WASHINGTON STATE
Academy of Sciences
Science in the Service of Washington State

Summary: A Discussion about the Science of 6PPD and 6PPD-Quinone

September 2024

Suggested citation: Washington State Academy of Sciences. (2024). Summary: A Discussion about the Science of 6PPD and 6PPD-Quinone. Seattle, WA: WSAS, 1-20.

This activity was supported by internal funds and donations. Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of the organization.

ABOUT THE WASHINGTON STATE ACADEMY OF SCIENCES

The Washington State Academy of Sciences (WSAS) is an independent, nonpartisan nonprofit organization of more than 430 elected members who are nationally recognized for their scientific and technical expertise. WSAS's mission is to provide expert scientific and engineering assessments to inform public policymaking and to increase the impact of research in Washington State. All members of the National Academies of Sciences, Engineering and Medicine who reside in Washington State are invited to join; others are elected in recognition of their scientific and technical contributions to our nation and their desire to contribute their expertise to inform issues in Washington State. WSAS mobilizes the expertise of its members and others to provide independent, unbiased, evidence-based scientific and engineering assessments on issues that impact the citizens, governments and businesses of Washington State.

WSAS was established by the legislature in 2005 at the request of Governor Christine Gregoire to improve public policies and programs by engaging scientists and engineers in Washington State.

Learn more at www.washacad.org.

© 2024 Washington Academy of Sciences. All rights reserved. Seattle, WA

Introduction

On Friday, May 3, the Washington State Academies of Science convened a meeting in Seattle, WA of scientists, state-level government officials, and interested parties to discuss the science and impact of the chemicals 6PPD and 6PPDQ. The meeting agenda and a list of attendees and their organizations are appended to this document. This meeting summary details the main topics of discussion, data gaps identified, and potential next steps.

This summary is broken down along four topics:

1. A brief high-level introduction to 6PPD and 6PPDQ.
2. The current state of research and what is known about the effects of 6PPDQ in the environment.
3. Identification of the key gaps in our knowledge of 6PPDQ and its effects.
4. Potential next steps toward addressing 6PPDQ in the environment.

What are 6PPD and 6PPDQ?
6-*para*-phenylenediamine (6PPD) is an antiozonant and anti-degradant used in tires. It prevents the oxidation of rubber by scavenging oxygen and ozone, prolonging the effective lifespan of rubber tires.[1] 6PPD-quinone (6PPDQ) is formed when 6PPD reacts with ozone or oxygen.[2] Various *para*-phenylenediamine chemicals (PPDs) have been developed to serve as rubber anti-degradants.

During regular tire usage, rubber particles are worn off the tires and deposited onto the road or become airborne, depending on their size. As they are exposed to the environment, these tire tread wear particles (TWP) leach 6PPDQ into the environment.[3] Physical tires on vehicles also act as important sources of 6PPDQ in the environment. During rainfall events, 6PPDQ on the surface of the tire washes off into stormwater runoff. Many stormwater conveyance systems discharge directly, or indirectly, to waterways near roadways, leading to episodic accumulation of these chemicals in near-road waters.[4] The resulting concentrations of 6PPDQ are a function of many factors, including the amount and type of road traffic, the time between rain fall events, the amount of rainfall, and the volume of water in the near-road water system.

---

[1] Department of Ecology, State of Washington, "Technical Memo: Assessment of Potential Hazards of 6PPD and Alternatives," November 29, 2021.
[2] Cao et al., "New Evidence of Rubber-Derived Quinones in Water, Air, and Soil"; Li et al., "First Insights into 6PPD-Quinone Formation from 6PPD Photodegradation in Water Environment."
[3] Tian et al., "A Ubiquitous Tire Rubber–Derived Chemical Induces Acute Mortality in Coho Salmon"; Cao et al., "New Evidence of Rubber-Derived Quinones in Water, Air, and Soil"; Cao et al.
[4] Johannessen, Helm, and Metcalfe, "Detection of Selected Tire Wear Compounds in Urban Receiving Waters"; Huang et al., "Occurrence of Substituted P-Phenylenediamine Antioxidants in Dusts."

Coho Salmon

Coho salmon are an ecologically and culturally important fish species native to the waters of the Pacific Northwest from California to Alaska.[5] Coho salmon return to freshwater streams in the fall months to spawn. In the 1980s and 1990s, researchers noticed that after rainfall, some populations of coho salmon in more urbanized watersheds were dying at high rates before they could spawn. In 2017, Dr. McIntyre and others linked coho mortality to unknown compounds found in TWP leachates, as was published in 2018 and 2021.[6] In 2020, research published in *Science* first identified the 6PPD transformation product 6PPDQ and reported that 6PPDQ is acutely toxic to coho salmon.[7] Several subsequent studies have confirmed both the high lethality of 6PPDQ to coho salmon and similar acute toxicity of 6PPDQ to several other salmonid species of fish.[8] Other species of fish do not seem sensitive to 6PPDQ[9].

Current state of 6PPD and 6PPDQ research: What is known?

The meeting began with presentations devoted to the state of research and our current understanding of 6PPDQ and its effects. The discussion and key points made by attendees are summarized here.

Coho Mortality

The attendees discussed the known effects of toxicity at length. 6PPDQ is extremely toxic to coho salmon; coho salmon mortality directly stems from exposure to 6PPDQ. Attendees noted that coho mortality occurs extremely quickly and at minimal 6PPDQ concentrations. As little as 0.1 parts per billion of 6PPDQ, or less, can lead to rapid (<24 hr) mortality in coho salmon. In juvenile coho, behavioral symptoms of irreversible damage can occur as soon as 45 minutes after exposure to 6PPDQ, and depending on the concentration of 6PPD in water, death can occur within two hours after exposure. Even if they are subsequently moved to clean water, these symptomatic coho salmon do not recover.

---

[5] Fisheries, "Coho Salmon | NOAA Fisheries."

[6] Peter et al., "Using High-Resolution Mass Spectrometry to Identify Organic Contaminants Linked to Urban Stormwater Mortality Syndrome in Coho Salmon"; McIntyre et al., "Treading Water."

[7] Tian et al., "A Ubiquitous Tire Rubber–Derived Chemical Induces Acute Mortality in Coho Salmon."

[8] Tian et al., "6PPD-Quinone"; Brinkmann et al., "Acute Toxicity of the Tire Rubber-Derived Chemical 6PPD-Quinone to Four Fishes of Commercial, Cultural, and Ecological Importance"; Hiki and Yamamoto, "The Tire-Derived Chemical 6PPD-Quinone Is Lethally Toxic to the White-Spotted Char *Salvelinus Leucomaenis Pluvius* but Not to Two Other Salmonid Species."

[9] Foldvik et al., "Acute Toxicity Testing of the Tire Rubber–Derived Chemical 6PPD-Quinone on Atlantic Salmon (Salmo Salar) and Brown Trout (Salmo Trutta)"; Hiki et al., "Acute Toxicity of a Tire Rubber-Derived Chemical, 6PPD Quinone, to Freshwater Fish and Crustacean Species."

While coho are known to be extremely sensitive to 6PPDQ, other species vary in sensitivity to 6PPDQ. Lethality is highest for coho salmon, white spotted char, brook trout, and rainbow trout. Other species are significantly less sensitive to 6PPDQ. While toxic effects have been observed, there are many questions regarding the toxicological mechanisms of these observed differences and species-specific mortality. Additionally, there are many species and ecological interactions which have not been assessed for their sensitivity to 6PPD and 6PPDQ, or other TWP-derived chemicals.

6PPD and 6PPDQ in the Environment

The primary environmental source of 6PPDQ is fairly well understood to be vehicle tire rubber. 6PPD is added to the rubber in tires as an antidegradant that can prolong the lifespan of the tire and maintain its functionality. Over the lifetime of the tire, 6PPD migrates to the tire's surface where it forms a protective layer against ozone, oxygen, thermal degradation, and mechanical fatigue. As 6PPD reacts with ozone or oxygen, 6PPDQ is formed as a transformation product. Normal wear on the tires creates tire wear particles that contain 6PPD. The 6PPD in those particles is washed by road runoff into the environment. Additionally, 6PPD and 6PPDQ are continuously worn from tires as the protective layer is continuously shed and more chemical diffuses to the tire's surface to regenerate the protective layer. The cycle of 6PPD's migration to the surface of the tire and the shedding of tire wear particles are how 6PPD and its reaction product 6PPDQ are released into the environment.

6PPDQ is not a "forever chemical" and has been shown to have a relatively short half-life (the time over which 50% of it will degrade into another compound) in the environment—ranging from days to months depending on type of environment 6PPDQ is exposed to, such as river water, salt water, earth, or air. However, even though 6PPDQ degrades in under a year, tire wear particles themselves are persistent for decades and harbor residual 6PPD that is continually released into the environment and transformed into 6PPDQ. Tire wear particles from ongoing traffic add more 6PPDQ to the environment, and any rainfall events will carry the resulting 6PPDQ into near-road waters.

Finally, the mechanism of 6PPDQ formation when 6PPD is exposed to ozone or oxygen may primarily, and potentially solely, occur through gas phase reactions with ozone or oxygen in air. The attendees noted that 6PPDQ may not form underwater, despite the existence of many deposits of 6PPD-containing tires underwater, although the fate and reaction pathways to 6PPDQ are still poorly understood. The process of wetting and drying in air leads to 6PPDQ contamination: if the tires are continuously submerged there is likely a considerably reduced potential for 6PPDQ formation.

Potential mitigation options: Knowns & unknowns

Meeting participants named and discussed three potential mitigation approaches that could be further evaluated for implementation. Key knowledge gaps related to 6PPD and 6PPDQ and potential replacement options for 6PPD in tire formulations are discussed in the next section.

Rain Gardens

Rain gardens use an engineered 'soil' matrix (sand and compost in Washington State) combined with plants to filter runoff. The attendees acknowledged that rain gardens are known to remove TWP leachates such as 6PPDQ. However, rain gardens face several challenges. They require significant land space for implementation, and while rain gardens seem to work for extended periods, how long they remain effective at removing 6PPDQ and other contaminants from runoff is unknown and represents an area where more research is needed.

The current unknowns regarding the use of raingardens are particularly related to land use. How much land would be needed to adequately utilize raingardens as a filtration mechanism for 6PPD and 6PPDQ? Where are those raingardens best placed to maximize filtration of particulate contaminants? Further, how can the filtration media be optimized to adequately filter out 6PPDQ?

Porous concrete roadways

Another potential method for mitigation of 6PPDQ is the use of permeable pavements. These pavements are porous and allow stormwater and other runoff through the pavement, while pollutants or other toxicants may be retained and filtered out. Carbon fiber additives to permeable pavements have shown great promise in small studies at mitigating 6PPDQ pollution from runoff, but the availability and cost of sufficient quantities of carbon fiber are unresolved issues at this time.

Several unknowns pertain to porous pavement as a 6PPDQ mitigation strategy. How much roadway or pavement would need to be permeable to achieve the desired effect? Where would the pavements need to be to have the greatest effect? Additionally, what are the associated costs with carbon fiber permeable pavements, and how much would replacement of current pavement cost overall?

Chemical Filtration

Peroxide-activating catalysts, a type of oxidation process, are another option for water disinfection and purification because they can degrade aqueous chemicals. Tetra-amido macrocyclic ligand

(TAML) catalysts are currently the most powerful activators of peroxides and have been shown to be very effective at removing 6PPDQ from water. Notably, TAML catalysts do not convert 6PPD into 6PPDQ and instead break both chemicals down into other byproducts. TAML/peroxide purification works best at high-flowthrough water junctions, such as water exiting urban wastewater treatment plants or storm drains. However, the catalyst could potentially be placed in sieves, in culverts, or in the outlets of porous pavement drainage systems to eliminate 6PPDQ. In culverts, the filters would need to be designed to allow fish passage while also forcing most of the water to pass through the catalyst. The feasibility and practicality of this approach requires further study.

There are four key unknowns for the chemical filtration mitigation strategy:

1. What chemical filter would be most suited to address 6PPDQ without introducing new detrimental effects into the environment?
2. Can the chemical filtration strategy be implemented at the scale necessary to address all the near-road waterways?
3. Assuming that answers to the first two challenges are found, how should the chemical filters be designed to ensure effective 6PPDQ mitigation without impacting the passage of fish or hurting the environment in unforeseen ways?
4. Additionally, for chemical filters that use catalyst activators of peroxides, such as TAML/peroxide, what are the byproducts of 6PPDQ degradation and how toxic are those byproducts?

For treatment of roadway runoff to be an adequate mitigation strategy, the use of pre-filters or other multi-barrier solutions would need to be investigated to ensure that the treatment system would remain functional. Despite these challenges, meeting attendees noted that several companies and other groups—particularly abroad—are exploring various types of treatment systems and treatment media suitable for roadway runoff systems (including the removal of pharmaceuticals and other chemicals co-occurring in stormwater runoff) that could also be useful for the removal of 6PPDQ.

What are the key gaps in knowledge related to 6PPD and 6PPDQ?

Throughout the meeting, participants were asked to identify knowledge gaps that need to be addressed both to ensure appropriate mitigations are put in place and to avoid introducing unintended consequences that are detrimental to coho and other species within the environment. This section briefly summarizes the key knowledge gaps identified during the meeting.

Mechanism of Toxicity

The overall mechanism of toxicity was discussed at length—particularly as it relates to the mortality of coho salmon versus other species. One hypothesis for the observed mortality is that exposure to 6PPDQ causes vascular permeability in the salmon. This has several potential downstream effects, including a demonstrated disruption in the blood-brain barrier (BBB) and neurological damage. Attendees noted that more research needs to be done to assess this and other potential mechanisms of toxicity. A more developed and well-understood mechanism of toxicity could lead to mitigation or other such pathways for addressing 6PPDQ toxicity among different animal species.

Additionally, the role and toxicity of other leachate-derived chemicals in aquatic species are less understood. How do these co-occuring compounds present in the TWP leachate play a role in the observed toxicity (or resistance, in other species) to 6PPDQ in runoff?

Finally, what is the role of the metabolic rate of 6PPDQ in the observed toxicity to species? Attendees noted that more and different 6PPD metabolites were found in less-sensitive species compared to more-sensitive species. Some speculated that a faster metabolic transformation rate might lead to less sensitivity to 6PPDQ, but more research needs to be done to investigate this hypothesis and sufficiently attribute the observed differences to metabolism versus other mechanisms (e.g., level of exposure to 6PPDQ).

Effects on Other Species

While the documented toxicity among coho salmon is dramatic and has quickly become well known in the scientific community, toxicity among other species (especially other keystone aquatic species) needs further assessment. Specifically, other species farther up and down the food chain need to be investigated, such as birds of prey which feed on salmon and other aquatic species, or species on which coho feed. Additionally, other aquatic species, especially orcas, are understudied with regards to the effects of 6PPDQ. The impact of 6PPDQ on other parts of the ecosystem (invertebrates, aquatic plants, algae, lichens, microbes, etc.) is largely unknown. Also critical to understand is the role of sublethal impacts within coho salmon and other species which survive 6PPDQ exposure but may have altered fitness, growth, development, or reproductive potential from sublethal exposures to 6PPDQ.

Human Effects

While the effects of 6PPDQ on a few aquatic species are beginning to be understood, its impact on humans is currently unknown. Human exposure is known to occur by inhalation of TWP and tire dusts near roadways—whenever you walk next to a road and a car goes by, you inhale TWP. The rate of exposure is likely primarily driven by traffic volume and atmospheric conditions. Assessments of the impacts of this exposure are just beginning. For example, 6PPDQ is known to cross the human blood-brain barrier, but its impacts on the brain are not understood. In addition to questions about the immediate effects of 6PPDQ on human health, questions about chronic exposure to these chemicals in humans need to be addressed. Attendees also highlighted that a focus of research on the human effects of exposure to 6PPDQ might generate more research interest in the chemical at large, leading to more mitigation efforts.

Viable Replacements for 6PPD

Identifying a suitable replacement for 6PPD is a critical long-term goal of the tire industry. A replacement will need to meet the federal tire performance standards and customer needs in addition to potential environmental concerns.

The tire industry proactively began investigating options very soon after 6PPDQ was identified as the cause of coho salmon mortality, but to date a suitable alternative has not been identified. Research into alternatives is ongoing and so far seven options have been identified for further evaluation in the USTMA Preliminary (Stage 1) Alternatives Analysis for 6PPD in Tires[10], which was accepted by the California Department of Toxic Substances Control (DTSC) in August 2024.

Assessments of 6PPD alternatives are ongoing particularly in California and Washington State. Such assessments evaluate the performance of each potential alternative in tires, as well as hazard-based assessments of the potential alternative and its reaction products. Several potential alternatives have been identified, and some of their toxicity has been assessed in salmonids.

However, there are several unknowns with the use of 6PPD alternatives that were highlighted in the discussion. For example, what are the toxicology and performance gaps between 6PPD and these alternatives? What is the potential timeline for identification, testing, implementation, and market penetration for these new additives? What is their risk to overall human and environmental health? More data are needed to assess the short- and long-term effects of 6PPD replacements.

It is clear that given the widespread reliance on automotive means of travel, the multi-year lifespan of tires, and the multi-year schedule required to identify, validate, and qualify any replacement may contribute to a substantial delay (e.g., 10-15 years) for significant changes to occur. However, industry innovation may potentially drive faster timelines.

[10] U.S. Tire Manufacturers Association (USTMA), "Preliminary (Stage 1) Alternatives Analysis Report."

Next steps

Key to the discussion of next steps was the acknowledgement among the group of attendees that it is important to address 6PPDQ by looking at both mitigation (short to medium term) *and* replacement (longer term) of 6PPD. Continued involvement of key interested parties in this discussion, including (but not limited to) the Washington Departments of Ecology, Health, Transportation, California DTSC, the U.S. Tire Manufacturers Association, tribal nations, affected municipalities, non-governmental organizations, the recreational and commercial fishing industry, and the research community, is crucial to informing and enabling adequate action on this issue.

Throughout the meeting, attendees also focused on being intentional with regards to replacement of 6PPD in tires and mitigation of 6PPDQ in the environment. This intentionality focused on making sure that the proper assessments and tests are done on alternatives so that the effects of 6PPD replacements are not themselves toxic to humans or wildlife, and that these consequences do not create severe unintended consequences in the future as we work toward the development and use of non-toxic vehicle tires.

Some proposed near-term next steps include the following:

Assessment of Mitigation Methods

Mitigation of 6PPDQ remains a short- and medium-term priority, especially given that replacement of 6PPD in tires will take at least several years to fully actualize. As such, mitigation of 6PPDQ is an important first goal and appropriate to critically sensitive locations, especially as 6PPDQ becomes a regulated parameter in roadway runoff. Next steps in this area include investigation and research into current mitigation methods, evaluation of the feasibility of the methods delineated to this point, and research and development of other cost-effective methods for mitigation of 6PPDQ.

Pilot Programs

Pilot programs for mitigation of 6PPDQ in the environment and replacement of 6PPD in tires represent a valuable next step in alleviation of 6PPDQ in the environment. These pilot programs would provide the opportunity to test methodologies at small scale and allow for assessment of their efficacy. Moreover, they would provide an opportunity to assess benefits and pitfalls of the methodology and potentially scale up methods that work well.

These pilot programs, furthermore, would allow for more collaboration among interested parties where collaboration might not have previously existed, e.g. among researchers and governmental agencies, or researchers and locals directly affected by the issue. WSAS as an organization, too, can play a key role in facilitating interaction among interested parties to help ensure success of pilot projects.

Conclusion

This summary represents the first of potentially several meetings on 6PPD replacement in tires and 6PPDQ mitigation in the environment. More research is needed to elucidate both acute and chronic effects of 6PPDQ on a variety of targets, as well as effective replacement of 6PPD in tires and mitigation of 6PPDQ in the environment. Collaboration among interested parties is key to addressing this issue for Washington State.

Bibliography

Brinkmann, Markus, David Montgomery, Summer Selinger, Justin G. P. Miller, Eric Stock, Alper James Alcaraz, Jonathan K. Challis, et al. “Acute Toxicity of the Tire Rubber-Derived Chemical 6PPD-Quinone to Four Fishes of Commercial, Cultural, and Ecological Importance.” *Environmental Science & Technology Letters* 9, no. 4 (April 12, 2022): 333–38. https://doi.org/10.1021/acs.estlett.2c00050.

Cao, Guodong, Wei Wang, Jing Zhang, Pengfei Wu, Xingchen Zhao, Zhu Yang, Di Hu, and Zongwei Cai. “New Evidence of Rubber-Derived Quinones in Water, Air, and Soil.” *Environmental Science & Technology* 56, no. 7 (April 5, 2022): 4142–50. https://doi.org/10.1021/acs.est.1c07376.

Department of Ecology, State of Washington. “Hazardous Waste and Toxics Reduction Program Technical Memo,” November 29, 2021. https://www.ezview.wa.gov/Portals/_1962/Documents/6ppd/6PPD%20Alternatives%20Technical%20Memo.pdf.

Fisheries, NOAA. “Coho Salmon | NOAA Fisheries.” NOAA, October 12, 2023. Alaska,West Coast. https://www.fisheries.noaa.gov/species/coho-salmon.

Foldvik, Anders, Fedor Kryuchkov, Roar Sandodden, and Silvio Uhlig. “Acute Toxicity Testing of the Tire Rubber–Derived Chemical 6PPD-Quinone on Atlantic Salmon (Salmo Salar) and Brown Trout (Salmo Trutta).” *Environmental Toxicology and Chemistry* 41, no. 12 (2022): 3041–45. https://doi.org/10.1002/etc.5487.

Hiki, Kyoshiro, Kenta Asahina, Kota Kato, Takahiro Yamagishi, Ryo Omagari, Yuichi Iwasaki, Haruna Watanabe, and Hiroshi Yamamoto. “Acute Toxicity of a Tire Rubber-Derived Chemical, 6PPD Quinone, to Freshwater Fish and Crustacean Species.” *Environmental Science & Technology Letters* 8, no. 9 (September 14, 2021): 779–84. https://doi.org/10.1021/acs.estlett.1c00453.

Hiki, Kyoshiro, and Hiroshi Yamamoto. “The Tire-Derived Chemical 6PPD-Quinone Is Lethally Toxic to the White-Spotted Char *Salvelinus Leucomaenis Pluvius* but Not to Two Other Salmonid Species.” *Environmental Science & Technology Letters* 9, no. 12 (December 13, 2022): 1050–55. https://doi.org/10.1021/acs.estlett.2c00683.

Huang, Wei, Yumeng Shi, Jialing Huang, Chengliang Deng, Shuqin Tang, Xiaotu Liu, and Da Chen. “Occurrence of Substituted P-Phenylenediamine Antioxidants in Dusts.” *Environmental Science & Technology Letters* 8, no. 5 (May 11, 2021): 381–85. https://doi.org/10.1021/acs.estlett.1c00148.

Johannessen, Cassandra, Paul Helm, and Chris D. Metcalfe. “Detection of Selected Tire Wear Compounds in Urban Receiving Waters.” *Environmental Pollution* 287 (October 15, 2021): 117659. https://doi.org/10.1016/j.envpol.2021.117659.

Li, Chenguang, Yanlei Zhang, Shiqi Yin, Qin Wang, Yuanyuan Li, Qiang Liu, Liuqingqing Liu, et al. “First Insights into 6PPD-Quinone Formation from 6PPD Photodegradation in Water Environment.” *Journal of Hazardous Materials* 459 (October 5, 2023): 132127. https://doi.org/10.1016/j.jhazmat.2023.132127.

McIntyre, Jenifer K., Jasmine Prat, James Cameron, Jillian Wetzel, Emma Mudrock, Katherine T. Peter, Zhenyu Tian, et al. “Treading Water: Tire Wear Particle Leachate Recreates an Urban

Runoff Mortality Syndrome in Coho but Not Chum Salmon." *Environmental Science & Technology* 55, no. 17 (September 7, 2021): 11767–74. https://doi.org/10.1021/acs.est.1c03569.

Peter, Katherine T., Zhenyu Tian, Christopher Wu, Peter Lin, Sarah White, Bowen Du, Jenifer K. McIntyre, Nathaniel L. Scholz, and Edward P. Kolodziej. "Using High-Resolution Mass Spectrometry to Identify Organic Contaminants Linked to Urban Stormwater Mortality Syndrome in Coho Salmon." *Environmental Science & Technology* 52, no. 18 (September 18, 2018): 10317–27. https://doi.org/10.1021/acs.est.8b03287.

Tian, Zhenyu, Melissa Gonzalez, Craig A. Rideout, Haoqi Nina Zhao, Ximin Hu, Jill Wetzel, Emma Mudrock, C. Andrew James, Jenifer K. McIntyre, and Edward P. Kolodziej. "6PPD-Quinone: Revised Toxicity Assessment and Quantification with a Commercial Standard." *Environmental Science & Technology Letters* 9, no. 2 (February 8, 2022): 140–46. https://doi.org/10.1021/acs.estlett.1c00910.

Tian, Zhenyu, Haoqi Zhao, Katherine T. Peter, Melissa Gonzalez, Jill Wetzel, Christopher Wu, Ximin Hu, et al. "A Ubiquitous Tire Rubber–Derived Chemical Induces Acute Mortality in Coho Salmon." *Science* 371, no. 6525 (January 8, 2021): 185–89. https://doi.org/10.1126/science.abd6951.

U.S. Tire Manufacturers Association (USTMA). "Preliminary (Stage 1) Alternatives Analysis Report." Washington, D.C., March 25, 2024.

Appendices

Appendix A – Meeting Agenda

Appendix B – Participant List

Agenda

A Discussion about the Science of 6PPD and 6PPD-Quinone

Hosted by the Washington State Academy of Sciences

The Rainier Club, Seattle
Friday, May 3, 2024
10:00 AM – 3:00 PM – Cutter Room

Meeting Purpose: An exploratory meeting of researchers and state-level policy leaders to share what is known about the human and environmental health impacts of 6 PPDq. This initial meeting may be a precursor gathering for future meetings or activities, to be determined.

10:00 AM Welcome and Meeting Purpose – Roger Myers

10:05 AM Introductions

Attendees briefly describe their interest in and professional work related to 6PPDq, as well as what would be the most useful outcome of this meeting for them.

10:30 AM Presentation and discussion of five 6PPDq related issues

Part A: What is known (~60min – 15 min for each topic with discussion leaders assigned)

1. Mode of action of 6PPD-Q – how it causes damage and to what target sites in the body of organisms *Discussion lead: Jen McIntyre*
2. Persistence of 6PPD-Q in the environment -- how long does this chemical persist? How wide-spread is this chemical in aquatic ecosystems? *Discussion lead: Ed Kolodziej*
3. Methods to reduce or eliminate 6PPD-Q in the environment *Discussion lead: John Stark*
4. Are there potential replacements for 6PPD-Q in tires from a performance, lifetime, economic and toxicological perspective? *Discussion lead: Terry Collins*

Part B: Areas of divergence, unknowns (~30 min)

Brainstorm about unknowns and challenges to capture the collective knowledge of the group

Noon **Lunch with continued informal discussion**

Continue to capture areas of divergence and knowns and knowledge gaps.

1:00 PM **Discussion of the current landscape of 6PPDq research and mitigation**

As a way to tap into the expertise and experiences across sectors, we encourage all participants to be prepared to discuss current and emerging research, discussions and plans in academe, agencies (in WA State and in collaboration with other states and the federal government), industry, and elsewhere (ngos, etc.). The goal is to identify areas where there is convergence, divergence, and gaps in our knowledge.

2:00 PM **Discussion of possible next steps for future discussions and/or action, when, and by whom**

Future meetings? If so, who should attend? Informational and/or educational materials? Outreach efforts?

3:00 PM **Adjourn**

WSAS 6PPDQ Meeting Participants

* - indicates WSAS Member

*** Roger Myers (Meeting Chair and Moderator) –** Chair of the Washington State Joint Center for Aerospace Technology Innovation (JCATI), President of the Electric Rocket Propulsion Society (ERPS)

Roger Myers is an experienced aerospace leader with over 30 years of experience. From 1996 to 2016 he held executive positions at Aerojet Rocketdyne's Redmond Operations, the world's leading supplier of spacecraft propulsion systems, focusing on technology development and strategic planning for next-generation in-space missions and architectures, propulsion, power and integrated systems. Prior to joining Aerojet Rocketdyne in 1996, he worked at NASA's Glenn Research leading research and development of advanced space propulsion technologies. He has led dozens of development and space flight programs and published over 80 papers on electric and chemical propulsion technology and in-space transportation architectures. Additionally, Dr. Myers serves as chair of the Washington State Joint Center for Aerospace Technology Innovation and President of the Electric Rocket Propulsion Society (ERPS). He is a Fellow of the American Institute of Aeronautics and Astronautics (AIAA), was elected to the Washington State Academy of Sciences in 2012, won the AIAA Wyld Propulsion Award in 2014 and was elected to the Board of Trustees for the Seattle Museum of Flight in 2015. He has served on several committees for the National Research Council, and is a past President of WSAS. Dr. Myers holds a Bachelor of Science degree in Aerospace Engineering, summa cum laude, from the University of Michigan. He received his Ph.D. in Mechanical and Aerospace Engineering from Princeton University.

*** Joel Baker** – UW-Tacoma Urban Waters Center, Director Urban Waters

Professor Joel Baker holds the Port of Tacoma Chair in Environmental Science and is the Science Director of the Center for Urban Waters. He earned a B.S. degree in Environmental Chemistry from SUNY Syracuse (1982) and M.S. (1985) and Ph.D. (1988) degrees in Civil and Environmental Engineering from the University of Minnesota.
Dr. Baker's research interests center about the transport of organic contaminants in the environment, specifically atmospheric transport and deposition, aerosol chemistry, the dynamics of contaminant transport in estuaries, and modeling the exposure and transfer of bioaccumulative chemicals in aquatic food webs. He teaches courses in water quality modeling, environmental chemistry, and quantitative methods.

He has co-authored over one hundred papers on contaminant cycling in the Great Lakes, the Chesapeake Bay and coastal waters, and edited Atmospheric Deposition of Contaminants to the Great Lakes and Coastal Waters (SETAC Press, 1997). He was the lead author on a scientific review of PCBs in the Hudson River, a contributing author to the Pew Oceans Commission report Marine Pollution in the United States, and a member of the NRC's Committee on Oil in the Sea, chaired the New York Harbor Model Evaluation Group, advised the European Commission on water quality modeling, and served on the Board of Directors of the Society of Environmental Toxicology and Chemistry. Dr. Baker is a member of the Puget Sound Partnership Science Panel, which he chaired from 2007-2009.

Justine Capra – Director of Governmental Affairs, Nisqually Tribe, 2021-2024.

Terrence J. Collins – Carnegie Mellon University, Teresa Heinz Professor in Green Chemistry, Chemistry, Director, Institute for Green Science

A champion of sustainability science, Terry Collins is the Teresa Heinz Professor of Green Chemistry and the Director of the Institute for Green Science at Carnegie Mellon University. Collins invented "TAML® Activators", the first, full-functional, small molecule mimics of any of the great families of oxidizing enzymes. In the process, one challenge of reaction chemistry has been solved—easy deployment of the mimicked efficient catalytic cycles of oxidative metabolism. Collins learned of the insidious health damage caused by anthropogenic chemical pollutants in his native New Zealand, launching his academic career by creating an iterative catalyst design protocol to explore whether biomimetic processes for disinfecting water could be developed to replace chlorine and avoid chlorinated disinfection products. Collins was a member of a team who worked to produce the Tiered Protocol for Endocrine Disruption (TiPED), which allows EDs to be identified at the highest levels of contemporary science. These discoveries are underpinning new technologies for treating diverse wastewaters and enabling other products. For over two decades, Terry Collins has been perfecting what is the first university course in Green Chemistry—today the class is entitled "Chemistry and Sustainability". Collins earned his undergraduate and doctoral degrees from the University of Auckland, joining the Carnegie Mellon faculty in 1987. Collins has delivered over 600 public lectures, is an author on over 200 publications, and holds many honors, including the 2018 Carnegie Science Center Award for the Environment, the 2010 Heinz Award for the Environment, the inaugural Charles E. Kaufman Award of the Pittsburgh Foundation, and the USEPA's 1999 Presidential Green Chemistry Challenge Award. He is a Fellow of the Royal Society of New Zealand (Hon), the ACS, and the Alfred P. Sloan Foundation, and he received a Dreyfus Teacher-Scholar Award.

Rob Duff – Executive Director, Policy & Outreach, Governor Inslee's office

Robert Duff knows that certain environmental health issues can be contentious, especially with so many different stakeholders involved. With a academic training in toxicology, Duff has worked extensively in the public sector, and has been a public health voice at the table and in the community for cleanup of Superfund sites, the Duwamish River in Seattle and the Fairchild Air Force Base in Spokane. He has tackled legislative reform at the state level, including a ban on brominated flame retardants and a reduction of copper in brake pads. Previously, Duff was a senior policy advisor to Governor Jay Inslee on natural resource and environmental issues, and worked with the governor and others on the Toxics Reduction Initiative and associated Toxics Reduction bill. Further, he managed the Environmental Assessment Program in the Washington State Department of Ecology where he helped the agency push for an update to the federal Toxic Substances Control Act, the legislation that regulates the introduction of new or already existing chemicals or chemical mixtures. Additionally, he was involved in the state's reexamination of fish consumption rates, which ideally protect people who eat fish and shellfish and help determine how clean waters must be from contaminants such as polychlorinated biphenyls (PCBs) or mercury, which end up in fish tissue and pose risks to human health. Duff is an advocate for increased communication in science, and urges more scientists to use their background to influence policy.

Jake Fey – Washington State Representative, 27th District

Born and raised in Port Angeles, in the northwest corner of Washington state, Rep. Jake Fey's experience in the YMCA Youth and Government program pointed him early on toward a life of public service. He was the first in his family to graduate from college, earning a bachelor's degree in political science from the University of Washington and then an MPA from the University of Puget Sound. Rep. Fey served as the Director of the WSU Energy program from 2001 to 2019, providing leadership in alternative-energy and energy-efficiency. During his time as a Tacoma City Councilmember, Rep. Fey also served as a member of the Sound Transit and Pierce Transit Boards, and as Vice Chair of the Puget Sound Clean Air Agency. Elected to the Washington State House of Representatives in 2012, Rep. Fey currently serves as Chair of the House Transportation Committee and as a member of the House Environment and Energy Committee.

One of Rep. Fey's top priorities in the legislature is ensuring a cleaner, more sustainable transportation system for our state. During the 2019 Legislative session, he introduced the Green Transportation bill, aimed at helping switch to electric vehicles and cleaner fuels, with incentives to buy electric vehicles and help to build the infrastructure to charge electric cars in Washington state. During the 2022 Legislative Session, Jake led his colleagues in passage of the Move Ahead Washington transportation package—a $17 billion, 16-year package that makes unprecedented investments in transit, active transportation and highway preservation and maintenance.

Ed Kolodziej – Washington Stormwater Center, UW Tacoma Urban Waters Center, Analytical Chemist (Chemically identified 6PPDQ)

Ed Kolodziej began his academic studies with a B.S. in Chemical Engineering from Johns Hopkins University (1998), after which he focused on environmental issues and went to the University of California at Berkeley where he received his M.S. (1999) and a Ph.D (2004) in Environmental Engineering. He came to CEE in 2014 as part of the UW Freshwater Science Initiative after seven years as faculty at the University of Nevada, Reno, also in Civil and Environmental Engineering. He also holds a joint appointment with Interdisciplinary Arts and Sciences at UW Tacoma, and is affiliated with local and regional water quality efforts through The Center for Urban Waters.

Ed's interests include water quality and contaminant fate in natural and engineered systems, especially focusing on interdisciplinary approaches to complex environmental issues affecting water and ecosystem health. His research group works to characterize and control non-point source pollution, understand attenuation mechanisms in natural systems, and optimize engineered systems for trace contaminant removal. His research has been published in Science, and featured in news media such as Nature, Scientific American, U.S. News and World Report, Yahoo Health News, BBC Radio's "Inside Science", and the Huffington Post among others.

Jenifer McIntyre – Washington Stormwater Center, WSU Puyallup, Salmon Biologist, Ecotoxicologist (determined that 6PPDQ was toxic to Coho salmon)

Dr. Jenifer McIntyre is an Associate Professor of aquatic toxicologist at the Puyallup Research and Extension Center. She is very passionate about science that effectuates change. Her B.Sc. (1997) in environmental biology at Queen's University led to the ban of a pulp mill effluent used as a road dust suppressant. Her M.S. (2004) from the University of Washington on contaminant bioaccumulation led the Washington State Department of Health to issue a fish consumption advisory for Lake Washington. Her Ph.D. (2010) research at UW on olfactory neurotoxicity of copper in coho salmon helped pass legislation in Washington and California that phases out metals in brake pads. Dr. McIntyre currently researches the ecotoxicology of stormwater runoff and the biological effectiveness of green stormwater infrastructure as a project lead on the Puget Sound Stormwater Science

Team – a collaborative effort between WSU, US Fish & Wildlife Service, and NOAA National Marine Fisheries Service. In addition to the research conducted by PSSST, the group works to inform citizens about the impact that our urban areas have on aquatic wildlife like Pacific salmon, and what we can do to reduce those impacts. The research conducted by PSSST, the group works to inform citizens about the impact that our urban areas have on aquatic wildlife like Pacific salmon, and what we can do to reduce those impacts.

Tracey Norberg – U.S. Tire Manufacturers Association

Tracey Norberg is the Executive Vice President and General Counsel at the U.S. Tire Manufacturers Association (USTMA), leading the legal and policy advocacy for the tire industry on a range of issues, including environmental science and policy, manufacturing, transportation, product safety, antitrust, industry litigation, innovation, sustainability and trade. With more than 25 years in the association, Norberg has a deep understanding of the challenges and opportunities facing the tire industry in the U.S. and globally. Some notable achievements include protecting tire industry interests during the 2017 Section 232 steel tariff debate, spearheading tire industry's contributions to a groundbreaking National Academy of Sciences study on tire efficiency, and successfully advocating for an industry-supported tire efficiency provision in the Energy Independence and Security Act of 2007. Norberg is passionate about advancing the tire industry's vision of a sustainable future and enhancing its reputation as a responsible and innovative sector.

Carrie Sessions – Senior Policy Advisor for Environment and Water, Office of Washington State Governor Jay Inslee, 2022-present.

*** John Stark** – Professor of Entomology, Director of the Washington Stormwater Center, Washington State University

John Stark runs the Ecotoxicology Program at WSU Puyallup and is the Director of the Washington Stormwater Center. His research deals with protection of endangered species and ecological risk assessment of pollutants with particular emphasis on salmon and their food. John is also a population modeler and has developed population-level risk assessments based on matrix models and differential equation models. Recent projects involve determination of the effects of stormwater low impact development on salmon and invertebrate health and assessing the impact of pesticides on endangered butterfly species. John has published over 140 peer-reviewed papers in scientific journals, numerous book chapters, and a book on ecological risk assessment entitled "Demographic Toxicity: Methods in Ecological Risk Assessment."

Tanya Williams – 6PPD Lead Agency Planner, Washington State Dept. of Ecology

Tanya Williams is an environmental scientist specializing in the Clean Air Act, air dispersion modeling, health risk assessments, environmental management systems, sustainability, environmental justice, and the National Environmental Policy Act. Currently Williams is an environmental planner with the Washington Department of Ecology with 20 years of experience providing regulatory compliance, environmental program development, project management, and environmental assessments for public and private industries. Her role as the agency's 6PPD/q Planner and lead of the national Tire Anti-Degradant (6PPD) Team encourages collaboration across federal, tribal, state, and local governments to plan 6PPD research efforts and find solutions to the second most toxic aquatic chemical ever measured, 6PPD-quinone.

WSAS Staff

Donna Gerardi Riordan Executive Director
Tristan Fehr, Associate Program Officer
Josh Frost, Research Assistant/Writer (virtual)
Emma Rogers, Program Coordinator
Nichole Wamsley, Program Operations Manager