other uncertainties (not included in research agenda)

List	Uncertainty	Notes	9/12/2024 Votes	Uncertainty Source
Vital Sign	When do we have enough information about new contaminants to require sampling via permits?	Not added to research agenda because this question is presumably known by those in charge of permits, and is therefore not a research question.	0	9/12/2024 Toxics Workshop
Vital Sign	Is the Salish Sea model already working on understanding to what extent toxics in Puget Sound come from the region?	Not added to research agenda because this question is known; the model can do this but such work is not underway.	1	9/12/2024 Toxics Workshop
Microplastics	What are the human health impacts?	This uncertainty is not included in the microplastics research agenda because human health is outside the scope of the TIAL Implementation Strategy (the Implementation Strategy focuses on humans via consumption of aquatic life).	0	9/12/2024 Toxics Workshop

[Appendix Table A5](#) contains uncertainties from the Vital Sign and 6PPD-Q research agendas which either pertain to human health or for which experts suggested adding human health elements. PSI did not add human health elements to uncertainties because this is outside of the current scope of the TIAL Implementation Strategy. PSI edited some uncertainties, so the final version of the uncertainty (Uncertainty column) may differ from the original uncertainty/uncertainties as stated in the source(s).

Appendix Table A5. Human health uncertainties from the research agenda

List	Uncertainty	GUM ID	Notes	Priority Level (within List)	Uncertainty Source
Vital Sign	What biomarkers (cellular, molecular, genetic) can be used to monitor effects of chemical exposure in various organisms (fish, shellfish, etc.)?	TIF 61	Prioritization workshop participants (September 2024) suggested employing transcriptomics or other non-targeted approaches, asked whether effects are incorporated into existing mussel monitoring, and expressed interest in the development of biomarkers or toxicity thresholds specifically for shellfish to support the caged mussels indicator. Workshop participants also suggested investigating biomarkers in humans. Humans are not added to the uncertainty text because uncertainties should be focused on the TIAL Implementation Strategy which addresses human health exclusively via consumption of aquatic life.	Top	Pacific Northwest Aquatic Monitoring Partnership (2023)
Vital Sign	What are the cumulative effects of pharmaceuticals, CECs, and legacy contaminants (PCBs, PAHs, PBDEs, etc.) exposures on species in Puget Sound? (2019 top priority uncertainty)	TIF 15	Prioritization workshop participants (September 2024) suggested using effects-based monitoring and expertise from modelers to answer this uncertainty, and suggested studying humans. Humans are not added to the uncertainty text because uncertainties should be focused on the TIAL Implementation Strategy which addresses human health exclusively via consumption of aquatic life. Participants expressed that this uncertainty is more unknown for non-fish species. Participants also suggested possible connections with uncertainties TIF 92 and TIF 62.	Top	GUM (Starter Package)

List	Uncertainty	GUM ID	Notes	Priority Level (within List)	Uncertainty Source
6PPD-Q	Investigate toxicity of 6PPD-Q in various species, and across trophic levels, including microbial communities, algae, aquatic plants, terrestrial organisms (e.g., amphibians, reptiles, birds), mammals, and humans.	TIF 128	A prioritization workshop participant (September 2024) noted connections between uncertainties TIF 138, TIF 128, and TIF 125. Workshop participants noted that existing research on toxicity in humans specifically is preliminary, but that more research in this area would be useful for garnering management/policy action more rapidly. For TIAL Implementation Strategy purposes, research on this uncertainty should focus on species in Puget Sound, and impacts to humans should be considered only in relation to consumption of aquatic life.	Top	Adapted from ITRC (2024)
Vital Sign	What are the impacts on human health (i.e. poor health, disease) of contaminants of emerging concern through consumption?	TIF 66	Prioritization workshop participants (September 2024) suggested studying epidemiological impacts. Workshop participants also suggested expanding the uncertainty to address additional human exposure pathways, OneHealth, additional species such as southern resident killer whales, and legacy contaminants, and noted that understanding CEC impacts would be even harder for humans than for fish yet such work could motivate increased concern from the public about toxic pollution. Additional human exposure pathways and OneHealth are not added to the uncertainty text because uncertainties should be focused on the TIAL Implementation Strategy which addresses human health exclusively via consumption of aquatic life. Screening experts (August 2024) indicated the need for effects thresholds/benchmarks for aquatic species and humans.	High	Stormwater SIL Toxics Pod 2024 Investment Recommendations (D. Bilhimer, personal communication, July 22, 2024)
6PPD-Q	Characterize the occurrence and persistence of 6PPD-q in all environmental media, including indoor dust, pore water in sediment, snow, food (e.g., crops, seafood), and drinking water. Characterize ecological and human exposure from 6PPD used in rubber products other than tires and the relative importance of different exposure routes to humans. Measure impacts to multiple organs and organ systems.	TIF 130	Prioritization workshop participants (September 2024) noted connections between uncertainties #55 and #39 (workshop IDs), TIF 134, TIF 132, and TIF 144; the present uncertainty (TIF 130) combines #55 and #39 (workshop IDs). A workshop participant also asked about broadening this uncertainty to address the organism scale (human and animal); this is already addressed by TIF 128. For TIAL Implementation Strategy purposes, research should focus on media relevant for Vital Sign indicator species (caged mussels, Chinook salmon, Pacific herring, and English sole). Research on human exposure should focus only on the pathway of consumption of aquatic life.	High	Adapted from ITRC (2024)

List	Uncertainty	GUM ID	Notes	Priority Level (within List)	Uncertainty Source
6PPD-Q	Conduct biomonitoring on 6PPD and 6PPD-q in people (e.g., in urine, serum, organs).	TIF 132	Prioritization workshop participants (September 2024) noted connections to uncertainties TIF 130 and TIF 144. A workshop participant noted that 6PPD-Q might not bioaccumulate as much as 6PPD, so DOH would like to understand 6PPD. For TIAL Implementation Strategy purposes, impacts to humans should be considered only in relation to consumption of aquatic life. PSI will periodically review the research status of this and other uncertainties and will note existing or completed projects that increase understanding about the uncertainties.	High	Adapted from ITRC (2024)
Vital Sign	Can green stormwater infrastructure treat air and water?	TIF 71	Prioritization workshop participants (September 2024) indicated interest in studying this uncertainty specifically for PFAS and 6PPD-Q. For 6PPD-Q, this could be relevant for informing the level of concern about 6PPD-Q in other parts of the country. Workshop participants also indicated that this uncertainty is answered and pointed to several areas of research: EPA studies of 6PPD-Q air deposition and human health, and Wooster (Jennifer Faust) research on air deposition for PFAS. PSI will soon summarize this research (and how it addresses the uncertainty) in a GUM Research Note.	Medium	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b)
Vital Sign	Is air deposition an important pathway for transporting contaminants to stormwater?	TIF 75	Prioritization workshop participants (September 2024) indicated interest in studying this uncertainty specifically for PFAS and 6PPD-Q. For 6PPD-Q, this could be relevant for informing the level of concern about 6PPD-Q in other parts of the country; for PFAS there was also interest in research on air deposition generally (not limited to stormwater). Research on air deposition in receiving waters is relevant to understanding air transport of chemicals. Workshop participants also indicated that this uncertainty is answered and pointed to several areas of research: EPA studies of 6PPD-Q air deposition and human health, and Wooster (Jennifer Faust) research on air deposition for PFAS. PSI will soon summarize this research (and how it addresses the uncertainty) in a GUM Research Note. Screening experts (August 2024) noted the SIL-relevance of this uncertainty.	Medium	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021b)

List	Uncertainty	GUM ID	Notes	Priority Level (within List)	Uncertainty Source
Vital Sign	What is the effectiveness of pollution prevention programs? (2019 top priority uncertainty)	TIF 4	Prioritization workshop participants (September 2024) suggested using an ambient monitoring program to answer this uncertainty, suggested using specific monitoring data on toxics exposures and health metrics, and pointed to relevant findings about this uncertainty from the PPRC. PSI will soon summarize this work (and how it addresses the uncertainty) in a GUM Research Note.	Medium	GUM (HSS)
Vital Sign	What sources of toxic exposure from indoor air pose the greatest risk for human health?	TIF 84	Screening experts (August 2024) noted that this uncertainty didn't connect to the SIL.	Medium	Stormwater SIL Toxics Pod 2024 Investment Recommendations (D. Bilhimer, personal communication, July 22, 2024)
Vital Sign	What are the specific health risks from consumer products that inadvertently contain PCBs?	TIF 89	Screening experts (August 2024) expressed relevance of this uncertainty to TSCA and interest in discussion about this uncertainty for that reason. Screening experts also anticipated low exposure concentrations.	Medium	Stormwater SIL Toxics Pod 2024 Investment Recommendations (D. Bilhimer, personal communication, July 22, 2024)
Vital Sign	Which toxics in whole plastics pose the greatest biotic and human risks?	TIF 98	For TIAL Implementation Strategy purposes, impacts to humans should be considered only in relation to consumption of aquatic life.	Low	9/12/2024 Toxics Workshop
Vital Sign	What are cumulative impacts of chemicals in stormwater runoff on Puget Sound species (including "keystone" species and plankton)?	TIF 100	Prioritization workshop participants (September 2024) noted specific interest in understanding cumulative impacts on humans. Humans are not added to the uncertainty text because uncertainties should be focused on the TIAL Implementation Strategy which addresses human health exclusively via consumption of aquatic life. Screening experts (August 2024) thought this uncertainty is not sufficiently specific (before "cumulative" or other elements were added).	Low	McIntyre et al. (2022) (in Environmental Assessment Program and Water Quality Program (2022)); Northwest Indian Fisheries Commission (2019); Pacific Northwest Aquatic Monitoring Partnership (2023); Puget Sound Federal Task Force (2022)

List	Uncertainty	GUM ID	Notes	Priority Level (within List)	Uncertainty Source
Vital Sign	Do dioxins/furans impact Puget Sound species or their consumers?	TIF 101		Low	2021 Stormwater SIL Toxics Workshops (Stormwater Strategic Initiative, 2021d)
Vital Sign	What are the most timely, feasible, and effective whole watersheds to restore, to reduce toxics impacts to both humans and aquatic life?	TIF 102	Prioritization workshop participant (September 2024) expressed that the first question in this uncertainty is linked to fish and human co-benefits. For TIAL Implementation Strategy purposes, impacts to humans should be considered only in relation to consumption of aquatic life.	Low	9/12/2024 Toxics Workshop
6PPD-Q	Investigate disproportionate impacts from 6PPD-q to different groups of people, including overburdened communities, and characterize exposure factors in overburdened communities that may lead to increased exposure.	TIF 144	Prioritization workshop participants (September 2024) noted connections among uncertainties TIF 130, TIF 132, and TIF 144. For TIAL Implementation Strategy purposes, impacts to humans should be considered only in relation to consumption of aquatic life.	Low	Adapted from ITRC (2024)