Rationale Document for Motor Vehicle Tires Containing Zinc

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SAFER CONSUMER PRODUCTS
CALIFORNIA DEPARTMENT OF TOXIC SUBSTANCES CONTROL

DTSC
Department of Toxic Substances Control

CalEPA
California Environmental Protection Agency

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ABOUT THIS DOCUMENT

The Department of Toxic Substances Control's (DTSC) Safer Consumer Products (SCP) regulations allow any person to petition DTSC to add a product-chemical combination to the Priority Product List. In May 2018, the California Stormwater Quality Association (CASQA) petitioned DTSC to list motor vehicle tires with tire tread containing zinc as a Priority Product (CASQA 2018). In May 2019, CASQA submitted supplemental information to its original petition to address questions and gaps identified by DTSC in its merits review of the petition (CASQA 2019). For the purposes of this document, the term "petition" includes both the original petition and the supplemental information. This document provides an overview of DTSC's determination that the petition provides sufficient information to meet both of the key prioritization criteria for listing a Priority Product (California Code of Regulations, title 22, section 69503.2(a)):

(1) There must be potential public and/or aquatic, avian, or terrestrial animal or plant organism exposure to the Candidate Chemical(s) in the product.

(2) There must be the potential for one or more exposures to contribute to or cause significant or widespread adverse impacts.

This document largely relies on resources presented in the petition but incorporates other findings made by DTSC during its evaluation of the petition, as appropriate. Given the information provided in this document, DTSC proposes to list motor vehicle tires containing zinc as a Priority Product.

Readers should consider the following:

- This Rationale Document is not a regulatory document and does not impose any regulatory requirements.
- This Profile summarizes information compiled by DTSC as of February 2023 and includes consideration of stakeholder feedback provided during the comment period that closed on August 6, 2021. In preparation for rulemaking, DTSC also requested feedback on the scientific basis of this document from three external scientific peer reviewers. Their feedback was provided to DTSC on March 24, 2023.
- Since the publication of the public draft in June 2021, DTSC:
    - made several editorial changes to improve the clarity of the writing;
    - corrected a few minor errors identified by DTSC staff, public commenters, or the external scientific peer reviewers;
    - made some clarifications and changes to address points raised by public commenters and the external scientific peer reviewers; and
    - added new references subsequently identified.
- By proposing to list this product-chemical combination as a Priority Product containing a Chemical of Concern, DTSC is not asserting that the product cannot be used safely. The proposal indicates that there is a potential for people or the environment to be exposed to the

Chemical of Concern in the Priority Product, that such exposure has the potential to cause or contribute to significant or widespread adverse impacts, and that safer alternatives should be evaluated.

1. RATIONALE FOR GRANTING THE PETITION

DTSC has determined that the petition meets the criteria for quality and comprehensiveness specified in section 69504.1 of title 22 of the California Code of Regulations. Specifically, DTSC has determined that the petition has demonstrated the potential for exposure of aquatic organisms to zinc found in motor vehicle tires and for those exposures to contribute to or cause significant and widespread adverse impacts.

Zinc is added to tire rubber (typically, as zinc oxide) to encourage the vulcanization process. Vulcanization strengthens the rubber and allows manufacturers to mold tire rubber into the precise shapes found in tire treads and other tire components. This zinc remains part of the matrix of the final tire. Small pieces of tires, commonly referred to as tire wear particles (TWP), are generated as tires roll along the road. TWP can be deposited on roads and surrounding areas, where it can be carried by stormwater into waterways. Additionally, TWP can be transported through the air and deposited onto hard surfaces, such as building roofs, where it is also subject to transport to the aquatic environment via stormwater.

TWP represents a significant source of zinc in stormwater runoff, which in turn is a significant source to the aquatic environment. Once released into the environment, including local waterways, zinc can and does leach out of TWP; when TWP are ingested by aquatic organisms, zinc can leach into their gastrointestinal fluid. Additionally, TWP are transported to the environment in large quantities, and they represent a continuous and ever-increasing source of zinc releases. In urbanized parts of the state, TWP-containing stormwater runoff represents a significant source of zinc contamination in aquatic systems. Once released to the aquatic environment, the form of zinc can change as environmental conditions shift, resulting in forms of zinc that may be more or less bioavailable and toxic than the form that was originally released from tires.

It is clear that aquatic organisms in California's streams, rivers, and lakes may be adversely impacted by exposure to zinc. The U.S. Environmental Protection Agency (U.S. EPA) and the State Water Resources Control Board (State Water Board) have developed water quality criteria (WQC) for zinc to assist in this determination.

Especially in the southern part of the state, California waterways have been found to exceed zinc WQC, including at the point of stormwater discharge. In laboratory studies, water samples collected from impacted waterways induced toxic effects in native marine organisms, effects that have been attributed to zinc content. Additionally, several studies indicate that observed toxicity of TWP leachate to aquatic organisms is at least partially attributable to zinc. Some California waterways have been classified as impaired under the provisions of section 303(d) of the Clean Water Act (CWA) due to zinc contamination. Advanced stormwater treatment (referred to as “special handling” in the SCP regulations) is required to mitigate the adverse impacts of zinc exposure on aquatic organisms; however, such treatment is often prohibitively expensive or technically infeasible.

2. PRODUCT DEFINITION AND SCOPE

This section describes the product that forms the basis for the proposed product-chemical combination.

The petition describes the product-chemical combination as “motor vehicle tires with tire-tread containing zinc” and observes that the “main categories of tires are passenger, light truck, and medium/heavy truck.” DTSC has also initiated a rulemaking process to regulate motor vehicle tires containing N-(1,3-dimethylbutyl)-N’-phenyl-p-phenylenediamine (6PPD) and will align the definition of motor vehicle tires across these two efforts.

“Motor vehicle tires containing zinc” means a motor vehicle tire, as defined below, that contains zinc. “Tire” means any product that can be described or observed as a covering for a wheel, usually made of rubber reinforced with cords of nylon, fiberglass, or other material, whether filled with compressed gas (such as air or nitrogen), solid, or non-pneumatic (airless).

“Motor vehicle tire” includes any tire, as defined above, that is intended for use on light duty vehicles (passenger cars, light trucks, vans, and sport utility vehicles); motorcycles; motor homes; medium- and heavy-duty trucks; buses; and trailers (including trailer coaches, park trailers, and semitrailers). “Motor vehicle tire” also includes tire tread material: circular or linear precured tread and raw rubber solely for use in mold cure retreading of a tire.

“Motor vehicle tire” does not include a tire imported into or sold in California as a component of a motor vehicle. It also does not include a tire intended for exclusive use on off-road vehicles including aircraft; vehicles intended exclusively for off-road (e.g., dirt track) use; construction and agricultural equipment such as excavators, paving equipment, tractors, combines, bulldozers, and skidders (but not farm labor vehicles); industrial equipment such as forklifts, airport service equipment, and ice-grooming machines; and military vehicles (except those that are equivalent to civilian vehicles covered by this product definition, such as light-duty vehicles used as staff cars, buses, and delivery vehicles). Additionally, “motor vehicle tire” does not include the used component(s) of a retreaded tire; however, the new tire tread material that is used in a retreaded tire is included in the definition.

3. CANDIDATE CHEMICAL DEFINITION AND PROPERTIES

This section introduces the Candidate Chemical (or Chemicals) in the proposed product-chemical combination.

Reference: California Code of Regulations, title 22, section 69503.3(a)(1)(D).

Zinc (Zn) is element number 30 on the periodic table (PubChem 2021). It has an atomic weight of 65.38 and a density of 7.134 grams per cubic centimeter (PubChem 2021). It is a metal and is the 23rd most abundant element in the earth's crust (PubChem 2021; National Minerals Information Center 2022). Zinc is used in a wide variety of commercial applications, including rust prevention, and in alloys such as brass and bronze (PubChem 2021). Zinc is added to tire rubber, typically as zinc oxide (ZnO) particles, to aid in the vulcanization process, which creates chemical bonds (cross-links) among individual rubber polymer molecules to improve rubber performance (CASQA 2018). Many uses of zinc, including in tires and galvanized metal surfaces, result in its release to the aquatic environment.

The petition notes that "the dominant fate of zinc in the freshwater aquatic environment appears to be sorption [to particles]" and that these particles may remain suspended in the water column or be deposited in underlying sediment. It also states that, in general, zinc that is dissolved in the water column is more bioavailable than zinc compounds in sediments; however, zinc in sediments "may be a problem at higher concentrations or if re-suspended."

Because zinc is an element, it cannot break down in the environment; it can only form different compounds. Although ZnO is the primary form of zinc used in tire manufacturing, the chemical species of zinc to which organisms are ultimately exposed may vary due to the different environmental conditions that occur between release of zinc from TWP and exposure to organisms. Zinc's toxicity depends in part on its bioavailability – the fraction of zinc in the immediate environment that can be taken in by an organism (Mebane et al. 2020). For a chemical to be bioavailable, it must reach the site (e.g., a protein or other biotic ligand) in a biological system (e.g., an organism or cell) where it exerts its effect. The bioavailability of zinc is strongly influenced by factors such as pH, the amounts and types of other dissolved minerals, and the amounts and types of dissolved and suspended organic material available to bind zinc.

As an essential trace nutrient, zinc is required by organisms for normal function. It is important for metabolism, inflammation, wound healing, and other processes (Eisler 1993; Marreiro et al. 2017). Despite its necessity for living systems, zinc can cause adverse effects if its concentration is elevated beyond physiological tolerance (Eisler 1993; Sekler et al. 2007; Marreiro et al. 2017). For example, zinc has antioxidant effects at normal concentrations but can cause oxidative stress by forming reactive oxygen species (ROS) when levels are too high (Zheng et al. 2016; Marreiro et al. 2017). To maintain healthy levels, most organisms can regulate the transport of zinc into and out of their cells as needed

(Sekler et al. 2007). This allows cells to utilize zinc for essential functions while preventing its accumulation to levels that are toxic (Sekler et al. 2007). Organisms may also quickly metabolize zinc or create stress response proteins such as metallothioneins (Eisler 1993; Capdevila et al. 2012; Marreiro et al. 2017). Metallothioneins can protect the cell from the harmful effects of zinc and other metals by binding these metals and neutralizing ROS (Marreiro et al. 2017; Samuel et al. 2021). While aquatic organisms can adapt to regional background concentrations of essential metals, zinc can be toxic at high levels (Eisler 1993; Wood et al. 2012).

The level of zinc needed to cause toxicity depends on several factors including the organism affected and the environmental context of the exposure. Organisms in aquatic environments range from highly sensitive to highly tolerant of zinc (Eisler 1993). Toxicity can be observed in various types of organisms including plants (also algae) and animals (Eisler 1993; Nadella et al. 2013; Wu et al. 2019). Among freshwater animals, the 96-hour LC_{50} (lethal concentration for which zinc kills 50% of test subjects in a 96-hour period) for zinc ranges from 32 to 40,930 µg/L for invertebrates and 66 to 40,900 µg/L for bony fish (Eisler 1993). Similarly, among saltwater animals, the 96-hour LC_{50} for zinc ranges from 195 to more than 320,000 µg/L for invertebrates and 191 to 38,000 µg/L for bony fish (Eisler 1993). However, in sensitive aquatic species, significant adverse effects on survival, reproduction, and growth have been observed at zinc concentrations ranging between 10 and 25 µg/L in freshwater and marine settings (Eisler 1993). These effects have been observed in a wide range of taxa – plants, protozoans, sponges, mollusks, crustaceans, echinoderms, fish, and amphibians (Eisler 1993). Zinc is generally most toxic to developmental and juvenile stages of organisms and to organisms that are living under stressful conditions, such as starvation (Eisler 1993). Environmental parameters that enhance the aquatic toxicity of zinc include increased temperature, low pH, low alkalinity, low dissolved oxygen, presence of other toxic metals such as cadmium and mercury, and fluctuating ambient concentrations of zinc (Eisler 1993). These parameters may affect bioavailability of zinc (as discussed above), physiological changes in organisms, or both.

Some of the toxicological effects of zinc in representative aquatic organisms are outlined in Table 1 (Eisler 1993). While these data are derived from several different studies whose parameters may vary from those observed in the environment (such as exposure duration), the concentrations of zinc that elicited these effects (up to approximately 100 µg/L) are similar to those observed in stormwater plumes, which historically have averaged 215 µg/L (Schiff et al. 2002).

Table 1. Toxicological effects of zinc in representative aquatic organisms published in Eisler (1993).

Organism	Effect
Algae and Phytoplankton	Growth inhibition, reduced primary production, altered lipid metabolism, chlorophyll reduction, photosynthesis reduction
Protists	Growth reduction
Freshwater Sponges	Tissue deterioration
Snails	Reduced growth, reduced shell length, and reduced reproduction
Oysters	Reduced growth and fertilization success, abnormal shell development, reduced larval settlement
Mussels	Developmental inhibition and reduced growth
Abalone	Abnormal development
Crabs	Delayed molting
Daphnids	Reduced reproduction
Mayfly	Reduced growth
Polychaetes	Abnormal development
Sand Dollars	Reduced fertilization success
Sea Urchins	Inhibition of embryonic development
Fish	Reduced growth, increased incidence of developmental abnormalities, behavioral changes, decreased swimming ability, inhibited reproduction, hyperglycemia
Amphibians	Abnormal embryonic development

More effects can be found in the review by Eisler (1993) , primarily at zinc concentrations that are higher than those observed in most exposure scenarios. Some of these include: developmental effects and mortality in mollusk larvae; mortality in crustaceans; mortality in segmented worm larvae; mortality in sea stars; developmental effects and mortality in fish; and developmental effects and mortality in amphibian larvae (Eisler 1993). The Eisler (1993) review encompasses many of the studies that established the known aquatic hazards of zinc toxicity. More recent studies, including those focused on evaluating how environmental parameters and site-specific conditions can alter zinc toxicity, are described in publications such as the European Union's Zinc Risk Assessment Final Report (Munn et al. 2010). Additionally, several studies have linked the toxicity of TWP leachate to zinc, as summarized below in the *Lab Studies with Contaminated Environmental Media* section. Pursuant to section 69404.10 of the California Code of Regulations, DTSC has determined that there is strong evidence for the following environmental hazard traits: phytotoxicity, wildlife developmental impairment, wildlife growth impairment, wildlife reproductive impairment, and wildlife survival impairment.

According to the petition, zinc's toxicity may result from its disruption of aquatic organisms' ability to regulate the concentration of calcium across cell membranes (calcium homeostasis). This may be a particular issue for aquatic species whose reproductive strategy involves external fertilization and development. For example, studies indicate that dissolved zinc can impair the viability of sperm from the purple sea urchin (*Strongylocentrotus purpuratus*), resulting in decreased reproductive success (Schiff et al. 2002; Schiff et al. 2003). Zinc can also impair the uptake and accumulation of calcium during sensitive stages of embryonic and larval sea urchin development (Tellis et al. 2014); this may lead to developmental malformations including delayed or stunted growth, skeletal abnormalities, and atrophy (Rouchon and Phillips 2017; Nogueira et al. 2020). Zinc concentrations as low as 50 µg/L can impair reproduction of rainbow trout (*Oncorhynchus mykiss*), which may be an indirect effect caused by zinc's inhibition of calcium uptake (Hogstrand and Wood 1996; Santore et al. 2002). Effects on calcium homeostasis in aquatic organisms are also observed beyond the initial life stages. Whereas zinc makes direct contact with gametes or embryonic cells during reproductive and developmental processes, the exposure of larval, juvenile, or adult organisms occurs through direct contact of zinc with the gill epithelium or through absorption by the small intestine following ingestion (Eisler 1993).

U.S. EPA's ambient WQC for zinc derive from a model that predicts zinc's bioavailability in a given body of water based on the water's hardness (Code of Federal Regulations 1976). However, it is now recognized that other characteristics of natural waters, especially the concentrations of suspended, colloidal, and dissolved organic matter, can significantly affect the bioavailability – and hence the toxicity – of metals like zinc. This knowledge has led to the development of more sophisticated models for predicting metals' bioavailability, such as the Biotic Ligand Model (DeForest and Van Genderen 2012; Adams et al. 2020). Regardless of the differences between bioavailability models, DTSC has determined that concentrations of zinc found in some California waterbodies may be sufficient to harm a variety of aquatic taxa.

4. POTENTIAL FOR EXPOSURES TO ZINC FROM TIRES

Reference: California Code of Regulations, title 22, section 69503.3(b)(2).

In accordance with the SCP Regulations, DTSC found the following evidence of the potential for exposure to zinc from tires:

- The presence of zinc in motor vehicle tires.
- The generation and release of tire wear particles containing zinc to the environment (section 69503.3(b)(4)(F)).
- The potential for zinc to be released from tires and tire wear particles into stormwater during product use and end-of-life (section 69503.3(b)(4)(F)).
- The potential for zinc released from tires and tire wear particles into stormwater to expose aquatic organisms to zinc (section 69503.3(b)(4)(F)).
- Estimates of the amount of zinc released into stormwater from tires (section 69503.3(b)(4)(H)).

- Environmental monitoring data showing that zinc is present in California stormwater and receiving waters at concentrations that 1) exceed regulatory thresholds (section 69501.1(a)(58)(E)(5)), 2) may result in violations of permits issued to California municipalities responsible for managing stormwater streams (section 69501.1(a)(58)(E)(6)), and 3) require the expenditure of public funds to mitigate potential adverse impacts (section 69501.1(a)(58)(E)(2)).

Presence of the Candidate Chemical in the Product

The petition includes data from laboratory studies analyzing the zinc content in tires. The data show that rubber in car tires contains approximately 1% zinc by weight (10,000 mg/kg). Tires for heavier vehicles may have higher concentrations, up to 1.7% (17,000 mg/kg) (CASQA 2015).

Potential Exposures to Zinc During the Life Cycle of Tires

In general, potential exposures to a chemical may occur during any stage of a product's life cycle, including manufacturing, use, storage, transportation, and end-of-life management. The petition presents scenarios for aquatic species to be exposed to zinc through the use and end-of-life stages. As part of its evaluation, DTSC reviewed the exposure scenarios presented by the petition and conducted additional research on the potential for aquatic species to be exposed to zinc from tires.

Use

The petition identifies the movement of TWP from roads into nearby waterways – often via stormwater – as the primary means by which tires can expose aquatic organisms to zinc (see Figure 1). As vehicles are driven, tire tread slowly wears off, creating TWP. When TWP reach the road surface, they typically combine with minerals from the road to form what are often called tire and road wear particles (TRWP) (USTMA 2021). [1] A significant percentage of these particles remain on or near the road, where they may be washed off and enter stormwater drainage systems where they can be discharged to streams, rivers, or oceans (Prenner et al. 2021). TWP are eventually deposited in sediments at the bottom of streams, rivers, lakes, and oceans. TWP can build up in marine sediments impacted by urban runoff and release zinc for long periods of time, potentially resulting in perpetual exposure (Rice and Callender 2000; Roberts 2021).

Supporting documents provided with the petition estimate 245,000 kg of zinc from tires is discharged into Los Angeles County stormwater each year (CASQA 2015). DTSC's independent calculations for the same area estimate approximately 120,000 to 225,000 kg per year (Table 2).

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[1] This document refers to TWP when discussing the generation and toxicity of tire wear but will use the term TRWP when appropriate, based on the scientific literature being discussed.

Table 2: DTSC Estimate of Potential Amount of Zinc from Tires Discharged to Los Angeles County Stormwater

Population[2]	TWP Generated (kg/person/per year)[3,4]	TWP Zinc Content	Percentage of TWP Discharged to Aquatic Environment[5]	Potential Zinc Discharged (kg/year)
10,014,009	2.5 – 4.7	1%	48%	120,120 – 225,826

Once entering marine and freshwater environments, zinc can and does leach from TWP, exposing aquatic species (Wik and Dave 2009; Degaffe and Turner 2011; Rhodes et al. 2012; Roberts 2021; Yang et al. 2022). A number of factors have been found to enhance the leaching of zinc from TWP and/or TWRP, including smaller size and larger surface area (Wik and Dave 2009; Masset et al. 2021), decreased pH (Degaffe and Turner 2011; Rhodes et al. 2012; Masset et al. 2021), and salinity of the leachate (Degaffe and Turner 2011). Enhanced leaching with decreased pH is of particular concern, given the anticipated decrease in the pH of surface water as a result of climate change (Hauri et al. 2009; Gruber et al. 2012), which may result in greater release of zinc from TWP to the aquatic environment. Yang et al. (2022) found leaching of zinc from TWP in marine environments to be slow but continuous, while Degaffe and Turner (2011) found that zinc leaches from TWP more quickly in freshwater environments compared to marine. Initial findings from Roberts (2021) indicated no difference between the amount of zinc leached from nonweathered TWP compared to TWP that had been weathered in the marine environment for almost three months. Degaffe and Turner (2011) also noted that the presence of sediment can reduce the concentration of zinc in leachate but that zinc can be expected to be found in interstitial waters of sediment beds once equilibrium has been reached between TWP and sediment particles. Zinc in interstitial waters could then potentially serve as a source of zinc to overlying waters when that sediment is disturbed.

Aquatic animals may also be exposed to zinc through the ingestion of TWP and/or TWRP. TWRP have been detected in the digestive systems of several fish species, and recent evidence indicates that the gastrointestinal fluids of aquatic species have the potential to extract zinc from TWRP (Masset et al. 2021). Additional evidence indicates that there is potential for sediment-feeding invertebrates to ingest TWP, extract the zinc from TWP via their digestive fluids, and then release the zinc through excretion back into the water column (Turner and Hallett 2012).

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[2] United States Census Bureau 2020

[3] USTMA 2021

[4] Kole et al. 2017

[5] Prenner et al. 2021

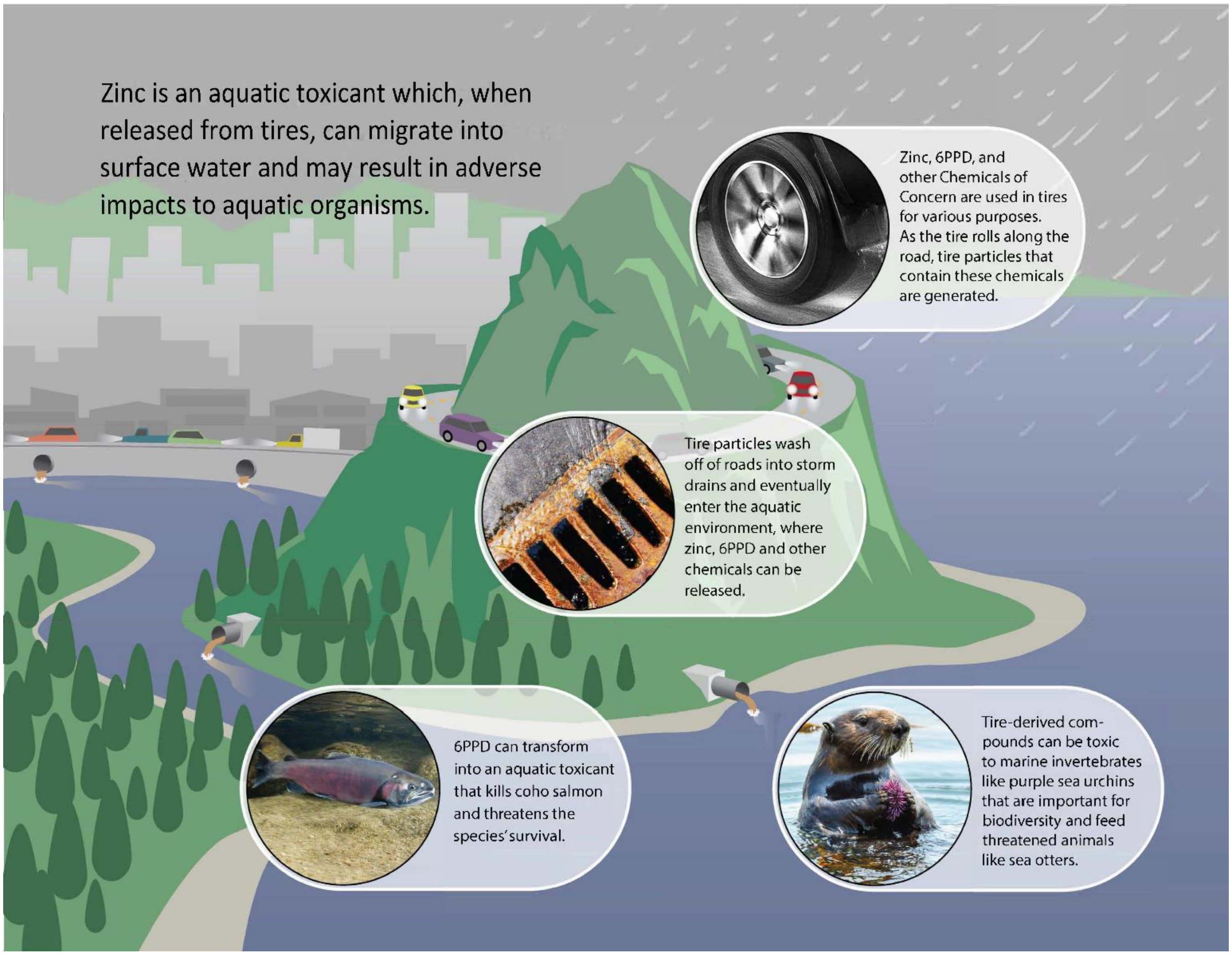

Figure 1. Environmental release of tire-related chemicals and their impacts on sensitive aquatic ecosystems.

There is a diverse array of organisms in the coastal water column along the California coast that may be exposed to stormwater plumes containing chemicals derived from TWP, including zinc. The California coast is subject to upwelling, which is a process that brings nutrient-rich waters from the bottom of the ocean to the surface (Carr 2001). This is part of the larger California Current System, which is one of the world's four major coastal upwelling systems. Together, the four major upwelling systems account for 5% of global marine primary production (that is, the formation of organic matter from carbon dioxide). These systems account for 17% of global fish catch, despite occupying less than an estimated 1% of the world's oceans (Carr 2001). The upper meters of the water column host a diverse range of species along the California coast, which is considered among the most biodiverse and productive in the world (USC Sea Grant 1999; Harley et al. 2006). Among marine invertebrates, the diversity of wildlife along the California coast includes species of tunicates, echinoderms, mollusks, crustaceans, polychaetes, and many others, although presence and abundance can vary with seasonal and climate cycles (Barnett and Jahn 1987; USC Sea Grant 1999; Lavaniegos and Ohman 2007). Many of these species reproduce by releasing gametes, embryos, or larvae to the water column (Crimaldi and Zimmer 2014), which may be exposed to large stormwater plumes that contain zinc from TWP.

End of Life

The petition states that pavement that contains recycled tire rubber also has the potential to expose aquatic species to zinc, particularly given that Caltrans is required by law to use recycled tire rubber in 35% of its paving projects. As evidence, the petition cites a study of two sites in Texas (Barrett and Sampson 2013) that shows substantially higher zinc levels in stormwater runoff from asphalt formulated with tire rubber than without.

To supplement the information in the petition, DTSC conducted additional research on the potential for rubberized asphalt to expose aquatic species to zinc. A 2021 study by the California Department of Resources Recycling and Recovery (CalRecycle) found that the contribution of rubberized asphalt to zinc levels in roadway stormwater runoff was likely negligible compared to other sources such as tires and/or galvanized guard rails (Finney et al. 2021). This study found that while concentrations of zinc in the first few runoff events on newly laid rubberized asphalt were higher than those in subsequent runoff events, the concentrations in these initial events were comparable to zinc contributions from TWP on non-rubberized asphalt roads.

Indicators of potential exposures

Under the SCP framework regulations, monitoring data showing a chemical’s presence in the environment is an indicator of potential exposure. During its evaluation of the petition, DTSC found multiple indicators of potential exposures, including monitoring data showing zinc in urban runoff and impacted sediments with TWP as a likely source.

Zinc is routinely detected in stormwater runoff and sediments throughout California (CEDEN 2022). Sediment monitoring conducted by the California State Water Resources Control Board has shown that concentrations of zinc in sediments are significantly increasing statewide (State Water Resources Control Board 2022).

Stormwater and sediment samples collected in the San Francisco Bay area by the San Francisco Estuary Institute (SFEI) contained black rubbery fragments suspected to be from tires (SFEI and 5 Gyres 2019; Werbowski et al. 2021). Studies have also reported that marine sediments near major highways may contain more than 10% TWP by mass (Turner and Hallett 2012).

Studies have shown that when particulate zinc is detected in urban runoff, TWP is often a likely source. Stormwater monitoring conducted by CalTrans indicates significantly higher levels of zinc in transportation areas, with approximately 69% of the measured zinc occurring in particulate form (Caltrans 2003). Other studies have shown direct correlations between particulate zinc concentrations in urban runoff and traffic density (Rice and Callender 2000). Environmental sampling from across the United States has shown that zinc concentrations in marine sediments near urban settings has increased over the past 50 years, with strong correlations between the accumulation rate of zinc and traffic density (Callender 2003; Councell et al. 2004). The relationship between zinc and traffic density in multiple environmental media indicates that TWP is a likely source of zinc in the aquatic environment.

5. POTENTIAL FOR SIGNIFICANT OR WIDESPREAD ADVERSE IMPACTS

This section integrates the information provided in the petition to demonstrate how the key prioritization principles, as identified in the SCP regulations, are met.

Reference: California Code of Regulations, title 22, section 69503.2(a).

Zinc released from motor vehicle tires may contribute to significant and widespread adverse impacts to aquatic organisms in California. For example, the City of San Diego indicated that zinc is “one of the highest priority pollutants in the region” (Kleis 2021). As outlined above, TWP can contribute significant quantities of zinc to stormwater, which represents a major source of zinc to aquatic environments, and the presence of TWP in waterways represents the potential for ongoing release of zinc to the aquatic environment. The petition and DTSC’s own research indicate that tire leachate is toxic to aquatic organisms and that this toxicity is at least partially attributable to zinc (Nelson et al. 1994; Gualtieri et al. 2005; Wik et al. 2009; Kolomijeca et al. 2020; Roberts 2021; Yang et al. 2022).

The petition outlines three lines of evidence for the potential for significant or widespread impacts to aquatic organisms from zinc in motor vehicle tires:

1. Lab studies on the effects of stormwater-influenced water samples and TWP leachate on aquatic organisms (section 69503.3(a)(1)(A)).
2. Exceedances of regulatory water quality standards (section 69501.1(a)(4)(E).
3. Special handling efforts required of California stormwater agencies to attempt to mitigate adverse impacts of zinc in stormwater (section 69501.1(a)(8)(B)).

DTSC has also identified a fourth line of evidence:

4. Potential for cumulative effects with other chemicals (section 69503.3(a)(1)(C)).

Lab Studies

Lab Studies with Contaminated Environmental Media

The petition highlights several instances in which researchers have assessed the toxicity of stormwater, receiving water, and discharge plumes to aquatic organisms. In these experiments, researchers expose organisms to water samples they have collected to assess their toxicity. Further investigation can identify candidate compound(s) responsible for this toxicity. Lab studies, by nature, cannot exactly replicate *in situ* conditions due to technical limitations; however, they can provide evidence that can be used to understand the potential for adverse impacts in the environment.

Several studies conducted in Southern California using samples collected at the point of stormwater discharge and in receiving waters indicate that zinc has either caused or contributed to toxicity to local aquatic organisms (USC Sea Grant 1999; Schiff et al. 2002; Schiff et al. 2003). In some instances, these toxic effects continue to be observed even when test organisms are exposed to samples that have been diluted ten to one with clean water (USC Sea Grant 1999). Even in large waterbodies, evidence of aquatic toxicity can be observed at significant distances away from stormwater discharges. One study found that stormwater collected from a plume that extended more than 2 kilometers offshore from the mouth of Ballona Creek exhibited aquatic toxicity due to its zinc content (USC Sea Grant 1999), while another study estimated a 2.25 square-kilometer area of San Diego Bay was contaminated with toxic levels of zinc from stormwater released from Chollas Creek (Schiff et al. 2003).

The petition indicates that the first storms of a rainy season result in particularly toxic stormwater, as rain washes accumulated TWP and other chemicals and debris off roads. This runoff has been shown to be between two and 10 times more toxic than stormwater from later storms (USC Sea Grant 1999). This is particularly relevant in Southern California, which can experience months with no rain, during which large amounts of TWP accumulate on road surfaces (Schiff et al. 2003).

Some of the strongest evidence for the toxicity of zinc in stormwater comes from studies that use the purple sea urchin (*S. purpurates)* fertilization bioassay (USC Sea Grant 1999; Schiff et al. 2003). As a native organism, the purple sea urchin possesses biological and ecological properties that make it useful as a standard representative model for marine ecotoxicological screens in California (U.S. EPA 1995; Phillips et al. 1998; OEHHA 2004). The purple sea urchin is ecologically important as a keystone species in coastal environments, where it has well-described symbioses (ecological relationships) with other important species, including macroalgae (kelp), sea otters, and sunflower stars (McGaw and Twitchit 2012; Winer et al. 2013; Burt et al. 2018; USGS and DOI 2019). Developmental and reproductive endpoints such as fertilization are commonly used in ecotoxicological screens because they are sensitive to contaminants and are ecologically relevant (Hudspith et al. 2017). The purple sea urchin and many other marine species reproduce through broadcast spawning (a form of external fertilization), and previous studies have linked exposure to metals in marine systems with the potential to disrupt fertilization in broadcast spawning invertebrates (Hudspith et al. 2017; Han et al. 2019). Such effects may impair population recruitment and maintenance. The evidence for zinc-induced stormwater toxicity toward sea urchin fertilization demonstrates the potential for adverse population effects in other broadcast spawners as well. It additionally demonstrates that exposure to zinc in stormwater may adversely impact other biological processes that are at least as sensitive as fertilization.

Lab Studies with TWP Leachate

Numerous studies have demonstrated the acute and chronic toxicity of tire leachates (Wik and Dave 2009). The known tendency of zinc to leach from TWP (see *Potential for Exposures to Zinc from Tires*) suggests it may be a cause of this observed toxicity; however, many studies of TWP leachate toxicity do not attribute toxicity to a specific chemical or chemicals. Doing so is challenging for many reasons, including variations in tire chemical composition (Wik and Dave 2009), differences in leachability of chemicals related to TWP size and shape (Wik and Dave 2009), complex interactions between the large number of chemicals found in TWP and TWP leachate (Halsband et al. 2020; Liu et al. 2022), variations in the observed toxicity of TWP leachate (Wik et al. 2009; Chibwe et al. 2022), differences between freshwater and marine environments (Yang et al. 2022), and differences in species sensitivity (Wik and Dave 2009; Wik et al. 2009; Halsband et al. 2020). Halsband et al. (2020) also suggest that environmental weathering of TWP may increase toxicity to marine organisms compared to nonweathered TWP.

In spite of these variables, several studies indicate that zinc is a leading cause of toxicity to aquatic organisms exposed to TWP leachate, including those described below and summarized by Wik and Dave (2009). Additionally, studies such as that by Liu et al. (2022) suggest that zinc may be indirectly responsible for toxicity to aquatic organisms through more complex interactions, such as the generation of environmentally persistent free radicals.

Wik et al. (2009) assessed the toxicity of sequential leachates of TWP to the green algae *Pseudokirchneriella subcapitata* (growth inhibition), the crustaceans *Daphnia magna* and *Ceriodaphnia dubia* (immobility, impaired reproduction, reduced survival) and *Danio rerio* (zebra fish) eggs (lethality). The most sensitive endpoint assessed was the reproduction of *C. dubia*; the toxicity of the leachates decreased with sequential leaching. While leachability of different compounds varied by rubber formulation, the authors concluded that there is potential for extended adverse impacts to organisms such as *C. dubia.* This toxicity was attributable, at least in part, to zinc, and the authors concluded that the variation in sensitivity to TWP leachate observed among the test organisms could be largely explained by variation in their sensitivity to zinc.

Additional studies have observed toxicity to *Ceriodaphnia dubia* (Nelson et al. 1994), *Raphidocelis subcapitata* (algae), *Daphnia magna* (planktonic crustacean), and *Xenopus laevis* (frogs) (Gualtieri et al. 2005) from tire leachate. These studies attribute the observed toxicity, at least in part, to zinc. In addition, preliminary evidence from Roberts (2021) indicates that mortality in *Americamysis bahia* (mysid shrimp) exposed to TWP leachate may similarly be attributable, in part, to zinc. Yang et al. (2022) evaluated the toxicity of TWP leachate to the marine copepod *Tigriopus japonicus* and confirmed that the observed lethality of the TWP was attributable to zinc, although the TWP themselves may have also contributed. Interestingly, these authors determined that organic compounds in the leachate, such as benzothiazoles, can reduce the observed zinc toxicity. Finally, Kolomijeca et al. (2020) noted that zinc may be a factor in the observed lack of eye pigment in *Pimephales promelas* (fathead minnows) exposed to TWP leachate; however, additional research is needed to understand the role zinc may play and the implications of these observations for the health of the fish. These authors also found that exposure to TWP leachate under warmer conditions resulted in increased deformity severity.

These studies, collectively, provide strong evidence for the potential for adverse impacts to aquatic organisms due to the presence of zinc in TWP and the subsequent release of zinc to the aquatic environment.

Water Quality Standard Exceedances

Under the Safer Consumer Products framework regulations, exceedance of water quality standards is one indication of the potential for adverse impacts (section 69501.1(a)(4)(E)), and this is one of several lines of evidence that DTSC is using to indicate the potential for adverse impacts from zinc in motor vehicle tires. U.S. EPA and the State Water Board set water quality standards to ensure protection of aquatic species and beneficial uses of waterbodies (Code of Federal Regulations 1976; U.S. EPA 2000). In California, 37 waterbodies are listed as impaired on the CWA 303(d) list due to exceedances of zinc water quality standards (State Water Resources Control Board 2019). These exceedances indicate the potential for significant adverse impacts to aquatic organisms in these waterbodies. The petition states that the number of waterbodies listed as impaired may increase as monitoring is expanded.

Efforts are underway to update existing WQC using updated models that better predict the bioavailability of zinc, such as the acute and chronic freshwater zinc biotic ligand model proposed by DeForest and Van Genderen (2012) or a multiple linear regression approach such as that used by the Canadian Council of Ministers of the Environment (CCME 2018). Adoption of these new approaches establish new WQC and may result in reduced frequency of water quality exceedances (International Zinc Association 2021). However, each of these methods has its own shortcomings in comprehensively assessing the potential for adverse impacts, as noted below in the *Additional Considerations: Data Gaps* section.

Special Handling to Mitigate Adverse Impacts

Zinc from motor vehicle tires contributes to adverse impacts, as evidenced by the special handling that stormwater agencies must employ to mitigate the impacts of zinc to the aquatic environment. This is of particular concern given that the special handling needed to reduce zinc contamination of stormwater is not always financially or technically feasible. Per the petition, some of these efforts are already in place (e.g., street sweeping), yet ongoing zinc contamination of stormwater indicates that they are insufficient. Physical treatment of stormwater through filtration and other approaches is expensive and infeasible in some parts of California due to the infrastructure that would be needed to capture and treat (or store) runoff. Additionally, redirection of stormwater for infiltration into groundwater requires significant land availability and may also require storage and treatment before discharge. Ultimately, as the petition highlights, source control of zinc is a far more effective option to mitigate zinc contamination of California aquatic ecosystems.

Cumulative Effects

In researching the potential for significant and adverse impacts from motor vehicle tires containing zinc, DTSC found additional studies indicating the potential for cumulative effects. Organisms often face multiple stressors simultaneously, especially in the face of anthropogenic changes to the environment. For example, exposure of marine organisms to stormwater plumes generally involves multiple chemicals, including those found in TWP and other sources (USC Sea Grant 1999; Schiff et al. 2002; Schiff et al. 2003). Metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, and other chemicals are among those that have been found in stormwater plumes off the Southern California coast (USC Sea Grant 1999). Further, environmental conditions are dynamic, due to both natural oscillations and anthropogenic climate change (Harley et al. 2006). In particular, aquatic and aquatic-dependent organisms are anticipated to experience greater physiological stress as environmental conditions change due to increased atmospheric and dissolved CO_2 levels caused by human activities (Tomanek and Helmuth 2002; Harley et al. 2006; Woodward et al. 2010). As the climate changes, ecological resilience (the ability of ecosystems to maintain critical functions while coping with stressors) is expected to decrease, especially in coastal ecosystems (He and Silliman 2019). In marine environments, climate change can modify local human-imposed stressors (e.g. fisheries, tourism, nutrient input, littering, and other activities) to either intensify or mitigate their effects (Gissi et al. 2021). It is therefore important to consider exposure to a stressor in the context of other environmental variables that may have additive, greater than additive (synergistic), or less than additive (antagonistic) effects (Hooper et al. 2013). Although there are other mechanisms of interest, oxidative stress is a common mechanism of toxicity shared by zinc and many other stressors, as described below.

Several metals, like zinc, are vital for normal biological function but are toxic at high concentrations (Wood et al. 2012). Different metals may interfere with different biological processes, but fish bioassays indicate that some share common mechanisms of toxicity and endpoints, including ROS formation, oxidative stress, and apoptosis (programmed cell death) (Morcillo et al. 2016). While zinc has antioxidant properties at homeostasis (i.e., at healthy levels), high concentrations can cause oxidative stress in aquatic organisms (Zheng et al. 2016). Co-exposure to other metals is therefore an important consideration when evaluating the toxicity of zinc. However, modeling mixture effects is often challenging. Additionally, organisms tend to be regionally adapted to background concentrations of metals in the environment (Wood et al. 2012). The concentration threshold for adverse effects of metals may therefore vary between locales.

Santore and Ryan (2015) developed a multimetal, multibiotic ligand model (mBLM) and evaluated its ability to predict the bioavailability and toxicity of metal mixtures to aquatic organisms. They found that the cumulative toxicity of multiple metals estimated without the mBLM was predicted to be greater than additive (synergistic). When the mBLM was applied to normalize bioavailability, the cumulative toxicity of metals was predicted to be additive or less than additive (antagonistic). However, additive or even antagonistic effects can still add up to an increased toxicity of metals toward ecological receptors when considered cumulatively. For example, a study on freshwater mussels found that regulatory limits based on single metal toxicity may be under-protective when multiple metals are present (Timpano et al. 2022). This study found that a mixture of copper, nickel, and zinc at concentrations of 21%, 29%, and 37% of their respective WQC inhibited growth of freshwater mussels by 61% dry weight when compared to controls. This study simulated water influenced by alkaline mine drainage, which may impact bioavailability and toxicity of metals differently than common exposure scenarios in California. However, it demonstrates the importance of breaking with the common practice of considering individual metal toxicities and instead evaluating cumulative metal toxicity in aquatic systems.

In aquatic environments, co-exposure to metals and other chemicals can lead to synergistic effects, either through common mechanisms or exacerbation of toxicity. As detailed in a review by Gauthier et al. (2014), both PAHs and metals can generate ROS and cause oxidative stress, and certain metal-PAH mixtures can enhance each other’s effects. PAHs can increase the toxicity of metals by disrupting cell membrane integrity and increasing membrane permeability, allowing metals to enter the cell more freely. They can also inhibit the detoxifying effects of proteins such as metallothionein on metals. Likewise, metals can increase the toxicity of PAHs by inhibiting the cytochrome P450 enzyme pathway (Gauthier et al. 2014). It is unclear whether PAHs and zinc have similar interactions. As common tire additives that are unbound to the tire matrix, zinc and PAHs are often observed together in tire crumb rubber leachate. In a laboratory study that evaluated different types of tire crumb rubber, as the leachability of zinc and PAHs from crumb rubber increased, so did the toxicity of the leachate to *D. magna* (Lu et al. 2021). The authors proposed that both zinc and PAHs contributed to the toxicity of the leachates. Most PAHs primarily cause toxicity through their interaction with the aryl hydrocarbon receptor, which, upon activation, increases the expression of pro-oxidant enzymes and may lead to oxidative stress (Gauthier et al. 2014; Shankar et al. 2020). Like PAHs, PCBs and several pesticides also cause oxidative stress in aquatic organisms (Leit?o et al. 2003; Lehmann et al. 2007; Slaninova et al. 2009; Paškov? et al. 2011; Liu et al. 2016). Given that zinc causes oxidative stress when present in high concentrations, it is possible that PAHs, PCBs, and pesticides could enhance zinc toxicity. Similarly, zinc may increase the toxicity of some biocides. The biocide zinc pyrithione is commonly painted on ship hulls as an anti-fouling agent, following the ban of tributyltin (Soon et al. 2019), and is also used in personal care products such as anti-dandruff shampoos (Warner et al. 2001). In a bioassay using the sea urchin *Anthocidaris crassispina,* the toxicity of zinc pyrithione was orders of magnitude higher than that of copper pyrithione (Kobayashi and Okamura 2002), although it is not clear whether the increased toxicity was due to a metal-biocide interaction effect or due to zinc having a higher toxicity than copper. Sublethal concentrations of zinc pyrithione were also shown to impair growth and survival of polychaetes through oxidative stress (Haque et al. 2020).

Environmental stressors that are affected by climate change, such as temperature, pH, hypoxia, and salinity, can also influence the absorption, distribution, metabolism, and excretion of chemicals and their interactions with target molecules (Hooper et al. 2013). These stressors can all cause oxidative stress in aquatic organisms as well (Tomanek 2015) and may interact with zinc through this common mechanism. Although cross-tolerance among some stressors is possible, organisms often have less energy to cope with one stressor when simultaneously faced with another (Dinh Van et al. 2013; Gunderson et al. 2016; Vasquez et al. 2020; Collins et al. 2021). Thermal stress increases the toxicity of zinc and other metals in aquatic invertebrates such as flatworms, segmented worms, and mollusks (Sokolova and Lannig 2008). The ability of some aquatic invertebrate species to adapt to higher temperatures due to climate change may also come at the cost of tolerance to contaminants like zinc (Dinh Van et al. 2013). More studies are needed to understand how climate change will affect the toxicity of zinc in aquatic environments.

Climate-influenced stressors are also expected to influence metal toxicity through changes in bioavailability. Sediment-bound contaminants become remobilized and more bioavailable when sediments are resuspended (Eggleton and Thomas 2004). Climate change may increase resuspension of sediments in some locations due to increased frequency and severity of storms. Climate change may also increase the bioavailability of sediment-bound contaminants by altering water chemistry (Schiedek et al. 2007). The areas of near-shore hypoxia events are expanding in the California Current System (Dussin et al. 2019), and pH is decreasing (Hauri et al. 2009; Gruber et al. 2012). Studies have demonstrated that decreased pH and hypoxia may both contribute to the mobilization of metals, including zinc, from marine sediments into the water column, although the effect of pH may be greater (Schiedek et al. 2007; Atkinson et al. 2007).

6. OTHER REGULATORY PROGRAMS

Reference: California Code of Regulations, title 22, section 69503.2(b)(2).

When deciding whether to list a product-chemical combination as a Priority Product, DTSC must consider other California and federal laws that regulate the product or the Candidate Chemical in the product and the extent to which these other regulations provide adequate protections with respect to the same exposures and adverse impacts. If the exposures or impacts are regulated by another entity, DTSC may only list a product-chemical combination as a Priority Product if it determines that doing so would meaningfully enhance protection of public health or the environment.

DTSC has assessed all applicable state and federal laws and regulations and international treaties and agreements with the force of domestic law related to the proposed Priority Product and the Candidate Chemical in the product. The results of these assessments are summarized below. DTSC has determined that these programs do not overlap or conflict with this proposal to list motor vehicle tires containing zinc as a Priority Product, nor with any subsequent regulatory response that may result from such listing.

Regulations Addressing the Same Exposures and Impacts

The federal Clean Water Act prohibits the discharge of stormwater containing pollutants without a National Pollutant Discharge Elimination System (NPDES) permit. U.S. EPA delegates this federal permitting program to the state of California. California’s Municipal Stormwater Program manages NPDES permits for municipalities as well as the statewide permit for the California Department of Transportation (State Water Resources Control Board 2018). These permits are intended to address the same potential exposures and impacts described in the petition. In its petition, CASQA asserts that these requirements do not provide adequate protection.

DTSC has determined that listing motor vehicle tires containing zinc as a Priority Product could meaningfully enhance protection of the environment by requiring manufacturers to consider whether there are less-toxic alternatives to zinc that would still ensure that tires meet existing performance and safety requirements.

Regulations Addressing the Safety and Performance of Tires

The National Highway Traffic Safety Administration (NHTSA) regulates the safety of tires. NHTSA has established a number of Federal Motor Vehicle Safety Standards setting safety and performance requirements for tires (*Code of Federal Regulations, title 49, subtitle B, chapter V, part 571, subpart B*), including:

- Standard No. 109; New pneumatic and certain specialty tires.

- Tire selection and rims and motor home/recreation vehicle trailer load carrying capacity information for motor vehicles with a gross vehicle weight rating (GVWR) of 4,536 kilograms (10,000 pounds) or less.
- Standard No. 119; New pneumatic tires for motor vehicles with a GVWR of more than 4,536 kilograms (10,000 pounds) and motorcycles.
- Tire selection and rims and motor home/recreation vehicle trailer load carrying capacity information for motor vehicles with a GVWR of more than 4,536 kilograms (10,000 pounds).
- Standard No. 139; New pneumatic radial tires for light vehicles.

DTSC has determined that these regulations do not overlap or conflict with the proposal to list motor vehicle tires containing zinc as a Priority Product, as they do not address the potential exposures or adverse impacts under consideration. If motor vehicle tires containing zinc were listed as a Priority Product, they would still be required to meet the same standards for safety and performance. The SCP regulations do not allow DTSC to require the use of alternatives to a Chemical of Concern that would compromise a Priority Product's compliance with health and safety requirements.

Regulations Addressing the Recycling, Reuse, and Disposal of Tires

Current laws and regulations require people who store, stockpile, accumulate, or discard waste tires to comply with tire storage and disposal standards and to obtain a waste tire facility permit. CalRecycle is responsible for administering waste tire programs in California and has established technical standards and a permitting program for waste tire facilities (CalRecycle 2020).

DTSC has determined that these regulations do not overlap or conflict with the proposal to list motor vehicle tires containing zinc as a Priority Product, as they do not address the potential exposures or adverse impacts under consideration. CalRecycle's waste tire and storage and disposal standards primarily address preventing fires and the breeding of mosquitoes, rodents, and other pests. If motor vehicle tires containing zinc were listed as a Priority Product, they would still be subject to the same requirements.

7. POTENTIAL ALTERNATIVES

Reference: California Code of Regulations, title 22, section 69503.2(b)(3).

This section summarizes information available to DTSC regarding alternatives that may or may not be safer than the Candidate Chemical. DTSC may summarize the hazards associated with these alternatives to illustrate readily available information. The sections below may include information such as how readily available an alternative is, product functions an alternative addresses, and implications for manufacturers using the alternative (e.g., use limitations, product reformulation, different equipment needs).

The CASQA petition observes, "Safer alternatives are tires containing less zinc or no zinc. Materials used to replace zinc would also need to not present a risk to water quality or public health." Metals other than zinc could be used to vulcanize rubber (Mostoni et al. 2019). Alternatives such as cadmium, lead, and mercury are unsuitable due to their toxicities. The petition refers to one published study that discusses magnesium as a possible substitute for some, if not all, of the zinc used in tires; however, the ramifications of this substitution for tire performance and human and environmental health are unclear. Strategies to use less zinc focus on technologies that enhance zinc's ability to participate in the chemical reactions involved in vulcanization. Technologies that enhance the dispersion of zinc in rubber during vulcanization, thereby improving the efficiency of the process, may allow tire manufacturers to use less zinc without diminishing the quality of the finished product (Mostoni et al. 2019; Wang et al. 2022). The Alternatives Analysis required by the SCP regulations is designed to answer the question of whether such technologies are available and feasible.

8. ADDITIONAL CONSIDERATIONS

Data Gaps

The science surrounding the presence, fate, and toxicity of zinc and tire wear particles has advanced significantly in recent years. However, data gaps exist that limit our ability to comprehensively understand the full scope of potential impacts of zinc from motor vehicle tires to aquatic organisms.

Existing regulatory frameworks and water quality derivation criteria may not sufficiently evaluate the ongoing potential for release of zinc from TWP as they are weathered. As noted above, Roberts (2021) found that TWP continued to leach appreciable quantities of zinc into saltwater even after almost three months of weathering in the environment. TWP serve as a vast reservoir of zinc to the aquatic environment, and approaches to better understand the exposure concerns related to this ongoing release are needed.

Evaluation of zinc in the aquatic environment through models such as the biotic ligand model do not currently consider the role of ingestion as an exposure pathway (Mebane et al. 2020; Van Genderen et al. 2020). The importance of this exposure pathway to total zinc exposure is not completely understood, although recent data from Masset at al. (2021) suggest that involuntary ingestion of TWRP results in greater leaching of zinc in the gut of aquatic organisms than in water. Additionally, the amount of zinc that leaches from a particle has been shown to increase as particle size decreases. Although TWP/TWRP size distributions in the environment are not fully understood, due to sampling and analytical challenges, most particles are expected to be at or below the sizes considered by Masset et al. (Kreider et al. 2010; SFEI 2021; Masset et al. 2021). This research suggests that current estimates of exposure to zinc due to the release of TWP may be low. Additional research is needed to better understand exposure to tire-derived contaminants, such as zinc, through the ingestion pathway.

In addition to the unclear role of ingestion, there are other complexities of zinc exposure and toxicity that are difficult to model. These complexities may lead models to underestimate the potential adverse impacts of zinc in motor vehicle tires. Metal speciation, temporal and spatial water quality changes, and variations in the equilibrium of the waterbody can all impact bioavailability and are difficult to sufficiently account for in models (Mebane et al. 2020; Van Genderen et al. 2020). For example, most bioavailability models assume that a waterbody is in equilibrium; however, large pulses of stormwater can disrupt equilibrium and may result in enhanced bioavailability of zinc that would otherwise be assumed to not be bioavailable (Mebane et al. 2020). Additionally, temperature has been shown to impact metal toxicity; however, more research is needed to understand the role that temperature may play (Mebane et al. 2020), particularly given anticipated changes in global climate.

It is difficult to observe the effects of stormwater plumes as they occur and difficult to identify specific components responsible for stormwater plume toxicity in the field. Toxicity identification evaluation (TIE) bioassays, such as those used in the laboratory studies described above, provide some of the most direct evidence available for the role of zinc in the toxicity of stormwater plumes (USC Sea Grant 1999; Schiff et al. 2002; Schiff et al. 2003). However, since the water column is chemically and ecologically complex, there are limitations to these studies that may result in over- or under-estimation of toxicity to different forms of aquatic life (Chapman 2000; OEHHA 2004). One major constraint is that the toxicity of stormwater samples is often determined from exposure to a single organism or life stage, often with standardized qualities. Organisms used in TIE studies must be healthy, sensitive to environmental toxicants but adaptable to test conditions, physiologically well-characterized, and must fit other applicable criteria (U.S. EPA 1993). In contrast, multiple taxa at different life stages are present in the marine water column (Barnett and Jahn 1987; USC Sea Grant 1999; Schiff et al. 2003; Lassiter et al. 2006; Lavaniegos and Ohman 2007). In natural conditions, organisms in the water column are heterogenous and are therefore likely to have variable susceptibility to environmental toxicants compared to model organisms in the laboratory (Chapman 2000). The relationship between single species toxicity tests and ecological impacts at the population and community levels is a matter of ongoing research (Schiff et al. 2003).

The purple sea urchin is a useful marine model organism for TIE bioassays because urchins are easy to collect, amenable to laboratory culture, environmentally adaptable, sensitive to toxicants, and produce gametes on demand to generate sensitive life stages (U.S. EPA 1995; Phillips et al. 1998; OEHHA 2004). Because sea urchin fertilization takes place in minutes, it is an appropriate biological process for measuring adverse impacts due to short term exposure scenarios such as stormwater plumes (U.S. EPA 1995; Phillips et al. 1998; USC Sea Grant 1999; Schiff et al. 2003; OEHHA 2004). It is important to use a sensitive bioassay such as purple sea urchin fertilization to maintain protectivity of more sensitive species (Connon et al. 2012). It is not possible or desirable to conduct toxicity studies on all species or life stages present in an aquatic environment or to evaluate all possible endpoints (Chapman 2000; Connon et al. 2012). However, impacts to development, growth, structure and function, and behavior are among the toxicological effects caused by zinc exposure (Eisler 1993) that may be missed in a bioassay that only evaluates a single endpoint. Additionally, organisms that are physiologically resistant to a given toxicant may still be indirectly affected due to ecological effects (e.g., loss of prey) (Chapman 2000). Population- and community-level impacts of stormwater plumes and associated zinc exposures, either through direct or indirect effects of toxicity, remain to be directly evaluated.

9. CONCLUSIONS

The presence of zinc in motor vehicle tires and its release from TWP expose aquatic organisms in California waterways to this toxic metal. TWP represents a significant source of zinc in stormwater runoff, which is a significant source of zinc introduced to the aquatic environment. Additionally, TWP are transported in large quantities to the environment, where they represent an ever-growing, continual source of zinc to aquatic organisms. Zinc is routinely detected in stormwater runoff and sediments throughout California.

Lab studies have connected observed stormwater and TWP leachate toxicity to zinc. Especially in the southern part of the state, California waterways have been found to exceed zinc WQC, including at the point of stormwater discharge. This results in the need for stormwater agencies to employ special handling of stormwater to mitigate the impacts of zinc to the aquatic environment. Based on its evaluation of CASQA’s petition and the factors discussed above, DTSC has concluded that there is potential for exposure of aquatic organisms to zinc from motor vehicle tires and that such exposures have the potential to contribute to or cause significant or widespread adverse impacts. Based on these findings, DTSC intends to designate motor vehicle tires containing zinc as a Priority Product.

ACRONYMS AND ABBREVIATIONS

CalRecycle	California Department of Resources Recycling and Recovery
CASQA	California Stormwater Quality Association
CWA	Clean Water Act
DTSC	Department of Toxic Substances Control
GVWR	Gross Vehicle Weight Rating
GPC	GS1 Global Product Classification
LC_{50}	Median Lethal Concentration
mBLM	Multibiotic Ligand Model
NHTSA	National Highway Traffic Safety Administration
NPDES	National Pollutant Discharge Elimination System
NAICS	North American Industry Classification System
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
ROS	Reactive Oxygen Species
SCP	Safer Consumer Products
State Water Board	State Water Resources Control Board
SUV	Sport Utility Vehicle
TIE	Toxicity Identification Evaluation
TRWP	Tire and road wear particles
TWP	Tire wear particles
U.S. EPA	United States Environmental Protection Agency
WQC	Water Quality Criteria
Zn	Zinc
ZnO	Zinc oxide

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APPENDIX A: POTENTIAL RELEVANT FACTORS

Non-exhaustive list of adverse impact factors that may be relevant to this proposed Priority Product

Relevant factors are used in SCP's Alternatives Analysis (AA) to make a focused and meaningful comparison between the adverse impacts of a Priority Product throughout its life cycle and those of the alternative(s). This Rationale Document has identified relevant factors in the following categories:

- Adverse environmental impacts
- Adverse waste and end-of-life effects
- Environmental fate
- Associated exposure pathways
- Life cycle segments
  - Use
  - Operation and maintenance
  - Waste generation and management
  - Reuse and recycling
  - End-of-life disposal

At a minimum, all AAs submitted for this product-chemical combination must include a discussion of these factors and how their impacts compare between the Priority Product and the alternative(s) that have been identified, at the appropriate point in the lifecycle. This list is not intended to be exhaustive. In addition, alternatives evaluated in the AA Report will likely have additional adverse impacts that do not apply to the Priority Product; these will also need to be assessed in the AA Report. Product performance and economics are generally not evaluated in the Rationale Document.

APPENDIX B: REPORT PREPARATION

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