8 Information Gaps and Research Needs

Since the discovery of 6PPD-q in 2020 (Tian et al. 2021[X8BRFG3P] Tian, Zhenyu, Haoqi Zhao, Katherine T. Peter, Melissa Gonzalez, Jill Wetzel, Christopher Wu, Ximin Hu, et al. 2021. “A Ubiquitous Tire Rubber–Derived Chemical Induces Acute Mortality in Coho Salmon.” Science 371 (6525): 185–89. https://doi.org/10.1126/science.abd6951.), researchers around the world have prioritized learning more about environmental occurrences, sampling protocols, mitigation strategies, and toxicity to aquatic species, but there is still a lot to learn. This section highlights knowledge gaps and research needs that, if addressed, could further characterize and mitigate the risks associated with 6PPD-q or its parent compound, 6PPD.

8.1 Effects Characterization and Toxicity

Section 2 provides an overview of the emerging research on the toxicity of 6PPD-q and 6PPD, the ecological and human-health effects associated with exposure to these contaminants, biomonitoring results, and populations of concern. That research is still in its infancy and many knowledge gaps remain related to the toxicological concerns for human and ecological receptors. Table 8-1 provides a tabulated list of these knowledge gaps and why they are needed areas of research.

Table 8-1. Research Needs and Knowledge Gaps—Effects Characterization and Toxicity

Research Need /Knowledge Gap	**Justification**
ECOLOGICAL TOXICITY	
• Understand the toxicity mechanism of 6PPD-q, including responses from same species with different life histories (e.g., migratory vs non-migratory, dwelling completely in fresh water vs. living in both fresh water and marine ecosystems).	• Predicting 6PPD-q toxicity to a given species is difficult because research has shown that closely related salmonids have varying responses to exposure. • Further research into the mode of toxicity will help explain species sensitivity. • Sensitive species predictions can help inform the selection of a replacement chemical to avoid regrettable substitutions.
• Investigate toxicity in other species and trophic levels, including microbial communities, algae, aquatic plants, and terrestrial organisms (for example, amphibians, reptiles, birds).	• Broaden the understanding of potential ecological impacts of these chemicals. • Inform water quality criteria and other media-specific criteria. • Knowledge of 6PPD-q ecological impacts will help inform mitigation strategies and regulatory solutions.

• Investigate sublethal and/or chronic impacts to both acutely affected and tolerant species. • Assess whether sublethal and/or chronic impacts alter survivorship.	• Understanding whether 6PPD-q has long-term effects on species populations can inform impacts to ecosystems. • Inform ongoing salmon and ecosystem recovery assessments. • Inform fisheries planning and yearly catch limits. • Inform ESA consultations.
HUMAN TOXICITY	
• Test 6PPD-q toxicity for mammalian and human-health endpoints.	• Toxicity values are needed to derive human-health–based guideline values and points of departure to inform risk.
• Conduct tests on short- and long-term exposures to 6PPD-q through different exposure routes (for example, inhalation, ingestion) that assess the health of multiple organs and organ systems.	• Provide information on potential human exposure. • Provide information on potential human toxicity.
HUMAN BIOMONITORING	
• Conduct biomonitoring on 6PPD and 6PPD-q in people in the United States (for example, urine, serum, organs).	• Compare with findings in international studies. • Correlate occurrence data with traffic patterns and urban planning to inform mitigation strategies. • Provide information relevant to human risk assessment.
SOCIAL AND CULTURAL IMPACTS	
• Investigate disproportionate impacts from 6PPD-q to different groups of people, including overburdened communities. • Characterize exposure factors in overburdened communities that may lead to increased exposure.	• Evaluate health and cultural impacts for tribal communities due to decline of coho populations, particularly in the Pacific Northwest (DTSC 2022[2M3Z8Z4F] DTSC. 2022. “Product-Chemical Profile for Motor Vehicle Tires Containing N-(1,3-Dimethylbutyl)-N′-Phenyl-p-Phenylenediamine (6PPD) from the California Department of Toxic Substances Control (DTSC).” https://dtsc.ca.gov/wp-content/uploads/sites/31/2022/05/6PPD-in-Tires-Priority-Product-Profile_FINAL-VERSION_accessible.pdf.). • Understand socioeconomic impacts to subsistence and commercial fishers. • Assess impacts on communities near heavily trafficked roads. • Consider potential cumulative impacts, especially in overburdened communities and those conducting subsistence activities.

8.2 Occurrence, Fate, Transport, and Exposure to 6PPD and 6PPD-q

6PPD and 6PPD-q are emerging contaminants and subjects of ongoing research. Widespread sampling has yet to begin; therefore, our understanding of TRWP, 6PPD, and 6PPD-q and their movement through the environment is limited. Section 3 reviews the modeled and measured physicochemical properties of 6PPD and 6PPD-q. Section 4 reviews the fate, transport, occurrence of tire particles containing 6PPD and 6PPD-q in the environment, potential sources of the chemicals, and how people may come into contact with 6PPD-q and 6PPD. Section 5 reviews a variety of methods for assessing and measuring 6PPD and 6PPD-q among variable environmental matrices and landscapes. Table 8-2 provides a tabulated list of knowledge gaps related to these subject areas.

Table 8-2. Research Needs and Knowledge Gaps—Physicochemical Properties, Fate and Transport, Occurrence, and Sources

Research Need /Knowledge Gap	Justification
PHYSICOCHEMICAL PROPERTIES	
• Determine the persistence and half-life of 6PPD and 6PPD-q in the environment and understand how it varies with different environmental conditions. • Verify fugacity modeling that predicts where 6PPD-q will partition in the environment, with sampling of media. • Identify other transformation and degradation products of 6PPD and 6PPD-q.	• Verification of the characteristics of 6PPD and 6PPD-q is needed to guide planning and mitigation strategies and support human and environmental health impact analysis.
• Validate estimated or predicted properties with observations and measurements from natural systems.	• Environmental data (for example, occurrence data) can support laboratory observations to increase confidence in our understanding of the physicochemical properties of 6PPD and 6PPD-q.
• Investigate bioaccumulation of 6PPD and 6PPD-q in organisms and concentrations of the chemicals in edible tissues, including organism (plant and animal) uptake and exposure through the food web.	• Understanding uptake of 6PPD and 6PPD-q in different species and its absorption, metabolism, and excretion in organisms will help inform exposure assessments. • Determine whether bioaccumulation modeling predictions for the chemicals are valid. • Inform water quality criteria. • Inform health-based guideline values (for example, fish consumption advisories).
FATE AND TRANSPORT	
• Identify all transport pathways for TRWP, whole tire, tire debris, 6PPD, and 6PPD-q. • Investigate leaching rates of 6PPD and 6PPD-q from TRWP and whole tires.	• Inform our understanding of exposure routes and managing sources of 6PPD-q to aid preventive measures.
• Determine air dispersion potential of 6PPD and 6PPD-q and variability based on environmental conditions and land use. • Determine size fractions of TRWP containing 6PPD and 6PPD-q and analyze how these change under different tire, road, or other environmental conditions.	• Identify factors (chemical, physical, biological) that influence the fate, transport, distribution, and persistence of 6PPD and 6PPD-q in the environment
• Determine conditions (for example, temperature, concentration of ozone in air, presence of other oxidants) that impact the reaction of 6PPD into 6PPD-q. • Characterize factors that influence the formation of 6PPD-q in tires and TRWP in the environment, as well as the factors that cause its degradation.	• Assist with understanding conditions where more or less 6PPD-q is produced. • Information can be applied in mitigation strategies.
OCCURRENCE	

• Investigate the levels of 6PPD and 6PPD-q in environmental media in the United States.	• Compare with environmental monitoring results internationally in environmental media (for example, marine and freshwater, sediment, soil). • Inform exposure in humans and biota.
• Characterize the occurrence and persistence of 6PPD-q in data-poor media, such as in indoor dust, pore water in sediment, snow, food (for example, crops, seafood), and drinking water.	• Characterize sources of 6PPD-q and routes of human exposure. • Support setting media-specific contaminant level goals. • Data needed to quantify human exposure and risk.
OTHER PRODUCTS, PPDS, AND SOURCES	
• Identify additional product sources of 6PPD and 6PPD-q. These may include newly manufactured products, as well as products or uses of end-of-life tires. • Characterize ecological and human exposure from 6PPD used in other rubber products (sneaker soles, garden hoses, climbing shoes, and windshield wipers) and, potentially electronics, (see Liang et al. 2022[SZPLJY9T] Liang, Bowen, Jiehua Li, Bibai Du, Zibin Pan, Liang-Ying Liu, and Lixi Zeng. 2022. “E-Waste Recycling Emits Large Quantities of Emerging Aromatic Amines and Organophosphites: A Poorly Recognized Source for Another Two Classes of Synthetic Antioxidants.” Environmental Science & Technology Letters, June, acs.estlett.2c00366. https://doi.org/10.1021/acs.estlett.2c00366.). • Products made from recycled tires can contain 6PPD and 6PPD-q. Recycled tires are used mainly in outdoor products (tire reefs, erosion control along embankments, crumb-rubber infill for artificial turf, playground surfaces, tire mulch, and tire aggregate used in civil engineering projects) and some indoor uses (indoor mats, flooring, ramps).	• Understanding whether other products that use 6PPD, products made from recycled tires, or other uses of recycled tires may act as sources—and the relative importance of those sources—can help to inform ecological and human exposures. • May identify the need to find safer alternatives to 6PPD for use in other rubber products. • Inform how and where recycled tires and products made from recycled products can be used to minimize exposures.
• Determine what products contain other PPDs, their capacity to form quinones, their toxicity, and their occurrence in different environmental media or products.	• A range of PPDs and transformation products originating from tires, industrial uses, and other consumer goods, are known to exist and occur, but little is known about their toxicity or transport.
• Determine the potential for particular facilities, such as those that produce rubber, manufacture tires, or retread tires, to emit or release tire-related particulates, 6PPD, or 6PPD-q.	• Classify all potential sources to inform planning and risk assessments
• Determine the impacts of combined sewer systems and application of biosolids on 6PPD and 6PPD-q fate and transport.	• Combined sewer systems direct stormwater into WWTP. 6PPD-q transport may vary depending on the capacity of the system during events, especially during overflow events. 6PPD is predicted, and 6PPD-q has been observed (Dennis, Braun, and Gan 2024[RNAS6357] Dennis, Nicole M., Audrey J. Braun, and Jay Gan. 2024. “A High-Throughput Analytical Method for Complex Contaminant Mixtures in Biosolids.” Environmental Pollution 345:123517. https://doi.org/10.1016/j.envpol.2024.123517.), to sorb to biosolids from WWTP, which can then be applied to urban landscapes, agricultural lands, or cultivated forests. • Inform mitigation strategies to reduce 6PPD and 6PPD-q in the environment.

• Determine whether decant facilities that process the waste collected by street sweeping potentially act as another source of 6PPD or 6PPD-q	• Inform solutions planning that includes street sweeping as a recommended form of mitigation
HUMAN EXPOSURE	
• Identify different exposure routes to humans and their relative importance. Potential exposure routes include ambient air, drinking water, diet and subsistence activities, recreational activities in water, use of recycled or manufactured rubber products, and worker exposure at tire and tire recycling facilities.	• Data are needed to quantify human exposure and risk. • Data are needed to estimate levels of exposure in different sectors of the population. • Inform mitigation needs.

Notes: PPDs=para-phenylenediamines, TRWP=tire- and road-wear particles, WWTP=wastewater treatment plants

8.3 How Effective Are the Proposed Solutions?

Significant uncertainty surrounds the effectiveness of the various solutions discussed in this document (Table 8-3). Section 6 provides possible mitigation strategies and potential solutions, including assessing chemical alternatives to 6PPD in tires; mitigating the impacts of 6PPD-q in the environment through pollution prevention, air particulate mitigation, and stormwater source control measures; and assessing remediation of 6PPD-q if it persists in the environment.

Table 8-3. Research Needs and Knowledge Gaps—Mitigation Strategies and Alternatives

Research Need /Knowledge Gap	Justification
STORMWATER BEST MANAGEMENT PRACTICES	
• Identify the effectiveness of SCMs such as street sweeping, catchment/management, biochar-enhanced SCMs, and permeable pavement at preventing 6PPD-q exposure. • Assess the effectiveness of SCMs across various land uses, factoring in location and space availability. • Evaluate the potential impact of fate and transport of TRWP in air on 6PPD-q concentrations in stormwater and how this may influence SCMs. • Identify the fate of 6PPD and 6PPD-q in infiltration-based SCMs and their impact on groundwater.	• Informs measures that intercept, prevent, and manage pathways to exposures from 6PPD-q in waterways. • Develop SCMs that provide the greatest mitigation. • Increase understanding of effective mitigation strategies.
• Characterize the capacity of roadside barriers and vegetation to modify the fate and transport of 6PPD and 6PPD-q.	• Informs BMPs and their effectiveness in reducing 6PPD and 6PPD-q in the environment.
• Determine how street sweeping affects the transport and loading of TRWP, 6PPD, or 6PPD-q.	• Increase understanding of the contribution of street-sweeping activities to TRWP, 6PPD, or 6PPD-q loading. • Informs BMP selection.
• Determine which policies may reduce 6PPD-q exposures (for example, road design, stormwater permitting).	• Informs which proposed solutions are effective and provides direction for implementation.
• Characterize the amount of 6PPD and 6PPD-q in sediment and the potential for TRWP to act as ongoing sources of these chemicals in sediment.	• Informs whether sediment-disturbing processes (for example, dredging, dam removal) might generate pulses of the chemicals. • Informs exposure assessment for sediment-dwelling organisms.
ALTERNATIVES	

• Identify safer alternatives to 6PPD (either within the PPD chemical family or non-PPD alternatives) that provide required antiozonant, antioxidant, and anti-fatigue protection to tires. • Investigate toxicity and transformation products for identified alternatives. • Identify potential environmental trade-offs associated with alternatives.	• Informs long-term replacement of 6PPD in tires and removal of 6PPD-q from TRWP and subsequent exposures.

Notes: BMPs=best management practices, SCM=stormwater control measure, TRWP=tire- and road-wear particles,

8.4 Current Research

Many institutions, including, but not limited to, federal agencies (NOAA, USDA, USEPA, and USGS), state agencies, tribes, academia, and citizen science groups, are funding and conducting research to address information gaps on 6PPD and 6PPD-q. Resources for learning more are listed below:

- USEPA’s website on 6PPD-q highlights ongoing research, as well as funding opportunities associated with 6PPQq.

- The USGS has been leading research on monitoring surface water and studying toxicity in different fishes. USGS’s Western Fisheries Research Center has a cooperative research and development agreement with the USTMA to screen the toxicity of several potential alternatives using cell lines.

- The NOAA Northwest Fisheries Science Center first characterized URMS, and researchers are actively engaged in understanding 6PPD-q’s aquatic toxicity, bioaccumulation, and fate.

- The USDA has been researching the properties of 6PPD to inform the development of safer and bio-based alternatives to 6PPD. The Agricultural Research Service has a cooperative research and development agreement with Flexsys, a manufacturer of 6PPD.