Technical Supporting Documentation for Priority Chemicals

Safer Products for Washington Cycle 2 Implementation Phase 1

Hazardous Waste and Toxics Reduction

Washington State Department of Ecology
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Related information

- Safer Products for Washington Cycle 1 Implementation Phase 2: Report to the Legislature on Priority Consumer Products[1]
- Safer Products for Washington Cycle 1 Implementation Phase 3: Final Report to the Legislature on Regulatory Determinations[2]
- Safer Products for Washington Cycle 1 Implementation Phase 4:
    - Chapter 173-337-WAC—Safer Products Restriction and Reporting[3]
    - Concise Explanatory Statement[4]
- Safer Products for Washington Cycle 2: Identification of Priority Chemicals Report to the Legislature[5]

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[1] apps.ecology.wa.gov/publications/summarypages/2004019.html
[2] apps.ecology.wa.gov/publications/summarypages/2204018.html
[3] app.leg.wa.gov/wac/default.aspx?cite=173-337
[4] apps.ecology.wa.gov/publications/summarypages/2304033.html
[5] apps.ecology.wa.gov/publications/summarypages/2404025.html
[6] www.ecology.wa.gov/contact

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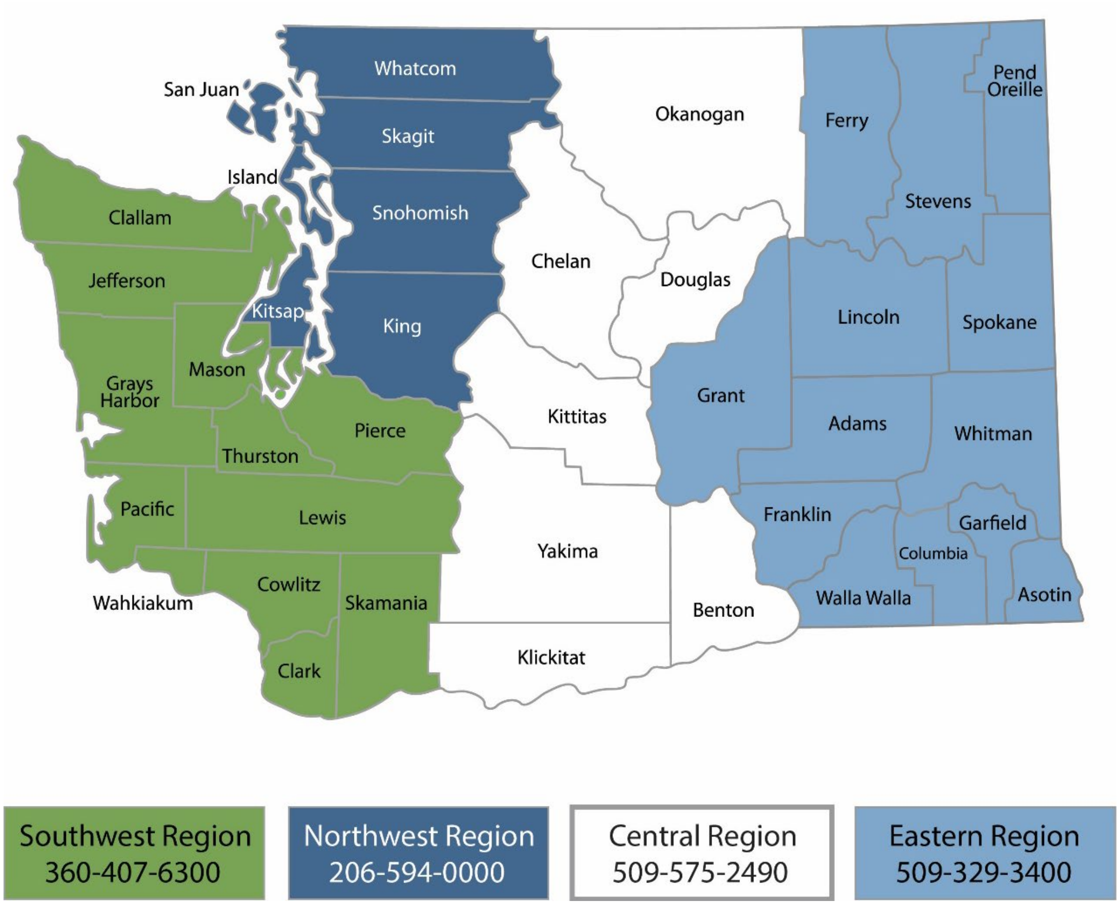

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DEPARTMENT OF
ECOLOGY
State of Washington

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Process overview

RCW 70A.350.020[7] outlines clear criteria for identifying priority chemicals. However, there are more chemicals that meet the criteria in the law than can be included in a single Safer Products for Washington cycle. We developed a prioritization process with the following goals:

- Use a transparent approach that is grounded in science and public input to identify priority chemicals.
- Center our work around equitably reducing exposure to toxic chemicals.
- Show that the priority chemicals selected meet the criteria in the law.

In a September 2022 webinar,[8] we described our proposed methods for identifying priority chemicals. In June 2023, we shared a draft report[9] for public comment and held a second webinar[10] describing our research results. At each step, we heard feedback from stakeholders and refined our process.

Figure 1 shows the process for identifying priority chemicals. We started by researching chemicals found in products included in our public survey. We bolstered this by reviewing exposure data to identify chemicals with disproportionate exposure and environmental concerns. Then we screened these chemicals for known and potential hazards. We narrowed our list and defined the chemical classes. Lastly, we evaluated the chemical classes against the criteria in the law. Each of these steps are described below.

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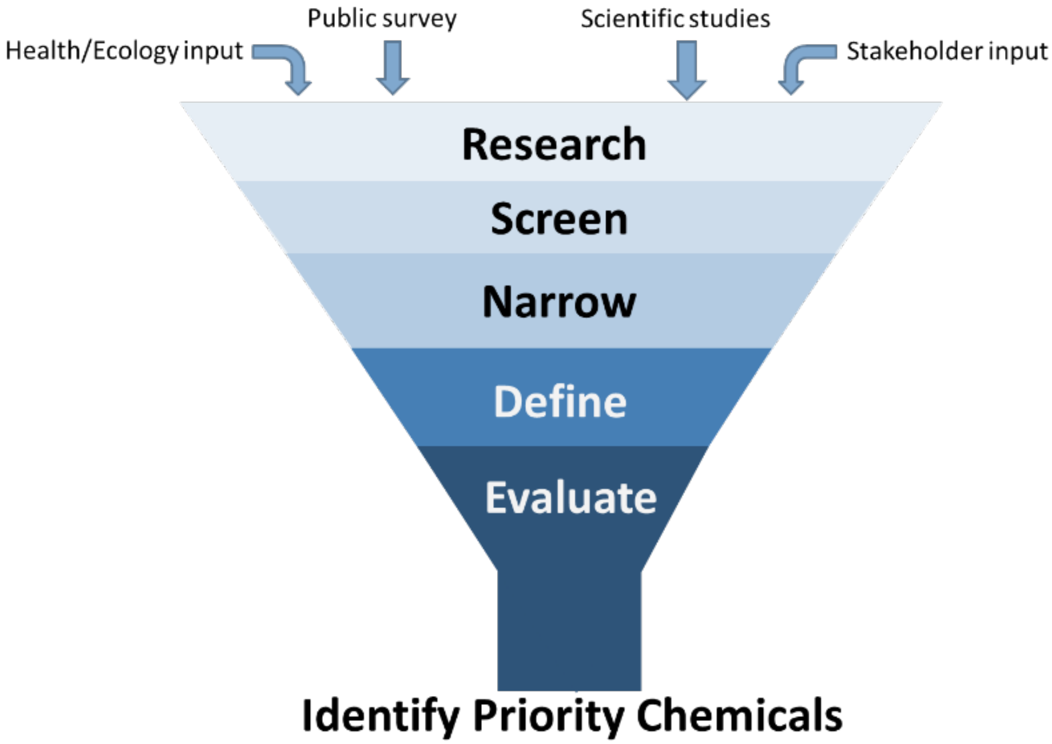
[7] app.leg.wa.gov/rcw/default.aspx?cite=70A.350.020

[8] www.ezview.wa.gov/Portals/_1962/Documents/saferproducts/Cycle2Chemicals_September_2022_Webinar_Presentation.pdf

[9] apps.ecology.wa.gov/publications/summarypages/2304038.html

[10] www.ezview.wa.gov/Portals/_1962/Documents/saferproducts/June%202023_Cycle2%20Phase%201_Presentation_Revised.pdf

Figure 1. Process for identifying priority chemicals.



Identifying priority chemicals

We grounded our chemicals research in public input and focused on chemicals with disproportionate exposures and environmental concerns. We identified chemicals for screening from three primary sources:

- Chemicals in products identified in our public survey.
- Chemicals with disproportionate exposures or environmental concerns.
- Existing chemical priorities from Health and Ecology.

Public input

Between November 2021 and January 2022, we conducted a public survey in English and Spanish. We distributed the survey using multiple media channels. Almost 400 people responded to our survey. We asked participants to share which products containing toxic chemicals caused them the most concern. The most common products identified were:

- Apparel.
- Automotive and tire products.
- Cleaning products.
- Food packaging and food contact materials.
- Personal care and beauty products.

- Plastic packaging.
- Residential pesticides.

We started with the products identified in the survey because we wanted to be responsive to stakeholders, including members of the general public. We took information about what products people use and then identified chemicals found in these products. We used safety data sheets, ingredient lists, EPA tools like CPCat and CPDat, and peer-reviewed literature to identify chemicals in products (EPA, n.d.-c).

Disproportionate and environmental exposures

We reviewed biomonitoring data, occupational exposure data, and product use information to identify chemicals with higher exposure potential in sensitive populations. We relied on data from the National Health and Nutrition Examination Survey, peer-reviewed literature, and Health and Ecology's existing priorities. People can have different exposures to chemicals from consumer products based on sociodemographic factors, such as age, race, ethnicity, gender, and socioeconomic status. For example, a recent analysis of racial disparities in women's chemical exposure found Black and Hispanic women's exposure to some chemicals was twice as high as non-Hispanic White women (Nguyen et al., 2020). By prioritizing chemicals with disproportionate exposures, our work is more likely to benefit people with the highest exposures.

Lastly, we reviewed environmental monitoring data from our own research and peer-reviewed literature to identify chemicals with the potential to expose sensitive species. We prioritized chemicals widely detected in the environment, critical habitats, or sensitive species. For example, we prioritized chemicals of known concern to Washington's salmon populations and chemicals capable of long-range transport in the environment.

Screening chemicals for potential hazards

We screened chemicals for known or potential hazards. We used methods similar to those published in our 2022 Regulatory Determinations Report to the Legislature.[11] We leveraged authoritative sources, existing hazard assessments, predictive models and tools, and peer-reviewed literature. We screened chemicals for carcinogenicity, mutagenicity, reproductive and developmental toxicity, endocrine disruption, aquatic toxicity, persistence, and bioaccumulation. To manage our workload, we limited our screening to easily accessible information on well-characterized chemicals. We further characterized hazards of priority chemicals when we evaluated those chemicals against the statutory criteria.

Narrowing our priorities

Through our research and screening, we identified chemicals with disproportionate exposures in people. We also identified chemicals that may contribute to environmental exposure. We

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[11] apps.ecology.wa.gov/publications/summarypages/2204018.html

focused on chemicals with known or potential hazards to human health and chemicals that are found in consumer products. We narrowed the chemicals identified to the seven classes in this report by deprioritizing those with existing effective regulatory structures and prioritizing those with potential for:

- Equitably reducing exposure. We used data from the National Health and Nutrition Examination Survey and the peer-reviewed literature to identify chemicals with higher exposure in sensitive populations.
- Preventing regrettable substitutions. We reviewed available data to determine potential functions of chemicals in products. We used safety data sheets, EPA's functional use database, and the peer-reviewed literature (Phillips et al., 2017).
- Reducing environmental persistence. We reviewed environmental persistence data and considered peer-reviewed literature describing how the molecular structures of chemicals contribute to their persistence the environment.
- Reducing carcinogens, mutagens, reproductive and developmental toxicants, and endocrine disruptors. We reviewed authoritative lists, government reports, and the peer-reviewed literature to identify chemicals that were associated with these hazards.
- Reducing production and release volumes. We used EPA's high production volume list and the toxics release inventory to characterize chemical production and releases (EPA, n.d.-f, n.d.-d).

Safer Products for Washington is a cyclical, repeating process. We identified more priorities than we could address in a single cycle. For that reason, we also considered how the chemicals fit within existing Ecology and Health priorities, and the expected workload associated with each class. Chemicals were prioritized for different reasons. Some examples of ways we prioritized chemicals are below.

- To identify opportunities to equitably reduce exposure, we prioritized chemicals tied to research suggesting disproportionate exposures in sensitive populations. We also prioritized chemicals when existing efforts, such as regulations in other jurisdictions or products, demonstrate the potential to reduce exposure to these chemicals.
- To prevent regrettable substitutions, we considered whether two classes of chemicals could serve the same function in products. If they could serve the same function, we prioritized both.
- To find ways to reduce persistent chemical use, we prioritized chemical classes with molecular structures that increase the likelihood of them persisting in the environment.
- To protect people and wildlife, we prioritized chemicals associated with carcinogenicity, mutagenicity, reproductive toxicity, developmental toxicity, and endocrine disruption.
- To focus on chemicals with substantial uses and releases, we prioritized chemical classes with high production and release volumes.

By integrating the considerations above into our process for prioritizing chemicals and chemical classes, we focused our work to better protect people and the environment. For example, we can begin to find ways to equitably reduce exposures by identifying disproportionate exposures. By identifying chemicals that serve the same function, we will also effectively use our resources to prevent regrettable substitutions.

We can help mitigate environmental contamination and reduce the need for large-scale cleanups by prioritizing persistent chemicals. We can reduce the potential for adverse impacts in people and the environment by prioritizing chemicals with hazards that can contribute to enduring health effects. We also increase the likelihood of our work having a meaningful impact by prioritizing chemicals with substantial uses and releases to the environment.

Defining classes

After we identified preliminary chemicals, we focused on defining the scope of the chemical class. Chemicals with shared molecular structures often share biological mechanisms. Chemicals with shared biological mechanisms can share hazards. When exposed to multiple chemicals that have the same hazards, those chemicals can cause cumulative impacts. Exposure to chemicals that have similar breakdown products can also cause cumulative impacts.

Likewise, chemicals with similar molecular structures can have comparable functions in products. That means when manufacturers avoid one problematic chemical but replace it with a chemical that has a similar molecular structure, the new chemical might function the same but also have the same hazards. This is called a regrettable substitution.

When grouping chemicals into classes we considered:

- Similarities in molecular structures.
- Similarities in hazards.
- Cumulative and aggregate exposure concerns.
- Developmental impacts.
- Persistence.
- History or potential for regrettable substitutions.
- Common breakdown or byproducts.

Evaluating priority chemicals

The statute requires that priority chemicals or chemical classes meet specific criteria as described in RCW 70A.350.020:[12]

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[12] app.leg.wa.gov/RCW/default.aspx?cite=70A.350.020

(1) The chemical or a member of a class of chemicals are identified by the department as a:

    (a) High priority chemical of high concern for children under chapter 70A.430 RCW;[13] or

    (b) Persistent, bioaccumulative toxin under chapter 70A.300 RCW;[14]

(2) The chemical or members of a class of chemicals are regulated:

    (a) In consumer products under chapter 70A.430, 70A.405,[15] 70A.222,[16] 70A.335,[17] 70A.230,[18] or 70A.400 RCW;[19] or

    (b) As a hazardous substance under chapter 70A.300 or 70A.305 RCW;[20] or

(3) The department determines the chemical or members of a class of chemicals are a concern for sensitive populations and sensitive species after considering the following factors:

    (a) A chemical's or members of a class of chemicals' hazard traits or environmental or toxicological endpoints;

    (b) A chemical's or members of a class of chemicals' aggregate effects;

    (c) A chemical's or members of a class of chemicals' cumulative effects with other chemicals with the same or similar hazard traits or environmental or toxicological endpoints;

    (d) A chemical or members of a class of chemicals' environmental fate;

    (e) The potential for a chemical or member of a class of chemicals to degrade, form reaction products, or metabolize into another chemical or a chemical that exhibits one or more hazard traits or environmental or toxicological endpoints, or both;

    (f) The potential for the chemical or class of chemicals to contribute to or cause adverse health or environmental impacts;

    (g) The chemical's or class of chemicals' potential impact on sensitive populations, sensitive species, or environmentally sensitive habitats;

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[13] app.leg.wa.gov/rcw/default.aspx?cite=70A.430
[14] app.leg.wa.gov/rcw/default.aspx?cite=70A.300
[15] app.leg.wa.gov/rcw/default.aspx?cite=70A.405
[16] app.leg.wa.gov/rcw/default.aspx?cite=70A.222
[17] app.leg.wa.gov/rcw/default.aspx?cite=70A.335
[18] app.leg.wa.gov/rcw/default.aspx?cite=70A.230
[19] app.leg.wa.gov/rcw/default.aspx?cite=70A.400
[20] app.leg.wa.gov/rcw/default.aspx?cite=70A.305

(h) Potential exposures to the chemical or members of a class of chemicals based on:

    (i) Reliable information regarding potential exposures to the chemical or members of a class of chemicals; and

    (ii) Reliable information demonstrating occurrence, or potential occurrence, of multiple exposures to the chemical or members of a class of chemicals.

We evaluated the chemicals and classes against the criteria in the law using chemical hazard assessments, authoritative lists, peer-reviewed data, government reports, and other relevant information.

We characterized the known and potential hazards by reviewing third-party chemical hazard assessments. We focused on examples of data-rich chemicals in the class. In this context, data-rich chemicals are those with authoritative listings or chemical hazard assessments. Chemical hazard assessments review primary literature and government reports to score hazard endpoints.

The chemical hazard assessments referenced in this report include GreenScreen® reports and SciveraLENS® GHS+ chemical hazard assessments. We evaluated each of these methods for transparency, independence, and thoroughness in our 2022 Regulatory Determinations Report to the Legislature.[21] Each of these assessments have transparent methods, data requirements, and hazard criteria that align with the globally recognized system for classifying and labeling chemicals. In the following technical chapters, we describe the key findings from these assessments and provide references to the assessments, when possible.

Using chemical hazard assessments helped us take a systematic approach to reviewing and interpreting the data and peer-reviewed literature. We also used chemical hazard assessments to identify known and potential hazards.

We used authoritative sources to characterize known and potential hazards. Using authoritative sources leverages the work done by governments and other authoritative bodies and aligns our work with others in the space. In this report, we rely on authoritative lists from government agencies and intergovernmental organizations including the United States (U.S.), the European Union (EU), and the United Nations (UN). We used many of these lists in previous regulations, including the Children's Safe Products Act List of Chemicals of High Concern to Children.[22]

When characterizing exposure potential, we primarily relied on data from peer-reviewed literature, demonstrating the presence of chemicals in people's bodies and the environment. We also considered data on chemicals in house dust and indoor air, and chemical use in consumer products, particularly if biomonitoring data were not available.

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[21] apps.ecology.wa.gov/publications/summarypages/2204018.html

[22] apps.leg.wa.gov/wac/default.aspx?cite=173-334-130

Finally, when determining the potential for adverse impacts in sensitive species and populations, we focused on hazards and exposure potential. In RCW 70A.350.010,[23] sensitive species and sensitive populations are defined below.

- **Sensitive population** means a category of people that is identified by the department that may be or is disproportionately or more severely affected by priority chemicals, such as:
    - Men and women of childbearing age.
    - Infants and children.
    - Pregnant women.
    - Communities that are highly impacted by toxic chemicals.
    - Persons with occupational exposure.
    - The elderly.
- **Sensitive species** means a species or grouping of animals that is identified by the department that may be or is disproportionately or more severely affected by priority chemicals, such as:
    - Southern resident Orcas.
    - Salmon.
    - Forage fish.

When possible, we included observed impacts on sensitive populations and species. In cases with limited data, we assessed the potential for adverse impacts by considering:

- Known and potential hazards of chemicals in the class.
- Potential exposures for people and wildlife.
- Potential for cumulative and aggregate effects.

When sensitive populations and species are exposed to chemicals with hazards, there is potential for adverse impacts. This is especially true when exposures occur from multiple routes (such as air, water, and consumer products) and at the same time as other chemicals that impact the same biological systems. There is ample evidence that people and wildlife are exposed to a range of chemicals throughout their lives. In some cases, we added further support to this conclusion by citing observational studies and epidemiological studies showing an association between chemicals and adverse impacts. However, we did not find epidemiological and observational studies for every chemical and class under consideration. When observational and epidemiological studies were not available, we relied on information

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[23] app.leg.wa.gov/rcw/default.aspx?cite=70A.350.010

about the hazards and exposure in sensitive populations to determine whether there was the potential for adverse impacts.

In the following technical chapters, we demonstrate how, using the methods described above, the chemical classes in this report meet the criteria in RCW 70A.350.020.

Chapter 2: Technical Support for Cadmium and Cadmium Compounds

Chapter overview

Cadmium has a variety of uses such as the manufacture of nickel-cadmium batteries, as a stabilizer for polyvinyl chloride, and as pigments for plastics, ceramic, and glass. It can also be a contaminant in metal products. Children's products, jewelry, and other consumer products contain cadmium and people can be exposed to cadmium by interacting with these products. Cadmium is a known carcinogen, and it is associated with reproductive and developmental toxicity.

We selected cadmium and cadmium compounds as a priority chemical class for this cycle of Safer Products for Washington because they are widely detected in the environment and in people's bodies. They are also associated with concerning human and environmental hazards that impact sensitive populations and species. Washingtonians have higher exposure to cadmium than the national average. Cadmium has been detected in Washington's waters, sediment, and air, with some samples exceeding environmental limits. Because cadmium is toxic to salmon, these exposures may be impacting this and other sensitive species. Ecology's successful implementation of regulations on cadmium in children's products demonstrates that reducing cadmium levels in some consumer products is possible.

Cadmium meets the high priority chemical criteria because it is:

- A high priority chemical of high concern to children, identified by Ecology under Chapter 70A.430 RCW.[24]
- Regulated in numerous relevant consumer products.
- Considered a hazardous substance in Washington.
- A concern for sensitive species and populations.

Rationale and references are described below.

Scope of priority chemical class

This report identifies cadmium and cadmium compounds (CAS number 7440-43-9) as a priority chemical.

Rationale for class approach

Cadmium and cadmium compounds are grouped in a chemical class due to the presence of cadmium.

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[24] app.leg.wa.gov/rcw/default.aspx?cite=70A.430

This grouping is reasonable and supported by scientific evidence. All members of the class contain cadmium, which has multiple known and potential hazards. Cadmium and cadmium compounds as a class are known human carcinogens, according to the International Agency for Research on Cancer (IARC). This determination was made after reviewing multiple cadmium compounds. Cadmium and cadmium compounds as a class are considered chemicals of high concern to children (Table 1).

Meeting the statutory requirements

The statute requires that priority chemicals or chemical classes meet specific criteria. Priority chemical classes must meet at least one of the criteria described in RCW 70A.350.020[25] and listed below.

- A member of the chemical class has been identified by Ecology as a chemical of concern, specifically:
    - A chemical of high concern to children under Chapter 70A.430 RCW[26] or
    - A persistent, bioaccumulative, and toxic (PBT) chemical under Chapter 70A.300 RCW.[27]
- A member of the chemical class is regulated in relevant consumer product statutes in Washington.
- A member of the chemical class is a hazardous substance under Chapter 70A.300 RCW or Chapter 70A.305 RCW.[28]
- Members of the chemical class are a concern for sensitive populations and sensitive species.

Cadmium and cadmium compounds meet at least one of the criteria necessary to be considered priority chemicals. Each of the criteria are discussed below.

Chemicals of concern by Ecology

Chemical classes with members that are chemicals of high concern to children (CHCC), identified under Chapter 70A.430 RCW, meet the criteria for designation as priority chemical class under RCW 70A.350.020(1)(a). Ecology identifies chemicals of high concern to children based on their hazards and exposure potential in Chapter 173-334 WAC.[29]

Cadmium and cadmium compounds are on our CHCC list in WAC 173-334-130[30] (Table 1). To review the rationale for CHCC listing, please refer to the Rationale for Reporting List of Chemicals of High Concern to Children 2011 to 2017 (Ecology, 2021b).

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[25] app.leg.wa.gov/rcw/default.aspx?cite=70A.350.020
[26] app.leg.wa.gov/rcw/default.aspx?cite=70A.430
[27] app.leg.wa.gov/rcw/default.aspx?cite=70A.300
[28] app.leg.wa.gov/rcw/default.aspx?cite=70A.305
[29] apps.leg.wa.gov/wac/default.aspx?cite=173-334
[30] app.leg.wa.gov/wac/default.aspx?cite=173-334-130

Table 1. Cadmium and cadmium compounds on the Chemical of High Concern to Children List, identified under Chapter 70A.430 RCW.

Chemical	CAS RN
Cadmium and cadmium compounds	7440-43-9

Chemical classes with members identified as persistent, bioaccumulative, and toxic substances (PBTs) under Chapter 70A.300 RCW[31] meet the criteria for designation as a priority chemical class under RCW 70A.350.020(1)(b). Ecology identifies chemicals that are persistent, bioaccumulative, and toxic in WAC 173-333-310.[32]

Cadmium is not listed as a PBT under Chapter 173-333 WAC;[33] however, cadmium is listed in WAC 173-333-315[34] as a metal of concern. The PBT rule treats metals differently because they are inherently persistent. Chemicals found in the class that are PBTs or metals of concern are described in Table 2.

Table 2. Cadmium and cadmium compounds that are metals of concern under WAC 173-333-315.

Chemical or metal of concern	CAS RN	Rationale
Cadmium	7440-43-9	Pose a threat to human health and the environment in Washington

Regulation in consumer products under relevant Washington statutes

Chemical classes with members regulated in consumer products under Chapters 70A.430,[35] 70A.405,[36] 70A.222,[37] 70A.335,[38] 70A.230,[39] or 70A.400 RCW[40] meet the criteria for designation as a priority chemical class under RCW 70A.350.020(2)(a).[41] Cadmium is regulated in consumer products in Washington under the statutes identified in Table 3.

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[31] app.leg.wa.gov/rcw/default.aspx?cite=70A.300
[32] app.leg.wa.gov/wac/default.aspx?cite=173-333-310
[33] app.leg.wa.gov/wac/default.aspx?cite=173-333
[34] app.leg.wa.gov/wac/default.aspx?cite=173-333-315
[35] app.leg.wa.gov/rcw/default.aspx?cite=70A.430
[36] apps.leg.wa.gov/rcw/default.aspx?cite=70A.405
[37] app.leg.wa.gov/rcw/default.aspx?cite=70A.222
[38] app.leg.wa.gov/rcw/default.aspx?cite=70A.335
[39] app.leg.wa.gov/rcw/default.aspx?cite=70A.230
[40] app.leg.wa.gov/rcw/default.aspx?cite=70A.400
[41] app.leg.wa.gov/rcw/default.aspx?cite=70A.350.020

Table 3. Cadmium and cadmium compounds regulated in consumer products in Washington.

Chemical	CAS RN	Product	RCW
Cadmium	NA	Children’s products	RCW 70A.430.020
Cadmium	NA	Packaging	RCW 70A.222.020
Cadmium and cadmium compounds	NA	Brake friction materials	RCW 70A.430.040

Hazardous substances in Washington

Under Chapter 70A.350 RCW,[42] chemical classes with members that are hazardous substances under Chapter 70A.300 RCW[43] (Hazardous Substances Waste Management Act) or Chapter 70A.305 RCW[44] (Model Toxics Control Act) can be considered priority chemical classes.

Cadmium and cadmium compounds meet at least one of the criteria to be considered a hazardous substance under these statutes. Thus, cadmium and cadmium compounds meet the criteria in RCW 70A.350.020(2)(b) for designation as a priority chemical class under Chapter 70A.350 RCW.

Hazardous substances are defined in RCW 70A.300.010 to include any material that exhibits the characteristics or criteria of dangerous wastes identified under Chapter 173-303 WAC.[45] WAC 173-303-090[46] includes cadmium on the toxicity characteristic list, which provides one way to identify dangerous waste. Wastes with concentrations greater than 1 mg/L cadmium in an extract of the waste created using the Toxic Characteristic Leaching Procedure are considered dangerous waste. Wastes can also be designated as dangerous waste based on the toxicity criteria under WAC 173-303-100[47] through book designation or bioassay.

Cadmium compounds are listed under section 101(14)[48] of the federal cleanup law, 42 U.S.C. Sec. 9601(14) Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and therefore are incorporated into the definition of hazardous substance under RCW 70A.305.020(13).[49]

Chemicals of concern for sensitive populations and species

Cadmium and cadmium compounds are a concern for sensitive populations and sensitive species based on assessment of available data to consider the following factors, as outlined in RCW 70A.350.020:[50]

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[42] app.leg.wa.gov/rcw/default.aspx?cite=70A.350
[43] app.leg.wa.gov/rcw/default.aspx?cite=70A.300
[44] app.leg.wa.gov/rcw/default.aspx?cite=70A.305
[45] app.leg.wa.gov/wac/default.aspx?cite=173-303
[46] app.leg.wa.gov/wac/default.aspx?cite=173-303-090
[47] app.leg.wa.gov/wac/default.aspx?cite=173-303-100
[48] www.ecfr.gov/current/title-40/chapter-I/subchapter-J/part-302/section-302.4
[49] app.leg.wa.gov/rcw/default.aspx?cite=70A.305.020
[50] app.leg.wa.gov/rcw/default.aspx?cite=70A.350.020

(a) A chemical’s or members of a class of chemicals’ hazard traits or environmental or toxicological endpoints;

(b) A chemical’s or members of a class of chemicals’ aggregate effects;

(c) A chemical’s or members of a class of chemicals’ cumulative effects with other chemicals with the same or similar hazard traits or environmental or toxicological endpoints;

(d) A chemical’s or members of a class of chemicals’ environmental fate;

(e) The potential for a chemical or members of a class of chemicals to degrade, form reaction products, or metabolize into another chemical or a chemical that exhibits one or more hazard traits or environmental or toxicological endpoints, or both;

(f) The potential for the chemical or class of chemicals to contribute to or cause adverse health or environmental impacts;

(g) The chemical’s or class of chemicals’ potential impact on sensitive populations, sensitive species, or environmentally sensitive habitats;

(h) Potential exposures to the chemical or members of a class of chemicals based on:

    (i) Reliable information regarding potential exposures to the chemical or members of a class of chemicals; and

    (ii) Reliable information demonstrating occurrence, or potential occurrence, of multiple exposures to the chemical or members of a class of chemicals.

We concluded that cadmium and cadmium compounds are a concern for sensitive species and populations because of their hazards and exposure potential.

- Cadmium is a known carcinogen, and it is associated with reproductive and developmental toxicity.
- Cadmium is widely detected both in the environment and in people’s bodies. Washingtonians have higher exposure to cadmium than the national average.
- Cadmium has been detected in Washington’s waters, sediment, and air, with some samples exceeding environmental limits. Because cadmium is toxic to salmon, these exposures may be impacting sensitive species.
- Epidemiological and environmental studies provide evidence supporting the potential for cadmium exposure to contribute to adverse impacts.

The sections below describe our evaluation of this criteria and support our conclusion.

Hazards of priority chemical class

We evaluated data-rich chemicals within the class for hazards, including environmental and human health toxicological endpoints, and environmental fate, transport, and potential breakdown products. To identify these hazards, we used similar methods to those found in our 2022 Regulatory Determinations Report to the Legislature (Ecology, 2022).[51]

Hazard endpoints of concern are discussed below. Table 4 shows a more comprehensive list of potential hazards of cadmium and cadmium compounds. We identified hazard endpoints of concern if at least one member of the chemical class is either included on an authoritative list or scored as “high” or “very high” in hazard assessments. In some cases, we supplemented these endpoints with specific concerns that may be relevant to sensitive populations.

Cadmium and cadmium compounds are associated with several hazard traits and have the potential to cause adverse impacts to humans and the environment. Cadmium and cadmium compounds are classified as carcinogenic and toxic to reproduction and development in humans and other organisms. Cadmium and cadmium compounds are toxic to aquatic organisms, persist in the environment, and can bioaccumulate. Some hazard traits of cadmium and cadmium compounds are described below.

Carcinogenicity and genotoxicity/mutagenicity

Cadmium and cadmium compounds are classified together as carcinogenic by several authoritative organizations (Table 4).

EPA classifies cadmium as a probable human carcinogen (Group 1B), while the IARC and the National Toxicology Program (NTP) both classify cadmium as a known human carcinogen (IARC, 2012a; NTP, 2021). Cadmium and cadmium compounds are included on the California Proposition 65 list as carcinogens (OEHHA, 2023). The European Chemicals Agency also classifies cadmium as a carcinogen (H350, Carc. 1B), and it is included on their Substance of Very High Concern Candidate List (ECHA, 2023). The 15th Report on Carcinogens (15th RoC) published by the U.S. Department of Health and Human Services cites the 2009 finding by IARC, which classified the evidence of cadmium’s carcinogenicity in humans as sufficient for lung cancer and limited for both prostate and kidney cancer (NTP, 2021).

The IARC monograph also describes several mechanisms of genotoxicity for cadmium and how they may contribute to development of mutations. The European Chemicals Agency classifies cadmium as a suspected mutagen (ECHA, 2023).

Reproductive and developmental toxicity

Cadmium is listed on the California Proposition 65 list for developmental toxicity and male reproductive toxicity (OEHHA, 2023). Cadmium is also classified by the European Chemicals Agency as suspected to be toxic to reproduction and as suspected of damaging the unborn child (ECHA, 2023).

In addition, there is evidence that links cadmium exposure to adverse effects on neurophysiological development, leading to neurological and cognitive deficits in children (Chandravanshi et al., 2021).

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[51] apps.ecology.wa.gov/publications/summarypages/2204018.html

Systemic toxicity

Exposure to cadmium is associated with toxicity in several organs and tissues, including the kidney, bone, and lung. Cadmium is retained in the kidney for long periods of time (half-life of 6–38 years), and cadmium toxicity to the kidney is well established (ATSDR, 2012).

Respiratory sensitization

A cross-sectional study of adults in the 2007 to 2012 National Health and Nutrition Examination Survey (NHANES) suggests that cadmium exposure negatively affects lung function in non-smoking U.S. adults, and high levels of cadmium exposure in people who currently smoke increase their risk of wheeze and asthma (G. Yang et al., 2019).

Ecological toxicity

Cadmium and cadmium compounds are classified as metals of concern under WAC 173-333-315[52] based on the determination that they pose a threat to human health and the environment in Washington.

EPA updated the aquatic life ambient water quality criteria for cadmium in 2016 and recommended 1.8 ppb and 33 ppb as maximum concentrations for acute criterion (1-hour) in freshwater and estuarine or marine waters, respectively. They also recommended 0.72 ppb and 7.9 ppb as maximum concentrations for chronic criterion (4 days) in freshwater and for estuarine or marine waters. They concluded that cadmium is a non-essential metal with no biological function in aquatic life and that acute exposure caused increased mortality in aquatic organisms. Further, they concluded cadmium has chronic toxicity in aquatic organisms, including adverse effects on growth, reproduction, development, immunity, endocrine systems, and behavior (EPA, 2016a).

Cadmium is also classified by the European Chemicals Agency as hazardous to the aquatic environment, for both acute and chronic aquatic toxicity (ECHA, 2023).

Environmental fate

Understanding the environmental impacts of chemicals includes assessing persistence, bioaccumulation, and known and potential breakdown products.

Cadmium is a chemical element and is persistent and does not break down in the environment. Cadmium compounds have the potential to release cadmium to the environment.

Bioaccumulation factor (BCF) is the ratio of the amount of a chemical in an organism to the amount of that chemical in its surrounding environment. Cadmium has a range of reported BCFs that vary based on the organism and tissue type. According to the 2016 EPA report, the range of BCFs reported in freshwater organisms is from 3 to 65,600. The reported BCF values range from 5 to 3,160 in estuarine or marine organisms (EPA, 2016a).

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[52] app.leg.wa.gov/wac/default.aspx?cite=173-333-315

Referenced hazard assessments

The hazard assessments referenced in Table 4 are described in the Technical Methods chapter of this report. We reviewed each method for transparency and consistency in scoring methods and data requirements (Ecology, 2022). Using hazard assessments allows us to apply a consistent, non-biased approach to evaluating chemicals across multiple endpoints and levels of data. In this report, hazard assessments allow us to identify known and potential hazards of chemicals within the priority chemical classes.

Due to inclusion on authoritative lists as a carcinogen, as well as reproductive and developmental toxicant, cadmium scores as a LT-1 chemical using the GreenScreen® list translator. This indicates it would score as a BM-1 chemical if assessed and that its use should be avoided (Healthy Building Network, 2023). Cadmium and several cadmium compounds also score as [Red] in SciveraLENS® because of these listings (Scivera, 2023r).

In the SciveraLENS GHS+ chemical hazard assessment, cadmium was assigned high hazard scores for carcinogenicity, reproductive toxicity, developmental toxicity, acute toxicity (oral), systemic toxicity, and persistence. Cadmium was assigned very high hazard scores for acute toxicity (inhalation), acute aquatic toxicity and chronic aquatic toxicity (Scivera, 2023r).

The SciveraLENS GHS+ assessment for cadmium (CAS: 7440-43-9) is available in the SciveraLENS database[53] (Scivera, 2023r).

Table 4. Known and potential hazards of cadmium and cadmium compounds.

Common name, associated CAS(s)	Known or potential hazards	Referenced hazard assessments	Relevant authoritative listings
Cadmium and cadmium compounds, CAS RN: 7440-43-9	Carcinogenicity†, mutagenicity‡, reproductive toxicity†, developmental toxicity†, endocrine activity‡, acute toxicity†, systemic toxicity†, acute and chronic aquatic toxicity†, persistence†	GreenScreen LT-1, SciveraLENS [Red]	CA Prop. 65—Carcinogen, Reproductive toxicity (male), Developmental toxicity; IARC Group 1 Carcinogen; EU GHS—H350 (Carc. 1B), H341 (Mut. 2), H361fd (Repro. Tox. Cat. 2), H330 (Acute Tox. Cat. 2), H372 (Sys. Tox. Rep. 1), H400 (Acute Aq. Tox. 1), H410 (Chronic Aq. Tox. Cat. 1); U.S. EPA—Priority PBT; OSPAR PBT—Chemical for Priority Action

† Endpoints scored as high or very high in referenced hazard assessments
‡ Endpoints scored as moderate in referenced hazard assessments

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[53] rapidscreen.scivera.com/users/login

Potential exposures to people and the environment

Human exposure

People are exposed to cadmium through inhalation and ingestion, from environmental contamination, household sources, and occupational uses.

Blood cadmium reflects both recent and cumulative exposures while urinary cadmium reflects both cumulative exposure and the concentration of cadmium in the kidney. Cadmium accumulates in the kidney with a half-life of 10–40 years (CDC, 2022a). Absorption of cadmium is affected by dietary intake of essential nutrients (iron, calcium, zinc, and copper) and protein (ATSDR, 2012).

NHANES, the national population-based study conducted by the Centers for Disease Control and Prevention (CDC), includes measurements of cadmium in both blood and urine. Higher levels of cadmium are seen in people who smoke, women, people who live near contaminated soil, and people who are occupationally exposed (CDC, 2022a). A comprehensive analysis of women's exposure to 143 environmental chemicals found that Asian, Mexican, and Hispanic women had higher exposure than non-Hispanic White women (Nguyen et al., 2020).

The 2010 to 2011 Washington Environmental Biomonitoring Survey (WEBS) includes urinary cadmium concentrations from a statewide representative sample of Washington residents. The data can be seen on the Washington Tracking Network Biomonitoring Dashboards (DOH, 2023a). For unknown reasons, Washington residents, particularly children, had higher levels of cadmium compared to the general U.S. population in NHANES.

Environmental exposure

Cadmium is a naturally occurring heavy metal and is ubiquitous in water and sediment samples from both freshwater and marine environments. However, levels of cadmium have increased in the environment due to anthropogenic activities, including manufacturing, mining, fuel combustion, and agriculture (Ecology, 2011).

Ecology conducted seasonal monitoring for toxics in the Spokane River, at the eastern Spokane Tribal boundary, during 2015–2016 (Ecology, 2017b). Cadmium levels measured in surface water samples were below the Washington State and Spokane Tribe of Indians' hardness-based chronic criteria for protection of aquatic life. However, cadmium measured in suspended sediment samples exceeded Washington's freshwater Sediment Cleanup Objective and Cleanup Screen level.

In 2012, Ecology collected sediment samples from ten lakes and wetlands in the Upper Columbia River watershed and found that six of the northern and centrally located lakes—Cedar, Phillips, Silver Crown, Bowen, Phalon, and Williams (sampled in 2010)—exceeded one or more probable effect concentration thresholds for cadmium (Ecology, 2013b).

Cadmium has also been measured in ambient air in Washington. The 2005 Spokane Air Toxic Study reported an annual average concentration of 0.2ng/m^3 for cadmium (Washington State University Laboratory for Atmospheric Research & RJ Lee Group Inc. Center for Laboratory

Sciences, 2007). This was consistent with concentrations reported for Seattle in 2005 and the average of ten large and small urban areas monitored in EPA's 2001 Pilot Cities Project (Washington State University Laboratory for Atmospheric Research & RJ Lee Group Inc. Center for Laboratory Sciences, 2007).

The 2011 Puget Sound Toxics Assessment estimated approximately 1 metric ton of cadmium is released each year into Puget Sound from anthropogenic sources, with the largest contributor thought to be roofing materials (0.6 t/yr); followed by fertilizers (0.26 t/yr); air emissions from industrial, commercial, and institutional sources (0.06 t/yr); tire wear (0.03 t/yr); and brake pad wear (0.01 t/yr) (Ecology, 2011).

Cadmium has been linked to adverse effects on Washington aquatic species, including salmonids. Studies show cadmium impacts coho salmon (*Oncorhynchus kisutch*) olfactory neurobehavioral functions. These impacts are linked to impaired survival and increased susceptibility to predation (Williams & Gallagher, 2013).

Potential for aggregate and cumulative effects

Exposure to chemicals can result in aggregate effects and cumulative effects. Aggregate effects can occur when people or other organisms are exposed to a single chemical from multiple routes, pathways, and sources (*e.g.*, house dust, drinking water, air, and food). Cumulative effects can occur when people or other organisms are exposed to multiple chemicals simultaneously. These cumulative exposures may come from multiple exposure routes, pathways, and sources, or just a single source.

Potential for aggregate effects

Cadmium is a naturally occurring substance that is widely detected in the environment. Biomonitoring data on cadmium in blood and urine reflects people's aggregate exposure from all routes, pathways, and sources. People are exposed to cadmium through inhalation and ingestion from environmental contamination, household sources, and occupational uses. Wildlife can be exposed to cadmium from water, air, sediment, and soil that contain cadmium.

We concluded that cumulative effects are possible because people and wildlife are exposed to cadmium from multiple sources. These exposures add up and can contribute to adverse impacts.

Potential for cumulative effects

People and wildlife are exposed to cadmium, in addition to other chemicals that impact the same biological systems. For example, we know cadmium and phthalates impact male reproductive tract development (Ma et al., 2020). A comprehensive analysis of women's exposure to 143 chemicals found that women were exposed to cadmium in addition to other chemicals that can impact reproduction and development and increase cancer risks (Nguyen et al., 2020).

A recent analysis of over 200 organic contaminants of emerging concern in Puget Sound supports the conclusion that Puget Sound wildlife are exposed to a wide range of contaminants from multiple sources (James et al., 2020). This conclusion is also supported by other studies documenting the presence of multiple chemicals of concern in Washington's environment (Conn et al., 2020; Meador et al., 2016). Exposure to cadmium and other metals lead to increased toxicity in water fleas, zebra mussels, frogs, and fathead minnows (Heys et al., 2016). Co-exposure to cadmium and other heavy metals has been associated with toxicity in daphnids and rainbow trout (Spehar & Fiandt, 1986).

We concluded that cumulative impacts are possible because people and wildlife are exposed to cadmium in addition to other chemicals that can impact similar biological systems.

Potential to contribute adverse impacts

Sensitive populations

When people are exposed to chemicals with known or suspected toxicities, there is the potential for adverse impacts. The impacts may be greater when people are also exposed to other environmental contaminants that impact the same biological systems.

People, including sensitive populations, are exposed to cadmium. Exposure to cadmium is associated with carcinogenicity, reproductive and developmental toxicity, and systemic toxicity. Therefore, cadmium has the potential to contribute to adverse impacts in humans, including sensitive populations such as the elderly, workers, people of childbearing age, developing fetuses, and children.

This conclusion is supported by epidemiological studies that have found associations between cadmium exposure in people and adverse health impacts. We list key examples below.

- In elderly populations, cadmium exposure has the potential to contribute to kidney impairment and osteoporosis (Åkesson et al., 2006; Inaba et al., 2005; Satarug et al., 2010).
- Cadmium exposure may increase the risk of type 2 diabetes. Some meta-analyses have found an association between cadmium exposure and type 2 diabetes risk (Filippini et al., 2022; Y. Li et al., 2017). Evidence from cell lines, animal studies, and humans suggests that the increased risk of diabetes may be related to perturbation of insulin signaling and production (Buha et al., 2020).
- Cadmium and cadmium compounds are carcinogenic to humans (IARC, 1993). Workers with occupational exposures to cadmium have increased risk of cancer (IARC, 1993; Stayner et al., 1992).
- Cadmium may reduce sperm quality and impair male fertility (Y. Zhang et al., 2019) and has been implicated as a potential contributing factor in the worldwide decline in sperm quantity (Mann et al., 2020).
- Cadmium exposure during pregnancy may be associated with reduced birth weight (Flannery et al., 2022; S. Huang et al., 2019; Ronco et al., 2009).

Sensitive species

When chemicals are released into the environment, they have the potential to expose sensitive species, such as forage fish, salmon, or orcas. If these chemicals have aquatic toxicity, reproductive or developmental toxicity, systemic toxicity, or endocrine disruption, there is potential to contribute to adverse impacts in sensitive species. Cadmium exists in the environment and has the potential to harm wildlife, including sensitive species, because it has acute and chronic aquatic toxicity.

This conclusion is supported by environmental studies showing adverse impacts of cadmium in sensitive species. We list key examples below.

- Cadmium accumulated in the intestine, kidney, and liver of salmon consuming a diet containing cadmium. Cadmium exposure led to oxidative stress and tissue limited peroxidation (Berntssen et al., 2000).
- Environmentally relevant concentrations of cadmium can lead to olfactory disfunction in salmon. Impaired olfaction has been linked to loss of fitness and increased mortality in salmon (Williams et al., 2016; Williams & Gallagher, 2013).

Chapter 3: Technical Support for Lead and Lead Compounds

Chapter overview

Lead is a naturally occurring heavy metal that is ubiquitous in Washington's environment. Concentrations of lead have increased in the environment due to anthropogenic activities. Lead is a potent neurotoxicant, carcinogen, and reproductive and developmental toxicant that can harm children and prevent them from reaching their full potential. There is no safe level of lead exposure for children, and models suggest that even seemingly small exposure is associated with meaningful impacts on brain development at the population level. CDC reports exposure disparities based on factors including income, occupation, and whether people live in buildings constructed before 1978.

We selected lead and lead compounds as a priority chemical class for this cycle of Safer Products for Washington because they are widely detected in the environment and people's bodies, and they can have damaging impacts on children's development. Lead exposure is associated with disproportionate impacts. Because lead is already regulated in some consumer products, it could be feasible to reduce exposures from other products and ultimately reduce disproportionate impacts.

Lead meets the high priority chemical criteria because it is:

1. Regulated in numerous relevant consumer products.
2. Considered a hazardous substance in Washington.
3. A concern for sensitive species and populations.

Rationale and references are described below.

Scope of priority chemical class

This report identifies lead and lead compounds (CAS number 7439-92-1) as a priority chemical.

Rationale for class approach

We approached lead and lead compounds as a priority chemical class. This class is unified by the presence of lead in the compounds.

This grouping is reasonable and supported by scientific evidence.

- Lead is part of all members of the class and has multiple known and potential hazards.
- Lead and lead compounds as a class are probable human carcinogens, according to the International Agency for Research on Cancer (IARC), and reasonably anticipated to be carcinogenic in humans by the National Toxicology Program (NTP). These determinations were made after reviewing multiple lead compounds.

- Other authoritative bodies approach lead and lead compounds as a group. One example is EPA's toxic release inventory reporting.

Meeting the statutory requirements

The statute requires that priority chemicals or chemical classes meet specific criteria. Priority chemical classes must meet at least one of the criteria described in RCW 70A.350.020[54] and listed below.

- A member of the chemical class has been identified by Ecology as a chemical of concern, specifically:
    - A chemical of high concern to children under Chapter 70A.430 RCW[55] or
    - A persistent, bioaccumulative, and toxic (PBT) chemical under Chapter 70A.300 RCW.[56]
- A member of the chemical class is regulated in relevant consumer product statutes in Washington.
- A member of the chemical class is a hazardous substance under Chapter 70A.300 RCW or Chapter 70A.305 RCW.[57]
- Members of the chemical class are a concern for sensitive populations and sensitive species.

Lead and lead compounds meet at least one of the criteria to be considered priority chemicals. Each of the criteria are discussed below.

Chemicals of concern by Ecology

Chemical classes with members that are chemicals of high concern to children (CHCC) identified under 70A.430 RCW meet the criteria for designation as priority chemical class under RCW 70A.350.020(1)(a) RCW. Ecology identifies chemicals that are persistent, bioaccumulative, and toxic in WAC 173-333-310[58] under Chapter 70A.300 RCW.

Lead is not listed as a PBT under Chapter 173-333 WAC.[59] However, lead is listed in WAC 173-333-315[60] as a metal of concern. The PBT rules treat metals differently because they are inherently persistent. Chemicals found in the class that are PBTs or metals of concern are described in Table 5.

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[54] app.leg.wa.gov/rcw/default.aspx?cite=70A.350.020
[55] app.leg.wa.gov/rcw/default.aspx?cite=70A.430
[56] app.leg.wa.gov/rcw/default.aspx?cite=70A.300
[57] app.leg.wa.gov/rcw/default.aspx?cite=70A.305
[58] app.leg.wa.gov/wac/default.aspx?cite=173-333-310
[59] app.leg.wa.gov/wac/default.aspx?cite=173-333
[60] app.leg.wa.gov/wac/default.aspx?cite=173-333-315

Table 5. Lead and lead compounds are metals of concern under WAC 173-333-315.

Chemical or metal of concern	CAS RN	Rationale
Lead	7439-92-1	Pose a threat to human health and the environment in Washington

Chemical classes with members that are chemicals of high concern to children (CHCC) identified under Chapter 70A.430 RCW[61] meet the criteria for designation as priority chemical class under RCW 70A.350.020(1)(a).[62] Ecology identifies chemicals of high concern to children based on their hazards and exposure potential in Chapter 173-334 WAC.[63] Lead is not a CHCC in Washington but it is restricted in children's products.

Regulations in consumer products under relevant Washington statute

Chemical classes with members regulated in consumer products under Chapters 70A.430, 70A.405,[64] 70A.222,[65] 70A.335,[66] 70A.230,[67] or 70A.400 RCW[68] meet the criteria for designation as a priority chemical class under RCW 70A.350.020(2)(a). Lead is regulated in children's products, packaging, and brake friction material (Table 6). It is also regulated in wheel weights under Chapter 70A.435 RCW[69].

Table 6. Members of the class that are regulated in consumer products in Washington.

Chemical	Product	RCW
Lead	Children's products	70A.430
Lead	Packaging	70A.222
Lead and its compounds	Brake friction material	70A.340

Hazardous substances in Washington

Under Chapter 70A.350 RCW,[70] chemical classes with members that are hazardous substances under Chapter 70A.300 RCW[71] (Hazardous Substances Waste Management Act) or Chapter 70A.305 RCW[72] (Model Toxics Control Act) can be considered priority chemical classes. Lead

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[61] app.leg.wa.gov/rcw/default.aspx?cite=70A.430
[62] app.leg.wa.gov/rcw/default.aspx?cite=70A.305.020
[63] apps.leg.wa.gov/wac/default.aspx?cite=173-334
[64] apps.leg.wa.gov/rcw/default.aspx?cite=70A.405
[65] app.leg.wa.gov/rcw/default.aspx?cite=70A.222
[66] app.leg.wa.gov/rcw/default.aspx?cite=70A.335
[67] app.leg.wa.gov/rcw/default.aspx?cite=70A.230
[68] app.leg.wa.gov/rcw/default.aspx?cite=70A.400
[69] app.leg.wa.gov/rcw/default.aspx?cite=70A.435
[70] app.leg.wa.gov/rcw/default.aspx?cite=70A.350
[71] app.leg.wa.gov/rcw/default.aspx?cite=70A.300
[72] app.leg.wa.gov/rcw/default.aspx?cite=70A.305

and lead compounds meet at least one of the criteria to be considered a hazardous substance under Chapter 70A.305 RCW or Chapter 70A.300 RCW. Thus, lead and lead compounds are considered hazardous substances for the purposes of the implementation of Chapter 70A.350 RCW.

Hazardous substances are defined in RCW 70A.300.010[73] to include any material that exhibits any of the characteristics or criteria of dangerous wastes identified under Chapter 173-303 WAC. WAC 173-303-090[74] includes lead on the toxicity characteristic list, which provides one way to identify dangerous waste. Wastes with concentrations greater than 5 mg/L lead in an extract of the waste created using the Toxic Characteristics Leaching Procedure are considered dangerous waste. Wastes can also be designated as dangerous waste based on the toxicity criteria under WAC 173-303-100[75] through book designation or bioassay.

Lead compounds are listed under section 101(14)[76] of the federal cleanup law, 42 U.S.C. Sec. 9601(14) Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and therefore are incorporated into the definition of "hazardous substance" under RCW 70A.305.020(13).[77]

Chemicals of concern for sensitive populations and species

After assessing available data to consider the factors below, as outlined in RCW 70A.350.020, we found that lead and lead compounds are a concern for sensitive populations and sensitive species.

(a) A chemical's or members of a class of chemicals' hazard traits or environmental or toxicological endpoints;

(b) A chemical's or members of a class of chemicals' aggregate effects;

(c) A chemical's or members of a class of chemicals' cumulative effects, with other chemicals with the same or similar hazard traits or environmental or toxicological endpoints;

(d) A chemical's or members of a class of chemicals' environmental fate;

(e) The potential for a chemical or members of a class of chemicals to degrade, form reaction products, or metabolize into another chemical or a chemical that exhibits one or more hazard traits or environmental or toxicological endpoints, or both;

(f) The potential for the chemical or class of chemicals to contribute to or cause adverse health or environmental impacts;

(g) The chemical's or class of chemicals' potential impact on sensitive populations, sensitive species, or environmentally sensitive habitats;

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[73] app.leg.wa.gov/rcw/default.aspx?cite=70A.300.010
[74] app.leg.wa.gov/wac/default.aspx?cite=173-303-090
[75] app.leg.wa.gov/wac/default.aspx?cite=173-303-100
[76] www.ecfr.gov/current/title-40/chapter-I/subchapter-J/part-302/section-302.4
[77] app.leg.wa.gov/rcw/default.aspx?cite=70A.305.020

(h) Potential exposures to the chemical or members of a class of chemicals based on:

  (i) Reliable information regarding potential exposures to the chemical or members of a class of chemicals; and

  (ii) Reliable information demonstrating occurrence, or potential occurrence, of multiple exposures to the chemical or members of a class of chemicals.

We concluded that lead and lead compounds are a concern for sensitive species and populations because of their hazards and exposure potential. Lead is a potent neurotoxicant, carcinogen, and reproductive and developmental toxicant that can prevent children from reaching their full potential.

There is no safe level of lead exposure for children, and models suggest that even seemingly small exposures are associated with meaningful impacts on brain development at the population level. Exposure to lead is not equal. CDC reports exposure disparities based on income, occupation, and whether people live in buildings constructed before 1978.

Lead is widely detected in Washington's environment and, although it is a naturally occurring substance, levels have increased due to anthropogenic activities. Lead poisoning in wildlife has been reported in places where there are high levels of lead contamination. This demonstrates the potential for wildlife to be exposed to lead contamination in the environment.

The sections below describe our evaluation of this criteria and support our conclusions.

Hazards of priority chemical class

We evaluated data-rich chemicals within the class for hazards, including environmental and human health toxicological endpoints, and environmental fate, transport, and potential breakdown products. To identify these hazards, we used similar methods to those found in our 2022 Regulatory Determinations Report to the Legislature (Ecology, 2022).[78]

We discuss hazard endpoints of concern below. Table 7 shows a more comprehensive list of potential lead and lead compounds hazards. We identified hazard endpoints of concern if at least one member of the chemical class is either included on authoritative lists or scored as high or very high in hazard assessments. In some cases, we supplemented these endpoints with specific concerns that may be relevant to sensitive populations.

Lead and lead compounds have been thoroughly studied and are associated with several hazard traits, with the potential to cause adverse impacts to humans and the environment. Lead and lead compounds are carcinogenic and toxic to reproduction and development in humans and other organisms. Lead and lead compounds are also toxic to aquatic ecosystems, can bioconcentrate in organisms, and are persistent in the environment. Some hazard traits of lead and lead compounds are described below.

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[78] apps.ecology.wa.gov/publications/summarypages/2204018.html

Carcinogenicity and genotoxicity/mutagenicity

Several authoritative organizations classify lead and lead compounds as known or probable human carcinogens. The EPA classifies lead and lead compounds as probable human carcinogens, and the NTP concluded lead and lead compounds are reasonably anticipated to be human carcinogens (EPA, 2004). EPA reaffirmed this finding in 2013, in the Integrated Science Assessment for Lead which concluded that there is likely a causal relationship between lead exposure and cancer (EPA, 2013). California also includes lead and lead compounds on the Proposition 65 List for carcinogenicity (OEHHA, 2023). The 15th Report on Carcinogens (15th RoC) reports lead exposure is associated with increased risk of lung, stomach, and urinary-bladder cancer in humans (NTP, 2021). The 15th RoC also describes animal studies that demonstrate lead and lead compounds cause tumors in multiple tissues, through several routes of exposure. The 15th RoC discusses several potential mechanisms of toxicity, including genotoxicity.

Lead compounds have evidence of genotoxicity and mutagenicity and are classified as Germ Cell Mutagen 3A by the German MAK-Commission, indicating lead induces genetic damage in mammalian cells *in vivo* and that lead is bioavailable in germ cells (MAK Value Documentation, 2012).

There is also evidence that lead may cause cancer through epigenetic mechanisms. In 2013, EPA published the Integrated Science Assessment for Lead that reviewed toxicological and epidemiological studies and found consistent evidence of genotoxicity, oxidative stress, and DNA damage and decreased DNA repair (EPA, 2013). EPA also reports that lead can alter gene expression through epigenetic mechanisms and interact with proteins, which induce carcinogenicity (EPA, 2013).

Reproductive and developmental toxicity

Lead and lead compounds are known reproductive and developmental toxicants. The NTP monograph on health effects of low-level lead concluded that there is sufficient evidence of adverse effects on child development and reproduction in adult women (NTP, 2012). Lead and lead compounds are classified as reproductive and developmental toxicants by the European Chemicals Agency (ECHA, 2023). Lead and lead compounds are also included on the California Proposition 65 list for developmental toxicity and reproductive toxicity in both males and females (OEHHA, 2023). In addition, there is a large body of evidence that lead and lead compounds cause developmental neurotoxicity in children (Lidsky & Schneider, 2003).

EPA's 2013 Integrated Science Assessment for Lead (EPA, 2013) concluded there is evidence supporting or suggesting a causal relationship between lead exposure and:

- Effects on birth outcomes.
- Effects on development.
- Decrements in cognitive function in children.
- Effects on female reproductive function.
- Effects on male reproductive function.

It is important to note that no safe level of lead has been identified for developmental neurotoxicity and cognitive deficits resulting from lead exposure in children (ATSDR, 2020).

Endocrine disruption

Lead is not included on any authoritative lists for endocrine activity, however there is some evidence that lead can cause effects on several endocrine pathways (ATSDR, 2020; ToxServices, 2021a).

Neurotoxicity

Lead causes neurotoxicity in both children and adults. Neurological effects in children exposed to lead include deficits in learning and memory, alterations in behavior and mood, and changes in neuromotor and neurosensory function (ATSDR, 2020). These effects are observed in adults as well. Other effects have also been documented, including peripheral neuropathy, psychiatric symptoms, changes in regional brain volumes, and neurochemistry (ATSDR, 2020).

Ecological toxicity

The European Chemicals Agency classifies lead as very toxic to aquatic life, with long lasting effects. Lead bioaccumulates in fish tissues, can cause oxidative stress leading to neurotoxicity in fish, and influences fish immune responses (Lee et al., 2019).

The lowest acute environmental reference value (ERV) for lead was determined to be 20.5 ug/L by ECHA, so lead is classified as category 1 for acute aquatic toxicity (H400) (ECHA, n.d.-a). The lowest chronic ERV is 6.1 ug/L, so lead is also classified as category 1 for chronic aquatic toxicity (H410) (ECHA, n.d.-a).

Environmental fate

Understanding the environmental impacts of chemicals includes assessing persistence, bioaccumulation, and known and potential breakdown products.

Lead is an element, so it is persistent and does not break down in the environment. Compounds that contain lead have the potential to release lead to the environment. Lead is expected to form lead salts, such as lead sulfate, lead carbonate, lead phosphate, lead sulfide, and lead monoxide, in the environment (ToxServices, 2021a).

Lead can bioaccumulate to varying degrees across terrestrial and aquatic species. The U.S. Department of Health and Human Services Agency for Toxic Substances and Disease Registry (ATSDR) reports lead bioconcentrates in plants and animals, but it does not appear to biomagnify in food chains (ATSDR, 2020). The U.S. EPA classifies lead and lead compounds as persistent, bioaccumulative, and toxic (EPA, 2001).

Referenced hazard assessments

In the Technical Methods chapter of this report, we describe the hazard assessments referenced in Table 7. We reviewed each method for transparency and consistency in scoring methods and data requirements (Ecology, 2022). Using hazard assessments allows us to apply a consistent, unbiased approach to evaluating chemicals across multiple endpoints and levels of data. In this report, hazard assessments allow us to identify known and potential hazards of chemicals within the priority chemical classes.

Lead and lead compounds score as Benchmark-1 and [Red] in GreenScreen® and SciveraLENS® GHS+ chemical hazard assessments, respectively, indicating their use should be avoided (Scivera, 2023ad; ToxServices, 2021a).

The GreenScreen assessment showed high lead hazard scores for carcinogenicity, mutagenicity, reproductive toxicity, developmental toxicity, endocrine activity, systemic toxicity (single and repeat dose), neurotoxicity (repeat dose), and bioaccumulation. The assessment also showed very high lead hazard scores for neurotoxicity (single dose), acute aquatic toxicity, chronic aquatic toxicity, and persistence (ToxServices, 2021a).

The SciveraLENS GHS+ chemical hazard assessment assigned high lead hazard scores for carcinogenicity, mutagenicity, reproductive toxicity, developmental toxicity, systemic toxicity, and neurotoxicity. The SciveraLENS GHS+ chemical hazard assessment also assigned very high lead hazard scores for persistence, bioaccumulation, acute aquatic toxicity, and chronic aquatic toxicity (Scivera, 2023ad).

- The GreenScreen assessment for lead (CAS: 7439-92-1) is available from the ToxServices database[79] (ToxServices, 2021a).
- The SciveraLENS GHS+ chemical hazard assessment for lead (CAS: 7439-92-1) is available in the SciveraLENS database[80] (Scivera, 2023ad).

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[79] database.toxservices.com/

[80] rapidscreen.scivera.com/

Table 7. Known and potential hazards of lead and lead compounds.

Common name, associated CAS(s)	Known or potential hazards	Referenced hazard assessments	Relevant authoritative listings
Lead and lead compounds, CASRN: 7439-92-1	Carcinogenicity†, mutagenicity†, reproductive toxicity†, developmental toxicity†, endocrine activity†, acute toxicity‡, systemic toxicity (single and repeat dose)†, neurotoxicity (single and repeat dose)†, acute and chronic aquatic toxicity†, persistence†, bioaccumulation†	GreenScreen® BM-1, SciveraLENS® [Red]	EU GHS—H360Df and H360FD (Repro. 1A), H362 (Repro. Lactation), H332 and H302 (Acute Tox. 4), H373 (Systemic Tox. Repeat Exp.), H400 (Acute Aq. Tox. 1), H410 (Chronic Aq. Tox. 1); EU Substances of Very High Concern (SVHC) Candidate List—Toxic to Reproduction; U.S. EPA – TRI PBT, California Prop. 65 List (Carcinogenicity, Developmental Toxicity, Female and Male Reproductive Toxicity); IARC (Carc. 2A, lead compounds, Carc. 2B, lead); MAK (Carc. 2); EPA IRIS Carcinogen (Group B2), US NIH Report on Carcinogens—Reasonably anticipated human carcinogen; US NIH—Reproductive and Developmental Monographs—Reproductive Toxicity, Developmental Toxicity

† Endpoints scored as high or very high in referenced hazard assessments
‡ Endpoints scored as moderate in referenced hazard assessments

Potential exposures to people and the environment

Human exposure

There is widespread exposure to lead. We are particularly concerned about exposures to children, as they absorb more lead than adults and are more sensitive to the effects of lead. Children may be exposed to lead from inhalation and ingestion from environmental contamination, household sources, and residues that can come into homes when workers' skin, clothes, or possessions get contaminated at work. King County recently found high concentrations of lead in cookware used by Afghan refugees (Fellows et al., 2022).

Lead can be measured in different tissues, with blood being the most common. Most lead in the body is stored in bones, although this is not often measured. Blood lead reflects both recent lead exposures and stored lead, while lead in urine is from recent exposures (ATSDR, 2020).

The National Health and Nutrition Examination Survey (NHANES) is a population-based study conducted by the Centers for Disease Control (CDC). According to NHANES, blood lead levels in U.S. children and adults decreased from 1999 to 2018. The geometric mean in the youngest children (ages 1 to 5) decreased from 2.23 ug/dL in 1999 to 0.670 ug/dL in 2018. The geometric mean in adults aged 20 and above decreased from 1.75 ug/dL in 1999 to 0.855 ug/dL in 2018. NHANES also collected data for children 6 to 11 and 12 to 19 years old, and those groups also showed decreases in blood lead levels (DOH, 2023b).

As there are no known safe levels of lead, there are definitions of elevated blood lead levels for both children and adults, to prioritize actions. In 2021, the CDC updated the Blood Lead Reference Value (BLRV) to 3.5 µg/dL (CDC, n.d.-c). The BLRV is a screening tool to identify children who have higher levels of lead in their blood compared with most children. In Washington, children are considered to have an elevated blood lead level at 5 ug/dL, and adults are considered to have elevated blood lead level at 10 ug/dL. Some biomonitoring data is presented as above or below these levels. The Washington Tracking Network contains Washington data for the percentage of young children's blood lead test results at or above 5 ug/dL (DOH, 2023b). The lead exposure risk mapping tool shows which areas in the community are at higher risk for lead exposure based on age of housing.

The National Institute for Occupational Safety and Health is a part of the CDC that focuses on occupational health and safety and includes a national Adult Blood Lead Epidemiology and Surveillance (ABLES) program. In this program and state programs, people aged 16 years or older are considered adults. The ABLES program in Washington is at the Department of Labor and Industries. The Washington ABLES program identifies adults with elevated blood lead levels; identifies industries, occupations, and activities that may contribute to elevated blood lead levels; and implements strategies to prevent elevated blood lead levels and lead exposures (LNI, 2017). Industries with higher lead exposure include battery manufacturing, ceramics, and construction (ATSDR, 2020). As not all workers in Washington are tested for blood lead levels, the information is not necessarily representative.

Groups who may have higher exposure to lead

- Children younger than 6 years old.
- Children in low-income households.
- Children who live in pre-1978 housing.
- Occupational users.
- Hobbyists.
- Recent immigrants (CDC, n.d.-d; Gochfeld & Burger, 2011).

Environmental exposure

Lead is a naturally occurring heavy metal and is ubiquitous in water and sediment samples from both freshwater and marine environments. However, levels of lead have increased in the environment due to anthropogenic activities and materials, including lead-based ammunition, fishing weights, wheel weights, roofing materials, aviation fuel, brake pads, plumbing materials, and the use of tetra-ethyl lead in gasoline between 1973–1996 (Ecology, 2011).

In 2023, we collected sediment samples from ten lakes and wetlands in the Upper Columbia River watershed. We found that six of the northern and centrally located lakes—Cedar, Phillips, Silver Crown, Bowen, Phalon, and Williams (sampled in 2010)—exceeded one or more probable effect concentration thresholds for lead (Ecology, 2013b).

In 2015, we analyzed 28 samples of suspended particulate matter from seven Washington cites, with a focus on small urban streams and large rivers with substantial lead contamination. Although there are no regulatory criteria for lead in suspended particulate matter, six of the 28 samples (21%) contained lead above Washington's freshwater Sediment Cleanup Objective criteria for lead in bottom sediments (Ecology, 2016a).

Measurements of lead in ambient air have also been reported in Washington. The Spokane Air Toxic Study reported a mean concentration of 4.9 ng/m^3 in ambient air for the Spokane area, based on measurements from four sites in 2005 (Washington State University Laboratory for Atmospheric Research & RJ Lee Group Inc. Center for Laboratory Sciences, 2007). This was relatively consistent with the average concentration reported for Seattle in 2005 of 4.4 ng/m^3, and less than reported for the average of ten large and small urban areas monitored in EPA's 2001 Pilot Cities Project (Washington State University Laboratory for Atmospheric Research & RJ Lee Group Inc. Center for Laboratory Sciences, 2007). This was comparable to the annual average concentration of 5.16 ng/m^3 reported for ambient air in Longview, Washington, for 2004 to 2005 (Southwest Clean Air Agency, 2007a). A 2012 study of two Washington airports reporter higher concentrations of lead in air. Auburn Municipal Airport and Harvey Airfield had maximum three-month rolling average concentrations reported at 55 ng/m^3 and 32 ng/m^3, respectively (Ecology, 2013a). These higher concentrations are thought to reflect the use of leaded aviation gasoline at these sites. Neither site exceeded the National Ambient Air Quality Standard for lead set at a maximum of 75 ng/m^3 for a three-month rolling average concentration (Ecology, 2013a).

The 2011 Puget Sound Toxics Assessment estimated approximately 520 metric tons of lead are released each year into Puget Sound from anthropogenic sources. The largest contributor is likely hunting ammunition (373 t/yr), followed by releases from army bases (39 t/yr), fishing sinker loss (36 t/yr), wheel weight loss (28 t/yr), and roofing materials (18 t/yr) (Ecology, 2011).

Potential for aggregate and cumulative effects

Exposure to chemicals can result in aggregate effects and cumulative effects. Aggregate effects can occur when people or other organisms are exposed to a single chemical from multiple routes, pathways, and sources (e.g., house dust, drinking water, air, and food). Cumulative effects can occur when people or other organisms are exposed to multiple chemicals simultaneously. These cumulative exposures may come from multiple exposure routes, pathways, and sources, or just a single source.

Potential for aggregate effects

Biomonitoring data on blood lead levels reflects people's aggregate exposure from all routes, pathways, and sources. People may be exposed to lead from inhalation and ingestion from environmental contamination, household sources, and occupational sources. When people are exposed at work, they can introduce lead into the home via clothes, skin, or possessions.

People are exposed to lead from multiple sources and routes of exposure, so there is the potential for aggregate impacts.

Lead that is not excreted accumulates in bones over time. Under some physiological conditions, such as calcium deficiency, pregnancy, lactation, and bone injury, the lead stored in bone is mobilized and enters the bloodstream where it is distributed to other body tissues. This means that the impact of lead is potentially cumulative with other health conditions. Mobilization of lead from bone is of particular concern during pregnancy, when it raises the level of fetal exposure and the potential for neurodevelopmental effects (ATSDR, 2020). Blood lead levels are known to increase during pregnancy, due to mobilization of lead stored in bones, when calcium in maternal bones is used for skeletal growth in the fetus. This increase in blood lead level can lessen with higher intakes of calcium and iron (McElroy et al., 2020) Osteoporosis in the elderly can also mobilize lead from bones to blood, with the potential for cognitive impacts.

Similarly, lead is released into the environment through multiple pathways. While lead is naturally occurring, anthropogenic activities release lead to water, sediment, soil, and air. Once in the environment, lead is inherently persistent and can bioaccumulate in the food chain. We concluded that there is the potential for aggregate effects because people and wildlife are exposed to lead from multiple sources. These exposures add up and can lead to biological impacts.

Potential for cumulative effects

Lead exposure in children often co-occurs with other environmental chemicals that impact neurodevelopment (Dórea, 2019; Grandjean & Landrigan, 2014). Co-exposure to multiple chemicals that impact the same biological target can enhance toxic effects (Heffernan & Hare, 2018). For example, co-exposure to lead and other metals, such as mercury, has been associated with stronger neurodevelopmental impacts in children (Koendjbiharie et al., 2023).

Other studies have emphasized the importance of considering nonchemical stressors when addressing toxic chemicals. A recent study of over 300 mother and toddler pairs found that nonchemical stressors and lead exposure were associated with neurodevelopmental impairment, both individually and combined (Koendjbiharie et al., 2023).

Cumulative impacts may also be related to nonchemical stressors, such as income or nutritional status. Lead intake is higher when there is a dietary deficiency, particularly of iron. Additionally, children living in older buildings may be more likely to be exposed to lead from legacy consumer product uses, like paint and plumbing (CDC, n.d.-d, Gochfeld & Burger, 2011).

Lead is one of many contaminants found in the environment. A recent analysis of over 200 organic contaminants of emerging concern in Puget Sound supports the conclusion that Puget Sound wildlife are exposed to a wide range of contaminants from multiple sources (James et al., 2020). This is supported by other studies documenting the presence of multiple chemicals of concern in Washington's environment (Conn et al., 2020; James et al., 2020; Meador et al., 2016). For example, co-exposure to lead and other heavy metals has been associated with toxicity in daphnids and rainbow trout (Spehar & Fiandt, 1986).

We concluded that there is the potential for cumulative effects because people and wildlife are exposed to multiple chemicals in addition to lead. There is evidence that these co-exposures can contribute to adverse impacts.

Potential to contribute adverse impacts

In sensitive populations

When people are exposed to chemicals with known or suspected toxicities, there is the potential for adverse impacts. People are exposed to lead, and lead is associated with carcinogenicity, reproductive and developmental toxicity (including neurodevelopmental toxicity), and systemic toxicity. Therefore, lead has the potential to contribute to adverse impacts in humans, including sensitive populations such as the elderly, workers, people of childbearing age, developing fetuses, and children.

The potential for lead to impair neurodevelopment in children is particularly concerning. Neurodevelopmental disorders are prevalent in the United States. A recent analysis estimated that for children between 3 and 17 years old, attention-deficit/hyperactivity disorder, autism spectrum disorder, intellectual disorder, and learning disability had prevalence rates of about 8.5%, 2.9%, 1.4% and 6.4%, respectively (Y. Yang et al., 2022). About 30 to 40% of neurodevelopmental diseases are expected to have genetic causes. The remainder are expected to be the results of environmental factors or a mix of environmental and genetic factors (Grandjean & Landrigan, 2014). Lead exposure can contribute to neurodevelopmental disorders.

Delayed puberty in children is also a concern. EPA concluded that lead has causal effects on puberty in both boys and girls (EPA, 2013).

Adults of childbearing age exposed to lead may be a sensitive population for cardiovascular impacts. EPA concluded that there are causal relationships between exposure to lead and hypertension and cardiovascular disease (EPA, 2013).

In elderly people with osteoporosis, lead stored in the bone can be mobilized into the bloodstream. Lead in the bloodstream can impact cognition. Elderly people are a sensitive population in terms of increased risk of osteoporosis and heightened impacts of cognitive declines. EPA concluded that there is a likely causal relationship between lead and decrements in cognitive function in adults as well as children (EPA, 2013).

The potential for lead to cause cumulative impacts is supported by epidemiological studies that found associations between lead exposure in people and adverse health impacts. We discuss key examples below.

- Epidemiological evidence supports the conclusion that there is no safe dose of lead for children (ATSDR, 2007a). Childhood lead exposure is associated with loss of intelligence quotient (IQ) points, which can prevent children from reaching their full potential (Boyle et al., 2021; McFarland et al., 2022).

- According to IARC and EPA, lead is a probable human carcinogen. Workers may be particularly vulnerable to cancer risks from lead exposure. Occupational exposure to lead is associated with increased cancer risk (Ahn et al., 2020; Anttila et al., 2022; Liao et al., 2016).
- Occupational and environmental exposure to lead is associated with reproductive impairment in both men and women (Kumar, 2018).

In sensitive species

When chemicals are released into the environment, they have the potential to expose sensitive species. Sensitive species include forage fish, salmon, orcas, and species that may be disproportionately or more severely impacted by lead. When sensitive species are exposed to chemicals that are known or suspected of having relevant hazards, we conclude that these chemicals have the potential to contribute to adverse impacts in sensitive populations.

Lead is found in the environment and has the potential to harm wildlife—including sensitive species—because it has carcinogenicity, reproductive and developmental toxicity, endocrine disruption, systemic toxicity, neurotoxicity, and aquatic toxicity. Further, it is inherently persistent in the environment.

Lead poisoning in wild birds can have pronounced negative impacts on species populations. Predatory birds consume lead ammunition inadvertently, when scavenging on remains left by hunters. Other birds may consume lead pellets from ammunition, mistaking it for seeds or grit normally used to aid in grinding food in gizzards. Similarly, lead fishing weights can be ingested by birds and contribute to lead poisoning. We discuss examples of studies demonstrating the potential for lead to impact wildlife populations below.

- A recent study of bald and golden eagles across the United States found 46–47% of eagles sampled contained lead in their bones, indicating chronic lead poisoning. In addition, 27–33% of bald eagles and 7–35% of golden eagles had evidence of acute lead poisoning (Slabe et al., 2022).

- This corroborates another study focusing on bald and golden eagles in the Pacific Northwest (Washington, Idaho, Oregon, Montana, and Alaska) that found 48% of bald eagles and 62% of golden eagles had blood lead levels consistent with chronic lead poisoning (Stauber et al., 2010).

Chapter 4: Technical Support for Organobromine and/or Organochlorine Substances

Chapter overview

Organobromine and/or organochlorine substances are commonly used in consumer products. They serve a wide range of functions, including solvents, pigments and dyes, biocides, flame retardants, and pesticides. They have multiple shared hazards, including carcinogenicity, developmental toxicity, reproductive toxicity, and aquatic toxicity. Some organobromine and/or organochlorine substances persist in the environment and bioaccumulate in people and wildlife.

We selected organobromine and/or organochlorine substances as a priority chemical class for this cycle of Safer Products for Washington because they can cause cancer, are toxic for reproduction and development, and are toxic to fish. There is widespread exposure to organobromine and/or organochlorine substances. Organobromine and/or organochlorine substances have been detected in air, drinking water, house dust, groundwater, soil, and sediment. They have also been detected in people's bodies and in the bodies of sensitive species. People in occupations where organobromine and/or organochlorine substances are used may have higher exposure.

Organobromine and/or organochlorine substances meet the high priority chemical criteria because at least one member of the class is:

1. A high priority chemical of high concern to children identified by Ecology under Chapter 70A.430 RCW.[81]
2. A persistent, bioaccumulative, and toxic (PBT) chemical under WAC 173-333-320.[82]
3. Regulated in relevant consumer products in Washington.
4. Considered a hazardous substance in Washington.
5. A concern for sensitive species and populations.

We are approaching organobromine and/or organochlorine substances as a class because the presence of bromine or chlorine bound to carbon is associated with similarities in hazard when considering their functional uses in products. These chemicals have a history of regrettable substitution, and many can persist and bioaccumulate in the environment.

Rationale and references are described below.

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[81] app.leg.wa.gov/rcw/default.aspx?cite=70A.430

[82] app.leg.wa.gov/wac/default.aspx?cite=173-333-320

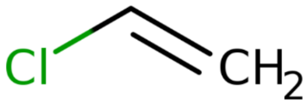
Scope of priority chemical class

Organobromine and/or organochlorine substances are defined as any chemical containing chlorine or bromine bonded to carbon. Inorganic chemicals that do not contain carbon, such as inorganic bromides or chlorides, or chloride or bromide salts, are excluded.

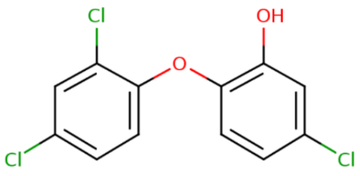
This chemical class intersects two previously defined priority chemical classes: organohalogen flame retardants and polychlorinated biphenyls.

Examples of chemicals in the class with carbon bonded to bromine or chlorine are shown in Figure 2.

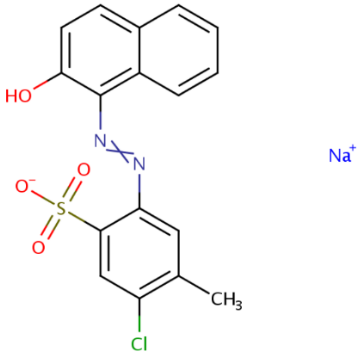
Figure 2. Molecular structures of example chemicals within the class.



Vinyl chloride, PVC monomer

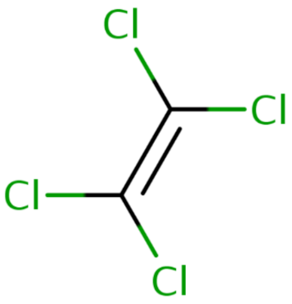


Triclosan, antimicrobial

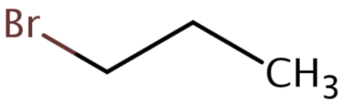


D&C Red No. 8, pigment

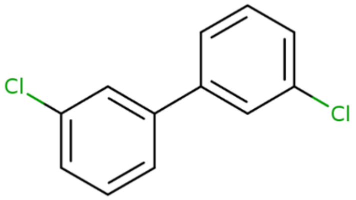
Dichloromethane, solvent



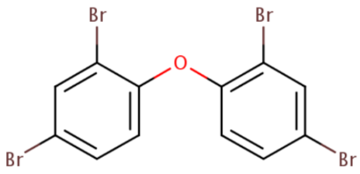
Tetrachloroethylene, solvent



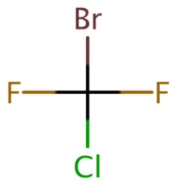
1-bromopropane, solvent



PCB 11, pigment contaminant



BDE-47, flame retardant



Halon 1211, fire supressant

Rationale for class approach

We are approaching organobromine and/or organochlorine substances as a class because many of these chemicals have:

- Related physicochemical properties due to covalent carbon-halogen bond(s).
- Similarities in hazards.
- The potential for cumulative impacts.
- A history of regrettable substitutions, when considering their functional use in consumer products.
- Environmental persistence and bioaccumulation potential.

The presence of chlorine and/or bromine bound to carbon defines the class and contributes to the shared hazards of these chemicals when considering their functional use. The shared properties imparted by chlorine and bromine in organic molecules relates to their functional use in products and increases the likelihood of regrettable substitutions within the class.

Structural similarities and shared hazards

Not all organobromine and/or organochlorine substances are hazardous, but many current and past uses of these substances are associated with adverse effects on human health and the environment. In part, this is due to how chlorine and bromine modify the chemical properties of organic molecules.

Bromine and chlorine belong to a group of chemical elements known as halogens. Elements in this group contribute significant properties to organic molecules. The presence of a carbon atom bound to chlorine or bromine generally increases the lipid solubility and decreases water solubility of an organic molecule. Chlorine and bromine also can alter the chemical reactivity of a molecule in several ways, including by inducing steric constraints and through their strong electron-withdrawing effect (Häggblom & Bossert, 2004). The physical and chemical properties that bromine and chlorine impart to molecules relate to their hazards to human health and environmental impacts.

There are naturally occurring organobromine and/or organochlorine substances in the environment, and there are also organisms able to perform dehalogenation of certain organic substances. However, the observed persistence of many organochlorine and organobromine substances in the environment suggests this capacity is not sufficient to cope with the volume and complexity of these substances arising from anthropogenic sources. Organobromine and/or organochlorine substances that have been banned or restricted for several decades still remain as global environmental contaminants (Kodavanti & Loganathan, 2017). This is despite efforts made to clean up these chemicals at contaminated sites, including hundreds of sites in Washington.

In general, organobromine and/or organochlorine substances are not as easily degraded in the environment as chemicals similar in structure but that do not contain halogens. For example, polychlorinated biphenyls (PCBs) and biphenyl are similar in structure, but PCBs are more persistent, and their persistence increases relative to the number and pattern of chlorine substituents present. This is not to say that all organobromine and/or organochlorine substances are inherently persistent, but persistence generally increases as the degree of halogenation increases (Hatzinger & Kelsey, 2022; Puzyn et al., 2011). This is in part due to the stability of covalent carbon-halogen bonds and their resistance to microbial degradation in natural environments.

The biodegradation potential of organobromine and/or organochlorine substances is also limited by their bioavailability to microorganisms in the environment. As mentioned above, the presence of bromine and chlorine generally decrease the water solubility of molecules and increase their hydrophobicity. Hydrophobic organic compounds in the environment often undergo hydrophobic sorption to organic matter, such as suspended particulate matter, soils, or sediments. This process can reduce the amount of a substance that is bioavailable for degradation by microorganisms. This is thought to be partly responsible for persistence observed for a diverse range of organobromine and/or organochlorine substances, from relatively small molecules such as organochlorine solvents (trichloroethene, tetrachloroethylene) to larger molecules like organochlorine pesticides, polychlorinated biphenyls (PCBs), and organohalogen flame retardants (Ecology, 2022; Nam & Kukor, 2004).

The persistence of some organobromine and/or organochlorine substances also increases the likelihood of long-range transport and distribution in the environment (Franklin, 2006). Some organobromine and/or organochlorine substances can also partially degrade to form other toxic chemicals. For example, chloroethenes such as tetrachloroethene and trichloroethene may undergo partial dechlorination reactions to form vinyl chloride in the environment (Findlay et al., 2016).

The effect of increased hydrophobicity can also contribute to the potential of organic substances to bioaccumulate in organisms. Many organobromine and/or organochlorine substances have high lipid solubility and tend to accumulate in the fatty tissues of exposed organisms. Similar to persistence, the bioaccumulation potential of chemicals generally increases as the degree of halogenation increases.

For example, this trend of increasing bioaccumulation potential with increasing chlorination is apparent in the bioaccumulation factors and bioconcentration factors (BCF) reported for PCB congeners (Ivanciuc et al., 2006; NRC, 2001). When organisms higher up the food chain ingest organisms contaminated with organobromine or organochlorine substances with high lipid solubility, those substances often increase in concentration. This process is termed biomagnification (Häggblom & Bossert, 2004).

In addition to increasing the potential for persistence and bioaccumulation of molecules, the presence of chlorine and bromine bound to carbon can also directly influence and oftentimes increase their toxicity in organisms (Häggblom & Bossert, 2004). An example of this are polychlorinated biphenyls (PCBs). Biphenyl is classified as a Group D chemical (not classifiable as to human carcinogenicity) by U.S. EPA, whereas polychlorinated biphenyls are classified as Group B2 chemicals (probable human carcinogens) (U.S. EPA, 2000a, 2000b).

When it was first adopted in Sweden, in 2001, the United Nations Environment Programme's (UNEP) Stockholm Convention identified twelve initial chemicals and chemical classes as persistent organic pollutants (POPs). POPs are characterized as persistent organic chemicals for which exposure can lead to serious health effects such as cancer, reproductive and developmental toxicity, neurotoxicity, immune dysfunction, and increased susceptibility to disease. All of the initial twelve chemicals and chemical classes are examples of organochlorine substances. Since 2001, sixteen additional chemicals and chemical classes have been added to the POPs list. Of these, fifteen are organochlorine or organobromine substances—the only exception being a subset of PFAS chemicals, which are also halogenated chemicals. In addition, a screening assessment of potential POPs across a set of 93,144 chemicals using predicted properties estimated 98% of chemicals identified as potential POPs were halogenated chemicals (Scheringer et al., 2012).

It is also important to note that not all organobromine and/or organochlorine substances are associated with the same degree of adverse impacts. For example, EPA's Safer Chemical Ingredients List contains several chemicals that have chlorine in their structure, including chemicals that function as surfactants, a preservative, a defoamer, and a polymer (EPA, n.d.-i). Many pharmaceuticals, which are intended to cause biological effects, also include chlorine or bromine in their structure and are designed to take advantage of how bromine or chlorine can modify bioactivity of compounds in controlled therapeutic uses (Benedetto Tiz et al., 2022).

There is variability in the persistence and bioaccumulation potential of organobromine and/or organochlorine substances. However, the physicochemical properties imparted by carbon-bromine and carbon-chlorine bonds in molecules (e.g., decreased water solubility, increased lipophilicity) contribute to these potential hazards. This variability in hazards for some organobromine and/or organochlorine substances, including persistence and bioaccumulation potential, will be taken into account as we focus our work on functional uses and products.

Despite some variability in hazards for members of this chemical class, it is necessary to critically evaluate their uses due to the shared hazards common to many organobromine and/or organochlorine substances. With that in mind, the hazards of organobromine and/or organochlorine substances are often related to their specific functional use, including in consumer products, as discussed below.

Shared functions and the potential for regrettable substitutions

While there is variability of hazards across the range of organobromine and/or organochlorine substances, similar hazards are often associated when grouping these chemicals by their functional use in products. To highlight this, some of the major functional uses of organobromine and organochlorine substances and past actions taken in response to hazards identified for members of this class of chemicals are summarized below. We also provide several examples of regrettable substitutions than have been made within these functional uses.

Examples of contemporary functional uses

Solvents

Organobromine and/or organochlorine substances are frequently used as solvents. Organochlorine solvents have properties, such as low or non-flammability, that can be advantageous relative to non-halogenated solvents in certain applications (Jordan et al., 2021). The volatility and low boiling point of many organochlorine solvents is also advantageous in some applications, including vapor degreasing, cleaning electronics, and dry cleaning.

However, there are tradeoffs as this volatility also contributes to an increased potential for human exposure through inhalation and mobility in the environment (B. Huang et al., 2014). As volatile organic chemicals (VOCs), organobromine and organochlorine solvents released into the environment can also reenter buildings from contaminated soil and groundwater, through a process called vapor intrusion (EPA, n.d.-j).

Organobromine solvents are not as widely used as organochlorine solvents, but use of some organobromine solvents, such as 1-bromopropane, has increased due to phasing out of other harmful solvents, like trichloroethylene and tetrachloroethylene (ATSDR, n.d.; IARC, 2018). This is an example of a regrettable substitution, and in December 2022 the U.S. EPA determined 1-bromopropane presents an “unreasonable risk of injury to health under its conditions of use,” including in consumer uses (EPA, 2022a).

Most of the chemicals we use to characterize the hazards of organobromine and/or organochlorine substances are used as solvents (see section below on hazards of the priority chemical class). Switching from one organobromine or organochlorine solvent to another is often a regrettable substitution, and in some applications, there are established alternatives available (TURI, 2021).

Polymeric materials

Several types of polymeric materials, or plastics, are made with organochlorine substances and are organochlorine substances themselves. The most common organochlorine polymer is polyvinylchloride (PVC). Other examples of organochlorine plastics include polychloroprene (neoprene) and chlorinated polyethylene. Manufacturers react chlorine gas with PVC to makes chlorinated PVC. Monomers used to produce organochlorine polymers include vinyl chloride and chloroprene, used in the manufacture of PVC and neoprene, respectively.

Vinyl chloride used to produce PVC is recognized as a very toxic, hazardous substance and is associated with carcinogenicity, mutagenicity, reproductive and developmental toxicity. Vinyl chloride is also associated with systemic toxicity to target organs, including the liver, neurotoxicity, and persistence (Rosenblum, 2015c). The U.S. EPA classifies vinyl chloride as a known human carcinogen, and it is included on California’s Proposition 65 List as a carcinogen (EPA, 2000b; OEHHA, 2023). Chloroprene, used to produce neoprene, is included as a carcinogen on California’s Proposition 65 List and is classified by the U.S. EPA as likely to be carcinogenic to humans (EPA, 2016b; OEHHA, 2023). Chloroprene is also associated with neurotoxicity, systemic toxicity to target organs (including the liver), and immune system depression (EPA, 2016b).

PVC and neoprene are both examples of non-biodegradable materials. Continued and expanding use of non-biodegradable materials and their contribution to environmental pollution is a well-recognized problem (Persson et al., 2022). Production of organochlorine polymers also presents additional environmental health challenges, partly due to the energy-intensive processes and materials used in chlorine production (European Commission, 2004; Healthy Building Network, 2018).

Organobromine and/or organochlorine substances are also incorporated into polymers as flame retardants (Ecology, 2022). For example, tetrabromobisphenol A is used as a reactive flame retardant that can be incorporated into polymers such as polycarbonate.

Biocides

Organobromine and/or organochlorine substances have also been used as biocides in consumer products. In this capacity, these substances are described as antifungals, antimicrobials, pesticides (see agricultural pesticides below), disinfectants, and preservatives. Some notable examples include hexachlorophene, triclocarban, tribromsalan, and triclosan.

These antimicrobials were previously used as active ingredients in over-the-counter consumer antiseptic wash products. However, in 2016 the U.S. FDA issued a rule stating that these compounds were not generally recognized as safe and effective for consumer antiseptic wash products (FDA, 2016). This conclusion was informed by some data that highlighted the potential for health risks from these compounds related to bacterial resistance or hormonal effects as well as a lack of safety and efficacy data submitted by manufacturers. The 2016 rule did not apply to over-the-counter consumer hand sanitizers or wipes, but in 2019 FDA published a rule that expanded the 2016 rule to these uses as well (FDA, 2019).

Some manufacturers have also begun phasing out triclosan in other consumer products uses. Other consumer product uses reported for triclosan include housewares, clothing, kitchenware, home furnishings, children’s toys, sporting goods, and building materials (Biomonitoring California, 2018; FDA, n.d.). Triclocarban has reported uses in cosmetics, pet grooming spray, and clothing (OEHHA, n.d.). Since both triclosan and triclocarban are associated with adverse impacts, replacing one for the other in products would likely be another example of a regrettable substitution for this class of chemicals.

Dyes and pigments

Many dyes and pigments contain chlorine or bromine in their structure. Dyes and pigments are based on molecular structures known as chromophores, which are the part of a molecule responsible for its color. Bromine and chlorine are often added to existing chromophores where they can act as auxochromes. Auxochromes induce subtle changes to a chromophore’s color, when added to the existing chromophore structure. An example of this is phthalocyanine pigments. Phthalocyanine blue (observed as a brilliant blue) can be chlorinated to produce phthalocyanine green (observed as a blue green). Replacing chlorine with bromine in the structure forms phthalocyanine green 36 (observed as a yellow green) (Lewis, 2000).

To our knowledge, potential hazardous effects of chlorination or bromination on these pigments and dyes has not been extensively studied. Some organochlorine pigments have been shown to be contaminated with hazardous polychlorinated biphenyls (PCBs) as described in our previous Regulatory Determinations Report to the Legislature (Ecology, 2022).[83] Organobromine and/or organochlorine substances, including organochlorine solvents, are also used in the production of dyes and pigments.

Examples of regulated functional uses

Refrigerants

Organochlorine substances used as refrigerants have a history of regrettable substitution. Some organochlorine solvents were used as early refrigerants in 1920s, but these were replaced by chlorofluorocarbons (CFCs) in the 1930s. CFCs were considered less hazardous as refrigerants due to reduced overt toxicity and flammability.

Throughout the period from the 1930s to the 1950s, many types of CFCs and hydrochlorofluorocarbons (HCFCs) were developed and widely used in refrigeration and air conditioning into the 1990s. Since that time, international regulatory efforts have focused on reducing or banning the use of these organochlorine refrigerants, due to the recognition that CFCs and HCFCs can react with intense UV light in the stratosphere to release chlorine. Chlorine and bromine (see fire suppression section below) react and destroy ozone in the stratosphere. As described by the U.S. EPA, “One chlorine atom can destroy over 100,000 ozone molecules before it is removed from the stratosphere” (EPA, n.d.-b). Stratospheric ozone is essential for protection of living organisms from ultraviolet radiation from the sun. The 1985 Vienna Convention for the Protection of the Ozone Layer and subsequent Montreal Protocol on Substances that Deplete the Ozone Layer in 1987 were international agreements that focused on reducing the use and production of ozone-depleting substances, including CFCs and HCFCs (World Meteorological Organization, 2022).

Replacement of organochlorine solvents used as refrigerants with CFCs and HCFCs is another example of regrettable substitution within this chemical class.

Fire suppression

Bromine-containing gases such as bromofluorocarbons (BFCs), bromochlorofluorocarbons (BCFCs) and hydrobromofluorocarbons (HBFCs) were commonly used in fire suppression systems and referred to generally as halons. Similar to CFCs and HCFCs used as refrigerants, it was recognized that these organobromine substances are also harmful to stratospheric ozone. Due to this recognized environmental impact, the Montreal Protocol covers BFCs and HBFCs to control their production and use (World Meteorological Organization, 2022). In 1994, the U.S. phased out importing and producing virgin halons; only recycled halons are still employed for specialty fire suppression applications (EPA, n.d.-g).

Agricultural pesticides

Organochlorine substances have been broadly used as agricultural pesticides, usually referred to as organochlorine pesticides. The most well-known organochlorine pesticide is dichlorodiphenyltrichloroethane, commonly referred to as DDT. DDT was banned in the United

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[83] apps.ecology.wa.gov/publications/summarypages/2204018.html

States in 1972, based on its persistence in the environment, adverse environmental effects to wildlife, and risks to human health (EPA, n.d.-e).

Many other organochlorine pesticides have been developed, and some are still in use. The hazards of organochlorine pesticides are well established, and many uses have been discontinued or restricted (CDC, n.d.-b). In general, organochlorine pesticides are persistent in the environment, bioaccumulative, and associated with adverse effects in wildlife and humans (Jayaraj et al., 2016).

Organobromine substances are also used as pesticides. Ethylene dibromide was used as a nematocide in the United States in the 1940s, mostly replaced in the mid-1950s by another compound 1,2-dibromo-3-chloropropane (DBCP), and then used again after DBCP was removed from the market completely in 1985 by the U.S. EPA due to its carcinogenic potential and reproductive toxicity (EPA, 2000a). Methyl bromide was used as a fumigant, but due to its role in ozone depletion, the United States has phased out most uses while implementing the Montreal Protocol (EPA, n.d.-h).

In the context of their hazards and history of regrettable substitution, organobromine and/or organochlorine substances used as agricultural pesticides support the rationale for considering these substances as a priority chemical class. However, when used as agricultural pesticides, they are less relevant to Safer Products for Washington because products are exempted in the statute from identification as priority products when used for production of an agricultural commodity (RCW 70A.350.030(5)(vii)). With that in mind, we do not elaborate further on the hazards of organobromine and/or organochlorine substances used as agricultural pesticides in this chapter, except where other non-agricultural uses have been identified.

Pharmaceuticals

Halogens, including bromine and chlorine, are found in a number of pharmaceutical drug and drug candidates in development. Halogens can induce steric effects on drug molecules and be involved in halogen bonds in drug-target complexes (Hernandes et al., 2010). Although this speaks to the chemical properties bromine and chlorine impart to organic molecules, organobromine and/or organochlorine substances used as drug products are not relevant to Safer Products for Washington because these products are regulated by the U.S. Food and Drug Administration and are exempted in the statute from identification as priority products (RCW 70A.350.030(5)(iv)). As such, we will not elaborate further on the hazards of substances used as pharmaceuticals.

Functional uses and by-products previously evaluated by Safer Products for Washington

Flame retardants

We evaluated organohalogen flame retardants as a priority chemical class as directed by the Legislature during our first implementation cycle of Safer Products for Washington. Organohalogen flame retardants are primarily organobromine and/or organochlorine substances, and we determined this class of chemicals was potentially hazardous to the environment and human health (Ecology, 2022). This determination was based on the finding that several hazards were associated with organohalogen flame retardants, including carcinogenicity, developmental toxicity, aquatic toxicity, persistence, and bioaccumulation.

In the report, we also discussed the history of regrettable substitution associated with organobromine flame retardants. Briefly, polybrominated biphenyls were used in the 1970s, until they were banned in 1976 by the U.S. EPA due to health concerns. Polybrominated diphenyl ethers (PBDEs) were used as flame retardants until use was ceased, and the U.S. EPA published a significant new use rule in 2012, due to additional concerns for human health and the environment. Following the 2012 rule, PBDEs were largely replaced by a variety of other organobromine and/or organochlorine flame retardants, which are also associated with adverse effects, as described in our report (Ecology, 2022). This is a strong example of regrettable substitution for this class of chemicals.

Polychlorinated biphenyls (PCBs)

We also evaluated the hazards of PCBs as a priority chemical class during the first implementation cycle of the Safer Products for Washington program (Ecology, 2022). Although PCBs are no longer intentionally manufactured and added to consumer products for specific functional uses, they are another example of organochlorine substances that are hazardous to human health and have long-lasting environmental impacts. Ecology published a PCB Chemical Action Plan in 2015 that described some of the sources and impacts of PCBs in the state and made recommendations to reduce human exposure and environmental contamination in Washington (Ecology, 2015).

As part of our ongoing work, Ecology provides guidance to reduce environmental contamination and human exposure from legacy PCBs used in building materials (Ecology, n.d.-c). The Spokane River Regional Toxics Task Force developed a comprehensive plan specifically to reduce PCBs present in the Spokane River. PCB contamination in the Spokane River can be attributed to both legacy uses banned at the federal level in 1979 and inadvertent PCBs still produced in product manufacturing. Together, these necessary actions speak to the ongoing and costly impacts of past intentional PCB use and their continued presence as contaminants in consumer products.

Summary

As noted throughout this section, many organobromine and/or organochlorine substances have already been the subject of restrictions, bans, and phaseouts due to evidence of adverse impacts on human health and the environment. However, the persistence of many of these substances in the environment and their widespread production and use has resulted in many organobromine and/or organochlorine substances still being commonly found in the environment and in humans (Patterson et al., 2009; Sjödin et al., 2014). Additionally, chemicals in this class have a history of regrettable substitution. The legacy associated with these chemicals supports our identification of organobromine and/or organochlorine substances as a priority chemical class because it demonstrates their potential to cause long-term impacts to human health and the environment. This is in addition to meeting the requirements set forth in the statute for identification of priority chemical classes.

In the hazards section that follows, we focused on identifying organobromine and/or organochlorine substances of most relevance to Safer Products for Washington, to further support our rationale for approaching organobromine and/or organochlorine substances as a chemical class.

Meeting the statutory requirements

The statute requires that priority chemicals or chemical classes meet specific criteria. Priority chemical classes must meet at least one of the criteria described in RCW 70A.350.020[84] and listed below.

- A member of the chemical class has been identified by Ecology as a chemical of concern, specifically:
    - A chemical of high concern to children under Chapter 70A.430 RCW[85] or
    - A persistent, bioaccumulative and toxic chemical under Chapter 70A.300 RCW.[86]
- A member of the chemical class is regulated in relevant consumer product statutes in Washington.
- A member of the chemical class is a hazardous substance under Chapter 70A.300 RCW or Chapter 70A.305.[87]
- Members of the chemical class are a concern for sensitive populations and sensitive species.

Organobromine and/or organochlorine substances meet at least one of the criteria to be considered priority chemicals. Each of the criteria are discussed below.

Chemicals of concern by Ecology

Chemical classes with members that are chemicals of high concern to children (CHCC), identified under Chapter 70A.430 RCW,[88] meet the criteria for designation as priority chemical class under RCW 70A.350.020(1)(a).[89] Ecology identifies chemicals of high concern to children based on their hazards and exposure potential in Chapter 173-334 WAC.[90] Twenty organobromine and/or organochlorine substances are CHCC (Table 8). To review the rationale for CHCC listing, please refer to the Rationale for Reporting List of Chemicals of High Concern to Children 2011 to 2017 (Ecology, 2021b).

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[84] app.leg.wa.gov/rcw/default.aspx?cite=70A.350.020
[85] app.leg.wa.gov/rcw/default.aspx?cite=70A.430
[86] app.leg.wa.gov/rcw/default.aspx?cite=70A.300
[87] app.leg.wa.gov/rcw/default.aspx?cite=70A.305
[88] app.leg.wa.gov/rcw/default.aspx?cite=70A.430
[89] app.leg.wa.gov/rcw/default.aspx?cite=70A.350.020
[90] apps.leg.wa.gov/wac/default.aspx?cite=173-334

Table 8. Organobromine and/or organochlorine substances that are chemicals of high concern to children.

Chemical	CAS RN
Vinyl Chloride	75-01-4
Methylene Chloride	75-09-2
1,1,2,2-Tetrachloroethane	79-34-5
Tetrabromobisphenol A (TBBPA)	79-94-7
Hexachlorobutadiene	87-68-3
4-Chloroaniline	106-47-8
Tris (2-chloroethyl) phosphate (TCEP)	115-96-8
Hexachlorobenzene	118-74-1
Tris (2,3-dibromopropyl) phosphate (TDBPP)	126-72-7
Tetrachloroethene	127-18-4
Pentachlorobenzene	608-93-5
2,2',3,3',4,4',5,5',6,6'-Decabromodiphenyl ether (BDE-209)	1163-19-5
Tris (1-chloro-2-propyl) phosphate (TCPP)	13674-84-5
Tris (1, 3-dichloro-2-propyl) phosphate (TDCPP)	13674-87-8
Hexabromocyclododecane (HBCD)	25637-99-4
Bis (2-ethylhexyl) tetrabromophthalate (TBPH)	26040-51-7
Bis(chloromethyl)propane-1,3-diyl tetrakis- (2-chloroethyl) bis(phosphate) (V6)	38051-10-4
Decabromodiphenyl ethane	84852-53-9
Short-Chain chlorinated paraffins (SCCP)	85535-84-8
2-ethylhexyl-2,3,4,5-tetrabromobenzoate (TBB)	183658-27-7

Chemical classes with members identified as persistent bioaccumulative toxic substances (PBTs) under Chapter 70A.300 RCW meet the criteria for designation as a priority chemical class under RCW 70A.350.020(1)(b). Ecology identifies chemicals that are persistent, bioaccumulative, and toxic in Chapter 173-333 WAC.[91] Organobromine and/or organochlorine substances are persistent, bioaccumulative, and toxic chemical under the criteria in WAC 173-333-320.[92] Specific chemicals can be found in Table 9.

Table 9. Organobromine and/or organochlorine substances that are persistent, bioaccumulative, and toxic, and identified WAC 173-333-310.

PBT	CAS RN
Chlordane	57-74-9
Chlordecone (Kepone)	143-50-0
Dichlorodiphenyltrichloroethane (DDT)	50-29-3
Heptachlor/Heptachlor epoxide	76-44-8/1024-57-3

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[91] app.leg.wa.gov/wac/default.aspx?cite=173-333

[92] app.leg.wa.gov/wac/default.aspx?cite=173-333-320

PBT	CAS RN
Hexabromobiphenyl	59536-65-1
Hexabromocyclododecane	25637-99-4
Hexachlorobenzene	118-74-1
Hexachlorobutadiene	87-68-3
Pentachlorobenzene	608-93-5
Short-chain chlorinated paraffins	85535-84-8
Tetrabromobisphenol A	79-94-7
Tetrachlorobenzene, 1,2,4,5	95-94-3
Toxaphene	8001-35-2
Polybrominated dibenzodioxins and furans	Multiple
Polybrominated diphenyl ethers	Multiple
Polychlorinated biphenyls (PCBs)	Multiple
Polychlorinated dibenzo-p-dioxins	Multiple
Polychlorinated dibenzofurans	Multiple
Polychlorinated naphthalenes	Multiple

Regulations in consumer products under relevant Washington statutes

Chemical classes with members regulated in consumer products under Chapters 70A.430,[93] 70A.405,[94] 70A.222,[95] 70A.335,[96] 70A.230,[97] or 70A.400 RCW[98] meet the criteria for designation as a priority chemical class under RCW 70A.350.020(2)(a).[99] Table 10 lists organobromine and/or organochlorine substances regulated in consumer products under relevant Washington statutes.

Table 10. Organobromine and/or organochlorine substances that are regulated in consumer products.

Chemicals	Relevant regulation
TDCPP, TCEP, Decabromodiphenyl ether, HBCD, additive TBBPA	Restricted in children's products or residential upholstered furniture (Chapter 70A.430 RCW)
PBDEs (excluding decaBDE)	Restricted in noncomestible products (Chapter 70A.405 RCW[100])

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[93] app.leg.wa.gov/rcw/default.aspx?cite=70A.430
[94] apps.leg.wa.gov/rcw/default.aspx?cite=70A.405
[95] app.leg.wa.gov/rcw/default.aspx?cite=70A.222
[96] app.leg.wa.gov/rcw/default.aspx?cite=70A.335
[97] app.leg.wa.gov/rcw/default.aspx?cite=70A.230
[98] app.leg.wa.gov/rcw/default.aspx?cite=70A.400
[99] app.leg.wa.gov/rcw/default.aspx?cite=70A.350.020
[100] app.leg.wa.gov/rcw/default.aspx?cite=70A.405

Chemicals	Relevant regulation
decaBDE	Restricted in mattresses, residential upholstered furniture, and TVs and computers that have electronic enclosures (Chapter 70A.405 RCW)

Hazardous substances in Washington

Under Chapter 70A.350 RCW,[101] chemical classes with members that are hazardous substances under Chapter 70A.300 RCW[102] (Hazardous Waste Management Act) or Chapter 70A.305 RCW (Model Toxic Control Act) can be considered priority chemical classes.

Hazardous substances are defined in Chapter 70A.305 RCW to include any material that exhibits any of the characteristics or criteria of dangerous wastes identified under Chapter 173-303 WAC.[103] Organobromine and/or organochlorine substances can be identified as dangerous wastes in at least two ways.

- Wastes with organobromine and/or organochlorine substances in concentrations greater than 0.01% meet the persistent, dangerous waste criteria under WAC 173-303-100.[104]
- WAC 173-303-090 also includes a contaminant toxicity characteristic list with many organobromine and/or organochlorine substances. Wastes with organobromine and/or organochlorine substances are considered dangerous wastes if the extract created using the Toxic Characteristic Leaching Procedure has concentrations above the limits in Table 11.
- Other members of the class may also designate based on the toxicity criteria in WAC 173-303-100.

Table 11. Organobromine and/or organochlorine substances on the contaminant toxicity characteristic list in WAC 173-303-090.

Chemical	CAS RN	Limit (mg/L)	Dangerous Waste Number
Carbon tetrachloride	56-23-5	5	D019
Chlordane	57-74-9	0.03	D20
Chlorobenzene	108-90-7	100	D021
Chloroform	67-66-3	6	D022
2, 4 D	95-75-7	10.0	D016
1, 4 dichlorobenzene	106-46-7	7.5	D027
1, 2 dichloroethane	107-06-2	0.5	D028
1, 2 dichloroethylene	75-35-4	0.7	D029
Endrin	72-20-8	0.02	D012

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[101] app.leg.wa.gov/rcw/default.aspx?cite=70A.350

[102] app.leg.wa.gov/rcw/default.aspx?cite=70A.300

[103] app.leg.wa.gov/wac/default.aspx?cite=173-303

[104] app.leg.wa.gov/WAC/default.aspx?cite=173-303-100

Chemical	CAS RN	Limit (mg/L)	Dangerous Waste Number
Heptachlor	75-44-8	0.008	D031
Hexachlorobenzene	118-74-1	0.13	D032
Hexachlorobutadiene	87-68-3	0.5	D033
Hexachloroethane	67-72-1	3.0	D034
Lindane	58-89-9	0.4	D013
Methoxychlor	72-43-5	10.0	D014
Pentachlorophenol	87-86-5	100.0	D037
Tetrachloroethylene	127-18-4	0.7	D039
Toxaphene	8001-35-2	0.5	D015
Trichloroethylene	79-01-6	0.7	D040
2,4,5-trichlorophenol	95-95-4	400.0	D041
2,4,6 Trichlorophenol	88-06-2	2.0	D042
Vinyl Chloride	75-01-4	0.2	D043

Organobromine and/or organochlorine substances are listed under section 101(14)[105] of the federal cleanup law, 42 U.S.C. Sec. 9601(14) Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and therefore are incorporated into the definition of "hazardous substance" under RCW 70A.305.020(13).[106] Table 12 shows the organobromine and/or organochlorine substances listed as hazardous substances under the federal cleanup law. Not all chemicals in Table 12 are relevant to pollution prevention efforts under Safer Products for Washington. However, they still fall within the chemical class and are included in Table 12.

Table 12. Organobromine and/or organochlorine substances designated as hazardous substances under CERCLA.

Hazardous Substance	CAS RN
Cyclophosphamide	50-18-0
DDT	50-29-3
Carbon tetrachloride	56-23-5
Chlordane	57-74-9
Hexachlorocyclohexane (gamma isomer)	58-89-9
2,3,4,6-Tetrachlorophenol	58-90-2
p-Chloro-m-cresol	59-50-7
Dieldrin	60-57-1
Uracil mustard	66-75-1
Chloroform	67-66-3
Hexachloroethane	67-72-1

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[105] www.ecfr.gov/current/title-40/chapter-I/subchapter-J/part-302/section-302.4

[106] app.leg.wa.gov/RCW/default.aspx?cite=70A.305.020

Hazardous Substance	CAS RN
Hexachlorophene	70-30-4
Methyl chloroform	71-55-6
Endrin, & metabolites	72-20-8
Methoxychlor	72-43-5
DDD	72-54-8
Methyl bromide	74-83-9
Methyl chloride	74-87-3
Ethyl chloride	75-00-3
Vinyl chloride	75-01-4
Methylene chloride	75-09-2
Bromoform	75-25-2
Dichlorobromomethane	75-27-4
1,1-Dichloroethane	75-34-3
1,1-Dichloroethylene	75-35-4
Trichloromonofluoromethane	75-69-4
Dichlorodifluoromethane	75-71-8
Chloral	75-87-6
2,2-Dichloropropionic acid	75-99-0
Pentachloroethane	76-01-7
Heptachlor	76-44-8
Hexachlorocyclopentadiene	77-47-4
1,2-Dichloropropane	78-87-5
2,3-Dichloropropene	78-88-6
1,1-Dichloropropane	78-99-9
1,1,2-Trichloroethane	79-00-5
Trichloroethene	79-01-6
Chloroacetic acid	79-11-8
Methyl chloroformate	79-22-1
1, 1,2,2,-Tetrachloroethane	79-34-5
Pentachloronitrobenzene	82-68-8
2,6-Dichlorophenol	87-65-0
Hexachlorobutadiene	87-68-3
Pentachlorophenol	87-86-5
2,4,6-Trichlorophenol	88-06-2
2-Chloronaphthalene	91-58-7
3,31-Dichlorobenzidine	91-94-1
Propionic acid, 2-(2,4,5-trichlorophenoxy)-	93-72-1
Acetic acid, (2,4,5-trichlorophenoxy)	93-76-5
2,4-D Acid	94-75-7
1,2-Dichlorobenzene	95-50-1
2-Chlorophenol	95-57-8

Hazardous Substance	CAS RN
1,2,4,5-Tetrachlorobenzene	95-94-3
2,4,5-Trichlorophenol	95-95-4
1,2-Dibromo-3-chloropropane	96-12-8
Benzotrichloride	98-07-7
Benzal chloride	98-87-3
Benzyl chloride	100-44-7
4,4′-Methylenebis(2-chloroaniline)	101-14-4
Carbamic acid, (3-chlorophenyl)-, 4-chloro-2-butynyl ester (Barban)	101-27-9
4-Bromophenyl phenyl ether	101-55-3
1,4-Dichlorobenzene	106-46-7
p-Chloroaniline	106-47-8
1-Chloro-2,3-epoxypropane	106-89-8
Ethylene dibromide	106-93-4
1,2-Dichloroethane	107-06-2
Chloroacetaldehyde	107-20-0
Chloromethyl methyl ether	107-30-2
Dichloroisopropyl ether	108-60-1
Chlorobenzene	108-90-7
2-Chloroethyl vinyl ether	110-75-8
Dichloroethyl ether	111-44-4
Dichloromethoxy ethane	111-91-1
Endosulfan	115-29-7
Hexachlorobenzene	118-74-1
1,2,4-Trichlorobenzene	120-82-1
2,4-Dichlorophenol	120-83-2
Chlorodibromomethane	124-48-1
Tris(2,3-dibromopropyl) phosphate	126-72-7
Chloroprene	126-99-8
Perchloroethylene	127-18-4
1,3-Dichloropropane	142-28-9
Kepone	143-50-0
Melphalan	148-82-3
1,2-Dichloroethylene	156-60-5
Chlorambucil	30-503-3
Aldrin	309-00-2
Isodrin	465-73-6
Chlornaphazine	494-03-1
Chlorobenzilate	510-15-6
2-Chloroacetophenone	532-27-4
1,3-Dichlorobenzene	541-73-1
1,3-Dichloropropene	542-75-6

Hazardous Substance	CAS RN
3-Chloropropionitrile	542-76-7
Dichloromethyl ether	542-88-1
Trichloromethanesulfenyl chloride	594-42-3
Bromoacetone	598-31-2
Hexachlorocyclohexane (all isomers)	608-73-1
Pentachlorobenzene	608-93-5
3,4,5-Trichlorophenol	609-19-8
1, 1, 1,2-Tetrachloroethane	630-20-6
1,4-Dichloro-2-butene	764-41-0
2, 3,6-Tri chlorophenol	933-75-5
2, 3, 5-Tri chlorophenol	933-78-8
TCDD	1746-01-6
Hexachloropropene	1888-71-7
Diallate	2303-16-4
Carbamothioic acid, bis(1-methylethyl)-, S-(2,3,3-trichloro-2-propenyl) ester (Triallate).	2303-17-5
4-Chloro-o-toluidine, hydrochloride	3165-93-3
Thiourea, (2-chlorophenyl)-	5344-82-1
4-Chlorophenyl phenyl ether	7005-72-3
Toxaphene	8001352
Dichloropropane—Dichloropropene (mixture)	8003198
2, 3,4-Tri chlorophenol	15950660
Pronamide	23950585
Trichlorophenol	25167822
Dichlorobenzene	25321226
Dichloropropane	26638197
Dichloropropene	26952238

Chemicals of concern for sensitive populations and species

After assessing available data to consider the factors below, as outlined in RCW 70A.350.020,[107]we found that organobromine and/or organochlorine substances are a concern for sensitive populations and sensitive species.

(a) A chemical's or members of a class of chemicals' hazard traits or environmental or toxicological endpoints;

(b) A chemical's or members of a class of chemicals' aggregate effects;

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[107] app.leg.wa.gov/RCW/default.aspx?cite=70A.350.020

(c) A chemical’s or members of a class of chemicals’ cumulative effects with other chemicals with the same or similar hazard traits or environmental or toxicological endpoints;

(d) A chemical’s or members of a class of chemicals’ environmental fate;

(e) The potential for a chemical or members of a class of chemicals to degrade, form reaction products, or metabolize into another chemical or a chemical that exhibits one or more hazard traits or environmental or toxicological endpoints, or both;

(f) The potential for the chemical or class of chemicals to contribute to or cause adverse health or environmental impacts;

(g) The chemical’s or class of chemicals’ potential impact on sensitive populations, sensitive species, or environmentally sensitive habitats;

(h) Potential exposures to the chemical or members of a class of chemicals based on:

    (i) Reliable information regarding potential exposures to the chemical or members of a class of chemicals; and

    (ii) Reliable information demonstrating occurrence, or potential occurrence, of multiple exposures to the chemical or members of a class of chemicals.

Organobromine and/or organochlorine substances are a concern for sensitive species and sensitive populations because of their hazards and the potential for exposure to people and the environment. Organobromine and/or organochlorine substances have multiple shared hazards, including carcinogenicity, developmental toxicity, reproductive toxicity, and aquatic toxicity. Some organobromine and/or organochlorine substances persist in the environment and bioaccumulate in people and wildlife.

There is widespread exposure to organobromine and/or organochlorine substances. Organobromine and/or organochlorine substances have been detected in air, drinking water, house dust, groundwater, soil, and sediment. They have also been detected in people’s bodies and in the bodies of sensitive species. There is the potential for disproportionate exposure. People in occupations where organobromine and/or organochlorine substances are used may have higher exposure.

Organobromine and/or organochlorine substances have a history of regrettable substitutions, and many can persist and bioaccumulate in the environment. Persistent, bioaccumulative, and toxic chemicals can expose people for generations, even after they are no longer in use. Using these chemicals also leads to expensive environmental cleanups.

The sections below describe our evaluation of this criteria and support our conclusion.

Hazards of priority chemical class

We evaluated data-rich chemicals within the class for hazards, including environmental and human health toxicological endpoints, environmental fate, transport, and potential breakdown products. To identify these hazards, we used similar methods to those found in our 2022 Regulatory Determinations Report to the Legislature.

To facilitate characterization of the hazards of organobromine and/or organochlorine substances, we focused on a subset of data-rich chemicals in the class. We identified a set of data-rich chemicals using the U.S. EPA Chemical and Products Database (CPDat). CPDat contains information on more than 49,000 chemicals and aims to categorize their use or function in 16,000 consumer product types based on chemicals they contain (EPA, n.d.-c). CPDat categorizes these uses into product use categories (PUCs) that are searchable as part of the U.S. EPA CompTox Chemicals Dashboard. For example, a query can be performed in the dashboard that lists all chemicals contained in the “personal care” PUC, and then additional filters can be applied to this subset of chemicals.

To identify chemicals most relevant to our work in Safer Products for Washington, we searched the database for specific PUCs using the EPA CompTox Dashboard (EPA, n.d.-c, n.d.-d). PUCs contain chemicals from many functional use categories (such as solvent or preservative), so we focused on PUCs that were likely to contain functional uses of organobromine and/or organochlorine substances most relevant to Safer Products for Washington.

PUCs were selected using the PUCs dictionary that accompanies the CPDat Data File referred to by U.S. EPA (EPA, n.d.-c). PUCs that were included in our search were:

- Arts, crafts, and office supplies.
- Cleaning products and household care.
- Construction and building materials.
- Electronics and small appliances.
- Home maintenance.
- Furniture and furnishings.
- Manufactured formulations.
- Personal care.
- Pet care.
- Sports equipment.
- Toys and children’s products.

We intentionally did not include other PUCs that we deemed less relevant to our current work, including vehicle, pesticides, and batteries. We also did not include chemicals in the database that have not been categorized into PUCs.

This initial broad search resulted in over 3,000 database entries across the searched PUCs. It is important to note there is considerable overlap in chemicals in these PUCs, so the number of unique chemicals represented by these entries was significantly less. Of the resulting database entries, we identified 73 individual chemicals that met our definition of organobromine and/or organochlorine substances (*i.e.*, organic molecules containing chlorine or bromine bonded to carbon). We then removed chemicals from the list that fit definitions of previous priority chemical classes evaluated by Safer Products for Washington (organohalogen flame retardants, PFAS, and PCBs) or were less relevant to our work (e.g., pharmaceuticals). To further supplement this list, we added four organobromine and/or organochlorine substances already included on the CHCC list. Using this approach, we identified 60 organobromine and/or organochlorine substances relevant to our work in Safer Products for Washington.

Of those 60 chemicals, 26 have verified SciveraLENS® GHS+ chemical hazard assessments, and 6 of those have GreenScreen® hazard assessments as well. Two additional chemicals were scored as LT-1 using the GreenScreen List Translator, due to presence on authoritative lists (methyl chloroform and pentachlorobenzene). We used these 28 chemicals that either had existing hazard assessments or scored as LT-1 to characterize the hazards of the organobromine and/or organochlorine substances chemical class (Table 13).

One limitation of this approach is we are only characterizing the hazards of a subset of organobromine and/or organochlorine substances, based on those represented in the CPDat database and on the Washington CHCC list. This reflects information available for general uses of this chemical class in consumer products. That said, while this list of chemicals is far from exhaustive, it illustrates the hazards of chemicals in the class reportedly being used in consumer products.

The organobromine and/or organochlorine substances we identified as data rich are associated with several hazards to human health and the environment. This is consistent with hazards documented for this class of chemicals in the literature (Kodavanti & Loganathan, 2017). Members of the class are associated with hazards including carcinogenicity, reproductive and developmental toxicity, acute and chronic aquatic toxicity, persistence, and bioaccumulation as described below.

Carcinogenicity and mutagenicity

Carcinogenicity is a common hazard associated with this set of organobromine and/or organochlorine substances. Of the 28 organobromine and/or organochlorine substances on the list we used to characterize the class, 20 either scored as high hazard for carcinogenicity in hazard assessments or are present on authoritative lists for carcinogenicity (Table 13). Nine also scored as high hazard for mutagenicity (Table 13).

We reviewed thirteen substances as examples of organochlorine solvents. Organochlorine solvents are associated with an increased risk of multiple types of cancers, including bladder, liver, kidney, throat, cervix, and lymphomas (*e.g.*, 1-bromopropane is associated with carcinogenicity) (IARC, 2014). The International Agency for Research on Cancer (IARC) concluded that there was "sufficient evidence" of carcinogenicity of 1-bromopropane in animal studies and that 1-bromoproane is possibly carcinogenic to humans. The California Proposition 65 List also includes 1-bromopropane as a carcinogen (IARC, 2018; OEHHA, 2023).

Chemicals on the list used for other functions also are associated with carcinogenicity. Vinyl chloride is used as a monomer in production of PVC plastics; it is included on the California Proposition 65 List as a carcinogen and listed by the European Chemicals Agency (ECHA) for carcinogenicity (OEHHA, 2023). Epichlorohydrin, 4-chloroaniline, and hexachlorobenzene are examples of chemicals used in the production of other organochlorine substances and consumer products. These chemicals are also on the California Proposition 65 List as carcinogens. Chemicals used as biocides on the list are classified as carcinogens on the California Proposition 65 List as well, including 1,4-dichlorobenzene and folpet (OEHHA, 2023).

Reproductive and developmental toxicity

Several of the data-rich organobromine and/or organochlorine substances we identified are included on authoritative lists as reproductive and developmental toxicants. This includes the solvents 1-bromopropane and trichloroethylene, which are both included on the California Proposition 65 List for reproductive and developmental toxicity (OEHHA, 2023).

Triadimefon is a biocide used as an antifungal pesticide and is also included in CPDat for use in cleaning and household care products. It is included on the California Proposition 65 List for both developmental and reproductive toxicity. Epichlorohydrin is used in production of epoxy resins used in various products and is also listed under California Proposition 65 for reproductive toxicity. Hexachlorobenzene is listed on the Washington CHCC list and is listed on the California Proposition 65 List as a developmental toxicant (OEHHA, 2023).

Additionally, although tetrachloroethene is not listed for developmental toxicity, it was scored as high hazard for developmental toxicity in a GreenScreen® hazard assessment, due to effects observed in animal studies, including mortality, decreased growth, increased malformations, and developmental neurotoxicity in progeny (ToxServices, 2016b).

Systemic toxicity

Of the 28 organobromine and/or organochlorine substances on the list we used to characterize the class, 15 scored as high or very high hazard for systemic toxicity (single or repeat dose) in GreenScreen or SciveraLENS® GHS+ chemical hazard assessments (Table 13). Of those, 10 are organochlorine solvents. Organochlorine solvents can cause adverse effects on several target organs and systems, including in the liver, kidney, respiratory tract, central nervous system, and hematopoietic system (Cichocki et al., 2016; EPA, 2012b; Teschke, 2018). These effects can occur due to single or repeat exposures.

Other chemicals that scored as high or very high for systemic toxicity (single or repeat dose) were vinyl chloride, triclosan, epichlorohydrin, 4-chloroaniline, and hexachlorobenzene (Table 13).

Neurotoxicity

In GreenScreen and SciveraLENS GHS+ chemical hazard assessments, 5 of the 28 organobromine and/or organochlorine substances scored as high hazard for neurotoxicity (single or repeat dose) (Table 13). Tetrachloroethane, tetrachloroethene, and 1,2-dichloroethane are all are examples of organochlorine solvents associated with neurotoxicity. Vinyl chloride and hexachlorobenzene are also associated with neurotoxicity. Hexachlorobenzene is associated with convulsions, tremors, lethargy, and weakness in animal studies (ATSDR, 2015; Scivera, 2023aa). The EU Globally Harmonized System (GHS) also classified 1-bromopropane as H336 for causing narcotic effects (ECHA, 2023).

Ecological toxicity

Many of the data-rich organobromine and/or organochlorine substances we identified are toxic to aquatic organisms. For example, triclosan is acutely toxic to a variety of aquatic organisms, with reported 96-hour LC50 values of less than 1 mg/L in several species of fish including in *Danio rerio*, *Tanichthys albonubes*, *Lepomis macrochirus*, *Misgurnus anguillicaudatus*, *Pimephales promelas*, *Pseudorasbora parva*, and *Oryzias latipes*. The lowest 96-hour EC50 values reported for triclosan in an invertebrate, *Daphnia magna*, was 0.18 mg/L, and an EC50 of 0.00044 mg/L was reported for a species of algae, *Navicula pelliculosa* (ToxServices, 2018d).

The organochlorine solvent tetrachloroethylene is also acutely toxic in aquatic species, with the lowest LC50 reported in freshwater fish of 5mg/L in *Oncorhynchus mykiss*, lowest LC50 reported in marine fish of 5 mg/L in *Limanda limanda*, and a lowest EC50 of 3.64mg/L in a species of algae, *Chlamydomonas reinhardtii* (ToxServices, 2016b). Overall, 15 of the 28 organobromine and/or organochlorine substances we used to characterize the class scored as high or very high hazard for acute aquatic toxicity in GreenScreen® or SciveraLENS® GHS+ chemical hazard assessments (Table 13).

Fourteen of the 28 organobromine and/or organochlorine substances scored as high or very high for chronic aquatic toxicity (Table 13). For example, the lowest 72-hour no observable effect concentration (NOEC) reported for triclosan is 0.0005 mg/L for growth rate in a species of algae, *Scenedesmus subspicatus* (ToxServices, 2018d). For chronic aquatic toxicity of tetrachloroethylene, the lowest 28-day NOEC for reproduction was reported as 0.51 mg/L in the aquatic invertebrate *Daphnia magna* (ToxServices, 2016b).

Environmental fate

Of the 28 organobromine and/or organochlorine substances we used to characterize the hazards of the class, 17 scored as high or very high hazard for persistence in GreenScreen or SciveraLENS GHS+ chemical hazard assessments. Only 2 of 28 chemicals on our list scored as high or very high for bioaccumulation, however this is likely due to the relatively small molecular weight of most of the listed compounds.

Many organobromine and/or organochlorine substances, especially those with higher molecular weights, are bioaccumulative, including those characterized as POPs on the UNEP list and those predicted in the previously mentioned screening assessment (Scheringer et al., 2012).

Referenced hazard assessments

The hazard assessments referenced in Table 13 are described in the Technical Methods chapter of this report. We reviewed each method for transparency and consistency in scoring methods and data requirements (Ecology, 2022). Using hazard assessments allows us to apply a consistent, non-biased approach to evaluating chemicals across multiple endpoints and levels of data. In this report, hazard assessments allow us to identify known and potential hazards of chemicals within the priority chemical classes.

- The SciveraLENS® GHS+ chemical hazard assessments referenced in Table 13 are available in the SciveraLENS database[108] (Scivera, 2023g, 2023ap, 2023b, 2023ai, 2023an, 2023am, 2023c, 2023s, 2023a, 2023v, 2023al, 2023f, 2023e, 2023i, 2023af, 2023ah, 2023t, 2023h, 2023ab, 2023l, 2023aa, 2023ak, 2023j, 2023m, 2023k, 2023n).
- The GreenScreen® assessments for benzyl chloride (CAS: 100-44-7), 1,2-dichloroethane (CAS: 107-06-2), tetrachloroethene (CAS: 127-18-4), and triclosan (CAS: 3380-34-5) are available from the ToxServices database[109] (ToxServices, 2015b, 2016b, 2018d, 2018b).
- The GreenScreen assessments for 1-bromopropane (CAS: 106-94-5) and vinyl chloride (CAS: 75-01-4) are available from the Pharos website[110] (Rosenblum, 2015a, 2015c).

Table 13. Data-rich organobromine and/or organochlorine substances and their known and potential hazards.

Common name, associated CAS(s)	Known or potential hazards	Referenced hazard assessments	Relevant authoritative listings
1-bromopropane, CAS RN: 106-94-5	Carcinogenicity†, reproductive toxicity†, developmental toxicity†, acute toxicity‡, systemic toxicity (single and repeat dose)‡, neurotoxicity (single- and repeat-dose)‡, skin irritation†, eye irritation†, acute aquatic toxicity‡, chronic aquatic toxicity‡ persistence†	GreenScreen BM-1, SciveraLENS [Red]	California Proposition 65 List (carcinogen, female reproductive toxicity, developmental toxicity); EU GHS—H360FD (Repr. 1B), H335 (Sys. Tox. Single Exp. Resp. 3), H336 (Sys. Tox. Narcotic 3), H373 (Sys. Tox. Rep. Exp. 2), H315 (Skin Irr. 2), H319 (Eye Irr. 2)
Benzyl chloride, CAS RN: 100-44-7	Carcinogenicity†, mutagenicity‡, developmental toxicity‡, acute toxicity†, systemic toxicity (single dose)‡, systemic toxicity (repeat dose) †, skin sensitization‡, skin irritation†, eye irritation†, acute aquatic toxicity†, chronic aquatic toxicity†	GreenScreen® BM-1, SciveraLENS® [Red]	California Proposition 65 List (carcinogen); EU—GHS H350 (Carc. 1), H331 (Acute Tox. Inhal. 3), H302 (Acute Tox. 4), H335 (Sys. Tox. Single Exp. Resp. 3), H373 (Sys. Tox. Rep. Exp. 2), H315 (Skin Irr. 2), H318 (Eye Irr. 1)

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[108] rapidscreen.scivera.com/
[109] database.toxservices.com/
[110] pharosproject.net/

Common name, associated CAS(s)	Known or potential hazards	Referenced hazard assessments	Relevant authoritative listings
1,2-dichloroethane, CAS RN: 107-06-2	Carcinogenicity†, mutagenicity‡, acute toxicity‡, systemic toxicity (single and repeat dose)†, neurotoxicity (single dose)‡, neurotoxicity (repeat dose)†, skin irritation†, eye irritation†, acute aquatic toxicity‡, persistence‡	GreenScreen BM-1, SciveraLENS [Red]	California Proposition 65 List (carcinogen); EU GHS—H350 (Carc. 1), H302 (Acute Tox. 4), H335 (Sys. Tox. Single Exp. Resp. 3), H315 (Skin Irr. 2), H319 (Eye Irr. 2)
Tetrachloroethene, CAS RN: 127-18-4	Carcinogenicity†, mutagenicity‡, reproductive toxicity‡, developmental toxicity†, endocrine activity‡, acute toxicity†, systemic toxicity (single dose)‡, systemic toxicity (repeat dose) †, neurotoxicity (single dose)‡, neurotoxicity (repeat dose)†, skin sensitization‡, respiratory sensitization‡, skin irritation†, eye irritation†, acute aquatic toxicity†, chronic aquatic toxicity†, persistence†	GreenScreen BM-1, SciveraLENS [Red]	Washington CHCC List, California Proposition 65 List (carcinogen); EU GHS—H351 (Carc. 2), H411 (Chron. Aq. Tox. 2)
Vinyl chloride, CAS RN: 75-01-4	Carcinogenicity†, mutagenicity†, reproductive toxicity‡, developmental toxicity‡, endocrine activity‡, systemic toxicity (repeat dose)†, neurotoxicity (single dose)‡, neurotoxicity (repeat dose)†, eye irritation‡, persistence†	GreenScreen® BM-1, SciveraLENS® [Red]	Washington CHCC List, California Proposition 65 List (carcinogen); EU GHS—H350 (Carc. 1A)

Common name, associated CAS(s)	Known or potential hazards	Referenced hazard assessments	Relevant authoritative listings
Triclosan, CAS RN: 3380-34-5	Reproductive toxicity‡, developmental toxicity‡, endocrine activity‡, systemic toxicity (single dose)†, systemic toxicity (repeat dose)‡, skin irritation†, eye irritation†, acute aquatic toxicity†, chronic aquatic toxicity†, persistence†, bioaccumulation†	GreenScreen BM-1, SciveraLENS [Red]	EU GHS—H315 (Skin Irr. 2), H319 (Eye Irr. 2), H400 (Acute Aq. 1), H410 (Chronic Aq. 1)
1,2-Dichloropropane, CAS RN: 78-87-5	Carcinogenicity†, mutagenicity‡, developmental toxicity‡, acute toxicity‡, systemic toxicity†, neurotoxicity‡, dermal sensitization†, dermal irritation†, eye irritation†, acute aquatic toxicity†, chronic aquatic toxicity‡	GreenScreen LT-1, SciveraLENS [Red]	California Proposition 65 List (carcinogen); EU GHS—H302 (Acute Tox. 4)
Carbon tetrachloride, CAS RN: 56-23-5	Carcinogenicity†, mutagenicity‡, developmental toxicity‡, acute toxicity†, systemic toxicity†, dermal sensitization‡, respiratory sensitization‡, dermal irritation‡, eye irritation†, acute aquatic toxicity‡, chronic aquatic toxicity‡, persistence†	GreenScreen® LT-1, SciveraLENS® [Red]	California Proposition 65 List (carcinogen); H351 (Carc. 2), H331 (Acute Tox. Inhal. 3), H311, H301 (Acute Tox. 3), H372 (Sys. Tox. Rep. 1), H412 (Chron. Aq. Tox. 3), H420 (Harms ozone layer)

Common name, associated CAS(s)	Known or potential hazards	Referenced hazard assessments	Relevant authoritative listings
Tetrachloroethane, CAS RN: 79-34-5	Carcinogenicity†, mutagenicity‡, reproductive toxicity‡, developmental toxicity‡, acute toxicity†, systemic toxicity†, neurotoxicity†, dermal irritation†, eye irritation†, acute aquatic toxicity†, chronic aquatic toxicity†, persistence†	GreenScreen LT-1, SciveraLENS [Red]	Washington CHCC List, California Proposition 65 List (carcinogen); H310, H330, H411 (Chron. Aq. Tox. 2)
Methylene chloride, CAS RN: 75-09-2	Carcinogenicity†, mutagenicity‡, developmental toxicity‡, endocrine activity‡, acute toxicity‡, systemic toxicity†, neurotoxicity‡, dermal irritation†, eye irritation†, acute aquatic toxicity‡	GreenScreen LT-1, SciveraLENS [Red]	Washington CHCC List, California Proposition 65 List (carcinogen); H351 (Carc. 2)
Trichloroethylene, CAS RN: 79-01-6	Carcinogenicity†, mutagenicity†, reproductive toxicity†, developmental toxicity†, endocrine activity‡, acute toxicity‡, systemic toxicity†, neurotoxicity‡, dermal sensitization†, respiratory sensitization‡, dermal irritation†, eye irritation†, acute aquatic toxicity‡, chronic aquatic toxicity† persistence†	GreenScreen® LT-1, SciveraLENS® [Red]	California Proposition 65 List (carcinogen, developmental toxicity, male reproductive toxicity); H350 (Carc. 1), H341 (Mut. 2), H336 (Sys. Tox. Narcotic 3), H315 (Skin Irr. 2), H319 (Eye Irr. 2), H412 (Chron. Aq. Tox. 3)

Common name, associated CAS(s)	Known or potential hazards	Referenced hazard assessments	Relevant authoritative listings
1,4-dichlorobenzene, CAS RN: 106-46-7	Carcinogenicity†, mutagenicity†, reproductive toxicity‡, developmental toxicity‡, endocrine activity†, dermal sensitization†, dermal irritation‡, eye irritation†, acute aquatic toxicity†, chronic aquatic toxicity†, persistence‡	GreenScreen LT-1, SciveraLENS [Red]	California Proposition 65 List (carcinogen); EU GHS—H351 (Carc. 2), H319 (Eye Irr. 2), H400 (Acute Aq. 1), H410 (Chronic Aq. 1)
Triadimefon, CAS RN: 43121-43-3	Carcinogenicity†, reproductive toxicity†, developmental toxicity†, endocrine activity‡, acute toxicity‡, dermal sensitization†, acute aquatic toxicity‡, chronic aquatic toxicity‡, persistence‡	GreenScree LT-1, SciveraLENS [Red]	California Proposition 65 List (developmental toxicity, female reproductive toxicity), EU GHS—H302 (Acute Tox. 4), H317 (Skin Sens. 1), H411 (Chronic Aq. 2)
1-Chloro-4-nitrobenzene, CAS RN: 100-00-5	Carcinogenicity†, mutagenicity†, reproductive toxicity‡, developmental toxicity‡, acute toxicity†, dermal irritation‡, eye irritation‡, acute aquatic toxicity†, chronic aquatic toxicity†, persistence‡	GreenScreen LT-1, SciveraLENS [Red]	California Proposition 65 List (carcinogen), EU GHS—H351 (Carc. 2), H341 (Muta. 2), H331, H311, H301 (Acute Tox. 3), H373 (Sys. Tox. Rep. Exp. 2), H411 (Chronic Aq. 2)
Folpet, CAS RN: 133-07-3	Carcinogenicity†, mutagenicity‡, developmental toxicity‡, endocrine activity‡, acute toxicity‡, systemic toxicity‡, dermal sensitization†, eye irritation†, acute aquatic toxicity†, chronic aquatic toxicity†, persistence†	GreenScreen® LT-1, SciveraLENS® [Red]	California Proposition 65 List (carcinogen), EU GHS—H351 (Carc. 2), H332 (Acute Tox. 4), H319 (Eye Irr. 2), H317 (Skin Sens. 1), H400 (Acute Aq. 1)

Common name, associated CAS(s)	Known or potential hazards	Referenced hazard assessments	Relevant authoritative listings
1-Hydroxy-2,3,4,5,6-pentachlorobenzene, CAS RN: 131-52-2	Carcinogenicity†, reproductive toxicity‡, developmental toxicity‡, acute toxicity†, dermal irritation†, eye irritation†, acute aquatic toxicity† persistence†, bioaccumulation‡	GreenScreen LT-1, SciveraLENS [Red]	US NIH Report on Carcinogens (Reasonably anticipated human carcinogen), UNEP Stockholm Conv. POP, EU GHS—H351 (Carc. 2), H330, H311, H301 (Acute Tox. 3), H335 (Sys. Tox. Single Exp. Resp. 3), H315 (Skin Irr. 2), H319 (Eye Irr. 2), H400 (Acute Aq. 1), H410 (Chronic Aq. 1)
1-chloroethane, CAS RN: 75-00-3	Carcinogenicity†, mutagenicity†, systemic toxicity†, neurotoxicity‡, dermal irritation†, eye irritation†, acute aquatic toxicity‡	GreenScreen LT-1, SciveraLENS [Red]	California Proposition 65 List (carcinogen), EU GHS—H351 (Carc. 2), H412 (Chronic Aq. 3)
Epichlorohydrin, CAS RN: 106-89-8	Carcinogenicity†, mutagenicity†, reproductive toxicity†, developmental toxicity‡, endocrine activity†, acute toxicity†, systemic toxicity†, dermal sensitization†, respiratory sensitization†, dermal irritation†, eye irritation†, acute aquatic toxicity‡, chronic aquatic toxicity‡	GreenScreen® LT-1, SciveraLENS® [Red]	California Proposition 65 List (carcinogen, male reproductive toxicity), MAK (Skin Sens.), EU GHS—H350 (Carc. 1B), H331, H311, H301 (Acute Tox. 3), H314 (Skin Corr. 1B), H317 (Skin Sens. 1)
Hexachlorobutadiene, CAS RN: 87-68-3	Carcinogenicity†, mutagenicity‡, endocrine activity‡, acute toxicity†, dermal sensitization†, acute aquatic toxicity†, chronic aquatic toxicity†, persistence†, bioaccumulation‡	GreenScreen LT-1, SciveraLENS [Red]	Washington CHCC List, California Proposition 65 List (carcinogen), EU—ESIS PBT, POP

Common name, associated CAS(s)	Known or potential hazards	Referenced hazard assessments	Relevant authoritative listings
4-chloroaniline, CAS RN: 106-47-8	Carcinogenicity†, mutagenicity‡, reproductive toxicity‡, developmental toxicity‡, endocrine activity‡, acute toxicity†, systemic toxicity†, dermal sensitization†, eye irritation‡, acute aquatic toxicity†, chronic aquatic toxicity†, persistence†	GreenScreen LT-1, SciveraLENS [Red]	Washington CHCC List, California Proposition 65 List (carcinogen), MAK (Skin Sens.), EU GHS—H350 (Carc. 1B), H331, H311, H301 (Acute Tox. 3), H317 (Skin Sens. 1), H400 (Acute Aq. 1), H410 (Chronic Aq. 1)
Hexachlorobenzene, CAS RN: 118-74-1	Carcinogenicity†, reproductive toxicity†, developmental toxicity†, endocrine activity†, acute toxicity†, systemic toxicity†, neurotoxicity†, dermal sensitization‡, acute aquatic toxicity†, chronic aquatic toxicity†, persistence†, bioaccumulation†	GreenScreen® LT-1, SciveraLENS® [Red]	Washington CHCC List, California Proposition 65 List (carcinogen, developmental toxicity), U.S. EPA—Priority PBT, EU GHS – H350 (Carc. 1B), H372 (Sys. Tox. Rep. 1), H400 (Acute Aq. 1), H410 (Chronic Aq. 1)
trans-1,2-dichloroethylene, CAS RN: 156-60-5	Carcinogenicity‡, mutagenicity‡, endocrine activity‡, acute toxicity‡, systemic toxicity†, neurotoxicity‡, dermal sensitization‡, dermal irritation‡, eye irritation†, acute aquatic toxicity‡, chronic aquatic toxicity‡, persistence†	SciveraLENS [Red]	EU GHS—H332 (Acute Tox. 4), H412 (Chronic Aq. 3)
2-chlorotoluene, CAS RN: 95-49-8	Carcinogenicity‡, reproductive toxicity‡, acute toxicity‡, systemic toxicity‡, neurotoxicity‡, dermal irritation‡, eye irritation‡, acute aquatic toxicity†, chronic aquatic toxicity†, persistence†	SciveraLENS [Red]	EU GHS—H312, H302 (Acute Tox. 4), H411 (Chronic Aq. 2)

Common name, associated CAS(s)	Known or potential hazards	Referenced hazard assessments	Relevant authoritative listings
Methylchloroisothiazolinone, CAS RN: 26172-55-4	Developmental toxicity‡, acute toxicity†, systemic toxicity‡, dermal sensitization†, dermal irritation†, eye irritation†, acute aquatic toxicity†, chronic aquatic toxicity†, persistence‡	SciveraLENS [Yellow]	NA
4,4'-[(3,3'-dichlorobiphenyl-4,4'-diyl)didiazene-2,1-diyl]bis(5-methyl-2-phenyl-2,4-dihydro-3H-pyrazol-3-one), CAS RN: 3520-72-7	Developmental toxicity‡, reproductive toxicity‡, dermal irritation‡, eye irritation‡, chronic aquatic toxicity‡, persistence†	SciveraLENS® [Yellow]	NA
Carbazole Violet, CAS RN: 6358-30-1	Carcinogenicity‡, reproductive toxicity‡, developmental toxicity‡, eye irritation‡, chronic aquatic toxicity‡, persistence†	SciveraLENS [Yellow]	NA
Methylchloroform, CAS RN: 71-55-6	Carcinogenicity†, acute toxicity†	GreenScreen® LT-1	IARC (Carc. 2A); EU GHS—H332 (Acute Tox. 4), H420 (Harms ozone layer)
Pentachlorobenzene, CAS RN: 608-93-5	Acute toxicity†, acute aquatic toxicity†, persistence†, bioaccumulation†	GreenScreen LT-1	Washington CHCC List, US EPA Priority PBT, EU GHS—H302 (Acute Tox. 4), H400 (Acute Aq. 1), H410 (Chronic Aq. 1)

† Endpoints scored as high or very high in referenced hazard assessments

‡ Endpoints scored as moderate in referenced hazard assessments

Potential exposures to people and the environment

The class of organobromine and/or organochlorine chemicals is large. The chemicals in this class serve a variety of functions in products consumers can encounter. Rather than attempt to provide detailed exposure information for each chemical in the class, we looked for overall patterns and identified disproportionate exposures for some chemicals, to illustrate the complexities of the class.

Much of the available exposure data focuses on chemicals with lower current use patterns. However, because of the persistence and bioaccumulation potential of many chemicals within this class, exposures still have the potential to contribute to adverse impacts in sensitive populations and species. Newer chemicals in the class that are more commonly used today share hazards and environmental fate and transport concerns, though they are less commonly measured in people and the environment. The exposure patterns identified here highlight the potential for people and wildlife to be exposed to organobromine and/or organochlorine substances. It is non-exhaustive but illustrative of how chemicals in this class have the potential for exposure.

Human exposure

People are exposed to organobromine and/or organochlorine substances through multiple routes, including inhalation, contaminated drinking water, house dust, and direct interaction with consumer products. Our 2020 Priority Consumer Products Report to the Legislature[111] discusses human exposure to PCBs and organobromine and/or organochlorine flame retardants (Ecology, 2020b).

Indoor air at home is a significant source of exposure to volatile organochlorine chemicals. A study in 126 Detroit homes of asthmatic children found that 1,4-dichlorobenzene, chloroform, 1,2-dichloroethane, tetrachloroethene, and trichloroethylene were found in some homes at levels that exceeded health guidance values (Chin et al., 2014). Less volatile organobromine and/or organochlorine substances have been detected in house dust (Ecology, 2020b; Mitro et al., 2016; Niu et al., 2019). There is often an association between children's exposures to organobromine and/or organochlorine substances and concentrations in house dust (Ecology, 2020b; Sahlström et al., 2015; Y. Zeng et al., 2020).

Personal care products can also result in exposure to organochlorine substances in the home. Lindane was formerly a front-line treatment for lice, until it was found to be neurotoxic. Lindane is now a prescription-only, second-line lice treatment, but one of the substitute active ingredients in lice treatments is another organochlorine pesticide, permethrin. The anti-bacterial compound triclosan is banned in the United States for use in hand soaps, but exposure through products like toothpaste and mouthwash remain (CDC, n.d.-a).

Levels of organobromine and/or organochlorine solvents in blood reflect recent exposure over the preceding few days. The National Health and Nutrition Examination Survey (NHANES) is a population-based study conducted by the Centers for Disease Control (CDC). NHANES includes 14 organobromine and/or organochlorine solvents in the survey, but most are infrequently detected above the limit of detection in most people (CDC, n.d.-a). There were generally not enough detections in NHANES surveys to calculate average levels or percentiles, except for higher levels of tetrachloroethene. Levels of these volatile organic compounds are usually measured in air, to assess people's exposures.

NHANES does not include biomonitoring for vinyl chloride, but people living near production facilities, hazardous waste disposal sites, and landfills may be exposed to higher levels of vinyl chloride in the air. Higher concentrations have been measured in the air above landfills and hazardous waste sites (ATSDR, 2006; IARC, 2012b). Also, workers at vinyl production facilities

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[111] apps.ecology.wa.gov/publications/summarypages/2004019.html

and those who weld PVC pipes are exposed to higher levels (ATSDR, 2006; IARC, 2012b). Due to the identification of a rare liver cancer in vinyl chloride workers, the Occupational Safety and Health Administration (OSHA) lowered the allowable exposure limits. This led to the development of a closed-loop production system that has reduced exposures (CDC, 1997). There are also historical reports of hairdressers and barbers, who were exposed to vinyl chloride propellent, with the same rare liver cancer (Infante et al., 2009).

People who use organobromine and/or organochlorine solvents at work may have higher exposure levels. As an example, methylene chloride was included in the Washington State Department of Labor & Industries surveillance of toxic inhalation in state workers' compensation claims from 2017 to 2020. Levels of methylene chloride are not included in the report, but two cases of methylene chloride exposure were observed in workers cleaning print screens in the commercial screen-printing industry (LNI, 2021).

An analysis of racial disparities in chemical exposure, based on NHANES data from 1999 to 2014 for U.S. women, reported significant differences in exposure levels to several chemicals, including some organobromine and/or organochlorine substances (Nguyen et al., 2020). Blood and urinary levels of 1,4 dichlorobenzene, a chemical used in mothballs and as deodorizer in bathrooms, were several times higher in women of color compared to White women. Black women were the most highly exposed. Bromodichloromethane, a by-product of drinking water disinfection, showed a similar pattern of racial disparity, although the differences were not as pronounced. We did not find a comparable study of men or children that identifies different organobromine and/or organochlorine substances with racial disparity in exposure.

Environmental exposure

Organobromine and/or organochlorine substances are commonly detected in the environment, including in Washington State. Many of these are examples of chemicals that have already been the subject of past regulations restricting their use, such as some organochlorine pesticides, PCBs, and PBDEs. We summarized some of this information in our previous priority products report, in sections focused on organohalogen flame retardants used in electric and electronic enclosures and inadvertent PCBs found as contaminants in paints and printing inks (Ecology, 2020b). Some other examples of organobromine and/or organochlorine substances detected in the environment are from current use or are environmental transformation products of chemicals in use. This includes organobromine and/or organochlorine substances used as solvents, antimicrobials, pharmaceuticals, and pesticides.

A 2006 survey conducted by the National Water-Quality Assessment Program summarized analyses of approximately 3,500 water samples collected nationally for VOCs. In the survey, 13 of the 15 most commonly detected VOCs were organobromine and/or organochlorine substances: chloroform, tetrachloroethene, trichloroethene, dichlorodifluoromethane, 1,1,1-trichloroethane, chloromethane, bromodichloromethane, trichlorofluoromethane, bromoform, dibromochloromethane, trans-1,2-dichloroethene, methylene chloride, and 1,1-dichloroethane (USGS, 2006). In addition, the report noted that several organobromine and/or organochlorine substances were found at concentrations of potential human-health concern, including trichloroethene, dibromochloropropane, tetrachloroethene, 1,1-dichloroethene, 1,2-dichloropropane, ethylene dibromide, methylene chloride, and vinyl chloride (USGS, 2006).

Some of these chemicals, such as trihalomethanes, are formed as a result of chlorination of drinking water. Others are examples of synthetic organobromine and/or organochlorine substances used in industry and commerce.

In 2008, Ecology conducted a study to characterize chemicals associated with pharmaceuticals and personal care products at five wastewater treatment plants in the Pacific Northwest. The study documented the presence of several organochlorine substances in wastewater treatment plant influent and effluent, including triclosan, triclocarban, and tris(2-chloroethyl) phosphate (Ecology et al., 2010).

A study of chemicals of emerging concern also reported several organochlorine substances measured in tissues from chinook salmon (*Oncorhynchus tshawytscha*) and staghorn sculpin (*Leptocottus armatus*) from Puget Sound. The authors found triclosan and triclocarban (organochlorine antimicrobials) in salmon tissue (Meador et al., 2016).

Several organochlorine substances were also detected in a contaminant screening study conducted in the nearshore marine environment in Puget Sound. These included two organochlorine flame retardants (tris(1-chloro-propyl) phosphate and tris(2-chloroethyl) phosphate)) (Tian et al., 2020).

Organobromine and/or organochlorine substances from both current and legacy uses have also been measured in forage fish from Puget Sound, including in Pacific sand lance (*Ammodytes personatus*) (Conn et al., 2020). This includes organochlorine pesticides (DDTs, chlordanes, dieldrin, hexachlorobenzene, and hexachlorocyclohexane), PCBs, PBDEs, and chlorinated paraffins. Although many of these compounds are no longer widely used, their continued presence in fish demonstrates the persistence of these substances in the environment. Further, many of these compounds are known to biomagnify. Their presence in forage fish highlights this because they serve as prey sources for many species, including seabirds, other fish, and marine mammals (Conn et al., 2020).

King County also recently published a report on chemicals of emerging concern in marine and freshwater fish[112] and found triclosan and methyl triclosan (organochlorine antimicrobial and associated metabolite) in rockfish (*Sebastes auriculatus* and *S. maliger*) from Elliot Bay (King County Department of Natural Resources and Parks, 2022). The same study also reported detections of methyl triclosan in smallmouth bass (*Micropterus dolomieu*) from Lake Union.

Monitoring of ambient air by the Puget Sound Clear Air Agency from 2008 to 2009 found that concentrations of carbon tetrachloride, chloroform, and tetrachloroethene exceeded health screening levels at sites in Tacoma and Seattle (Puget Sound Clean Air Agency, 2011). Carbon tetrachloride was found to contribute the greatest increased potential cancer risk of the air pollutants measured in the study, while chloroform and tetrachloroethene were the seventh and eighth greatest contributors, respectively (excluding diesel exhaust and wood smoke particulate).

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[112] your.kingcounty.gov/dnrp/library/2022/kcr3347.pdf

A 2018 study of ambient air in Seattle's Chinatown-International District reported measurements of carbon tetrachloride, chloroform, 1,2-dichloroethane, and tetrachloroethene that exceed health screening levels (Puget Sound Clean Air Agency, 2018).

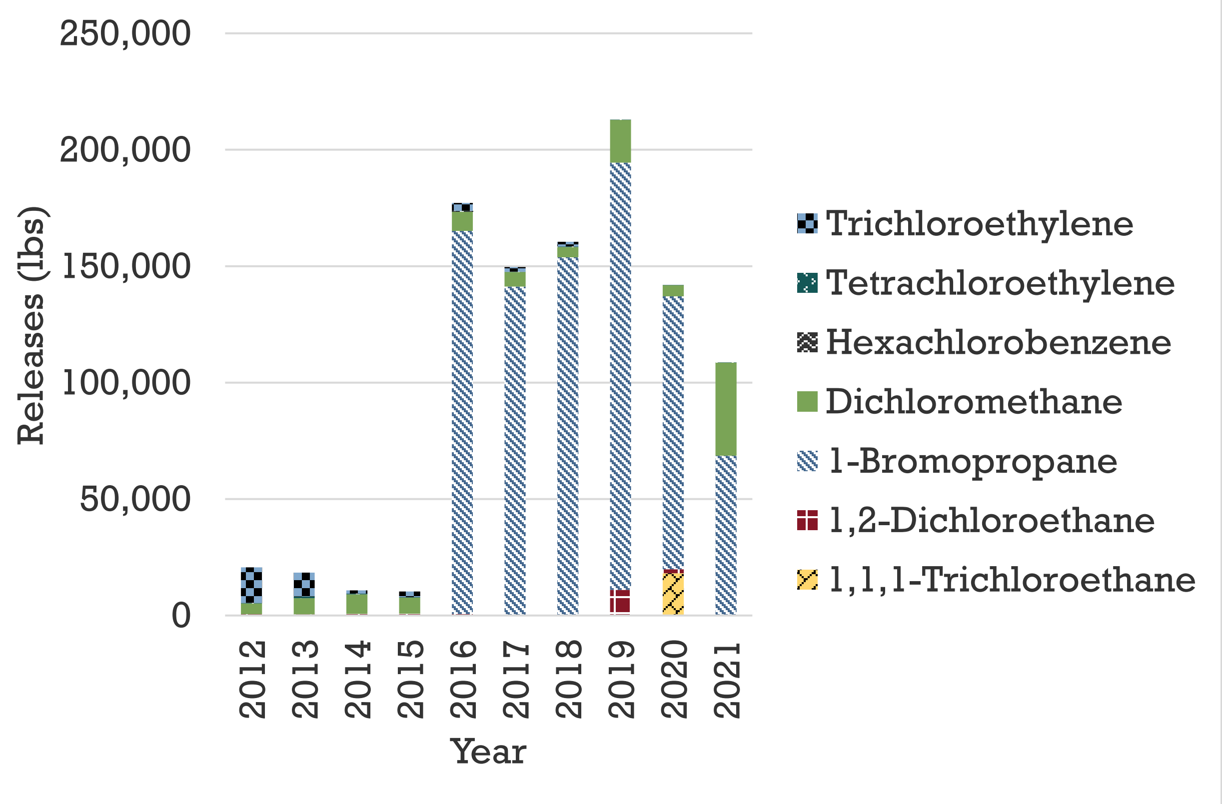
Ecology tracks cleanup sites in Washington State, and there are 2,465 sites with one of the following listed as a contaminant: halogenated organics, halogenated solvents, halogenated pesticides, other halogenated organics, PBDE, or PCBs; of these, only 937 sites are listed as requiring no further action (Ecology, n.d.-a).

Releases of organobromine and/or organochlorine substances have also been reported in the EPA Toxics Release Inventory (TRI) for Washington State, from 2012 to 2021 (Table 14 and Figure 3) (EPA, n.d.-f). The TRI summarizes releases of toxic chemicals from industrial facilities to air, water, and land. Table 14 and Figure 3 show chemicals from Table 13 that had releases reported in the TRI for Washington State. It should be noted that reporting 1-bromopropane was not required prior to November 2015, when EPA published a final rule that added 1-bromopropane to the list of reportable chemicals in the TRI. This is the reason for the apparent increase seen from 2016 onward (Figure 3) (EPA, n.d.-a).

Table 14. Toxics Release Inventory data for Washington State between 2012 and 2021 for some organobromine and/or organochlorine substances.

Chemical	Total Releases (lbs)
1-bromopropane	828,743
dichloromethane	108,882
trichloroethylene	36,587
1,1,1-trichloroethane	18,483
1,2-dichloroethane	15,713
tetrachloroethylene	2,513
hexachlorobenzene	128

Figure 3. Pounds of releases reported in Washington between 2012 and 2021 for some organobromine and/or organochlorine substances.



Potential for cumulative and aggregate effects

Exposure to chemicals can result in aggregate effects and cumulative effects. Aggregate effects can occur when people or other organisms are exposed to a single chemical from multiple routes, pathways, and sources (*e.g.*, house dust, drinking water, air, and food). Cumulative effects can occur when people or other organisms are exposed to multiple chemicals simultaneously. These cumulative exposures may come from multiple exposure routes, pathways, and sources, or just a single source.

Potential for aggregate effects

Organobromine and/or organochlorine substances are used in consumer products inside homes and can be released into outdoor environments from industrial activities, waste treatments, and disposal (CDC, n.d.-a; Environment Canada, 2016; Fay & Mumtaz, 1996; Matteucci et al., 2015; Squillace et al., 1999; H. Zhang et al., 2019). Many of these substances are volatile, so contaminants in subsurface soils and groundwaters can vaporize into the indoor spaces of overlying buildings to contaminate indoor air. People can be exposed to organobromine and/or organochlorine substances from multiple exposure routes, including drinking water, direct interactions with consumer products, indoor and outdoor air, and house dust (Chin et al., 2014; Weng et al., 2023; Zhu et al., 2023).

Organobromine and/or organochlorine substances are widely detected in the environment. Solvents often break down in surface water and air but are frequently detected in soil and groundwater (Environment Canada, 2016; Moran et al., 2007; USGS, 2006). Other organobromine and/or organochlorine substances can be found in water, sediment or soil, and wildlife (Harrad et al., 2009; Isosaari et al., 2000; Jans, 2016; R. Yang et al., 2012). Some are mobile and can contaminate areas of the globe far from where they were initially released. Because of the carbon-halogen bond, most organobromine and/or organochlorine solvents are persistent in the environment. This means that people and wildlife, including sensitive populations and species, can be exposed to organobromine and/or organochlorine substances from multiple sources and can experience aggregate effects.

Based on the evidence described above we concluded that people and wildlife are exposed to organobromine and/or organochlorine substances from multiple sources. Exposure to organobromine and/or organochlorine substances from multiple sources can lead to aggregate effects.

Potential for cumulative effects

Evidence from laboratory studies of animal models suggest that exposure to chemicals at sub-toxic levels can still produce adverse effects, especially when combined with other low-level chemical exposures.

The most well studied targets of organobromine and/or organochlorine solvents for potential cumulative effects include the central nervous system, kidney, and liver. For example, co-exposure to methylene chloride and ethanol aggravated oxidative stress-induced kidney and liver damage in rats (Owumi & Najophe, 2019). Similarly, exposure to 1,2-dichloropropane and methylene chloride was associated with enhanced liver damage, compared to exposure to just 1,2-dichloropropane (H. Wang et al., 2019). When rats were treated with carbon tetrachloride and the hepatoxic organochlorine pesticide chlordane, liver damage was more severe than exposure to chlordane alone (Tabet et al., 2016). In rats exposed to a mixture of 13 common environmental chemicals, including cytotoxic, histopathological, and the organochlorine fungicide triadimefon, changes in several organs were observed at exposure levels below the levels at which adverse effects are seen with exposure to the chemicals individually (Dinca et al., 2023; Tsatsakis et al., 2019).

This aligns with modeled data suggesting risks from co-exposure to multiple chemicals may be higher than exposure to single chemicals. A review of hexachlorobutediene (HBCD) in the environment found the potential for exposure to occur along with other organochlorine contaminants. The study concluded that, although risks from low-level exposure to HCBD were generally low, the risks from cumulative exposures to HCBD and other pollutants may be higher (H. Zhang et al., 2019).

People are co-exposed to multiple organobromine and/or organochlorine substances and other chemicals that can impact similar biological systems. Residential indoor air can contain a mixture of organochlorine compounds (Chin et al., 2014), as can outdoor air (discussed above). Drinking water contamination, some personal care products, and pesticide exposure can contribute to multi-route exposure to complex mixtures of organobromine and organochlorine substances.

Most epidemiological studies of the human health effects of organobromine and/or organochlorine substances are not designed to consider the cumulative impact of exposure to mixtures. A study of women in France reported that exposure to a mixture of perchloroethylene, trichloroethylene, and dichloroethylene was associated with elevated odds of lung cancer, with modification of the association by socioeconomic status (Mattei et al., 2014).

In the environment, wildlife is exposed to organobromine and/or organochlorine substances in addition to other chemicals that can impact similar biological systems. An analysis of 201 contaminants in eggs from three seabird species found PCBs, organophosphorus compounds, pesticides, and PFAS were the most abundant organic contaminants. PBDEs, PCBs, organobromine flame retardants, bromophenols, and chlorinated paraffins have co-occurred in eggs, along with PAHs, PFAS, and cyclic siloxanes among others (Huber et al., 2015). Many of the chemicals within these classes are associated with carcinogenicity, reproductive or developmental toxicity, endocrine disruption, or aquatic toxicity.

A review of hazardous waste sites found that trichloroethylene was the most common groundwater contaminant and that co-contamination with tetrachloroethylene was common (Fay & Mumtaz, 1996; Pohl et al., 2008). A different review of methylene chloride, perchloroethene, 1,1,1-trichloroethane, and trichloroethene in groundwater found that mixtures occurred in about 30% of samples with at least one solvent detected (Moran et al., 2007).

The Agency for Toxic Substances and Disease Registry (ATSDR) published an interaction profile for 1,1,1-Trichloroethane, 1,1-dichloroethane, trichloroethylene, and tetrachloroethylene. These chemicals frequently co-occur in the environment, especially at cleanup sites, and can impact similar biological pathways (ATSDR, 2004a). The CDC concluded that additive effects from exposure to multiple solvents is possible (ATSDR, 2004a).

We concluded that there was the potential for cumulative impacts because people and wildlife are exposed to multiple organobromine and/or organochlorine substances in combination with other environmental chemicals. These co-exposures can lead to cumulative effects, particularly when they impact similar biological systems.

Potential to contribute to adverse impacts

Organobromine and/or organochlorine substances are a large class of chemicals with varying levels of information on hazards and exposure. However, several chemicals within the class have been identified as problematic by authoritative bodies (Table 13). EPA has found unreasonable risk associated with multiple organobromine and/or organochlorine solvents (EPA, 2023a). As of March 2023, 10 organobromine and organochlorine solvents are on EPA's high priority chemical list. Of these ten, five have findings of reasonable risk, either draft or final (EPA, 2023a). EPA's conclusions reflect the potential for organobromine and/or organochlorine solvents to contribute to adverse impacts in sensitive populations and species.

In Washington, there are 640 contaminated sites with halogenated solvents listed as a contaminant; of these sites, only 147 are listed as requiring no further action (Ecology, n.d.-a).

Contamination from halogenated solvents at these sites has the potential to contribute to adverse impacts on people and the environment.

Below, we describe examples of observed and potential impacts on sensitive populations and species.

In sensitive populations

When people are exposed to chemicals with known or suspected toxicities, there is the potential for adverse impacts. The impacts may be greater when people are also exposed to other environmental contaminants that impact the same biological systems.

People, including sensitive populations, are exposed to organobromine and/or organochlorine substances. Exposure to organobromine and/or organochlorine substances is associated with carcinogenicity, reproductive and developmental toxicity, neurotoxicity, and systemic toxicity. Therefore, organobromine and/or organochlorine substances have the potential to contribute to adverse impacts in humans, including sensitive populations such as the elderly, workers, people of childbearing age, developing fetuses, and children. Examples of studies demonstrating associations between exposure to organobromine and/or organochlorine substances and adverse health impacts are described below.

People who were exposed to vinyl chloride from an accidental release after a train accident in Schönebeck, Germany, were found to have higher rates of chromosomal aberrations, which is a marker for genotoxic effects (Hüttner, 1998).

A series of papers that assessed exposure to 1,4-dichlorobenzene and outcomes associated with endocrine disruption in NHANES participants found some evidence that the 25% of people with highest exposure had higher odds of diabetes, insulin resistance, and metabolic syndrome (Wei et al., 2014; Wei & Zhu, 2016a, 2016c). In adolescents, a possible association between exposure and disruption of thyroid function was noted (Wei & Zhu, 2016b). A study of Dutch adolescents also reported thyroid changes in association with higher levels of 1,4-dichlorobenzene exposure (Croes et al., 2015). None of these observational studies demonstrate a causal relationship, but the pattern of findings suggests that disproportionate exposure to 1,4-dichlorobenzene in the population could lead to disproportionate health impacts.

Pregnant women are a sensitive population, and exposure to organochlorine chemicals has potential for developmental toxicity. A group of data analyses from the National Birth Defects Prevention Study found that the offspring of women who worked in occupations with likely exposure to organochlorine solvents may be at elevated risk of fetal growth retardation, neural tube defects, and congenital heart defects (Desrosiers et al., 2012, 2015; Gilboa et al., 2012). A recent French study reported related findings, with reduced head circumference in newborns of women with likely occupational exposure to organochlorine solvents (Enderle et al., 2023). Pregnant people and their developing fetuses could potentially experience these impacts in the absence of occupational exposure and are therefore a sensitive population of concern.

Organochlorine solvent exposure in occupational settings is associated with neurotoxicity (Sainio, 2015; White & Proctor, 1997). The organobromine solvent 1-bromopropane has been associated with neurotoxicity in workers with occupational exposure. Biomonitoring data suggest that women of non-White races have higher exposures to this chemical and may therefore be at greater risk of harm (Nguyen et al., 2020). The sources and potential consequences of this exposure are not currently known. EPA identified spray adhesives, spot remover, engine degreaser, brake cleaner, and electronics cleaner as key consumer exposure scenarios. In addition, a small sample of hairdressers working in salons that serve primarily women of color found exposure to 1-bromopropane was four times higher than in a comparison group of office workers (Louis et al., 2021).

Many chemicals in the class have the potential to cause cancer (see Hazards of Priority Chemical Class above). Evidence from studies of people exposed in the workplace has linked organochlorine chemicals to several different cancers, including non-Hodgkin's lymphoma, multiple myeloma, kidney, and head and neck cancer (Barul et al., 2017; Callahan et al., 2018; Gold et al., 2011; Purdue et al., 2017; R. Wang, Zhang, et al., 2009). Various epidemiologic studies of chronic tetrachloroethene exposure in dry cleaning workers found increased incidences of esophageal and cervical cancers and non-Hodgkin's lymphoma, but confounding exposures (*e.g.*, other solvents and trichloroethene) were likely (IPCS, 2006). Workers are a sensitive population that may be more likely to experience adverse impacts, including developmental toxicity, neurotoxicity, and cancer, from exposure to organobromine and/or organochlorine substances.

In sensitive species

When chemicals are released into the environment, they have the potential to expose sensitive species, such as forage fish, salmon, or orcas. If these chemicals have aquatic toxicity, reproductive or developmental toxicity, systemic toxicity, or endocrine disruption, there is potential to contribute to adverse impacts in sensitive populations.

Organobromine and/or organochlorine substances are released into the environment and have been detected in multiple environmental media. Sensitive species are exposed to organobromine and/or organochlorine solvents in the environment. Many organobromine and/or organochlorine substances have known or suspected toxicities that can impact wildlife, such as aquatic toxicity, carcinogenicity, and reproductive and developmental toxicity.

Organobromine and/or organochlorine substances are a broad class of chemicals. Not all have sufficient data to understand the potential for adverse impacts in sensitive species. Examples of organobromine and/or organochlorine substances that have the potential to impact sensitive species are described below.

In 2020, EPA concluded that tetrachloroethylene poses a hazard to aquatic receptors, including aquatic invertebrates, fish, amphibians, and aquatic plants (EPA, 2020). EPA also concluded that there was "a chronic risk to aquatic organisms from release of PCE [perchloroethylene] to surface waters from facilities using PCE for the COUs [condition of use] listed above"—these were "Manufacturing, Importing/Repackaging, Open-Top Vapor Degreasing, Closed-Loop Vapor Degreasing, Conveyorized Degreasing, Web Degreasing, Dry Cleaning (Industrial and Commercial), Adhesives, Paints, and Coatings, Maskants for Chemical Milling, Industrial

Processing Aid, Other Industrial Uses, Other Commercial Uses COUs, and Waste Handling, Disposal, Treatment, and Recycling." (EPA, 2020).

A risk assessment ranking potential environmental risks from solvents found that organochlorine solvents had among the highest environmental risks (Tobiszewski et al., 2017). Hexachlorobutadiene, trichloroethene, carbon tetrachloride, tetrachloroethene, dichloroform, 1,3-dichloropropene, 1,2-dichloroethane, and methylene chloride had among the highest environmental risk potential of 78 solvents assessed.

These risk assessments align with studies of the impacts of organochlorine solvent contamination on wildlife. A study on four species of North American amphibians found that exposure to both tetrachloroethylene and trichloroethylene was associated with developmental deformities in two amphibian species (Kim et al., 2021; McDaniel et al., 2004).

In addition to solvents, other types of organobromine and/or organochlorine substances can have adverse impacts on wildlife. Triclosan is associated with behavioral changes in guppies (*Poecilia reticulata) that could cause a fish population decline at sublethal levels (D. C. V. R. Silva et al., 2017). Another study found that triclosan and triclocarban were associated with olfactory disruption in goldfish (L. Huang et al., 2023). Olfactory disruption can be particularly problematic for species like salmon that rely on olfaction to complete their lifecycle. PBDEs exposure is associated with impacts on salmon health, specifically the thyroid and immune system (Arkoosh et al., 2010, 2017).*

Chapter 5: Technical Support for BTEX Substances

Chapter overview

Benzene, toluene, ethylbenzene, and xylenes (BTEX) are volatile organic compounds that are often used as solvents. They have multiple shared hazards, including impacts on carcinogenicity, the central nervous systems, developmental toxicity, and endocrine disruption. People and wildlife are often exposed to multiple BTEX substances, which can lead to cumulative impacts.

BTEX substances were selected as a priority chemical class for this cycle of Safer Products for Washington because exposures can lead to adverse developmental impacts and impair brain function. There is widespread exposure to BTEX substances, however people working in certain professions may have higher exposure. People in occupations where BTEX are used as degreasers, paint thinners, brush cleaners, adhesives, inks, and coatings may have higher exposure. People in working in construction, auto shops, or in nail salons may have higher exposure to BTEX substances. These occupational trends can lead to disproportionate exposures by race, ethnicity, or income. Nationwide, about 80% of nail salon workers are Asian-American women.

BTEX substances meet the high priority chemical criteria because at least one member of the class is:

1. A high priority chemical of high concern to children identified by Ecology under Chapter 70A.430 RCW.[113]
2. Considered a hazardous substance in Washington.
3. A concern for sensitive species and populations.

There have been many efforts to reduce occupational exposures to toxic chemicals, particularly in nail salon workers in King County. There may be the potential to extend some of the benefits and lessons learned from this work to protect more Washingtonians and reduce disproportionate exposures. Further, BTEX substances may be regrettable substitutions for organobromine and/or organochlorine substances used as solvents.

Rationale and references are described below.

Scope of priority chemical class

Benzene, toluene, ethylbenzene, and xylenes are a set of volatile organic compounds that are collectively known as BTEX. BTEX can be defined as a chemical class based on similarity in structure, physicochemical properties, and hazards to biological systems. BTEX are also commonly measured together in analytical methods.

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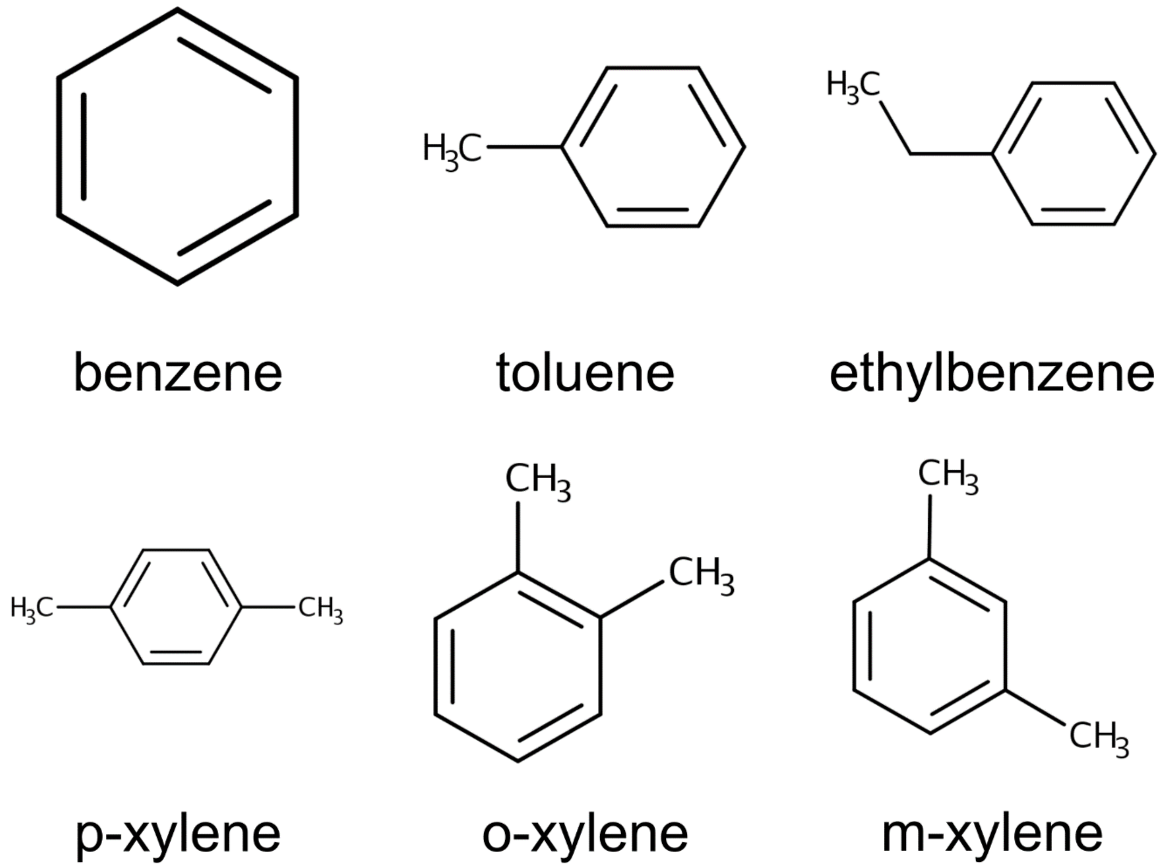
[113] app.leg.wa.gov/rcw/default.aspx?cite=70A.430

Based on chemical structure, BTEX can be defined as a six-membered aromatic ring containing up to a single ethyl substituent, or up to two methyl substituents (Figure 4).

Figure 4. Molecular structures for BTEX substances.



Rationale for class approach

BTEX substances are considered as a class because they have shared hazards, the potential for cumulative impacts, and the potential for regrettable substitutions. BTEX are a natural component of crude oil and are isolated for use in manufacture of a variety of products and as additives in gasoline (Bolden et al., 2015). BTEX impact the central nervous systems and are associated with reproductive and developmental toxicity. People and wildlife are often exposed to multiple BTEX substances, which can lead to cumulative impacts. The Agency for Toxic Substances and Disease Registry (ATSDR) found that exposure to multiple BTEX substances can lead to more severe impacts on the central nervous system (ATSDR, 2004b). Similarly, because people are more susceptible to chemical impacts during early life stages (Heindel & Vandenberg, 2015), the impacts of BTEX substances on development are concerning. BTEX substances often function as solvents. Because they have a shared function, there is the potential for regrettable substitutions to occur (EPA, 2022b). If manufacturers were to move from benzene to toluene, for example, that would be a regrettable substitution, since both chemicals have undesirable hazards.

Meeting the statutory requirements

The statute requires that priority chemicals or chemical classes meet specific criteria. Priority chemical classes must meet at least one of the criteria described in RCW 70A.350.020[114] and listed below.

- A member of the chemical class has been identified by Ecology as a chemical of concern, specifically:
    - A chemical of high concern to children under Chapter 70A.430 RCW[115] or
    - A persistent, bioaccumulative and toxic chemical under Chapter 70A.300 RCW.[116]
- A member of the chemical class is regulated in relevant consumer product statutes in Washington.
- A member of the chemical class is a hazardous substance under Chapter 70A.300 RCW or Chapter 70A.305 RCW.[117]
- Members of the chemical class are a concern for sensitive populations and sensitive species.

BTEX substances meet at least one of the criteria to be considered priority chemicals. Each of the criteria are discussed below.

Chemicals of concern by Ecology

Chemical classes with members that are chemicals of high concern to children (CHCC) identified under Chapter 70A.430 RCW meet the criteria for designation as priority chemical class under RCW 70A.350.020(1)(a). Ecology identifies chemicals of high concern to children based on their hazards and exposure potential in Chapter 173-334 WAC.[118] Chemicals in the class found in Chapter 173-334 WAC are listed in Table 15. To review the rationale for CHCC listing, please refer to the Rationale for Reporting List of Chemicals of High Concern to Children 2011 to 2017 (Ecology, 2021b).

Table 15. BTEX substances that are chemicals of high concern to children.

Chemical	CAS RN
Benzene	71-43-2
Toluene	108-88-3

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[114] app.leg.wa.gov/rcw/default.aspx?cite=70A.350.020
[115] app.leg.wa.gov/rcw/default.aspx?cite=70A.430
[116] app.leg.wa.gov/rcw/default.aspx?cite=70A.300
[117] app.leg.wa.gov/rcw/default.aspx?cite=70A.305
[118] apps.leg.wa.gov/wac/default.aspx?cite=173-334

Chemical classes with members identified as persistent bioaccumulative toxic substances (PBTs) under Chapter 70A.300 RCW[119] meet the criteria for designation as a priority chemical class under RCW 70A.350.020(1)(b).[120] Ecology identifies chemicals that are persistent, bioaccumulative, and toxic under WAC 173-333-310.[121] BTEX substances are not on the PBT list in WAC 173-333-310.

Regulation in consumer products under relevant WA statutes

Chemical classes with members regulated in consumer products under Chapters 70A.430,[122] 70A.405,[123] 70A.222,[124] 70A.335,[125] 70A.230,[126] or 70A.400 RCW[127] meet the criteria for designation as a priority chemical class under RCW 70A.350.020(2)(a). BTEX substances are not regulated in consumer products under relevant Washington statutes.

Hazardous substances in Washington

Under Chapter 70A.350 RCW,[128] chemical classes with members that are hazardous substances under Chapter 70A.300 RCW (Hazardous Waste Management Act) or Chapter 70A.305 RCW[129] (Model Toxics Control Act) can be considered priority chemicals under Chapter 70A.350 RCW. BTEX substances are considered hazardous substances under these statutes and therefore meet the criteria for designation as a priority chemical class under Chapter 70A.350 RCW.

Hazardous substances are defined in RCW 70A.300.010[130] to include any material that exhibits any of the characteristics or criteria of dangerous wastes identified under Chapter 173-303 WAC.[131] BTEX substances can be identified as dangerous wastes in at least two ways:

- WAC 173-303-090[132] includes Benzene (71-43-2) on the contaminant toxicity characteristic list, which is one way to identify dangerous waste. Substances with concentrations over the limits in Table 16 in an extract of the waste created using the Toxic Characteristic Leaching Procedure are considered dangerous wastes.
- Other members of the class designate based on the toxicity criteria in WAC 173-303-100[133] (Table 17).

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[119] app.leg.wa.gov/rcw/default.aspx?cite=70A.300
[120] app.leg.wa.gov/RCW/default.aspx?cite=70A.350.020
[121] app.leg.wa.gov/wac/default.aspx?cite=173-333-310
[122] app.leg.wa.gov/rcw/default.aspx?cite=70A.430
[123] apps.leg.wa.gov/rcw/default.aspx?cite=70A.405
[124] app.leg.wa.gov/rcw/default.aspx?cite=70A.222
[125] app.leg.wa.gov/rcw/default.aspx?cite=70A.335
[126] app.leg.wa.gov/rcw/default.aspx?cite=70A.230
[127] app.leg.wa.gov/rcw/default.aspx?cite=70A.400
[128] app.leg.wa.gov/rcw/default.aspx?cite=70A.350
[129] app.leg.wa.gov/rcw/default.aspx?cite=70A.305
[130] app.leg.wa.gov/RCW/default.aspx?cite=70A.300.010
[131] app.leg.wa.gov/wac/default.aspx?cite=173-303
[132] app.leg.wa.gov/WAC/default.aspx?cite=173-303-090
[133] app.leg.wa.gov/WAC/default.aspx?cite=173-303-100

Table 16. BTEX substances on the contaminant toxicity characteristic list in WAC 173-303-090.

Chemical	CAS RN	Limit (mg/L)	Dangerous Waste Number
Benzene	71-43-2	0.5	D018

The WAC 173-303-100 criteria considers the lethal concentration in fish, rats, and rabbits. Table 17 shows available data for BTEX substances, including the lowest reported LC50s from hazard assessments of these chemicals relevant to WAC 173-303-100 (ToxServices, 2018a, 2019d, 2019b, 2023). Toluene, ethylbenzene, and xylenes all have an LC50 in fish between 1 and less than 10 mg/L, which corresponds to the toxic category C. Ethylbenzene has an inhalation of LC50 in rats between 2 and less than 20 mg/L, which also corresponds to toxic category C. A mixture that is 100% toluene, ethylbenzene, or xylenes would be assigned the dangerous waste number WT02 and designated as dangerous waste.

Table 17. Relevant LC50s used in determining whether BTEX substances may be considered dangerous wastes under WAC 173-303-100.

Chemical	Fish LC50 (mg/L)	Oral Rat LC50 (mg/kg)	Inhalation Rat LC50 (mg/L)	Dermal Rabbit LC50 (mg/kg)
Toluene	5.5 mg/L (*Oncorhynchus kisutch*, fish)	> 5,000 mg/kg (rats)	> 20 mg/L (rats)	> 5,000 mg/kg (rabbits)
Xylenes	2.6 mg/L (*Oncorhynchus mykiss*, fish)	>4,000 mg/kg (rats) 1,590 mg/kg (mice)	26 mg/L (rats, p-xylene)	3,228 mg/kg/day (rabbits, m-xylene)
Ethylbenzene	4.2 mg/L (*Oncorhynchus mykiss*, fish)	3,500–5,460 mg/kg (rats)	17.8mg/L (rats)	15,433 mg/kg (rabbits)

BTEX substances are listed under section 101(14)[134] of the federal cleanup law, 42 U.S.C. Sec. 9601(14) Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA),[135] and are therefore incorporated into the definition of "hazardous substance" under RCW 70A.305.020(13).[136] BTEX substances listed in CERCLA are shown in Table 18.

Table 18. BTEX substances designated as hazardous substances under CERCLA.

Hazardous Substance	CAS RN
Benzene	71-43-2

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[134] www.ecfr.gov/current/title-40/chapter-I/subchapter-J/part-302/section-302.4

[135] dor.wa.gov/sites/default/files/2022-03/CERCLAHazardousSubstances.pdf?uid=6408ff778e6d7

[136] app.leg.wa.gov/RCW/default.aspx?cite=70A.305.020

Hazardous Substance	CAS RN
Toluene	108-88-3
Ethylbenzene	100-41-4
m-Xylene	108-38-3
o-Xylene	95-47-6
p-Xylene	106-42-3
Xylene (mixed)	1330-20-7

Chemicals of concern for sensitive populations and species

After assessing available data to consider the factors below, as outlined in RCW 70A.350.020,[137] we found that BTEX substances are a concern for sensitive populations and sensitive species.

(a) A chemical's or members of a class of chemicals' hazard traits or environmental or toxicological endpoints;

(b) A chemical's or members of a class of chemicals' aggregate effects;

(c) A chemical's or members of a class of chemicals' cumulative effects with other chemicals with the same or similar hazard traits or environmental or toxicological endpoints;

(d) A chemical's or members of a class of chemicals' environmental fate;

(e) The potential for a chemical or members of a class of chemicals to degrade, form reaction products, or metabolize into another chemical or a chemical that exhibits one or more hazard traits or environmental or toxicological endpoints, or both;

(f) The potential for the chemical or class of chemicals to contribute to or cause adverse health or environmental impacts;

(g) The chemical's or class of chemicals' potential impact on sensitive populations, sensitive species, or environmentally sensitive habitats;

(h) Potential exposures to the chemical or members of a class of chemicals based on:

    (i) Reliable information regarding potential exposures to the chemical or members of a class of chemicals; and

    (ii) Reliable information demonstrating occurrence, or potential occurrence, of multiple exposures to the chemical or members of a class of chemicals

We concluded that BTEX substances are a concern for sensitive species and sensitive populations because of their hazards and the potential for exposure. BTEX are carcinogenic,

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[137] app.leg.wa.gov/RCW/default.aspx?cite=70A.350.020

impact the central nervous system, are toxic during development, and disrupt the endocrine system. People and wildlife are often exposed to multiple BTEX substances, which can lead to cumulative impacts.

There is widespread exposure to BTEX substances, however people working in certain professions may have higher exposure, leading to disproportionate exposure. There is evidence that occupational exposure to BTEX substances is associated with adverse health impacts.

BTEX have been detected in outdoor air and water samples. Sensitive species, such as salmon, can be adversely impacted by BTEX substances.

The sections below describe our evaluation of this criteria and support our conclusion.

Hazards of priority chemical class

We evaluated data-rich chemicals within the class for hazards, including environmental and human health toxicological endpoints, and environmental fate, transport, and potential breakdown products. To identify these hazards, we used similar methods to those found in our 2022 Regulatory Determinations Report to the Legislature.[138]

Hazard endpoints of concern are discussed below. Table 19 shows a more comprehensive list of potential hazards of BTEX substances. We identified hazard endpoints of concern if at least one member of the chemical class is either included on authoritative lists or scored as high or very high in hazard assessments. In some cases, we supplemented these endpoints with specific concerns that may be relevant to sensitive populations.

BTEX substances are associated with several hazards to human health and the environment, including developmental toxicity, systemic toxicity, neurotoxicity, and aquatic toxicity. In general, BTEX substances are not characterized as persistent or bioaccumulative. Some of the hazards of BTEX substances are summarized below.

Carcinogenicity and mutagenicity

Benzene is a known human carcinogen and is classified as such by several authoritative organizations, including the EPA, National Institutes of Health (NIH), and European Chemicals Agency (ECHA) (Table 19) (ECHA, 2023; EPA, 2012a; NTP, 2021). Benzene is also included on the California Proposition 65 list as a carcinogen and is classified as a known human carcinogen by the International Agency for Research on Cancer (IARC) and by the German MAK-Commission (MAK) (Deutsche Forschungsgemeinschaft, 2018; IARC, 2012b). Benzene is also classified as genotoxic and mutagenic by ECHA and MAK (Deutsche Forschungsgemeinschaft, 2018; ECHA, 2023).

Ethylbenzene is also included on the California Proposition 65 list as a carcinogen. It is classified as a possible human carcinogen by IARC and as a non-genotoxic carcinogen by MAK (Deutsche Forschungsgemeinschaft, 2018; OEHHA, 2023).

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[138] apps.ecology.wa.gov/publications/summarypages/2204018.html

Reproductive and developmental toxicity

Several animal studies reported benzene to cause adverse effects on male and female reproductive tissues. Studies in humans exposed to benzene have also provided some evidence of reproductive toxicity, however interpretation of these studies is complicated due to simultaneous exposure in participants to other chemicals as well (ToxServices, 2018a). Benzene is included on the California Proposition 65 List for male reproductive toxicity (OEHHA, 2023).

Benzene and toluene are both included on the California Proposition 65 list for developmental toxicity (Table 19) (OEHHA, 2023). Several animal studies on toluene reported adverse effects on development, including increased mortality, reduced birth weight, skeletal abnormalities, and various developmental delays (ToxServices, 2019d). There is also evidence of developmental toxicity for benzene. Effects reported in animal studies include delayed bone ossification, skeletal abnormalities, and a reduction in birth weight (ToxServices, 2018a).

Similarly, ethylbenzene exposure during pregnancy is associated with developmental effects in animal studies, including skeletal abnormalities, delayed skeletal development, and uropoietic apparatus anomalies and reduced fetal weight (ToxServices, 2019b).

A recent hazard assessment of xylenes concluded that the available data is consistent with a Globally Harmonized System (GHS) category 1 classification as a developmental toxicant, using a weight of evidence approach. This was based on studies with reported effects that included skeletal abnormalities and reduction in birth weight, as well as neurobehavioral deficits (ToxServices, 2023). The assessment also noted that xylenes have been detected in the milk of human mothers, indicating the potential for lactational transfer (ToxServices, 2023).

Neurotoxicity

BTEX can all produce neurological effects (ATSDR, 2004b). Benzene inhalation exposure in humans has been shown to affect the central nervous system and cause a variety of symptoms, including drowsiness, vertigo, headache, tremor, loss of consciousness, and death at high concentrations (ATSDR, 2007b).

Toluene also causes central nervous system effects. As described by ATSDR, effects of acute exposure seen in animals include ataxia, tremors, hearing loss, impaired learning and memory, and decreased locomotor activity, coordination, and reflexes. Chronic exposure to toluene can cause permanent damage to the central nervous system (ATSDR, 2017).

As summarized by ATSDR, ethylbenzene inhalation is associated with central nervous system depression at higher concentrations of exposure and stimulation of the motor nervous system at lower concentrations. Ethylbenzene exposure was also associated with ototoxicity (hearing loss) (ATSDR, 2010b).

Xylenes are associated with similar neurological effects, including impaired memory, reaction time, balance, and ototoxicity (ATSDR, 2007c). The neurotoxic effects of BTEX are also likely additive with exposures to mixtures of these chemicals (ATSDR, 2004b).

Systemic toxicity

Benzene, ethylbenzene, and toluene are all classified for aspiration hazard under the EU GHS (H304, may be fatal if swallowed and enters airways) (ECHA, 2023). Benzene is also classified under EU—GHS for causing damage to organs through prolonged or repeated exposure (H372) and demonstrates clear adverse effects on the hematopoietic system following repeat exposures (ToxServices, 2018a).

Xylene is not classified for fatal aspiration hazard under EU—GHS, but Japan classifies xylene as Category 1 for systemic toxicity (single exposure) under GHS (H370). The available data suggests xylene also causes severe respiratory irritation after inhalation exposure (ToxServices, 2023).

Ecological toxicity

BTEX substances are all acutely toxic to aquatic life. BTEX substances each have a reported LC50 below 10 ppm in at least one aquatic species (ToxServices, 2018a, 2019b, 2019d, 2023). LC50 is the lethal concentration required to kill one half of exposed organisms.

In terms of chronic aquatic toxicity, BTEX substances all have reported no observable effect concentrations (NOECs) below or equal to 1 ppm (ToxServices, 2018a, 2019d, 2019b, 2023). NOEC is the highest concentration not shown or expected to cause effects in the organisms.

Environmental fate

Understanding the environmental impacts of chemicals includes assessing persistence, bioaccumulation, and known and potential breakdown products.

Benzene is volatile and degrades in the atmosphere through reaction with photochemically produced hydroxyl radicals, with a residence time on the order of hours to days (ToxServices, 2018a). In the atmosphere, benzene is thought to form several transformation products, including phenol, nitrobenzene, glyoxal, formaldehyde, maleic anhydride, formic acid, and isomers of nitrophenol and dinitrophenol (ATSDR, 2007b).

Benzene is also found in surface water, groundwater, and is mobile in soil. In water, benzene is subject to indirect photolysis and biodegradation, and can form phenol, catechol, and hydroquinone. Benzene also undergoes biodegradation in soil under aerobic and anaerobic conditions and has been shown to form catechol. However, aerobic biodegradation in soil is inhibited at concentrations above 2 ppm (ATSDR, 2007b; ToxServices, 2018a).

Ethylbenzene degrades in the atmosphere through reaction with hydroxyl and nitrogen oxide radicals and forms ethylphenols, benzaldehyde, acetophenone, and nitroethylbenzene isomers. In water, sediment, and soil, ethylbenzene can form benzaldehyde and acetophenone through indirect photooxidation. Ethylbenzene can be biodegraded under aerobic conditions to form several compounds, including hydroxyphenyl acetic acids, ethylphenols, 3-ethylcatechol, styrene, and 1-phenyl-1,2-ethanediol (ATSDR, 2010b).

Toluene primarily reacts with hydroxyl radicals in the atmosphere to form cresol and benzaldehyde as intermediates, which further degrade to simple hydrocarbons (ATSDR, 2017). In water, sediment and soil, toluene can be degraded in both aerobic and anerobic environments to form benzylsuccinic acid and benzylfumaric acid, and complete mineralization is possible under favorable conditions (ATSDR, 2017).

The three isomers of xylene (o-xylene, m-xylene, and p-xylene) are expected to behave similarly in the environment (ATSDR, 2007c). Xylenes undergo rapid photooxidation in the atmosphere, primarily by reaction with hydroxyl radicals. Atmospheric degradation products for o-xylene include o-tolualdehyde, methylglyoxal, 4-nitro-o-xylene, and 2,3-dimethylphenol. o-Xylene is also reported to form formaldehyde, acetaldehyde, biacetyl nitrate, and peroxyacetylnitrate. For m-xylene, degradation products include 2,6-dimethylphenol, 2,4-dimethylphenol, methylglyoxal, and m-tolualdehyde. For p-xylene, the degradation products are p-tolualdehyde and 2,5-dimethylphenol. Xylenes in water, sediment, and soils are amenable to biodegradation, and various metabolites have been reported, including methylbenzyl- succinic acids, fumaric acids, toluic acids, phthalic acids, and benzoic acids (ATSDR, 2007c).

In general, BTEX substances are not characterized in hazard assessments as persistent in the environment. This is due to fugacity modeling that predicts they will partition primarily to water or soil when released as a component of wastewater and their degradation rates observed in biodegradability tests (ToxServices, 2018a, 2019b). A fugacity model is used to predict the behavior of a chemical in different compartments (*i.e.*, air, water, sediment, or soil) to determine its expected environmental fate (Mackay et al., 1992). Benzene, ethylbenzene, and xylenes have all met the 10-day window in ready biodegradation tests. In BioWin modeling, Toluene has a predicted half-life of 15 days in water and 30 days in soil (ToxServices, 2018a, 2019d, 2019b, 2023). However, benzene, toluene, and ethylbenzene are all listed as persistent on the Domestic Substance List (DSL) under the Canadian Environmental Protection Act (CEPA) due to their expected half-lives in air.

BTEX have low to moderate bioaccumulation potential with the majority of measured or predicted bioconcentration factors reported as less than 100 (ATSDR, 2007c, 2007b, 2010b, 2017).

Referenced hazard assessments

The hazard assessments referenced in Table 19 are described in the Technical Methods chapter of this report. We reviewed each method for transparency and consistency in scoring methods and data requirements. Using hazard assessments allows us to apply a consistent, non-biased approach to evaluating chemicals across multiple endpoints and levels of data. In this report, hazard assessments allow us to identify known and potential hazards of chemicals within the priority chemical classes.

Benzene, toluene, ethylbenzene, and xylenes scored as Benchmark-1 chemicals in GreenScreen® assessments, indicating they are hazardous and should be avoided (ToxServices, 2018a, 2019b, 2019d, 2023).

Benzene, toluene, ethylbenzene, and xylene scored as [Red] in verified SciveraLENS® GHS+ chemical hazard assessments (Scivera, 2023o, 2023aj, 2023x, 2023ao).

- The GreenScreen® assessments for benzene (CAS: 74-43-2), toluene (CAS: 108-88-3), ethylbenzene (CAS: 100-41-4), and xylenes (CAS: 1330-20-7) are available from the ToxServices database[139] (ToxServices, 2018a, 2019d, 2019b, 2023).
- The GreenScreen assessment for o-xylene (CAS: 95-47-6) is available from the Pharos website[140] (Rosenblum, 2015b).
- The SciveraLENS® GHS+ chemical hazard assessments referenced in Table 19 are available in the SciveraLENS® database[141] (Scivera, 2023o, 2023aj, 2023ao, 2023x).

Table 19. Known and potential hazards of BTEX substances.

Common name, associated CAS(s)	Known or potential hazards	Referenced hazard assessments	Relevant authoritative listings
Toluene, CAS RN: 108-88-3	Developmental toxicity†, endocrine activity‡, systemic toxicity (single dose)†, neurotoxicity (single and repeat dose)‡, skin irritation†, acute aquatic toxicity†, chronic aquatic toxicity†, persistence‡	GreenScreen BM-1, SciveraLENS [Red]	California Proposition 65 (Developmental toxicity); EU GHS —H336 (Sys. Tox. Sing. 3), H373 (Sys. Tox. Rep. 2), H315 (Skin Irr. 2), H304 (Fatal Aspiration Hazard Sys. Tox. Rep. 1), H361d (Repr. Tox. 2)
Xylenes, CAS RN: 1330-20-7	Developmental toxicity†, endocrine activity‡, acute toxicity‡, systemic toxicity (single dose)†, neurotoxicity (single dose)†, neurotoxicity (repeat dose)‡, eye irritation†, skin irritation†, acute aquatic toxicity†, chronic aquatic toxicity†	GreenScreen BM-1, SciveraLENS [Red]	EU GHS—H332 (Acute Tox. Inhalation 4), H312 (Acute Tox. Dermal 4), H315 (Skin Irr. 2);
O-xylene, CAS RN: 95-47-6	Reproductive toxicity‡, developmental toxicity†, endocrine activity‡, acute toxicity‡, systemic toxicity (single dose)‡, systemic toxicity (repeat dose)†, neurotoxicity (single and repeat dose)‡, skin irritation†, eye irritation‡, acute aquatic toxicity†, chronic aquatic toxicity‡	GreenScreen BM-1	EU GHS—H332 (Acute Tox. Inhalation 4), H312 (Acute Tox. Dermal 4), H315 (Skin Irr. 2);

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[139] database.toxservices.com/
[140] pharosproject.net/
[141] rapidscreen.scivera.com/

Common name, associated CAS(s)	Known or potential hazards	Referenced hazard assessments	Relevant authoritative listings
Benzene, CAS RN: 71-43-2	Carcinogenicity†, mutagenicity†, reproductive toxicity†, developmental toxicity‡, endocrine activity‡, systemic toxicity (single and repeat dose)†, neurotoxicity (single dose)‡, neurotoxicity (repeat dose)†, skin irritation†, eye irritation†, acute aquatic toxicity†, chronic aquatic toxicity†	GreenScreen® BM-1, SciveraLENS® [Red]	California Proposition 65 List (carcinogen, male reproductive toxicity, developmental toxicity); EU GHS—H350 (Carc. 1A), H340 (Mut. 1B), H304 (Fatal Aspiration Hazard Sys. Tox. Rep. 1), H372 (Sys. Tox. Rep. 1), H315 (Skin Irr. 2), H319 (Eye Irr. 2)
Ethylbenzene, CAS RN: 100-41-4	Carcinogenicity†, developmental toxicity‡, endocrine activity‡, acute toxicity‡, systemic toxicity (single dose)†, systemic toxicity (repeat dose)‡, neurotoxicity (single and repeat dose)‡, skin irritation†, eye irritation‡, acute aquatic toxicity†, chronic aquatic toxicity†	GreenScreen BM-1, SciveraLENS [Red]	California Proposition 65 List (carcinogen); EU GHS—H332 (Acute Tox. Inhalation 4), H304 (Fatal Aspiration Hazard Sys. Tox. Rep. 1), H373 (Sys. Tox. Rep. 2)

† Endpoints scored as high or very high in referenced hazard assessments
‡ Endpoints scored as moderate in referenced hazard assessments

Potential exposures to people and the environment

Human exposure

People are exposed to BTEX compounds through inhalation of indoor air, outdoor air, and the air in other settings, such as vehicle interiors. BTEX chemicals can also be absorbed through the skin when they are present in the air or when people contact products that contain them. The presence of BTEX compounds in fuels and vehicle exhaust is a major source of outdoor air contamination that increases background human exposure levels. Urban areas are more heavily affected.

BTEX tend to co-occur in residential indoor air (Y. Li et al., 2019). Indoor air is likely the dominant exposure pathway to BTEX chemicals for most people. Indoor sources include consumer products such as adhesives, paint thinners, paints, and hobby products. Participation in arts and crafts hobbies can increase people's exposure to toluene, ethylbenzene, and the xylenes (Hinwood et al., 2007). BTEX present in outdoor air can enter buildings, contaminating indoor air (Health Effects Institute, 2005). Vapor intrusion can contribute to indoor air concentrations in buildings that are located over contaminated groundwaters or soils with limited aerobic degradation (EPA, 2015). BTEX chemicals in the subsurface can generate vapors that enter through basements or foundation materials.

Ingestion is a less common route of exposure than inhalation. Drinking water can be an important source when BTEX compounds migrate from spills or leaking tanks to contaminate drinking water. In foods, a Canadian diet study found m-xylene in 151 out of 153 composite food samples (X. L. Cao et al., 2016), and an older FDA diet study reported ethylbenzene in some foods.

Children may be exposed through consumer products. For example, the Danish EPA found toluene in:

- 1 of 5 infant jackets.
- 2 of 4 infant mittens.
- 2 of 3 school erasers.
- 1 or 4 pencil cases.
- 6 of 6 tents.
- 14 of 14 slimy toys.
- 2 of 15 wooden toys.

It was also reported in hobby adhesives (DEPA, n.d.). Toluene was identified as one of the top ten chemicals used in consumer products and ethylbenzene one of the top ten chemicals used in children's products (Bolden et al., 2015).

BTEX compounds are rapidly absorbed by the body after inhalation, ingestion, or skin contact (ATSDR, 2007c, 2007b, 2010b, 2017). In biomonitoring data available through the National Health and Nutrition Examination Survey (NHANES), a nationally representative sample of people shows that BTEX compounds are present in a large fraction of the population.

NHANES includes blood levels for people aged 12 and over and urinary metabolites for adults and children. Urinary biomarkers of BTEX and blood levels of toluene were reported up to 2016. Other BTEX compounds in blood were reported for the 2017 to 2018 cycle. In the most recent cycle of NHANES with available data, blood, and urinary metabolite levels of toluene and m-/p-xylenes indicated widespread exposure (CDC, 2022a).

Benzene, ethylbenzene, and o-xylene in blood indicate somewhat less widespread exposure but were detected in 25% of the sampled population. NHANES does not assess exposure to BTEX chemicals in the blood of children under age 12. In published studies on specific populations, children had roughly comparable blood concentrations to those found in NHANES for adults, with some varying results across different studies (Jain, 2015; Sexton et al., 2005).

Groups who may have higher exposure to BTEX chemicals include:

- People with occupational exposure. Petroleum refining, chemical and rubber manufacturing, and occupations that involve contact with fuels or vehicle exhaust are examples of workplaces that have BTEX exposure. People in occupations where BTEX are used as degreasers, paint thinners, brush cleaners, adhesives, inks, and coatings are also potentially exposed. An analysis of blood levels of BTEX chemicals in NHANES study participants noted an association between construction occupations and higher levels of toluene, ethylbenzene, and xylenes (K. Zhang et al., 2023). Toluene was detectable in most personal and area air samples during brake-cleaning tasks (Fries et al., 2018). Nail salon technicians are exposed to toluene in nail products (Quach et al., 2011). Salon workers may be less likely to benefit from personal protective equipment or workplace industrial hygiene practices than workers in large industrial facilities where occupational health standards are routinely enforced (Huynh et al., 2019).

- People with natural gas appliances in their residence (Lebel et al., 2022). An estimated 24% of Washington homes have a natural gas cooking appliance (EIA, 2020).
- People who live adjacent to or work at gas stations or former gas stations (ATSDR, 2007b, 2007c, 2010b, 2017). Spills or fuel leaks release BTEX to the air and to soil, where the chemicals can volatize to air or migrate into groundwater. There are over 7,000 leaking underground fuel storage tanks in Washington. Of these, 227 are awaiting or in progress toward clean up (Ecology, 2009).
- People who live near refineries, large fuel transfer operations, heavily trafficked roadways, or hazardous waste sites may have elevated background exposure to BTEX chemicals that are emitted from these sources (ATSDR, 2007c, 2007b, 2010b, 2017).

Environmental exposure

BTEX are components of fossil fuel extraction that are captured and used in industrial products as fuel additives, and in production of many consumer products. BTEX are released to the environment through fuel combustion, releases from fuel handing, and their use as solvents. The majority of BTEX release to outdoor air is through fuel combustion. BTEX can also volatilize from consumer products and contaminate both indoor air and outdoor air during manufacture, use, and disposal of products, contributing to environmental release (Bolden et al., 2015).

BTEX in the environment can be found in water, air, and soil. The three most important sources of BTEX in natural waters are sewage discharge, oil leaks, and water transport. BTEX levels in the environment are often associated with industrial activities (B. Yu et al., 2022).

A 2006 survey conducted by the National Water-Quality Assessment Program summarized analyses of approximately 3,500 water samples collected nationally and measured for volatile organic compounds, including BTEX (USGS, 2006). The survey reported toluene was found in 1.9% of aquifer samples above an assessment level of 0.2 ug/L and 9.9% of samples above 0.02 ug/L. Benzene was detected in 1.7%, ethylbenzene in 0.47%, and xylene (mixed and individual isomers combined) in 1.3% of samples above 0.02 ug/L. The survey noted that toluene was among the top five most frequently detected volatile organic compounds detected in the nation’s aquifers sampled in the survey.

Over the years, sampling of groundwater monitoring wells in Washington has found levels of BTEX that exceed Model Toxics Control Act (MTCA) cleanup levels near known releases, mostly associated with petroleum contamination (Ecology, 2002, 2009, 2016b, 2017a, 2020a, 2021c, 2021a). At the time of writing, benzene is associated with 1,843 confirmed or suspected contaminated sites in Washington State. There are also 1,720 sites listed that require no further action (Ecology, n.d.-b).

During Washington State air quality monitoring, the Puget Sound Clean Air Agency measured BTEX in ambient air. Benzene, toluene, and a combined measure of ethylbenzene and xylene were studied at sites in Tacoma and Seattle from 2008 to 2009 (Puget Sound Clean Air Agency and the University of Washington, 2010). In the study, the average concentration of benzene measured exceeded the health screening value and was the second largest contributor to increased potential cancer risk of the more than 100 air toxics studied, excluding diesel exhaust and wood smoke particulate (Puget Sound Clean Air Agency and the University of Washington, 2010).

A 2018 study of ambient air in Seattle's Chinatown-International District found that, of the air toxics measured, benzene was the second highest contributor to potential cancer risk, excluding diesel exhaust particulate (Puget Sound Clean Air Agency, 2018). The Southwest Clean Air Agency monitored ambient air in Longview, Washington, and Washington State University's Laboratory for Atmospheric Research monitored ambient air in Spokane. Both measured BTEX in ambient air and found levels of benzene that exceed the health screening value (Southwest Clean Air Agency, 2007a; Washington State University Laboratory for Atmospheric Research & RJ Lee Group Inc. Center for Laboratory Sciences, 2007).

BTEX releases have also been reported in the EPA Toxics Release Inventory (TRI) for Washington State from 2012 to 2021 (EPA, n.d.-f). The TRI summarizes releases of toxic chemicals from industrial facilities to air, water, and land. Between 2012 and 2021, releases of 16 million pounds of BTEX substances have been reported in Washington State (Table 20).

Table 20. Total BTEX releases reported in the Toxics Release Inventory from 2012 to 2021.

Chemical	Releases (lbs)
Toluene	10,017,500
Xylene (as mixed isomers)	5,575,220
Benzene	370,037
Ethylbenzene	323,372
m-Xylene	7,320
p-Xylene	4,112
o-Xylene	3,482

Potential for cumulative and aggregate effects

Exposure to chemicals can result in aggregate effects and cumulative effects. Aggregate effects can occur when people or other organisms are exposed to a single chemical from multiple routes, pathways, and sources (e.g., house dust, drinking water, air, and food). Cumulative effects can occur when people or other organisms are exposed to multiple chemicals simultaneously. These cumulative exposures may come from multiple exposure routes, pathways, and sources, or just a single source.

Potential for aggregate effects

Aggregate exposure is possible for all BTEX compounds, since exposure can potentially occur through inhalation of outdoor air; indoor air in workplaces, homes, schools, and transit vehicles; dermal contact with BTEX-containing products; and ingestion of foods and water. Once released to the environment, BTEX are commonly detected in air, water, and soil.

Biomonitoring of human blood or urine provides quantitative information about aggregate exposure over the short term and the potential for effects due to aggregate exposure in people. While biomonitoring data on wildlife is less common, the presence of BTEX substances in soil, air, and water suggests that there is the potential for aggregate exposures.

We concluded that there is the potential for aggregate effects because people and wildlife are exposed to BTEX substances from multiple sources. These exposures add up and can contribute to biological impacts.

Potential for cumulative effects

Cumulative effects occur when people and wildlife are co-exposed to chemicals that can have adverse effects on the same health endpoints, tissues, or biological pathways in the body. For BTEX, there is potential for cumulative impacts. For example, nail salon workers are exposed to toluene in the context of exposure to multiple volatile organic compounds (VOCs) (Quach et al., 2011).

At relatively high exposure levels, BTEX and other substances, such as non-BTEX solvents, affect the central nervous system. Combined exposure to BTEX is expected to increase the potential for neurotoxicity compared with effects of exposure to chemicals individually (ATSDR, 2004b). Mixture effects have been seen in laboratory rodents. In rats exposed to environmentally relevant mixtures of BTEX, subtle locomotor changes were seen (Davidson et al., 2022). Cumulative exposure to other neurotoxicants present in indoor or outdoor environments could heighten the concern.

In rodent studies, ethylbenzene, toluene, and xylenes have all been associated with some damage to the inner ear. A recent analysis of NHANES data found that solvent exposure, particularly benzene, toluene, and ethylbenzene, was significantly associated with increased odds of hearing loss in people (Staudt et al., 2019). Other solvents can impact hearing too, raising the possibility of cumulative effects with chemicals beyond BTEX.

A study of occupational exposure hazards reported that the odds of non-Hodgkin’s lymphoma was increased with exposure to benzene, toluene, and xylene (Miligi et al., 2006). Workers who were exposed to all three compounds had higher odds of disease compared to exposure to any of the three alone.

In the environment, wildlife (including sensitive species) are co-exposed to BTEX and other chemicals that can impact similar pathways. Multiple BTEX substances are associated with aquatic toxicity and endocrine disruption in wildlife. BTEX have been detected in air samples, along with other volatile organic compounds (A. J. Li et al., 2021). Urban waters are frequently contaminated with endocrine disrupting chemicals (Conn et al., 2020; D. A. M. da Silva et al., 2013).

We concluded that there is the potential for cumulative effects because people and wildlife are exposed to BTEX substances in addition to other chemicals that can impact similar biological systems.

Potential to contribute adverse impacts

In sensitive populations

When people are exposed to chemicals with known or suspected toxicities, there is the potential for adverse impacts. The impacts may be greater when people are also exposed to other environmental contaminants that impact the same biological systems. People, including sensitive populations, are exposed to BTEX. Exposure to BTEX substances is associated with carcinogenicity, reproductive and developmental toxicity, neurotoxicity, and systemic toxicity. Therefore, BTEX substances have the potential to contribute to adverse impacts in humans, including sensitive populations such as the elderly, workers, people of childbearing age, developing fetuses, and children.

People are widely exposed to BTEX substances. Exposure is likely to be concurrent for a significant portion of the population, due to environmental presence in ambient air. BTEX substances are variously associated with carcinogenicity, reproductive toxicity, and effects on the bone marrow, inner ear, and central nervous system. Large worker populations are exposed to some of these chemicals, which has produced a substantial number of studies in humans. Considering the patterns of exposure, the health effects associated with the chemicals individually, and the potential for cumulative effects, BTEX has the potential to contribute to adverse impacts on human health. Populations of concern include people with occupational exposure and pregnant people, and people with higher background exposures from air and drinking water that can cumulate when they are exposed from consumer product sources.

Benzene causes cancers and other serious adverse effects in the blood and bone marrow, including acute myelogenous leukemia, myelodysplastic syndrome, and aplastic anemia in highly exposed workers. People who have elevated background exposure to BTEX, through air or drinking water contamination, may be vulnerable to cancer and hematological toxicity if they have additional exposure from occupational or consumer sources (Bulka et al., 2013). As summarized above (Environmental Monitoring Data), benzene levels in ambient air exceed health screening levels that are set to protect against cancer.

Exposed workers are one sensitive population that can potentially experience adverse impacts from BTEX substances. Key examples are discussed below.

- Occupational exposure to solvents including BTEX substances has been linked to hearing loss in workers (Staudt et al., 2019).
- Exposed workers may be disproportionately in low-income jobs, such as auto shop workers and nail salon technicians. Further, nail salon workers are disproportionately Asian-American women (UCLA Labor Center, 2018).
- Solvents affect the central nervous system and are associated with neurologic and neurobehavioral effects (Kishi et al., 1994). Impaired color vision has been seen in toluene-exposed workers in multiple studies (Campagna et al., 2001; Cavalleri et al., 2000). While some neurological effects are associated with higher exposure levels, effects on color vision can occur at levels close to occupational exposure limits. The potential for cumulative exposures to BTEX and over 200 other neurotoxicants raises concern (Grandjean & Landrigan, 2014).
- Pregnant people are a sensitive population of concern for BTEX exposure, due to developmental toxicants in the class. Co-exposure to ethanol with BTEX is a concern for cumulative impacts of solvents on the developing fetus. Toluene is considered a developmental neurotoxicant along with other environmental chemicals (Grandjean & Landrigan, 2014).

In sensitive species

When chemicals are released into the environment, they have the potential to expose sensitive species, such as forage fish, salmon, or orcas. If these chemicals have aquatic toxicity, reproductive or developmental toxicity, systemic toxicity, or endocrine disruption, there is potential to contribute to adverse impacts in sensitive populations. BTEX substances are found in the environment and have the potential to harm wildlife, including sensitive species.

Most of the available data on the impact of BTEX substances in wildlife comes from studies exploring impacts and potential impacts of oil spills and oil contamination. These studies support the conclusion that BTEX substances can contribute to adverse impacts in sensitive species, particularly salmon.

- Exposure to benzene was associated with decreased respiration in chinook salmon and striped bass (Brocksen & Bailey, 1973).
- Salmon may have increased sensitivity to benzene exposure during out-migration because of the added stress of entering seawater and the necessary physiological changes during this transition (Moles et al., 1979).
- Salmon may also be particularly vulnerable to the impacts of BTEX substances early in development. Multiple studies have found that earlier exposure to oil contamination (including, but not limited to, BTEX substances) is associated with lifelong impacts that can impair salmon survival (Bérubé et al., 2023; F. Lin et al., 2022; Perugini et al., 2022).

Chapter 6: Technical Support for Formaldehyde and Formaldehyde Releasers

Chapter overview

Formaldehyde and formaldehyde releasers often act as preservatives in products but also serve other functions, such as providing wrinkle resistance or acting as cross-linkers. Formaldehyde is used as a preservative due to its antimicrobial and antifungal activity. Formaldehyde releasers added to products release formaldehyde over time, preserving ingredients and extending shelf life of products. Formaldehyde is also used as a feedstock for resin production (*e.g.*, formaldehyde is used to create resins based on urea, phenol, and melamine). Resins formed through reactions with formaldehyde may also act as formaldehyde releasers.

Formaldehyde is a carcinogen, respiratory toxicant, and sensitizing agent. It is associated with allergic reactions and asthma, particularly in occupational settings. People and wildlife, including sensitive species and populations, are exposed to formaldehyde. It is a high production volume chemical, according to EPA. From 2008 to 2009, Puget Sound Clean Air Agency monitored air quality in Washington State and found formaldehyde was the fourth largest contributor to increased potential cancer risk at sites in Tacoma and Seattle (excluding diesel exhaust and wood smoke particulate).

Formaldehyde and formaldehyde releasers were selected as a priority chemical class for this cycle of Safer Products for Washington because formaldehyde is a carcinogen and sensitizer with prevalent exposure in people and the environment. Formaldehyde may be associated with disproportionate exposures, particularly when it is used in cosmetic products marketed toward women of color. Multiple studies have found that women of color may be more likely to use products such as hair relaxers and straighteners that can contain formaldehyde and formaldehyde releasers. Formaldehyde exposure can also be associated with occupations, such salon workers. Reducing sources and uses of formaldehyde and formaldehyde releasers can reduce disproportionate exposures to a known human carcinogen and sensitizer.

Formaldehyde and formaldehyde releasers meet the high priority chemical criteria because at least one member of the class is:

1. A high priority chemical of high concern to children identified by Ecology under Chapter 70A.430 RCW.[142]
2. Considered a hazardous substance in Washington.
3. A concern for sensitive species and populations.

Rationale and references are described below.

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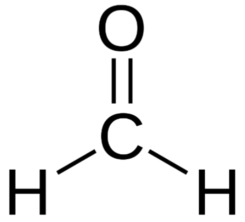
[142] app.leg.wa.gov/rcw/default.aspx?cite=70A.430

Scope of priority chemical class

This chemical class includes formaldehyde and chemicals or materials that may form formaldehyde. Formaldehyde is a simple, naturally occurring small molecule with the chemical formula CH_2O (Figure 5). In aqueous solutions, formaldehyde undergoes a rapid hydration reaction to form methylene glycol. The formation of methylene glycol is favored in aqueous solutions at room temperature and neutral pH, but the reaction is reversible. The equilibrium can be shifted depending on several factors, including increases in temperature, lower pH, and the presence of other chemicals in solution. Methylene glycol can also polymerize in solution to form small polymethylene glycols and paraformaldehyde. Aqueous solutions of formaldehyde in equilibrium with methylene glycol and small polymethylene glycols can be stabilized by the presence of methanol to reduce formation of paraformaldehyde. These solutions are generally 37% formaldehyde and methylene glycol by weight and are referred to as formalin (Boyer et al., 2013).

Some chemicals undergo hydrolysis to release formaldehyde as a degradation product. Table 23 contains some examples of chemicals that release formaldehyde and have been associated with hazards to human health. The rate and amount of formaldehyde release through hydrolysis can vary depending on temperature, pH, the amount of water present, and the reaction stoichiometry with respect to the parent molecule.

Figure 5. Molecular structure of formaldehyde.



Rationale for class approach

Formaldehyde and formaldehyde releasers are being considered as one class because they share common breakdown products. Formaldehyde releasers are chemicals that form formaldehyde over time. The formaldehyde can be found in consumer products and can contribute to exposure. Formaldehyde and formaldehyde releasers often serve similar functions, therefore replacing formaldehyde with a formaldehyde releaser would be a regrettable substitution.

Meeting the statutory requirements

The statute requires that priority chemicals or chemical classes meet specific criteria. Priority chemical classes must meet at least one of the criteria described in RCW 70A.350.020[143] and listed below.

- A member of the chemical class has been identified by Ecology as a chemical of concern, specifically:
    - A chemical of high concern to children under Chapter 70A.430 RCW[144] or
    - A persistent, bioaccumulative and toxic chemical under Chapter 70A.300 RCW.[145]
- A member of the chemical class is regulated in relevant consumer product statutes in Washington.
- A member of the chemical class is a hazardous substance under Chapter 70A.300 RCW or Chapter 70A.305 RCW.[146]
- Members of the chemical class are a concern for sensitive populations and sensitive species.

Formaldehyde and formaldehyde releasers meet at least one of the criteria to be considered priority chemicals. Each of the criteria are discussed below.

Chemicals of concern by Ecology

Chemical classes with members that are chemicals of high concern to children (CHCC) identified under Chapter 70A.430 RCW meet the criteria for designation as priority chemical class under RCW 70A.350.020(1)(a). Ecology identifies chemicals of high concern to children based on their hazards and exposure potential in Chapter 173-334 WAC.[147] Formaldehyde is in Chapter 173-334 WAC (Table 21). To review the rationale for CHCC listing, please refer to the Rationale for Reporting List of Chemicals of High Concern to Children 2011 to 2017 (Ecology, 2021b).

Table 21. Formaldehyde and formaldehyde releasers that are chemicals of high concern to children.

Chemical	CAS RN
Formaldehyde	50-00-0

Chemical classes with members identified as persistent bioaccumulative toxic substances (PBTs) under Chapter 70A.300 RCW meet the criteria for designation as a priority chemical class under RCW 70A.350.020(1)(b). Ecology identifies chemicals that are persistent, bioaccumulative, and

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[143] app.leg.wa.gov/rcw/default.aspx?cite=70A.350.020
[144] app.leg.wa.gov/rcw/default.aspx?cite=70A.430
[145] app.leg.wa.gov/rcw/default.aspx?cite=70A.300
[146] app.leg.wa.gov/rcw/default.aspx?cite=70A.305
[147] apps.leg.wa.gov/wac/default.aspx?cite=173-334

toxic under WAC 173-333-310.[148] Formaldehyde and formaldehyde releasers are not considered persistent, bioaccumulative, and toxic substances (PBTs) under WAC 173-333-310.

Regulations in consumer products under relevant statutes

Chemical classes with members regulated in consumer products under Chapters 70A.430,[149] 70A.405,[150] 70A.222,[151] 70A.335,[152] 70A.230,[153] or 70A.400 RCW[154] meet the criteria for designation as a priority chemical class under RCW 70A.350.020(2)(a).[155] Formaldehyde and formaldehyde releasers are not regulated by relevant consumer product statutes in Washington.

Hazardous substances in Washington

Under Chapter 70A.350 RCW,[156] chemical classes with members that are hazardous substances under Chapter 70A.300 RCW[157] (Hazardous Substances Waste Management Act) or Chapter 70A.305 RCW (Model Toxics Control Act) can be considered priority chemicals under Chapter 70A.350 RCW. Formaldehyde is considered a hazardous substance under these and therefore meets the criteria for designation as a priority chemical class under Chapter 70A.350 RCW.

Hazardous substances are defined in RCW 70A.300.010[158] to include any material that exhibits any of the characteristics of dangerous wastes identified under Chapter 173-303 WAC.[159] Formaldehyde meets the toxicity criteria for book designation under WAC 173-303-100.[160] The WAC 173-303-100 criteria considers the lethal concentration in fish, rats, and rabbits. Table 22 shows available data for formaldehyde. Formaldehyde has an LC50 in fish between 1 and less than 10 mg/L, which corresponds to the toxic category C. A mixture that is 100% formaldehyde would be assigned the dangerous waste number WT02 and designated as Washington State Dangerous Waste. References for LC50s can be found in the “Hazards of the priority chemical class” section of this chapter below.

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[148] app.leg.wa.gov/wac/default.aspx?cite=173-333-310
[149] app.leg.wa.gov/rcw/default.aspx?cite=70A.430
[150] apps.leg.wa.gov/rcw/default.aspx?cite=70A.405
[151] app.leg.wa.gov/rcw/default.aspx?cite=70A.222
[152] app.leg.wa.gov/rcw/default.aspx?cite=70A.335
[153] app.leg.wa.gov/rcw/default.aspx?cite=70A.230
[154] app.leg.wa.gov/rcw/default.aspx?cite=70A.400
[155] app.leg.wa.gov/rcw/default.aspx?cite=70A.350.020
[156] app.leg.wa.gov/rcw/default.aspx?cite=70A.350
[157] app.leg.wa.gov/rcw/default.aspx?cite=70A.300
[158] app.leg.wa.gov/rcw/default.aspx?cite=70A.300.010
[159] app.leg.wa.gov/wac/default.aspx?cite=173-303
[160] app.leg.wa.gov/wac/default.aspx?cite=173-303-100

Table 22. Relevant LC50s used in determining whether formaldehyde may be considered dangerous wastes under WAC 173-303-100.

Chemical	Fish LC50 (mg/L)	Oral Rat LC50 (mg/kg)	Inhalation Rat LC50 (mg/L)	Dermal Rabbit LC50 (mg/kg)
Formaldehyde	6.7 mg/L (*Morone saxatilis*, fish)	640 mg/kg (rats)	< 0.57 mg/L (4hr, rats)	270 mg/kg (rabbit)

Formaldehyde is listed under section 101(14)[161] of the federal cleanup law, 42 U.S.C. Sec. 9601(14) Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and is therefore incorporated into the definition of "hazardous substance" under RCW 70A.350.020.[162]

Chemicals in the class are a concern for sensitive populations and species

After assessing available data to consider the factors below, as outlined in RCW 70A.305.020, we found that we found that that formaldehyde and formaldehyde releasers are a concern for sensitive populations and sensitive species after assessing available data to consider the following factors:

(a) A chemical's or members of a class of chemicals' hazard traits or environmental or toxicological endpoints;

(b) A chemical's or members of a class of chemicals' aggregate effects;

(c) A chemical's or members of a class of chemicals' cumulative effects with other chemicals with the same or similar hazard traits or environmental or toxicological endpoints;

(d) A chemical's or members of a class of chemicals' environmental fate;

(e) The potential for a chemical or members of a class of chemicals to degrade, form reaction products, or metabolize into another chemical or a chemical that exhibits one or more hazard traits or environmental or toxicological endpoints, or both;

(f) The potential for the chemical or class of chemicals to contribute to or cause adverse health or environmental impacts;

(g) The chemical's or class of chemicals' potential impact on sensitive populations, sensitive species, or environmentally sensitive habitats;

(h) Potential exposures to the chemical or members of a class of chemicals based on:

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[161] dor.wa.gov/sites/default/files/2022-03/CERCLAHazardousSubstances.pdf?uid=6408ff778e6d7

[162] app.leg.wa.gov/RCW/default.aspx?cite=70A.350.020

(i) Reliable information regarding potential exposures to the chemical or members of a class of chemicals; and

(ii) Reliable information demonstrating occurrence, or potential occurrence, of multiple exposures to the chemical or members of a class of chemicals.

We concluded that formaldehyde and formaldehyde releasers are a concern for sensitive species and populations because of their hazards and the potential for sensitive species and populations to be exposed. Formaldehyde releasers used in consumer products release formaldehyde over time. Formaldehyde is a known human carcinogen and sensitizing agent. It is associated with allergic reactions and asthma, particularly in occupational settings. People and wildlife, including sensitive species and populations, are exposed to formaldehyde. According to EPA, it is a high production volume chemical. The Puget Sound Clean Air Agency monitored Washington State air quality from 2008 to 2009 and found formaldehyde was the fourth largest contributor to increased potential cancer risk at sites in Tacoma and Seattle (excluding diesel exhaust and wood smoke particulate).

Formaldehyde may be associated with disproportionate exposures, particularly when it is used in cosmetic products marketed toward women of color. Multiple studies have found that women of color may be more likely to use products such as hair relaxers and straighteners that can contain formaldehyde and formaldehyde releasers. Formaldehyde exposure can also be associated with occupations, such as in laboratory workers, metal workers, and embalmers. Reducing sources and uses of formaldehyde and formaldehyde releasers can reduce disproportionate exposures and protect sensitive populations.

The sections below describe our evaluation of this criteria and support our conclusion.

Hazards of priority chemical class

We evaluated data-rich chemicals within the class for hazards, including environmental and human health toxicological endpoints, and environmental fate, transport, and potential breakdown products. To identify these hazards, we used similar methods to those found in our 2022 Regulatory Determinations Report to the Legislature (Ecology, 2022).[163]

Hazard endpoints of concern are discussed below. Table 23 contains a more comprehensive list of potential hazards of formaldehyde and formaldehyde releasers. We identified hazard endpoints of concern if at least one member of the chemical class is either included on authoritative lists or scored as high or very high in hazard assessments. In some cases, we supplemented these endpoints with specific concerns that may be relevant to sensitive populations.

The hazards of this chemical class are primarily based on those of formaldehyde. Other chemicals in the class may also have additional inherent hazards, but the potential for those chemicals to release formaldehyde is the underlying hazard trait that unifies this chemical class.

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[163] apps.ecology.wa.gov/publications/summarypages/2204018.html

As such, we have focused on hazards of formaldehyde in this section. Formaldehyde is a known carcinogen, and there is evidence it is mutagenic. Formaldehyde is also associated with sensory irritation, sensitization, and respiratory toxicity, including effects on asthma. Respiratory effects are important when considering potential impacts to sensitive populations. There is some data suggesting formaldehyde may affect development and the endocrine system as well, but evidence is limited (ToxServices, 2019c).

Carcinogenicity and mutagenicity

Formaldehyde is classified or listed as carcinogenic by many authoritative organizations, including the EPA, CDC, National Toxicology Program (NTP), and International Agency for Research on Cancer (IARC) (Table 23). IARC concluded that there is sufficient evidence in animals and humans that formaldehyde is a human carcinogen. They note that exposure in humans is associated with nasopharygeal cancer, leukemia, and sinonasal cancer (IARC, 2012b). The NTP also concluded formaldehyde is a known human carcinogen and noted that there are likely several modes of action by which formaldehyde causes cancer (NTP, 2021).

There is evidence that formaldehyde is genotoxic and that this contributes to the carcinogenicity of formaldehyde in humans. Tests of various genetic endpoints in bacteria, yeast, fungi, plants, insects, nematodes, and cultured mammalian cells show that formaldehyde is genotoxic. It also has been shown to cause various types of DNA damage, inhibit DNA repair, and cause gene mutations in mammalian cells (NTP, 2021). Formaldehyde is classified as a Category 2 Mutagen by ECHA (ECHA, 2023).

Skin sensitization

Formaldehyde is a skin sensitizer and a common skin allergen. Exposure to formaldehyde and formaldehyde releasers can cause allergic contact dermatitis (Goossens & Aerts, 2022; Silverberg et al., 2021).

Respiratory sensitization and toxicity

Respiratory tract toxicity

Formaldehyde irritates sensory tissues such as the eyes, nose, and throat (ATSDR, 2010a). Changes in lung function are associated with long-term exposure to formaldehyde. For example, people can be exposed for years at work or in residences (NASEM, 2023). Effects on lung function include reduced respiratory flow and volume, particularly when exposure is at higher levels. Pathological changes in respiratory tract tissue, including altered growth and characteristics of nasal cells, occur in both rats and humans (ATSDR, 2010a).

Asthma

Asthmagens are substances that can cause or exacerbate asthma in people. A meta-analysis of the literature concluded, “there was ‘sufficient’ evidence supporting an association between childhood and adult exposures to formaldehyde with asthma diagnosis and symptoms” (Lam et al., 2021). The authors estimated the effect as an 8% increase in children’s asthma per 10-fold increase in formaldehyde exposure. This is consistent with another systemic review and meta-analysis, which also reported a significant association between indoor formaldehyde exposure and increased risk of asthma in children for both low (≤22.5 ug/m^3) and high exposures (>22.5 ug/m^3) (L. Yu et al., 2020). The study reported that high exposure (> 22.5ug/m^3) was also associated with increased risk of asthma in adults. The authors suggest measures should be taken to reduce indoor formaldehyde concentrations to protect children from asthma.

The Association of Occupational and Environmental Clinics lists formaldehyde as an asthmagen, and the Occupational Health and Safety Administration notes that formaldehyde can produce symptoms of bronchial asthma in humans and that formaldehyde is highly irritating to the upper airways (ToxServices, 2019c).

Ecological toxicity

Formaldehyde is acutely toxic to aquatic organisms, including species of fish, invertebrates, and algae. The lowest LC50, or highest toxicity, observed is reported in aquatic invertebrates at 0.46 mg/L (*Cypridopsis sp*.). The lowest LC50 value reported in fish is 6.7 mg/L in striped bass (*Morone saxatilis*). A half maximal effective concentration (EC50) of 3.48 mg/L was reported in green algae (*Desmodesmus subspicatus*) (ToxServices, 2019c). LC50 is the lethal concentration required to kill half of exposed organisms. The EC50 is the concentration required to achieve half the maximal effect (e.g., reduced biomass) for the organism.

Formaldehyde also displays chronic toxicity in aquatic organisms, with the lowest no observed effect concentration (NOEC) reported as 1 mg/L in a species of water flea (*Ceriodaphnia dubia*) (ToxServices, 2019c). NOEC is the highest concentration not shown or expected to cause effects in the organism.

Environmental fate

Understanding the environmental impacts of chemicals includes assessing persistence, bioaccumulation, and known and potential breakdown products.

Formaldehyde is not persistent in the environment. Fugacity modeling predicts soil is the dominant environmental compartment for formaldehyde, and both modeling and degradation studies have concluded formaldehyde is readily biodegradable (ToxServices, 2019c). A fugacity model is used to predict the behavior of a chemical in different compartments (*i.e.*, air, water, sediment, or soil) to determine its expected environmental fate (Mackay et al., 1992).

Formaldehyde does not bioaccumulate, and studies have reported bioconcentration factor values of less than one for formaldehyde in fish and invertebrates (ToxServices, 2019c).

Referenced hazard assessments

The hazard assessments referenced in Table 23 are described in the Technical Methods chapter of this report. We reviewed each method for transparency and consistency in scoring methods and data requirements (Ecology, 2022). Using hazard assessments allows us to apply a consistent, non-biased approach to evaluating chemicals across multiple endpoints and levels of data. In this report, hazard assessments allow us to identify known and potential hazards of chemicals within the priority chemical classes.

- The GreenScreen® assessments for formaldehyde (CAS: 50-00-0), DMDM Hydantoin (CAS: 6440-58-0), and benzylhemiformal (CAS: 14548-60-8) are available from the ToxServices database[164] (ToxServices, 2015a, 2019c, 2020).
- The GreenScreen assessment for methenamine (CAS: 100-97-0) is available from the Pharos website[165] (ToxServices, 2014).
- The SciveraLENS® GHS+ chemical hazard assessments referenced in Table 23 are available in the SciveraLENS® database[166] (Scivera, 2023z, 2023d, 2023ae, 2023q, 2023p, 2023y).

Table 23. Formaldehyde and examples of formaldehyde releasers and known or potential hazards.

Common name, associated CAS(s)	Known or potential hazards	Referenced hazard assessments	Relevant authoritative listings
Formaldehyde, CAS RN: 50-00-0	Carcinogenicity†, mutagenicity‡, developmental toxicity‡, acute toxicity†, systemic toxicity (single and repeat dose) †, neurotoxicity (single and repeat dose) †, skin sensitization‡, respiratory sensitization†, skin and eye irritation†, acute aquatic toxicity†, chronic aquatic toxicity†	GreenScreen BM-1, SciveraLENS [Red]	CA Prop. 65—Carcinogen, EU GHS—(Mut. Cat. 2), H311 (Acute Tox. Cat. 3), H314 (Skin & Eye Irr. Cat. 1), MAK—Sensitizing Substance Sh—danger of skin sensitization
DMDM Hydantoin, CAS RN: 6440-58-0	Carcinogenicity†, mutagenicity‡, systemic toxicity (single dose)‡, skin and respiratory sensitization‡, acute aquatic toxicity†, chronic aquatic toxicity‡	GreenScreen BM-1_{TP}, SciveraLENS [Red]	NA

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[164] database.toxservices.com/

[165] pharosproject.net/

[166] rapidscreen.scivera.com/

Common name, associated CAS(s)	Known or potential hazards	Referenced hazard assessments	Relevant authoritative listings
N,N'-methylenebismorpholine (MBM), CAS RN: 5625-90-1	Carcinogenicity†, mutagenicity‡, reproductive toxicity‡, developmental toxicity‡, acute toxicity†, systemic toxicity (repeat dose) †, dermal sensitization†, skin and eye irritation†	GreenScreen® LT-1, SciveraLENS® [Red]	EU CMR (Carc. Cat. 1B), EU—GHS H341 (Mut. Cat. 2), H302 (Acute Tox. 4), H373 (Sys. tox.—repeat Cat. 2), H314 (Skin irritation Cat. 1), H318 (Eye irritation Cat. 1), MAK—Sensitizing Substance Sh—danger of skin sensitization
Methenamine, CAS RN: 100-97-0	Systemic toxicity (repeat dose)†, respiratory sensitization†	GreenScreen BM-1$_{TP}$	H317 (Skin sensitization Cat. 1)
Bronopol, CAS RN: 52-51-7	Reproductive toxicity‡, developmental toxicity‡, endocrine activity‡, acute toxicity†, systemic toxicity‡, dermal sensitization†, dermal and eye irritation†, persistence†, acute aquatic toxicity†, chronic aquatic toxicity†	SciveraLENS [Red]	EU—GHS H302 (Acute Tox. 4), H335 (Sys. Tox. Single Exp. Resp. 3), H315 (Skin Irr. 2), H318 (Eye Irr. 1), H400 (Acute Aq. Tox. 1), MAK—Sensitizing Substance Sh—danger of skin sensitization
Benzylhemiformal (BMF), CAS RN: 14548-60-8	Carcinogenicity†, mutagenicity‡, acute toxicity‡, systemic toxicity (single dose) †, neurotoxicity (single and repeat dose) ‡, skin and respiratory sensitization‡, skin and eye irritation†, acute aquatic toxicity‡, chronic aquatic toxicity‡	GreenScreen BM-1, SciveraLENS [Red]	MAK—Sensitizing Substance Sh—danger of skin sensitization

Common name, associated CAS(s)	Known or potential hazards	Referenced hazard assessments	Relevant authoritative listings
(Ethylenedioxy)dimethanol (EDDM), CAS RN: 3586-55-8	Carcinogenicity†, mutagenicity‡, reproductive toxicity, endocrine activity‡, developmental toxicity†, acute toxicity‡, systemic toxicity (repeat dose)‡, neurotoxicity (single and repeat dose)‡, acute aquatic toxicity†, chronic aquatic toxicity‡	GreenScreen® BM-1, SciveraLENS® [Red]	NA
Sodium hydroxymethylglycinate, CAS RN: 70161-44-3	NA	GreenScreen LT-1	EU—GHS H350 (Carc. 1B), H341 (Mut. 2), H332 and H302 (Acute Tox. 4), H335 (Sys. Tox. Single Exp. Resp. 3), H315 (Skin Irr. 2), H319 (Eye Irr. 2), H317 (Skin Sens. 1)
Quaternium-15, CAS RN: 4080-31-3	NA	GreenScreen LT-P1	MAK (Skin Sens.)
Quaternium-15 (cis-form), CAS RN: 51229-78-8	NA	GreenScreen LT-P1	EU—GHS H361d (Repr. 2), H302 (Acute Tox. 4), H315 (Skin Irr. 2), H317 (Skin Sens. 1), H411 (Chron. Aq. Tox. 2)
Oxazolidine E, CAS RN: 7747-35-5	NA	GreenScreen LT-P1	NA
Diazolidinyl urea, CAS RN: 78491-02-8	NA	GreenScreen LT-P1	NA

† Endpoints scored as high or very high in referenced hazard assessments
‡ Endpoints scored as moderate in referenced hazard assessments

Potential exposures to people and the environment

Human exposure

People are exposed to formaldehyde and formaldehyde releasers primarily through inhalation and skin contact. Formaldehyde is a ubiquitous pollutant of indoor and outdoor air. Outdoor sources include industrial emissions, combustion emissions from vehicles and wildfires, and oxidation of hydrocarbons in the atmosphere. Emissions of formaldehyde indoors come from sources that include a range of products, such as building materials, glues, textiles, and a wide assortment of personal care products and cosmetics that contain formaldehyde releasers. Exposure studies in Finland found that adults' total exposure is best predicted by indoor residential air concentrations, with some contributions from outdoor and workplace air (J. Jurvelin et al., 2001). Measurements taken in U.S. homes indicated a median concentration of 16 ppb formaldehyde and also showed that indoor sources of formaldehyde were major contributors in residential air (ATSDR, 2010a; W. Liu et al., 2006; Salthammer et al., 2010).

Dermal exposure to formaldehyde and formaldehyde-releasing agents is a secondary route of exposure that may be important for some people. Higher dermal exposures and dermal sensitization have been noted in some workers, including hairdressers, wood and textile workers, embalmers, and people exposed to metal-working fluids. Cross-reactivity to formaldehyde and formaldehyde releasing agents has been noted (Goossens & Aerts, 2022).

It is important to note that the human body and other biological organisms naturally form formaldehyde from normal cellular metabolism (IARC, 2006; Swenberg et al., 2011). As a product of cellular processes, formaldehyde is found in blood and other body fluids (IARC, 2006). Formaldehyde is also present naturally in a wide range of foods, including fruits and vegetables, which may contribute to people's exposure by ingestion (EFSA, 2014).

Some potentially elevated exposure scenarios involving consumer products include people with occupational exposure and consumers who are exposed to formaldehyde and formaldehyde releasing chemicals in personal microenvironments. Both customers and workers may be exposed to formaldehyde in products at hair and nail salons (OSHA, 2023b). Product usage surveys found Black women are more likely to use hair straighteners, which often contain formaldehyde, than White women (Dodson et al., 2021; Ecology, 2023). Workers in medical laboratories and mortuaries have workplace exposure to formaldehyde (ATSDR, 2010a; OSHA, 2023a). Formaldehyde releasers in paints and metalworking fluids have been identified as sources of skin allergy in workers (Schubert et al., 2020).

People are also exposed to formaldehyde in resins and adhesives in building materials. There are concerns about people's exposure to formaldehyde in trailers and mobile homes supplied by the Federal Emergency Management Association (FEMA), particularly in temporary housing supplied after hurricane Katrina. CDC measured the levels of formaldehyde inside a selection of trailers and found the levels were higher than usually found in homes, and some levels were high enough to affect human health (ATSDR, 2008; Murphy et al., 2013). EPA's 2016 standard for formaldehyde in composite wood products has made progress toward reducing this exposure.

Groups who may have higher exposure to formaldehyde and formaldehyde releasers include:

- People who live, work, or study in mobile homes or similar temporary structures built prior to implementation of EPA's 2016 composite wood standard.
- People with high use of personal care products that contain formaldehyde releasers, particularly women of color who use hair straightening products.
- Occupationally exposed people.

Environmental exposure

Formaldehyde can be released into the air from natural and industrial sources as well as consumer products. The Puget Sound Clean Air Agency monitored Washington State air quality from 2008 to 2009 and found formaldehyde was the fourth largest contributor to increased potential cancer risk at sites in Tacoma and Seattle (excluding diesel exhaust and wood smoke particulate). The annual mean concentrations at sites in the study ranged from 1.013 ug/m^3 to 2.921 ug/m^3.

The Washington State Acceptable Source Impact Level (ASIL) is set at 0.17 ug/m^3 (Puget Sound Clean Air Agency and the University of Washington, 2010). Long-term air monitoring at Beacon Hill National Air Toxics Trend Site (NATTS) shows decreases from early 2000s to mid-2010s. A more recent trend shows leveling off or perhaps a slight increase in concentration (Puget Sound Clean Air Agency, 2022). The Puget Sound Clean Air Agency also monitored air quality in Seattle's Chinatown-International District in 2017 and found levels of formaldehyde that exceeded the Washington ASIL. They reported formaldehyde as one of the top five air toxics contributing to increased potential cancer risk (excluding diesel exhaust and woodsmoke particulate) (Puget Sound Clean Air Agency, 2018).

In 2005, the Southwest Clean Air Agency monitored air quality in Vancouver, Washington and Longview, Washington, and reported an annual average concentration of 1.95 ug/m^3 and 0.792 ug/m^3 for formaldehyde, respectively. Both values exceeded the Washington ASIL (Southwest Clean Air Agency, 2007a, 2007b). The Spokane Air Toxic Study sampled air at sites in Spokane in 2005 and reported annual average concentration of 2.5 ug/m^3, again exceeding the Washington ASIL (Washington State University Laboratory for Atmospheric Research & RJ Lee Group Inc. Center for Laboratory Sciences, 2007). It is important to note that much of the formaldehyde in outdoor air originates from secondary photochemical reactions. Concentrations in Washington are often lower than other locations in the U.S. (Strum & Scheffe, 2016).

To our knowledge, formaldehyde is not routinely measured in Washington State waters. In 2016, EPA, Ecology, the Idaho Department of Fish and Game, and the Washington State Department of Fish and Wildlife measured formaldehyde as part of a hatchery effluent study. We conducted the study to determine concentrations of formaldehyde discharged from hatcheries, after formalin treatment to control hatchery fish disease. The study found that levels of formaldehyde in effluents did not exceed the FDA and EPA Region 10 level of concern of 10 ppm for any of the five hatcheries sampled. EPA concluded that current levels of formalin use in hatcheries was generally protective of aquatic life, and the Endangered Species Act (ESA) listed salmonids in Pacific Northwest waters (EPA, 2017).

Between 2012 and 2021, 768,472 pounds of formaldehyde releases were reported in EPA's Toxics Release Inventory for Washington. An additional 6,099,663 pounds of formaldehyde was reported as waste managed in Washington. Reported releases were primarily to air (630,643 pounds), followed by off-site releases (70,968 pounds), water (66,553 pounds), and land (307 pounds) (EPA, n.d.-f).

Potential for cumulative and aggregate effects

Exposure to chemicals can result in aggregate effects and cumulative effects. Aggregate effects can occur when people or other organisms are exposed to a single chemical from multiple routes, pathways, and sources (*e.g.*, house dust, drinking water, air, and food). Cumulative effects can occur when people or other organisms are exposed to multiple chemicals simultaneously. These cumulative exposures may come from multiple exposure routes, pathways, and sources, or just a single source.

Potential for aggregate effects

People are exposed to formaldehyde from indoor air, outdoor air, and direct exposure with some consumer products that contain or release formaldehyde. These exposures add to the background levels produced naturally in the body and have the potential to cause health effects.

Formaldehyde is released into the environment from consumer products and industrial processes. Once in the environment, formaldehyde is primarily found in air. The EPA identified formaldehyde as a hazardous air pollutant. Wildlife and sensitive populations near urban and industrial areas can be exposed to formaldehyde in the air, and low levels of formaldehyde have been detected in water. People are also exposed to formaldehyde in indoor air. Concentrations of formaldehyde indoors are often higher than concentrations outdoors, possibly due to release of formaldehyde from consumer products (Kelly et al., 1999; R. Liu et al., 2019; Maung et al., 2022).

We concluded that there is the potential for aggregate impacts because people can be exposed to formaldehyde from multiple sources. These exposures add up and can contribute to adverse impacts.

Potential for cumulative effects

Cumulative effects occur when people and wildlife are co-exposed to chemicals that can have adverse effects on the same health endpoints, tissues, or biological pathways in the body. Formaldehyde exposure often occurs along with exposure to other chemicals and can cause cancer or developmental harm in both people and wildlife (Nguyen et al., 2020).

Air can contain multiple environmental contaminants that can impact sensitive species and populations. A recent analysis of formaldehyde and other volatile organic compounds from biogenic and anthropogenic sources, as well as from fires, found that formaldehyde was the largest contributor to cancer risk in people (Zhu et al., 2017). Wildlife, including sensitive species, are also affected by air pollution (Sanderfoot & Holloway, 2017).

Indoor air can expose people to multiple chemicals. Formaldehyde co-occurs in indoor air with other volatile organic chemicals, some of which also cause respiratory irritation or cancer (J. A. Jurvelin et al., 2003; Vardoulakis et al., 2020). For example, a review of indoor air pollution found that toluene, m-/p-xylene, alpha-pinene, and delta-limonene are the most reported volatile organic compounds in indoor air. Formaldehyde, acetaldehyde, and toluene had the highest concentrations in bedrooms (Maung et al., 2022).

Formaldehyde co-occurs with other air pollutants and people are exposed to these real-world mixtures. Consequently, researchers face challenges determining the precise levels of formaldehyde in air that can affect respiratory toxicity and other health effects in sensitive people (Golden & Holm, 2017). However, many of the co-occurring chemicals in indoor air are also respiratory toxicants and can potentially contribute to cumulative respiratory irritation and respiratory cancers (Pullen Fedinick et al., 2021).

We concluded that there is the potential for cumulative effects because people and wildlife are exposed to formaldehyde in addition to other chemicals. These exposures add up and can contribute to adverse impacts.

Potential to contribute adverse impacts

In sensitive populations

When people are exposed to chemicals with known or suspected toxicities, there is the potential for adverse impacts. The impacts may be greater when people are also exposed to other environmental contaminants that impact the same biological systems.

People, including sensitive populations, are exposed to formaldehyde. Exposure to formaldehyde is associated with carcinogenicity, developmental toxicity, systemic toxicity, and respiratory toxicity. Therefore, formaldehyde has the potential to contribute to adverse impacts in humans, including sensitive populations such as the elderly, workers, people of childbearing age, developing fetuses, and children.

This is supported by epidemiological studies and models that found associations between formaldehyde exposure in people and adverse health impacts. Key examples are listed below.

- Asthmatic children are a sensitive population for long-term exposure to formaldehyde. A study of lung function in people exposed to formaldehyde in their residences found that asthmatic children experienced greater decrease in the rate of peak exhaled air flow than adults or non-asthmatic children (Krzyzanowski et al., 1990).
- Black and Indigenous children are a potentially sensitive population for the respiratory toxicity and asthmagenicity of formaldehyde. These groups of children experience asthma at higher rates than White children (CDC, 2022b). Asthma is also associated with higher poverty. Indigenous and Black children, particularly those who are already experiencing health stress from poverty, may be vulnerable to additional formaldehyde that results from exposure to consumer products that can release formaldehyde into personal breathing zones.
- Workers are a potentially sensitive population. Salon workers are exposed to formaldehyde by using hair straightening and other products that contain formaldehyde releasers. A study in Korean salons found that workers were exposed to a mixture of chemicals, including levels of formaldehyde that exceeded health risk guidance values (Choi et al., 2023). Other workers who may have elevated exposure include mortuary workers exposed to formaldehyde and painters and metalworkers exposed to formaldehyde releasers (De Groot et al., 2010). Formaldehyde releasers used as

preservatives in paint and metal cutting fluids are associated with increased risk for skin allergies (Schubert et al., 2020; Schwensen et al., 2017).

- From 2008 to 2009, the Puget Sound Clean Air Agency monitored Washington State air quality and found formaldehyde was the fourth largest contributor to increased potential cancer risk at sites in Tacoma and Seattle (excluding diesel exhaust and wood smoke particulate) (Puget Sound Clean Air Agency and the University of Washington, 2010).
- The CDC measured formaldehyde levels inside a selection of trailers and found the levels were higher than usually found in homes. Levels ranged from 3 to 590 ppb, higher than typical residential exposure concentrations (ATSDR, 2008; Murphy et al., 2013).

In sensitive species

When chemicals are released into the environment, they have the potential to expose sensitive species, such as forage fish, salmon, or orcas. If these chemicals have relevant hazards, there is potential to contribute to adverse impacts in sensitive populations. Formaldehyde is found in the environment and has the potential to harm wildlife including sensitive species. While the major concerns around formaldehyde exposure and toxicity are centered around human exposure in sensitive populations, wildlife can also be exposed to formaldehyde, which can contribute to adverse impacts in sensitive species.

Most potential impacts in sensitive species are related to formaldehyde in air. EPA identified formaldehyde as one of the hazardous air pollutants that pose the greatest potential health threat in urban areas. Urban air can have higher concentrations of formaldehyde than rural air (Y. C. Lin et al., 2012). Air pollution impacts both sensitive species and populations (EPA, 2023b). A Canadian ecological risk assessment focused on formaldehyde in the environment, specifically air and water concentrations, found that there was the potential for harmful effects from formaldehyde in wildlife. However, the concentrations observed in the study were generally below the level of concern.

Following the use of formaldehyde as a parasiticide in aquaculture, there is evidence of adverse impacts on salmon. When intentionally added, formaldehyde can form formalin, which is highly toxic to fish. It can also kill algae, which can reduce dissolved oxygen levels and direct toxic effects on fish (Fidra & Best Fishes, 2021). The high levels of exposure associated with adverse impacts in hatchery fish are not relevant to most environmental exposure scenarios.

While current environmental concentrations of formaldehyde suggest exposure levels are not a current concern for sensitive species, the hazards, presence, and release of formaldehyde into the environment suggest that formaldehyde does have the potential to contribute to adverse impacts in sensitive species.

Chapter 7: Technical Support for Cyclic Volatile Methylsiloxanes

Chapter overview

Cyclic volatile methylsiloxanes (cVMS) are widely used in consumer products. They are used in the synthesis of polymeric silicones and can serve a variety of functions in personal care products, including as solvents, volatile carriers, emollients, and as hair conditioners. According to EPA, cVMS are high production volume chemicals. This is concerning because cVMS also persistent in the environment, many are expected to bioaccumulate, they have the potential for long-range transport, and they have been identified as a chemical of concern for the Arctic.

cVMS were selected as a priority chemical class for this cycle of Safer Products for Washington because they are persistent, likely bioaccumulative, and toxic chemicals that have high production volumes, potential disproportionate exposures, and hazards that can impact sensitive species and populations. Persistent chemicals are important targets for pollution prevention efforts. If we learn about toxic impacts after pollution has occurred, costly cleanups may be required because these chemicals do not readily break down in the environment. cVMS may also be associated with disproportionate exposure because they are used in haircare products marketed toward women of color. Because cVMS are associated with reproductive and developmental impacts, endocrine disruption, and aquatic toxicity, these environmental fate and disproportionate exposures are a concern for sensitive species and populations.

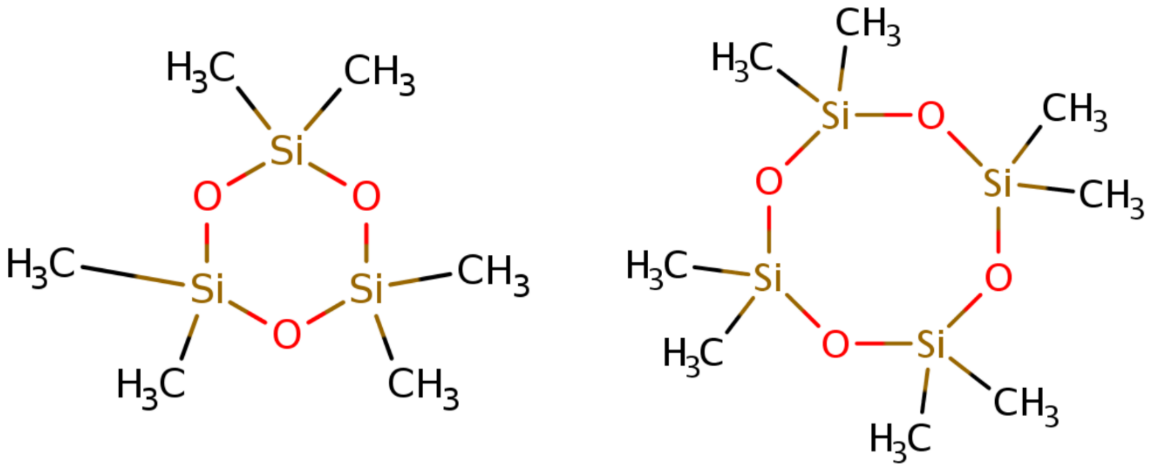
cVMS meet the high priority chemical criteria because they are a concern for sensitive species and sensitive populations.

Rationale and references are described below.

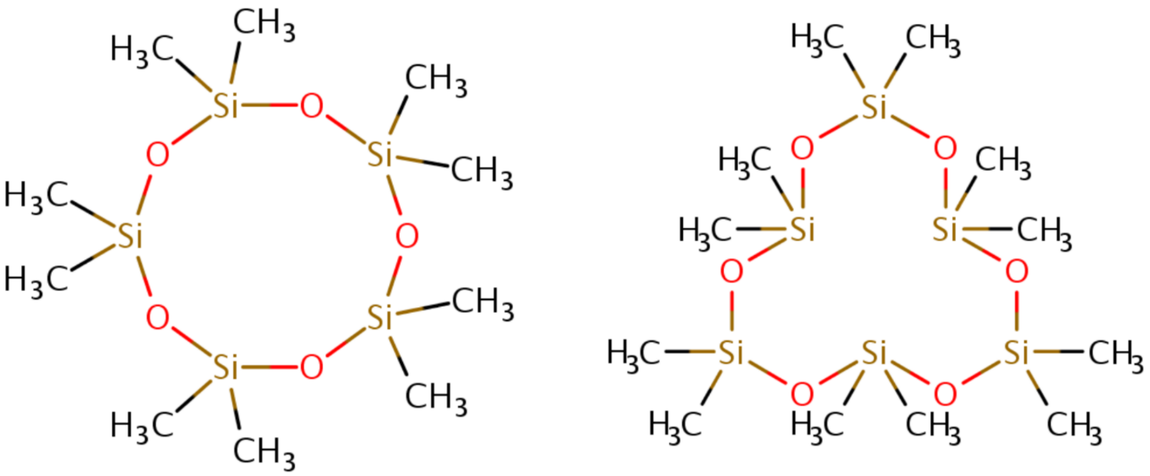
Scope of priority chemical class

Cyclic volatile methylsiloxanes can be defined as a class of chemicals based on their structure, chemical properties, and shared hazard traits. The structures of cVMS consist of alternating silicon and oxygen atoms in a cyclic arrangement, with each silicon atom also bonded to two methyl groups (Figure 6). The most used and studied cVMS are often referred to as D3, D4, D5, and D6, with the "**D**" representing the two methyl groups per silicon (*i.e.*, Dimethyl), and the number representing the number of silicon atoms in the cyclic arrangement.

Figure 6. Molecular structures of common cyclic volatile methylsiloxanes (cVMS).



Hexamethylcyclotrisiloxane (D3) Octamethylcyclotetrasiloxane (D4)



Decamethylcyclopentasiloxane (D5) Dodecamethylcyclohexasiloxane (D6)

Rationale for class approach

We are approaching cVMS as a chemical class due to similarity of these chemicals with respect to their hazards, chemical properties, uses, and potential for regrettable substitution. In terms of hazards, cVMS are all persistent in the environment, and there is evidence they are capable of long-range transport. D4, D5, and D6 are all also expected to bioaccumulate in organisms (ECHA, 2018c, 2018b, 2018a).

As the class name suggests, cVMS are volatile chemicals. This contributes to the potential for exposure to this class of chemicals from product use and from release to the environment through volatilization to ambient air. The cVMS have low water solubility, which decreases with increasing number of silicon atoms in the cyclic arrangement. For example, the water solubility of D3 is 1.6 mg/L at 23° C, while the solubility of D6 is only 0.0051 mg/L at 23° C (DEPA, 2014). Breakdown of cVMS in the environment also leads to a common degradation product in the form of dimethylsilanediol (S. Xu & Kropscott, 2012).

The majority of cVMS are used in the synthesis of polymeric silicones. They are also frequently used for a variety of functions in personal care products, such as solvents, volatile carriers, emollients, and hair conditioners. They can be used as waxes, sealants, adhesives, and coatings in consumer products (DEPA, 2014; NICNAS, 2020). The overlapping functional uses of cVMS in some consumer products increases the potential for regrettable substitution among this class of chemicals.

Meeting the statutory requirements

The statute requires that priority chemicals or chemical classes meet specific criteria. Priority chemical classes must meet at least one of the criteria described in RCW 70A.350.020[167] and listed below.

- A member of the chemical class has been identified by Ecology as a chemical of concern, specifically:
    - A chemical of high concern to children under Chapter 70A.430 RCW[168] or
    - A persistent, bioaccumulative and toxic chemical under Chapter 70A.300 RCW.[169]
- A member of the chemical class is regulated in relevant consumer product statutes in Washington.
- A member of the chemical class is a hazardous substance under Chapter 70A.300 RCW or Chapter 70A.305 RCW.[170]
- Members of the chemical class are a concern for sensitive populations and sensitive species.

cVMS meet at least one of the criteria to be considered priority chemicals. Each of the criteria are discussed below.

Chemicals of concern by Ecology

Chemical classes with members that are chemicals of high concern to children (CHCC) identified under Chapter 70A.430 RCW meet the criteria for designation as priority chemical class under

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[167] app.leg.wa.gov/rcw/default.aspx?cite=70A.350.020
[168] app.leg.wa.gov/rcw/default.aspx?cite=70A.430
[169] app.leg.wa.gov/rcw/default.aspx?cite=70A.300
[170] app.leg.wa.gov/rcw/default.aspx?cite=70A.305

RCW 70A.350.020(1)(a).[171] Ecology identifies chemicals of high concern to children based on their hazards and exposure potential in Chapter 173-334 WAC.[172]

Chemical classes with members identified as persistent bioaccumulative toxic substances (PBTs) under Chapter 70A.300 RCW[173] meet the criteria for designation as a priority chemical class under RCW 70A.350.020(1)(b). Ecology identifies chemicals that are persistent, bioaccumulative, and toxic under WAC 173-333-310.[174]

cVMS are not listed as chemicals of high concern to children in Chapter 173-334 WAC, and they are not on the PBT list in WAC 173-333-310.

Regulations in consumer products relevant Washington statute

Chemical classes with members regulated in consumer products under Chapters 70A.430, 70A.405,[175] 70A.222,[176] 70A.335,[177] 70A.230,[178] or 70A.400 RCW[179] can meet the criteria for designation as a priority chemical class under RCW 70A.350.020(2)(a). cVMS are not regulated in consumer products in Washington.

Hazardous substances in Washington

Under Chapter 70A.350 RCW,[180] chemical classes with members that are hazardous substances under Chapter 70A.300 RCW[181] (Hazardous Waste Management Act) or Chapter 70A.305 RCW[182] (Model Toxics Control Act) can be considered priority chemicals. Hazardous substances are defined in RCW 70A.300.010 to include any material that exhibits any of the characteristics or criteria of dangerous wastes identified under WAC 173-303-100.[183]

We did not identify any conclusive studies demonstrating lethal concentrations within the range that corresponds to toxic categories under WAC 173-303-100.

Under Chapter 70A.305 RCW, substances listed under section 101(14)[184] of the federal cleanup law, 42 U.S.C. Sec. 9601(14) Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), are also hazardous substances. cVMS are not listed as hazardous substances under the federal cleanup law.

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[171] app.leg.wa.gov/rcw/default.aspx?cite=70A.350.020
[172] apps.leg.wa.gov/wac/default.aspx?cite=173-334
[173] app.leg.wa.gov/rcw/default.aspx?cite=70A.300
[174] app.leg.wa.gov/wac/default.aspx?cite=173-333-310
[175] apps.leg.wa.gov/rcw/default.aspx?cite=70A.405
[176] app.leg.wa.gov/rcw/default.aspx?cite=70A.222
[177] app.leg.wa.gov/rcw/default.aspx?cite=70A.335
[178] app.leg.wa.gov/rcw/default.aspx?cite=70A.230
[179] app.leg.wa.gov/rcw/default.aspx?cite=70A.400
[180] app.leg.wa.gov/rcw/default.aspx?cite=70A.350
[181] app.leg.wa.gov/rcw/default.aspx?cite=70A.300
[182] app.leg.wa.gov/rcw/default.aspx?cite=70A.305
[183] app.leg.wa.gov/wac/default.aspx?cite=173-303
[184] dor.wa.gov/sites/default/files/2022-03/CERCLAHazardousSubstances.pdf?uid=6408ff778e6d7

Concern for sensitive populations and species

After assessing available data to consider the factors below, as outlined in RCW 70A.350.020,[185]we found that cVMS are a concern for sensitive populations and sensitive species after assessing available data to consider the following factors:

(a) A chemical's or members of a class of chemicals' hazard traits or environmental or toxicological endpoints;

(b) A chemical's or members of a class of chemicals' aggregate effects;

(c) A chemical's or members of a class of chemicals' cumulative effects with other chemicals with the same or similar hazard traits or environmental or toxicological endpoints;

(d) A chemical's or members of a class of chemicals' environmental fate;

(e) The potential for a chemical or members of a class of chemicals to degrade, form reaction products, or metabolize into another chemical or a chemical that exhibits one or more hazard traits or environmental or toxicological endpoints, or both;

(f) The potential for the chemical or class of chemicals to contribute to or cause adverse health or environmental impacts;

(g) The chemical's or class of chemicals' potential impact on sensitive populations, sensitive species, or environmentally sensitive habitats;

(h) Potential exposures to the chemical or members of a class of chemicals based on:

  (i) Reliable information regarding potential exposures to the chemical or members of a class of chemicals; and

  (ii) Reliable information demonstrating occurrence, or potential occurrence, of multiple exposures to the chemical or members of a class of chemicals.

We concluded that cVMS are a concern for sensitive species and sensitive populations because of their hazards and exposure potential. cVMS are associated with reproductive and developmental toxicity, endocrine disruption, and aquatic toxicity.

People and wildlife may be exposed to cVMS. According to EPA, cVMS are high production volume chemicals. This is concerning because cVMS are also persistent in the environment, many are expected to bioaccumulate, they have the potential for long-range transport, and they have been identified as a chemical of concern for the Arctic.

Persistent chemicals are a concern in the environment because these chemicals do not readily break down. If we learn about toxic impacts after pollution has occurred, costly cleanups may

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[185] app.leg.wa.gov/RCW/default.aspx?cite=70A.350.020

be required. Some populations may have higher exposure if they use products containing cVMS, such as hair smoothing products.

The sections below describe our evaluation of this criteria and support our conclusion.

Hazards of priority chemical class

We evaluated data-rich chemicals within the class for hazards, including environmental and human health toxicological endpoints, and environmental fate, transport, and potential breakdown products. To identify these hazards, we used similar methods to those found in our 2022 Regulatory Determinations Report to the Legislature (Ecology, 2022).[186]

Hazard endpoints of concern are discussed below. Table 24 shows a more comprehensive list of potential hazards of cVMS. We identified hazard endpoints of concern if at least one member of the chemical class is either included on authoritative lists or scored as high or very high in hazard assessments. In some cases, we supplemented these endpoints with specific concerns that may be relevant to sensitive populations.

In general, cVMS are persistent in the environment, and they can bioaccumulate in organisms. Some cVMS are also associated with other hazards, such as reproductive and developmental toxicity, endocrine activity, and chronic aquatic toxicity. For cVMS, we also include a description of endocrine activity based on a publication by the Danish EPA. They concluded that the estrogenic activity of D4 may be relevant to humans in absence of opposing evidence (DEPA, 2022). While there is also some evidence that cVMS could be carcinogenic, data is limited and the relevance to humans is debatable (ToxServices, 2016a, 2017, 2018c, 2019a).

Reproductive and developmental toxicity

D4 is classified as a Category 2 reproductive toxicant by the European Chemicals Agency (ECHA) and is suspected of damaging fertility. In animal studies, D4 has been demonstrated to cause reproductive toxicity and observed effects included reduced mating, reduced fertility index, reduced live litter size, reduced mean number of pups, increased estrous cycle length, and reduction in the corpora lutea and number of pregnancies (ToxServices, 2018c). In a reproductive and developmental toxicity screening test, D3 was associated with a reduction in the number of implantation sites in exposed females and atrophy of seminal vesicles in males. The study also reported decreased litter size and litter weight (ToxServices, 2017).

Endocrine disruption

Several in vitro studies on human estrogen receptors and estrogen-mediated pathways showed D4 to be estrogenic (DEPA, 2022). There is also evidence from in vivo studies in animals that suggests D4 can lead to adverse effects on female reproduction, through an endocrine-mediated mode of action (DEPA, 2022). D4 was associated with reduction in luteinizing hormone and decreased ovulation in female rats, as well as other apparent changes in reproductive hormones following exposure to D4 (Quinn et al., 2007).

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[186] apps.ecology.wa.gov/publications/summarypages/2204018.html

Ecological toxicity

There is some variability in the ecological toxicity between the cVMS. None of the cVMS are expected to be acutely toxic to aquatic organisms based on available data (ToxServices, 2016a, 2017, 2018c, 2019a). However, D3 and D4 have been demonstrated to be chronic aquatic toxicants in studies in fish and aquatic invertebrates. D3 has a reported no observable effect concentration (NOEC) of less than 0.067 mg/L in rainbow trout (*Oncorhynchus mykiss*) (ToxServices, 2017). D4 has a reported NOEC of 0.0044 mg/L in rainbow trout (*Oncorhynchus mykiss*) and 0.0079 mg/L in water flea (*Daphnia magna*) (ToxServices, 2018c).

Environmental fate

Understanding the environmental impacts of chemicals includes assessing persistence, bioaccumulation, and known and potential breakdown products.

D4, D5, and D6 are all classified as persistent, bioaccumulative, and toxic (PBT) and as very persistent and very bioaccumulative substances (vPvB) by ECHA (ECHA, 2019).

D3, D4, D5, and D6 can undergo hydrolysis in the environment to form silanediols (*e.g.*, dimethylsilanediol), but this is limited by their poor water solubility (ToxServices, 2016a, 2017, 2018c, 2019a).

D3, D4, D5, and D6 are all persistent in the environment. Fugacity modeling suggests D6 will primarily partition to sediment with a half-life of 542 days and meets the EU registration, evaluation, authorization, and restriction of chemicals (REACH) criteria as very persistent (ToxServices, 2019a). A fugacity model is used to predict the behavior of a chemical in different compartments (*i.e.*, air, water, sediment, or soil) to determine its expected environmental fate (Mackay et al., 1992). D5 is capable of partitioning to air, water, or sediment compartments depending on its primary release to air, water, or soil. The most conservative experimental half-lives reported for D5 are 14.8 days in air, 733 days in water, and 3,100 days in sediment. Both Environment Canada and ECHA's Member State Committee concluded that D5 is very persistent in sediment, water, and air (ToxServices, 2016a).

D4 partitions to air, water, and sediment. D4 is included on the Canadian Environmental Protection Act Domestic Substance List (CEPA DSL) as persistent due to its expected half-life of approximately 9 days in air. ECHA has also concluded that D4 meets the criteria for a very persistent substance based its measured and predicted half-life in sediment of >180 days (ToxServices, 2018c).

D3 has a short hydrolysis half-life of less 23 minutes in water. Due to this rapid degradation, the aquatic toxicity studies are based on the hydrolysis products, and a study in fish suggest there is the potential for chronic aquatic toxicity of these degradation products. D3 has a predicted half-life of 21 days in air and is listed as persistent on the CEPA DSL (ToxServices, 2017).

Based on predictive modeling and an experiment result in rainbow trout, D3 is not expected to bioaccumulate. In contrast, D4, D5, and D6 all are likely to bioaccumulate in organisms. D6 has reported bioconcentration factors (BCFs) up to 12,632 L/kg in fish and 2,400 L/kg in invertebrates. BCF is the ratio of the amount of a chemical in an organism to the amount of that chemical in its surrounding environment. There is also evidence D6 biomagnifies up the aquatic food chain (ToxServices, 2019a). ECHA concluded D6 meets the criteria for a very bioaccumulative substance (ECHA, 2018b). D5 also reported BCFs up to 13,000 L/kg in fish, and ECHA concluded it meets the EU REACH criteria as a very bioaccumulative substance (ECHA, 2018a; ToxServices, 2016a). D5 is also listed on the Canadian Environmental Protection Act (CEPA) Domestic Substances List (DSL) as bioaccumulative. D4 has reported BCFs up to 19,000 L/kg in fish and the EU Member State Committee has concluded that D4 meets the criteria for a very bioaccumulative substance (ECHA, 2018c; ToxServices, 2018c).

Results from studies that examined the biomagnification potential of cVMS vary, with some reporting biomagnification while others suggest biodilution is occurring (Bernardo et al., 2022). These disparate results may reflect differences in behavior of cVMS depending on the specific food web studied or variations in study design.

Regarding the bioaccumulation data for D4, D5, and D6, the ECHA Member State Committee said, “The available information on biomagnification and trophic magnification factors (BMF/TMF) in the field, indicating that biodilution occurs in some food chains or in parts of some food chains, does not invalidate the other lines of evidence.” They concluded that D4, D5, and D6 all meet the very bioaccumulative criterion (ECHA, 2018a, 2018c, 2018b).

Referenced hazard assessments

The hazard assessments referenced in Table 24 are described in the Technical Methods chapter of this report. We reviewed each method for transparency and consistency in scoring methods and data requirements (Ecology, 2022). Using hazard assessments allows us to apply a consistent, non-biased approach to evaluating chemicals across multiple endpoints and levels of data. In this report, hazard assessments allow us to identify known and potential hazards of chemicals within the priority chemical classes.

D3, D4, D5, and D6 have existing GreenScreen® and SciveraLENS® GHS+ chemical hazard assessments and are scored as BM-1 or [Red] chemicals, indicating their use should be avoided (Scivera, 2023w, 2023u, 2023ag, 2023ac; ToxServices, 2016a, 2017, 2018c, 2019a).

- The GreenScreen assessments for hexamethylcyclotrisiloxane (CAS: 541-05-9), octamethylcyclotetrasiloxane (CAS: 556-67-2), decamethylcyclopentasiloxane (CAS:541-02-6) and dodecamethylcyclohexasiloxane (CAS: 540-97-6) are available from the ToxServices database[187] (ToxServices, 2016a, 2017, 2018c, 2019a).
- The SciveraLENS GHS+ assessments for hexamethylcyclotrisiloxane (CAS: 541-05-9), octamethylcyclotetrasiloxane (CAS: 556-67-2), decamethylcyclopentasiloxane (CAS:541-02-6) and dodecamethylcyclohexasiloxane (CAS: 540-97-6) are available in the SciveraLENS database[188] (Scivera, 2023ag, 2023w, 2023u, 2023ac).

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[187] database.toxservices.com/

[188] rapidscreen.scivera.com/

Table 24. Data-rich cyclic volatile methylsiloxanes with known and potential hazards.

Common name, associated CAS(s)	Known or potential hazards	Referenced hazard assessments	Relevant authoritative listings
Hexamethylcyclotrisiloxane (D3), CAS RN: 541-05-9	Carcinogenicity‡, reproductive toxicity‡, developmental toxicity‡, endocrine activity‡, chronic aquatic toxicity†, persistence†	GreenScreen® BM-1, SciveraLENS® [Red]	NA
Octamethylcyclotetrasiloxane (D4), CAS RN: 556-67-2	Carcinogenicity‡, reproductive toxicity‡, endocrine activity‡, systemic toxicity (repeat dose) ‡, chronic aquatic toxicity†, persistence†, bioaccumulation†	GreenScreen BM-1, SciveraLENS [Red]	EU—GHS H361f (Repro, Cat. 2, CMR), EU—GHS H410 (Aquatic Chronic 1), EU SVHC Candidate List—PBT
Decamethylcyclopentasiloxane (D5), CAS RN: 541-02-6	Carcinogenicity‡, systemic toxicity (single and repeat dose)‡, persistence†, bioaccumulation†	GreenScreen BM-1, SciveraLENS [Red]	EU SVHC Candidate List—PBT
Dodecamethylcyclohexasiloxane (D6), CAS RN: 540-97-6	Carcinogenicity‡, developmental toxicity‡, systemic toxicity (single dose)‡, persistence†, bioaccumulation†	GreenScreen BM-1, SciveraLENS [Red]	EU SVHC Candidate List—PBT

† Endpoints scored as high or very high in referenced hazard assessments
‡ Endpoints scored as moderate in referenced hazard assessments

Potential exposures to people and the environment

Human exposure

People are exposed to cVMS primarily through use of personal care products. cVMS have been detected in shampoos, conditioners, body lotions, and other products (Brothers et al., 2017; T. M. Tran et al., 2019; R. Wang, Moody, et al., 2009). In addition to personal care products, cVMS have been detected indoor air and dusts associated with 3D printer operations, residential renovation, waste processing operations, automobile interiors, and in hair salons (Gu et al., 2019; Hoang et al., 2023; Meng & Wu, 2015; T. M. Tran et al., 2018), indicating that there is exposure potential in a wide range of environments.

People are exposed to cVMS primarily through inhalation (T. M. Tran et al., 2019). Air concentrations are generally higher indoors than outdoors (Molinier et al., 2022; Yucuis et al., 2013). The average indoor air concentrations reported in research studies range over orders of magnitude and have high variability within one location over time (T. M. Tran et al., 2019). Dust is a potentially important exposure pathway. cVMS are found in dust in a variety of indoor environments, from homes, to schools, and industrial facilities (T. M. Tran et al., 2019). Concentrations in industrial settings can be especially high (Guo et al., 2021). Dermal uptake appears to be minimal (DEPA, 2014). However, products applied to the skin, such as antiperspirants and skin lotions, volatilize into surrounding air and result in inhalation exposure (Biesterbos et al., 2015; Mackay et al., 2015).

Little is known about dietary intake levels of cVMS in people. cVMS are present in some food contact materials, including baby bottle nipples and silicone cookware. Migration from these materials into liquids that simulate infant formula was very limited in one study (K. Zhang et al., 2012). Low but detectable migration into baked goods was observed in oven baking experiments with new silicone bakeware (Fromme et al., 2019). Mean concentrations of D3, D4, D5, and D6 in finished food ranged from 0.06 to 1.16 mg/kg. Baking did release cVMS into kitchen air, with peak concentrations when ovens were opened after baking. There is some potential for foods to be contaminated from environmental media. A research group in Spain detected cVMS in 40 market samples of fish at nanogram to microgram per kilogram levels, an order of magnitude less than the baked goods cited above (Sanchís et al., 2016).

Exposure to cVMS has not yet been analyzed by the CDC in NHANES national biomonitoring assessments. Researchers have reported D4, D5, and D6 in human plasma and breast milk in selected populations. In Chinese college students, plasma levels were roughly ten times higher in females in comparison to males (Guo et al., 2020). In another study by the same authors, Chinese infants had the highest plasma concentrations of D4, D5, and D6 relative to other age groups of children (Guo et al., 2021). Two cohorts of Norwegian women and one of German adults reported 18–85% detection frequency for D4 in plasma, with low frequency of detection of D5 and D6 (Fromme et al., 2015). A Swedish study that found one or more cyclic siloxane in 11 of 39 breast milk samples from Swedish women (Kaj & Andersson, 2005).

The available exposure data are not adequate to determine whether there are disproportionate patterns of exposure; however, other chemicals present in personal care products have been noted to result in higher exposure to women than men. cVMS are used in hair straightening products, disproportionately marketed towards women of color (Dodson et al., 2021). In a Chinese study, workers were more highly exposed than the general population (L. Xu et al., 2015). The Chinese study concerned industrial workers in automotive, textile, and building industries. Biomonitoring studies of salon workers who are potentially exposed to cVMS at work were not identified in our limited review, but relatively high concentrations of cVMS were found in hair salon air and dust in Vietnam (T. M. Tran et al., 2018).

Environmental exposure

cVMS are synthetic substances that do not naturally occur in the environment. Emissions of cVMS can occur through use of cosmetics and personal care products, degradation of silicone fluids, release from silicone materials, and emissions from sewage treatment plants and landfills (NICNAS, 2020). We did not find any data available on the general presence of cVMS in the Washington State environment.

However, concentrations in air have been measured at nearby Canadian sites in Whistler, BC and Ucluelet, BC. Concentrations reported at these sites were 117, 45, 6.4, and 1.5 ng/m^3 in Whistler, BC and 81, 44, 7.3, and 1.2 ng/m^3 in Ucluelet, BC, for D3, D4, D5, and D6, respectively (Genualdi et al., 2011). The concentrations reported for D3 and D4 at these locations were the highest, or among the highest, concentrations reported across all locations globally in the study. However, the authors suggest this may be due to long-range transport from Asia rather than nearby sources (Genualdi et al., 2011).

cVMS can also be present in wastewater, from personal care products and cosmetics that are washed down the drain. Although cVMS are removed during wastewater treatment processes, removal may be incomplete in effluents. During wastewater treatment, cVMS are generally either volatized to the atmosphere or absorbed to sludge. Those that remain in effluent are thought to primarily absorb to sediment due to being very hydrophobic (NICNAS, 2020). For example, a level 3 fugacity calculation for wastewater released from a sewage treatment plant predicts 94% of D5 emitted to water in effluent would partition to sediment (Mackay et al., 2015). cVMS adsorbed to sludge may also contaminate soils if applied as biosolids. However, this is expected to be a relatively small fraction of those present in the untreated influent, and the levels reported in biosolids are highly variable (Mackay et al., 2015).

Once released, cVMS have the potential for long distance transport in the environment. They are globally distributed in the atmosphere, and air sampling in the Arctic has found D3 and D4 in remote areas. Additionally, D3, D4, D5, and D6 were detected in various samples of air and sediment, as well as in fish, birds, and whales in the European Arctic. In some cases, these were detected at locations far from any local sources, suggesting long range transport does occur (Rücker & Kümmerer, 2015). The presence of cVMS has also been reported in soils, lichens, mosses, and grass in terrestrial Antarctica and in phytoplankton and krill from the Southern Ocean; the study authors postulated this could be due to atmospheric deposition by snow events (Sanchís et al., 2015).

Potential for cumulative and aggregate effects

Exposure to chemicals can result in aggregate effects and cumulative effects. Aggregate effects can occur when people or other organisms are exposed to a single chemical from multiple routes, pathways, and sources (e.g., house dust, drinking water, air, and food). Cumulative effects can occur when people or other organisms are exposed to multiple chemicals simultaneously. These cumulative exposures may come from multiple exposure routes, pathways, and sources, or just a single source.

Potential for aggregate effects

There is potential for aggregate exposures to cVMS from use in consumer products. In particular, use of personal care products can result in indoor air and dust contamination in a range of environments. Ingestion via some foods is possible, although less is known about exposure levels via this route. People often use multiple personal care products simultaneously (Capela et al., 2016; Dudzina et al., 2014). For example, the average woman uses eight different beauty products every day (Dodson et al., 2021). People who work with personal care products, such as salon workers, can also experience occupational exposure to cVMS.

Infants can have aggregate exposure across routes of exposure—from inhaling cVMS present in skin products marketed for infant use, ingesting them via breast milk, and inhaling and ingesting house dusts. In a Chinese study of cVMS in plasma, infants had higher concentrations than older children (Guo et al., 2021).

Cyclic siloxanes have been found in air and water and have the potential for long-range transport. Wildlife can be exposed from cVMS in both the air and water. While there is limited data for the detection of cVMS in sensitive species in Washington, cVMS have been detected in river fish in Spain. In this study, nearly all fish tested contained cVMS (Sanchís et al., 2016).

We concluded that there is the potential for aggregate effects because people and wildlife can be exposed to cVMS from multiple sources. cVMS exposure in the air, water, and potentially food can contribute to exposures from consumer products. These exposures add up and can contribute to adverse impacts.

Potential for cumulative effects

People exposed to cVMS are also exposed to other chemicals that can impact the endocrine system. An analysis of over 80 chemicals in 50 pregnant women found multiple chemicals in blood and serum that have known impacts on the endocrine system (Buck Louis et al., 2019). While cVMS were not included in this analysis, this study demonstrates that exposure to cVMS occurs at the same time as exposure to other chemicals. Some of these other chemicals share activity toward estrogen receptors, which has been demonstrated for some cVMS chemicals. This is further supported by an analysis of personal care and beauty products marketed towards Black women. The analysis found cVMS in products that also contained other endocrine disruptors, such as phthalates, parabens, and bisphenols (Helm et al., 2018).

Like humans, wildlife (including sensitive species) are exposed to multiple chemicals at the same time, including other chemicals that can disrupt the endocrine system (Conn et al., 2020; Meador et al., 2016). For example, a recent analysis of over 200 organic contaminates of emerging concern in Puget Sound supports the conclusion that Puget Sound wildlife are exposed to a wide range of contaminants from multiple sources (James et al., 2020).

We concluded that there is the potential for cumulative effects because people and wildlife are exposed to cVMS in addition to other chemicals that can impact similar biological systems.

Potential to contribute adverse impacts

In sensitive populations

When people are exposed to chemicals with known or suspected toxicities, there is the potential for adverse impacts. The impacts may be greater when people are also exposed to other environmental contaminants that impact the same biological systems. People, including sensitive populations, are exposed to cVMS. Exposure to cVMS is associated with reproductive and developmental toxicity and endocrine disruption.

Considering exposure patterns and hazard together suggests that effects on reproductive health of women exposed through work or high use of personal care products may be an impact of concern in a sensitive population. Infants may also be a sensitive population for impacts of cVMS. To date, data on developmental effects is limited, but a new publication identifies neurodevelopmental effects of prenatal exposure to D4, in a study of laboratory mice (D. N. Tran et al., 2021). Further study is needed but, given the established evidence of infant exposure to cVMS (Guo et al., 2021), there is concern for potential developmental impacts.

We did not identify epidemiological studies of health impacts of cyclic siloxane in humans, and U.S. health protective guidance levels have not been established yet. However, D4, D5, and D6 are high production volume chemicals, persistent in the environment, with demonstrated exposure to people and toxic properties. Therefore, cVMS have the potential to contribute to adverse impacts in humans, including sensitive populations such as the elderly, workers, people of childbearing age, developing fetuses, and children.

In sensitive species

When chemicals are released into the environment, they have the potential to expose sensitive species, such as forage fish, salmon, or orcas. If these chemicals have toxicity, there is the potential to contribute to adverse impacts in sensitive populations.

cVMS are high production volume chemicals (D4, D5, and D6), persistent in the environment, and have the potential for long-range transport. Persistent chemicals are problematic because they do not readily breakdown in the environment. That means as more persistent chemicals are released, environmental concentrations will increase. Chemicals with the potential for long-range transport can become global contaminants (Xie et al., 2022). If we learn about toxic impacts after contamination has occurred, costly cleanups are necessary to protect people and the environment because the chemicals will not break down on their own. cVMS are already widely found in the environment and have known and potential hazards that can impact sensitive species, such as aquatic toxicity and endocrine disruption.

cVMS toxicity in aquatic organisms is thought to occur through a narcotic mode of action, so minimal or no toxicity is expected until a critical body burden is reached (Fairbrother & Woodburn, 2016; Redman et al., 2012). This, in combination with the low water solubility of cVMS, means that they are not thought to cause acute toxicity in aquatic organisms.

The chemical properties of cVMS indicate they primarily partition to sediments in the environment. This leads to accumulation of cVMS in benthic invertebrates and other aquatic life, likely due to ingestion (Redman et al., 2012). Lower toxicity to water column organisms is expected due to the low water solubility and therefore likely lower accumulation within water column dwelling species (Fairbrother & Woodburn, 2016).

Some cVMS have demonstrated chronic aquatic toxicity in organisms. D3 has a short-reported hydrolysis half-life of up to 23 minutes in water and degrades to hexamethyltrisiloxanediol. Because of this, a chronic aquatic toxicity study that reported a 14-day NOEC of less than 0.067 mg/L in rainbow trout may indicate toxicity of this hydrolysis product rather than only for D3 (ToxServices, 2017).

D4 is classified by ECHA as a Category 1 chronic aquatic toxicant, described as very toxic to aquatic life with long lasting effects. This was based on the lowest chronic aquatic toxicity value of 0.0079 mg/L in aquatic invertebrates (*Daphnia magna*) and supported by a NOEC of 0.0044 mg/L in fish (*Oncorhynchus mykiss*). The chronic toxicity observed in aquatic organisms, combined with the persistence of cVMS and the bioaccumulative properties of D4, suggests there is a potential for adverse effects to occur in aquatic organisms. D4 is classified as a persistent, bioaccumulative, and toxic substance by ECHA (ECHA, 2018c).

D5 and D6 also contain D4 as an impurity. Based on this, ECHA considers D5 and D6 as PBTs when concentrations of D4 are greater than or equal to 0.1% (ECHA, 2018b, 2018a).

Chapter 8: Technical Support for 6PPD

Chapter overview

N-(1,3-Dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD) is used as an antioxidant, antiozonant, and polymer stabilizer for rubber products. 6PPD forms several transformation products, including 6PPD-quinone (6PPD-q). Both 6PPD and 6PPD-q have concerning hazard properties, and 6PPD-q has been shown to be extremely toxic in coho salmon (*Oncorhynchus kisutch*).

6PPD meets the high priority chemical criteria because it is:

1. A hazardous substance in Washington.
2. A concern for sensitive species and populations.

6PPD was selected as a priority chemical for this cycle of Safer Products for Washington because 6PPD or 6PPD-q is highly toxic to salmon and likely other aquatic species, has growing human health concerns, and is found in the environment and people's bodies. Salmon are an important species for Washington State, culturally, economically, and ecologically.

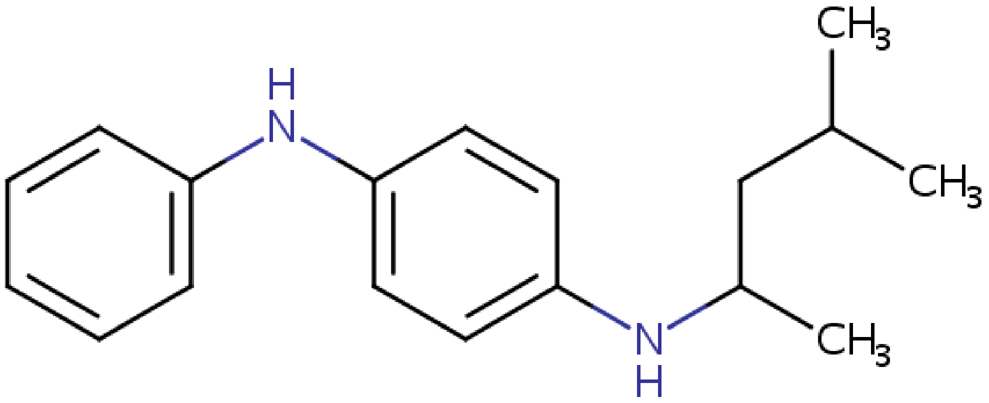
6PPD-q has been shown to kill salmon at extremely low concentrations. Concentrations of 6PPD-q above those known to kill salmon have been measured in Washington State. Reducing sources and uses of 6PPD-q in Washington is important for protecting aquatic life and particularly critical for salmon because they only reproduce after they return to freshwater.

Rationale and references are described below.

Priority chemical description

This report identifies N-(1,3-Dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD, CAS number 793-24-8) as a priority chemical. The molecular structure of 6PPD is shown in Figure 7. 6PPD is used as an antioxidant, antiozonant, and polymer stabilizer for rubber products.

Figure 7. Molecular structure of 6PPD.



Meeting the statutory requirements

The statute requires that priority chemicals or chemical classes meet specific criteria. Priority chemical classes must meet at least one of the criteria described in RCW 70A.350.020[189] and listed below.

- A member of the chemical class has been identified by Ecology as a chemical of concern, specifically:
  - A chemical of high concern to children under Chapter 70A.430 RCW[190] or
  - A persistent, bioaccumulative and toxic chemical under Chapter 70A.300 RCW.[191]
- A member of the chemical class is regulated in relevant consumer product statutes in Washington.
- A member of the chemical class is a hazardous substance under Chapter 70A.300 RCW or Chapter 70A.305 RCW.[192]
- Members of the chemical class are a concern for sensitive populations and sensitive species.

6PPD meets at least one of these criteria. Each of the criteria are discussed below.

Chemicals of concern by Ecology

Chemical classes with members that are chemicals of high concern to children (CHCC) identified under Chapter 70A.430 RCW meet the criteria for designation as priority chemical class under RCW 70A.350.020(1)(a) RCW. Ecology identifies chemicals of high concern to children based on their hazards and exposure potential in Chapter 173-334 WAC.[193] 6PPD is not listed as a chemical of high concern to children in Chapter 173-334 WAC.

Chemical classes with members identified as persistent, bioaccumulative, and toxic substances (PBTs) under Chapter 70A.300 RCW meet the criteria for designation as a priority chemical class under RCW 70A.350.020(1)(b). Ecology identifies chemicals that are persistent, bioaccumulative, and toxic under WAC 173-333-310.[194] 6PPD is not on the PBT list in WAC 173-333-310.

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[189] app.leg.wa.gov/rcw/default.aspx?cite=70A.350.020
[190] app.leg.wa.gov/rcw/default.aspx?cite=70A.430
[191] app.leg.wa.gov/rcw/default.aspx?cite=70A.300
[192] app.leg.wa.gov/rcw/default.aspx?cite=70A.305
[193] apps.leg.wa.gov/wac/default.aspx?cite=173-334
[194] app.leg.wa.gov/wac/default.aspx?cite=173-333-310

Regulation in consumer products under relevant Washington statutes

Chemical classes with members regulated in consumer products under Chapters 70A.430,[195] 70A.405,[196] 70A.222,[197] 70A.335,[198] 70A.230,[199] or 70A.400 RCW[200] meet the criteria for designation as a priority chemical class under RCW 70A.350.020(2)(a).[201] 6PPD is not currently regulated under any of these statutes.

Hazardous substances in Washington

Under Chapter 70A.350 RCW,[202] chemical classes with members that are hazardous substances under Chapter 70A.300 RCW[203] (Hazardous Waste Management Act) or Chapter 70A.305 RCW (Model Toxics Control Act) can be considered priority chemicals. 6PPD and 6PPD-q are considered hazardous substances under Chapter 70A.300 RCW and therefore meet the criteria for priority chemical designation under RCW 70A.350.202(2)(b).

Hazardous substances are defined in RCW 70A.300.100[204] to include any material that exhibits any of the characteristics or criteria of dangerous wastes identified under Chapter 173-303 WAC.

6PPD and its environmental transformation product, 6PPD-q, meet the toxicity criteria under WAC 173-303-100.[205] The WAC 173-303-100 criteria considers the lethal concentration in fish, rats, and rabbits. Available data for 6PPD identifies an LC50 of 0.14 mg/L in steelhead trout (ToxServices, 2021b), which corresponds to toxic category B. Chemicals in toxic category B have fish LC50s between 0.1 and 1 mg/L. A mixture that is 100% 6PPD would be assigned the dangerous waste number WT01 and the waste designates as extremely hazardous waste. 6PPD-q has an LC 50 of less than 0.1 µg/L (0.0001 mg/L) in coho salmon. This LC50 corresponds to toxic category X. Chemicals in toxic category X have fish LC50s less than 0.1 mg/L. A mixture of 100% 6PPD-q would designate as extremely hazardous waste and be assigned the dangerous waste number WT01. This section describes book designation. Wastes can also be designated through toxicity testing of specific wastes.

Chemical of concern for sensitive populations and species

After assessing available data to consider the factors below, as outlined in RCW 70A.350.020,[206] we found that we found that 6PPD is a concern for sensitive populations and sensitive species.

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[195] app.leg.wa.gov/rcw/default.aspx?cite=70A.430
[196] apps.leg.wa.gov/rcw/default.aspx?cite=70A.405
[197] app.leg.wa.gov/rcw/default.aspx?cite=70A.222
[198] app.leg.wa.gov/rcw/default.aspx?cite=70A.335
[199] app.leg.wa.gov/rcw/default.aspx?cite=70A.230
[200] app.leg.wa.gov/rcw/default.aspx?cite=70A.400
[201] app.leg.wa.gov/rcw/default.aspx?cite=70A.350.020
[202] app.leg.wa.gov/rcw/default.aspx?cite=70A.350
[203] app.leg.wa.gov/rcw/default.aspx?cite=70A.300
[204] app.leg.wa.gov/rcw/default.aspx?cite=70A.300.100
[205] app.leg.wa.gov/wac/default.aspx?cite=173-303
[206] app.leg.wa.gov/rcw/default.aspx?cite=70A.350.020

(a) Hazard traits or environmental or toxicological endpoints;

(b) Aggregate effects;

(c) Cumulative effects with other chemicals with the same or similar hazard traits or environmental or toxicological endpoints;

(d) Environmental fate;

(e) Breakdown and degradation products;

(f) Potential to contribute to or cause adverse health or environmental impacts;

(g) Potential impact on sensitive populations, sensitive species, or environmentally sensitive habitats;

(h) Potential exposures based on:

(i) Reliable information regarding potential exposures to the chemical or members of a class of chemicals; and

(ii) Reliable information demonstrating occurrence, or potential occurrence, of multiple exposures to the chemical or members of a class of chemicals.

We concluded that 6PPD is a concern for sensitive species and populations based on its hazards and exposure potential. Both 6PPD and 6PPD-q have concerning hazard properties, including aquatic toxicity and reproductive toxicity. However, 6PPD-q has been shown to be extremely toxic in coho salmon (*Oncorhynchus kisutch*).

Salmon are an important species for Washingtonians, culturally, economically, and ecologically. 6PPD-q has been shown to kill salmon at extremely low concentrations. Concentrations of 6PPD-q above those known to kill salmon have been measured in Washington State. Reducing sources and uses of 6PPD-q in Washington is critical for protecting aquatic life, but particularly important for salmon because they only reproduce after they return to freshwater.

Recently, human exposure data has shown that people are also exposed to 6PPD. Because 6PPD is a reproductive toxicant, this is a concern for sensitive populations.

The sections below describe our evaluation of this criteria and support our conclusion.

Hazards of 6PPD

We evaluated data-rich chemicals within the class for hazards, including environmental and human health toxicological endpoints, and environmental fate, transport, and potential breakdown products. To identify these hazards, we used similar methods to those found in our 2022 Regulatory Determinations Report to the Legislature (Ecology, 2022).[207]

Hazard endpoints of concern are discussed below. Table 25 shows a more comprehensive list of potential hazards of 6PPD and 6PPD-q. We identified hazard endpoints of concern if at least one member of the chemical class is either included on authoritative lists or scored as high or very high in hazard assessments. In some cases, we supplemented these endpoints with specific concerns that may be relevant to sensitive populations.

6PPD and 6PPD transformation products are associated with several hazard traits with the potential to cause adverse impacts to humans and the environment. 6PPD is toxic to reproduction, has high persistence and bioaccumulation potential, and is very toxic to aquatic organisms.

Besides the hazards of 6PPD itself, 6PPD can transform into a wide variety of transformation products upon exposure to ozone (Hu et al., 2022; Klöckner et al., 2021). The purpose of 6PPD in products is to act as an antiozonant and antioxidant. By virtue of this purpose and the mechanism of action, 6PPD transformation products are expected and have previously been found in the environment (Zhao, Hu, Tian, et al., 2023).

The transformation product that has undergone the most investigation is 6PPD-q. 6PPD-q is extremely toxic to certain salmonids, including coho salmon, where it is responsible for pre-spawn mortality causing widespread die-offs in migrating populations. The hazards of 6PPD-q are an active area of research, spurred in part by the findings on coho salmon toxicity. Recent papers have suggested it has bioaccumulation and genotoxicity potential (Wu et al., 2023). Papers also suggested 6PPD-q can induce hepatotoxicity in mice, where the proposed hepatotoxicity was caused by 6PPD-q inducing abnormal glycolipid metabolism that led to macrophage infiltration in the liver (Fang et al., 2023).

Reproductive and developmental toxicity

6PPD was associated with increased gestation length or dystocia (*i.e.*, difficult birth) in multiple studies on reproductive effects in rats (ECHA, n.d.-b; ToxServices, 2021b). In one study, female Sprague-Dawley rats exposed to 6PPD died or were euthanized near the point of death, and the authors attributed the deaths to prolonged labor or dystocia. These findings are consistent with classification as a Globally Harmonized System (GHS) Category 1B reproductive toxicant.

6PPD is classified by the MAK-Commission in Pregnancy Risk Group C and was associated with decreased fetal body weights or increased post-implantation loss in animal studies (Deutsche Forschungsgemeinschaft, 2018; ToxServices, 2021b). 6PPD also was reported to affect pubertal development and thyroid parameters in a study of juvenile female Sprague-Dawley rats, and the authors suggested this effect was endocrine mediated (ToxServices, 2021b).

A recent study of pregnant mice also found that 6PPD and the transformation product 6PPD-q can cross the placenta and expose the developing embryo (Zhao, Thomas, Zylka, et al., 2023).

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[207] apps.ecology.wa.gov/publications/summarypages/2204018.html

The researchers detected 6PPD and 6PPD-q in the bodies and brains of mouse embryos, suggesting these chemicals can cross the blood-brain barrier as well.

Endocrine disruption

As stated above, 6PPD has been associated with effects on female pubertal development, in a study of juvenile Sprague-Dawley rats, and the effects may be endocrine mediated. 6PPD was also found to be active in 4 of 6 estrogen receptor assays, 7 of 8 androgen receptor assays, 2 of 2 steroidogenesis assays, and 2 of 6 thyroid receptor assays in vitro, as part of EPA's Endocrine Disruptor Screening Program for the 21st Century. EPA ToxCast computational modeling also suggested 6PPD may be endocrine active (ToxServices, 2021b).

Ecological toxicity

6PPD is classified as very toxic to aquatic life by Japan, Korea, and New Zealand. Environment Canada classifies it as inherently toxic to the environment due to acute toxicity observed in multiple species of fish (ToxServices, 2021b). The lowest LC50 reported for 6PPD is 0.028 mg/L in Japanese rice fish (*Oryzias latipes*) (NITE, n.d.).

The environmental transformation product 6PPD-q has also been shown to be acutely toxic to juvenile coho salmon (*Oncorhynchus kisutch*) at very low concentrations, with a 24-hour LC50 of 0.000095 mg/L (Tian et al., 2022). Rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*) are also sensitive to 6PPD-q with LC50s of 0.001 mg/L (72-hour) and 0.00059 mg/L (24-hour), respectively (Brinkmann et al., 2022). 6PPD-q exposure to these fish leads to elevated hematocrit, disrupted energy metabolism, and abnormal behavior such as hovering close to the water surface, gasping, spiraling, and accelerated opercular movements (Brinkmann et al., 2022).

In addition to the acute toxicity of 6PPD and its transformation product 6PPD-q, chronic aquatic toxicity is also observed with a reported 30-day no observable effect concentration (NOEC) of 0.004 mg/L in Japanese rice fish (*Oryzias latipes*) for 6PPD (ToxServices, 2021b). 6PPD is classified as very toxic to aquatic life with long lasting effects by Japan, Korea, and New Zealand.

Environmental fate

6PPD forms several breakdown products, including 4-hydroxydiphenylamine, phenylbenzoquinone imine, 1,3-dimethylbutylamine aniline, 1,4-benzoquinone, 1,3-dimethylbutylamine, aniline, and 6PPD-q (ToxServices, 2021b). Up to 25 6PPD transformation products have been identified, with 6PPD-q, 1,3-DMBA, and two uncharacterized products called TP 274 and TP 282b frequently detected in roadway runoff and receiving waters (Zhao, Hu, Gonzalez, et al., 2023; Zhao, Hu, Tian, et al., 2023). As discussed above, 6PPD-q has been shown to be extremely toxic in coho salmon (*Oncorhynchus kisutch*) (Tian et al., 2022).

Fugacity modeling predicts that 6PPD will primarily partition to soil and sediment due to its low water solubility (ToxServices, 2021b). A fugacity model is used to predict the behavior of a chemical in different compartments (*i.e.*, air, water, sediment, or soil) to determine its expected environmental fate (Mackay et al., 1992).

No soil degradation data is available for 6PPD, however there is data available for a structurally similar compound, 1,4-benzenediamine,N-(1,4-dimethylpentyl)-N'-phenyl-. That compound was found to only achieve partial mineralization and is presumed to primarily degrade to intermediate transformation products (ToxServices, 2021b).

6PPD is known to form the aquatic toxicant 6PPD-q as an environmental transformation product. 6PPD-q has been detected in California waterways, which indicates it is sufficiently persistent to potentially expose aquatic organisms (DTSC, 2022). In water, 6PPD-q is more persistent than 6PPD (with a half-life of approximately days or weeks versus hours) (Di et al., 2022; Hiki & Yamamoto, 2022), although pH and temperature greatly affect the reaction rate, where a lower pH and higher temperature yield the longest persistence.

The structurally similar surrogate chemical, 1,4-benzenediamine,N-(1,4-dimethylpentyl)-N'-phenyl- was reported to have measured bioconcentration factors of 1,700 and 1,500 in carp exposed at 0.001 and 0.01 mg/L, respectively. These results for a strong surrogate chemical suggest that 6PPD is likely to bioaccumulate (ToxServices, 2021b). In a study of lettuce plants, 6PPD and 6PPD-q leached from tire wear particles into a nutrient solution were reported to accumulate in the leaves and roots of the lettuce plants over a 14-day period (Castan et al., 2023). Another study detected 6PPD and 6PPD-q in fish samples from a food market in China (Ji, Li, et al., 2022). Together, these studies also suggest elimination of 6PPD and 6PPD-q may be slower than uptake in some plants and animals.

Referenced hazard assessments

The hazard assessments referenced in Table 25 are described in the Technical Methods chapter of this report. We reviewed each method for transparency and consistency in scoring methods and data requirements (Ecology, 2022). Using hazard assessments allows us to apply a consistent, non-biased approach to evaluating chemicals across multiple endpoints and levels of data. In this report, hazard assessments allow us to identify known and potential hazards of chemicals within the priority chemical classes.

6PPD scored as a Benchmark-1 chemical in a GreenScreen® hazard assessments; indicating its use should be avoided (ToxServices, 2021b).

In the GreenScreen assessment, 6PPD was assigned hazard scores of high for reproductive toxicity, skin sensitization, persistence, and bioaccumulation. 6PPD was also assigned hazard scores of very high for acute aquatic toxicity and chronic aquatic toxicity (ToxServices, 2021b).

The GreenScreen assessment for 6PPD is available on the Research and Proposed Alternatives to 6PPD informational site (ToxServices, 2021b).[208]

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[208] www.ezview.wa.gov/site/alias__1962/37732/research_and_proposed_alternatives_to_6ppd.aspx

Table 25. Known and potential hazards of 6PPD and 6PPD-q.

Common name, associated CAS(s)	Known or potential hazards	Referenced hazard assessments	Relevant authoritative listings
N-(1,3-dimethylbutyl)-N′-phenyl-p-phenylenediamine (6PPD), CASRN: 793-24-8	Acute and chronic aquatic toxicity, reproductive toxicity, skin sensitization, persistence, bioaccumulation	GreenScreen® BM-1	MAK (Sensitizing Substance Sh—Danger of skin sensitization)
N-(1,3-Dimethylbutyl)-N'-phenyl-p-phenylenediamine-quinone (6PPD-q), CASRN: 2754428-18-5 (relevant environmental transformation product)	Acute aquatic toxicity, chronic aquatic toxicity	NA	NA

Potential exposures to people and the environment

Human exposure

People are exposed to 6PPD and 6PPD transformation products through inhalation, ingestion, and skin contact from environmental contamination and direct contact with products.

6PPD and 6PPD-q are not monitored in the National Health and Nutrition Examination Survey (NHANES) and other routine biomonitoring surveillance programs. We are aware of only one research report that demonstrates exposure to 6PPD and 6PPD-q in humans (Du et al., 2022). Both 6PPD and 6PPD-q were detected in 60–100% of urine samples, with highest concentrations in pregnant people (median 0.068 ng/mL 6PPD and 2.91 ng/mL 6PPD-q), compared to other adults (0.018 and 0.40 ng/mL) and children (0.015 and 0.076 ng/mL). The study did not address potential sources of exposure. However, a separate study measured 6PPD-q at low but detectable levels in 81% of PM2.5 (particle whose diameter is 2.5 µm or less) samples collected from urban locations in China (Y. Zhang et al., 2022). The factors that resulted in higher biomarkers of exposure in pregnant women relative to other population groups in the Du et al. study have not been identified.

The main sources and pathways of human exposure are not conclusively established. Inhaling particles and dust is a likely exposure pathway. A study estimated the total human exposure to paraphenylenediamines and their related quinones from air particles and roadside dust (G. Cao et al., 2022). The derived estimates suggest that ingestion and skin contact with dust may be important routes of exposure.

There is also some limited evidence that dietary sources can potentially add to human exposure. 6PPD and 6PPD-q can be taken up by lettuce plants under hydroponic growth conditions. If 6PPD or transformation products of 6PPD are present in soil, the soil could contaminate food crops. Soil could potentially be contaminated from roadside dust, runoff, or biosolids that contain 6PPD (Castan et al., 2023). 6PPD and 6PPD-q were detected in a small sample of fish for sale at a Chinese food market (Ji, Li, et al., 2022) and in a Chinese source for drinking water (R. Zhang et al., 2023).

Tire wear particles (TWP) are generated at an estimated 2.5 to 4.7 kilograms (kg) per capita per year (DTSC, 2022). Overall, increases in vehicle miles traveled results in increased TWP generation. Some primary TWP and re-entrained road dust containing TWP can be detected in respirable fractions of airborne particulate matter (X. Wang et al., 2023). People who live, work, play, or go to school near busy roadways have higher exposure to traffic related emissions, including non-tailpipe emissions. Further, communities with elevated exposure to airborne particulate matter, and by association elevated exposure to the tire wear components of particulate matter, are more likely to have lower socio-economic status (Jbaily et al., 2022; Shen et al., 2022).

Shredded tire materials used for crumb rubber infill in turf playfields are another potential exposure pathway for 6PPD and 6PPD-q. Children and adults who participate in sports and other activities on these fields are exposed to rubber tire components through inhalation, inadvertent ingestion, and skin contact. 6PPD has been found in playground dust (R. Liu et al., 2019; Y. J. Zhang et al., 2022). Experiments mixing crumb rubber with laboratory liquids that mimic body fluids suggest that 6PPD can migrate from crumb rubber into sweat or digestive tract fluids. Two reports found that 6PPD migrated into synthetic digestive fluid (Armada et al., 2023; NTP, 2019). The amount of 6PPD in the synthetic digestive fluid was not measured by Armada et al. Concerning sweat and potential exposure through skin, a European study of turf field infill reported migration of 6PPD from field samples into a synthetic sweat fluid (Schneider et al., 2020). Levels in the sweat appeared low, but the authors concluded that amines, including 6PPD, exhibited “high migration.”

Consumer products other than tires also represent a potentially important exposure source. PPD compounds and derivatives are found in consumer products made with rubber elastomers, including lab stoppers, doormats, shoe soles, and rubber garden hoses (Liang et al., 2022; Zhao, Hu, Gonzalez, et al., 2023).

Environmental monitoring data

As 6PPD is ubiquitous, it and its transformation products have been detected in various types of environmental media samples from countries around the world (G. Cao et al., 2022; Challis et al., 2021; Johannessen et al., 2021; Klöckner et al., 2021; Rauert, Charlton, et al., 2022; Rauert, Vardy, et al., 2022; Tian et al., 2021).

As discussed above, 6PPD is designed to react with ozone and other oxidants, so we know that transformation products will form under normal conditions. In addition, we know that 6PPD migrates to the surface of rubber products as it reacts, so rubber particles in the environment will likely continue to serve as sources of 6PPD and 6PPD transformation products for the foreseeable future.

6PPD and 6PPD-q are most prevalent in roadway runoff, where almost all 6PPD-q detections are above the reported LC50 for coho salmon of 0.000095 mg/L, and often exceed the LC50 of brook trout and rainbow trout as well (G. Cao et al., 2022; Challis et al., 2021; Tian et al., 2022; R. Zhang et al., 2023). 6PPD and 6PPD-q have also been detected in multiple receiving waters, including streams and rivers (Johannessen et al., 2022; Rauert, Charlton, et al., 2022; H.-Y.

Zhang et al., 2023; R. Zhang et al., 2023). Concentrations reported by Johannessen et al., 2022 exceeded the LC50 value for coho salmon.

In addition to roadway runoff and receiving waters, 6PPD and 6PPD transformation products also make their way into snow on the road (Challis et al., 2021; Maurer et al., 2023); standing water on roads (Nedrich, 2022); wastewater treatment plant influent and effluent (Maurer et al., 2023; Seiwert et al., 2022; H.-Y. Zhang et al., 2023); and river, estuary, coastal, and deep-sea sediment (Zeng et al., 2023).

Given the tendency of tires to wear and create small particles, it is no surprise that 6PPD and 6PPD-q have also been shown to occur in multiple types of dust. Concentrations have been highest in road dust (Hiki & Yamamoto, 2022) but have also been found in parking lot dust, house dust, urban PM2.5, electronic waste dust, and indoor dust (G. Cao et al., 2022; W. Huang et al., 2021; R. Liu et al., 2019; W. Wang et al., 2022; Y. Zhang et al., 2022; Y. J. Zhang et al., 2022).

Besides 6PPD and 6PPD-quinone, many other 6PPD ozonation products have been identified and detected in environmental samples (Challis et al., 2021; Hu et al., 2022; Klöckner et al., 2021). The toxicity of most of these transformation products has not been investigated.

Potential for cumulative or aggregate effects

Exposure to chemicals can result in aggregate effects and cumulative effects. Aggregate effects can occur when people or other organisms are exposed to a single chemical from multiple routes, pathways, and sources (*e.g.*, house dust, drinking water, air, and food). Cumulative effects can occur when people or other organisms are exposed to multiple chemicals simultaneously. These cumulative exposures may come from multiple exposure routes, pathways, and sources, or just a single source.

Potential for aggregate effects

6PPD is released into the environment through multiple pathways, and transformation in the environment can lead to transformation products concentrating in different media. Wildlife can be exposed to 6PPD and 6PPD transformation products through water, sediment, particulates, and air. These aggregate exposures have the potential to lead to aggregate impacts.

Inhalation of particulate matter or dust particles and inadvertent ingestion of dusts or rubber particles likely contribute to aggregate exposures. Although the presence of 6PPD in food and drinking water is not yet clearly documented, these sources would add to aggregate exposures.

Limited data show that 6PPD and 6PPD-q may be present in foods such as fish (including the Snakehead, Weever, and Spanish Mackerel) (Ji, Li, et al., 2022). Lettuce plants can take up tire wear contaminants from liquid media, raising the concern that food crops could be an exposure route if grown in soils contaminated by road dusts with 6PPD and transformation products (Castan et al., 2023). It is not known if tire dust can contaminate food crops.

Dermal exposure is possible too, especially to children participating in sports on crumb rubber playfields. Groups of people who are more exposed to contaminated food, water, or dust may be at higher risk of aggregate impacts from 6PPD and 6PPD transformation products.

We concluded that there is the potential for aggregate exposures to 6PPD because people and wildlife can be exposed from multiple sources. Wildlife is exposed to 6PPD and its transformation products through water and air. People can also be exposed when interacting with products containing 6PPD.

Potential for cumulative effects

Wildlife, including sensitive species, are exposed to 6PPD and 6PPD-q as well as other environmental contaminants (Conn et al., 2020; Meador et al., 2016). In fact, untargeted analyses of chemicals in stormwater have identified unique indicators of chemical contamination from urban stormwater (Peter et al., 2022).

Broadly, tire leachate (not 6PPD or 6PPD transformation products specifically) has also been shown to be acutely and chronically toxic to a broad range of aquatic species (Leazer, 2022; Page et al., 2022; Shin et al., 2022). 6PPD and 6PPD-q have not been specially tested on a number of these species. However, due to the high toxicity in many species that it has been tested on, it is likely that 6PPD contributes to the toxicity of tire leachate in at least some of these instances. In addition, consumption of TWP has been shown to expose aquatic species to the chemicals in tires, including 6PPD (Masset et al., 2022), and the addition of other chemicals, such as salt, increases the toxicity of 6PPD towards some aquatic species (Klauschies & Isanta-Navarro, 2022). The cumulative exposures described here have the potential to contribute to cumulative impacts in salmon.

There is also potential for cumulative effects in people because exposure via tire wear particles, traffic corridors, occupational exposure within tire factories, and crumb rubber in playfields results in co-exposure to highly complex mixtures of the chemicals that are present in tires and tire wear by-products as well as other traffic-related pollutants. Some chemicals in these mixtures that have potential to cause cumulative impacts from combined exposure with 6PPD include tire-associated chemical classes such as polycyclic aromatic hydrocarbons (PAHs), plasticizers, antioxidants, vulcanization accelerators, benzothiazoles, chlorinated paraffins, metals, and polychlorinated biphenyls (PCBs) (Armada et al., 2022, 2023). Many substances in these chemical classes are reproductive toxicants. As discussed above, oral exposure to 6PPD was associated with increased gestation length and difficult labor in rats (cited above).

We concluded that there is the potential for cumulative effects because people and wildlife are exposed to 6PPD and other chemicals that can impact the reproductive system or are toxic to fish, for example.

Potential to contribute adverse impacts

In sensitive populations

When people are exposed to chemicals with known or suspected toxicities, there is the potential for adverse impacts. The impacts may be greater when people are also exposed to other environmental contaminants that impact the same biological systems. People, including sensitive populations, are exposed to 6PPD. Exposure to 6PPD is associated with reproductive toxicity. Therefore, 6PPD has the potential to contribute to adverse impacts in humans, including sensitive populations such as people of childbearing age, developing fetuses, and children.

The direct effects of 6PPD and 6PPD-q toxicity in humans have not been characterized, but there is potential for cumulative impacts with co-exposure to other traffic-related pollutants. Populations that may be of concern for 6PPD exposure, in addition to Tribal populations and others who consume salmon, include:

- Pregnant people, because of the possible relevance of rat toxicity studies that show reproductive toxicity of 6PPD exposure.
- Children and professional athletes who spend more time actively playing on turf fields, because of potentially high aggregate exposure.
- People who live, play, work, or attend school near busy roadways. In particular, populations in low socio-economic status neighborhoods with heavily trafficked roadways may be both highly exposed and have greater susceptibility.
- People who work in occupations with exposure risk, including tire factories and tire recycling centers.

A critical impact of 6PPD on public health is the indirect impact that declining salmon populations have on food supplies and multiple elements of cultural health and well-being for Tribal populations and others who depend on salmon for food. This includes a large number of Washingtonians who are potentially impacted by 6PPD-q toxicity to salmon.

In sensitive species

When chemicals are released into the environment, they have the potential to expose sensitive species, such as forage fish (*i.e.*, small schooling species who are important sources of prey), salmon, or orcas. If these chemicals have toxic properties, there is potential to contribute to adverse impacts in sensitive species. 6PPD and 6PPD-q are found in the environment and are highly toxic to aquatic life, especially salmon. Salmon are also a food source for orca. Protecting salmon populations is crucial for orca recovery efforts, as highlighted in recommendations from the Southern Resident Orca Task Force (Southern Resident Orca Task Force, 2019).

6PPD-q was first discovered during a search for the causal toxicant in pre-spawn mortality in coho salmon. This was a condition where up to 90% of migrating coho salmon were killed by roadway runoff before they were able to spawn. 6PPD-q was shown to have a LC50 of 0.000095 mg/L towards coho salmon, making it one of the most potent aquatic toxicants known (Tian et al., 2022). Since then, several other species have also shown high susceptibility to this chemical, including brook trout with an LC50 of 0.00059 mg/L and rainbow trout with an LC50 of 0.001 mg/L (Brinkmann et al., 2022).

Since concentrations in this range and higher are often reached in roadway runoff and urban waterways, we know that fish are currently at risk because of the use of this chemical. Roadway runoff has been shown to be lethal to coho, steelhead, and chinook (French et al., 2022), and adverse effects have been detected on algae and zooplankton for decades (Portele et al., 1982).

Wild salmon populations are struggling in Washington, and most species are not meeting recovery goals. Pollution stormwater runoff is thought to be one of the leading pressures on salmon habitat (Governor's Salmon Recovery Office, 2023). It is estimated that localized extinction of coho populations could occur within the next decades if pre-spawn mortality is not addressed (Spromberg & Scholz, 2011).

Although 6PPD-q shows extremely high acute toxicity to some species, including coho salmon, brook trout, and rainbow trout, it shows much lower acute toxicity to other species, such as zebrafish (Brinkmann et al., 2022; Hiki et al., 2021). 6PPD-q was not acutely toxic, even at high concentrations, to species closely related to coho salmon, such as Atlantic salmon, chum salmon, and sockeye salmon. (We note the McIntyre et al. study on chum salmon focused on tire wear particle leachate and was not specific to 6PPD-q) (Foldvik et al., 2022; Greer et al., 2023; McIntyre et al., 2021).

Although most aquatic research on 6PPD-q has focused on acute toxicity and lethality, there is some evidence that it can have other adverse effects in organisms at concentrations lower than where lethality is observed (Ji, Huang, et al., 2022; Varshney et al., 2022; S.-Y. Zhang et al., 2023). For instance, 6PPD-q has been shown to induce neurodegeneration and alter intestinal permeability in the worm *C. elegans* at environmentally relevant concentrations that did not result in significant lethality; how this translates to other species is unknown (Hua et al., 2023a, 2023b).

6PPD also scores very high for acute and chronic aquatic toxicity, although it is not as toxic towards any species as 6PPD-q is towards coho salmon (ToxServices, 2021b).

Appendix A. Acronyms and Abbreviations

Table 26. Acronyms and abbreviations with definitions.

Term	Definition
2,4-D	2,4-Dichlorophenoxyacetic acid
6PPD	N-(1,3-dimethylbutyl)-N’-phenyl-p-phenylenediamine
6PPD-q	N-(1,3-dimethylbutyl)-N’-phenyl-p-phenylenediamine-quinone
µg/cm^{3}	Micrograms per centimeter cubed
µg/L	Micrograms per liter
µg/dL	Micrograms per deciliter
µg/m^{3}	Micrograms per meter cubed
µg	Microgram
µm	Micron
ABLES	Adult Blood Lead Epidemiology and Surveillance
AHA	American Heart Association
ATSDR	Agency for Toxic Substances and Disease Registry
BCF	Bioconcentration Factor
BLRV	Blood Lead Reference Value
BM	Benchmark
BOD	Biochemical Oxygen Demand
BTEX	Benzene, toluene, ethylbenzene, and xylenes
CAP	Chemical Action Plan
CAS	Chemical Abstracts Service
CAS RN	Chemical Abstracts Service Reference Number
CDC	Centers for Disease Control and Prevention
CEPA	Canadian Environmental Protection Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CHCC	Chemicals of High Concern to Children
CMR	Carcinogenic, mutagenic, reproductive toxics
COD	Chemical Oxygen Demand
COU	Conditions of Use
CPE	Chlorinated polyethylene
CPDat	Chemical and Products Database
cVMS	Cyclic volatile methylsiloxanes
D3	Hexamethylcyclotrisiloxane
D4	Octamethylcyclotetrasiloxane
D5	Decamethylcyclopentasiloxane

Term	Definition
D6	Dodecamethylcyclohexasiloxane
DDT	Dichlorodiphenyltrichloroethane
DecaBDE	Decabromodiphenyl ether
DEPA	Danish Environmental Protection Agency/Danish Ministry of the Environment
DSL	Domestic Substances List
DTSC	California Department of Toxic Substances Control
Health	Washington State Department of Health
ECHA	European Chemicals Agency
Ecology	Washington State Department of Ecology
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
ESIS	European chemical Substances Information System
EU	European Union
FDA	U.S. Food and Drug Administration
FEMA	Federal Emergency Management Agency
GHS	Globally Harmonized System of Classification and Labeling of Chemicals
HBCD	Hexabromocyclododecane
IARC	International Agency for Research on Cancer
IQ	Intelligence quotient
IPCS	International Programme on Chemical Safety
kg	Kilogram
K_{OW}	Octanol—water partition coefficient
LC_{50}	Lethal Concentration for 50% of test animals studied
LD_{50}	Lethal Dose for 50% of test animals studied
LNI	Washington State Department of Labor and Industries
LT	List Translator
mg	Milligram
mg/L	Milligrams per liter
mg/kg	Milligrams per kilogram
NA	Not applicable
NAS	National Academies of Sciences
NATTS	National Air Toxics Trend Site
ng	Nanogram
ng/kg	Nanograms per kilogram
ng/m^3	Nanograms per meter cubed
ng/mL	Nanograms per milliliter
NHANES	National Health and Nutrition Examination Survey

Term	Definition
NICNAS	National Industrial Chemicals Notification and Assessment Scheme
NITE	National Institute of Technology and Evaluation
NOAEL	No Observed Adverse Effect Level
NOEC	No Observed Effect Concentration
NTP	National Toxicology Program (at US Department of Health and Human Services)
OEHHA	California Office of Environmental Health Hazard Assessment
OSHA	Occupational Safety and Health Administration
OSPAR	Oslo and Paris Conventions Commission
PAH	Polyaromatic hydrocarbon
PBDE	Polybrominated diphenyl ether
PBT	Persistent, bioaccumulative, toxic
PCB	Polychlorinated biphenyl
PCE	Perchloroethylene
PFAS	Per- and polyfluoroalkyl substances
$PM_{2.5}$	Fine particulate matter
POP	Persistent Organic Pollutant
ppb	Parts per billion
ppm	Parts per million
PUC	Product Use Category
PVC	Polyvinyl chloride
RCW	Revised Code of Washington
REACH	Registration, Evaluation, Authorisation, and Restriction of Chemicals
RoC	Report on Carcinogens
SVHC	Substances of Very High Concern
t/yr	Metric tons per year
TBBPA	Tetrabromobisphenol A
TCDD	2,3,7,8-Tetrachlorodibenzodioxin
TCEP	Tris(2-chloroethyl) phosphate
TDCPP	Tris(1,3-dichloro-2-propyl) phosphate
TNBP	Tri-n-butyl phosphate
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
TWP	Tire wear particle
UNEP	United Nations Environmental Programme
USGS	U.S. Geological Survey
VOC	Volatile organic compound
vPvB	Very persistent and very bioaccumulative
WAC	Washington Administrative Code

Appendix B. Citation List

Overview

The following citation list was developed to meet the requirements outlined in RCW 70A.350.050[209] and RCW 34.05.272.[210] It identifies the peer-reviewed science, studies, reports, and other sources of information used to support our identification of priority chemicals. The following are the types of sources used to support this report:

1. Peer review is overseen by an independent third party.
2. Review is by staff internal to Ecology.
3. Review by persons that are external to and selected by Ecology.
4. Documented open public review process that is not limited to invited organizations or individuals.
5. Federal and state statutes.
6. Court and hearings board decisions.
7. Federal and state administrative rules and regulations.
8. Policy and regulatory documents adopted by local governments.
9. Data from primary research, monitoring activities, or other sources, but that has not been incorporated as part of documents reviewed under other processes.
10. Records of best professional judgment of Ecology employees or other individuals.
11. Sources of information that do not fit into one of the other categories listed.

Citation list

Table 27. References, categorized by source type.

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Appendix C. Exemptions

The following products are exempted from consideration under Safer Products for Washington (RCW 70A.350.030[211]):

- Plastic shipping pallets manufactured prior to 2012.
- Food or beverages.
- Tobacco products.
- Drug or biological products regulated by the United States Food and Drug Administration.
- Finished products certified or regulated by the Federal Aviation Administration or the Department of Defense, or both, when used in a manner that was certified or regulated by such agencies, including parts, materials, and processes when used to manufacture or maintain such regulated or certified finished products.
- Motorized vehicles, including on and off-highway vehicles, such as all-terrain vehicles, motorcycles, side-by-side vehicles, farm equipment, and personal assistive mobility devices.
- Chemical products used to produce an agricultural commodity, as defined in RCW 17.21.020.[212]

Ecology may identify the packaging of products listed above as priority consumer products.

For an electronic product identified by Ecology as a priority consumer product under this section, the department may not make a regulatory determination under RCW 70A.350.040[213] to restrict or require the disclosure of a priority chemical in an inaccessible electronic component of the electronic product.

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[211] app.leg.wa.gov/rcw/default.aspx?cite=70A.350.030
[212] app.leg.wa.gov/rcw/default.aspx?cite=17.21.020
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