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# Product-Chemical Profile for Personal Care and Cleaning Products Containing 1,4-Dioxane



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## ABOUT THIS PROFILE

The Department of Toxic Substances Control (DTSC) identifies product-chemical combinations for consideration as Priority Products in accordance with the process identified in Article 3 of the Safer Consumer Products (SCP) regulations.<sup>1</sup>

This Product-Chemical Profile (Profile) demonstrates that the regulatory criteria have been met and serves as the basis for Priority Product rulemakings listing personal care or cleaning products containing 1,4-dioxane. The Profile does not provide a comprehensive assessment of all available literature on adverse impacts and exposures for 1,4-dioxane or personal care and cleaning products. We will finalize this Profile after considering public comments and may then begin the rulemaking process. If a Priority Product regulation is adopted, responsible entities must follow the reporting requirements pursuant to the SCP Regulations.<sup>2</sup>

Readers should consider the following:

- This Profile summarizes information compiled by DTSC as of June 2023.
- This Profile is not a regulatory document and does not impose any regulatory requirements. The definitions of the Chemical of Concern and the product categories provided here, as well as any method performance criteria, may be changed during public engagement and rulemaking. If we identify one or more Priority Products based on the information in this document, responsible entities must follow the requirements in the Priority Product listing regulations.
- We request that stakeholders provide data on the chemical and products described in this document to assist us in the evaluation process that may lead to our regulatory proposal. Written comments can be submitted using our information management system, CalSAFER.<sup>3</sup>
- We are not asserting that these products cannot be used safely. The information presented in this Profile only indicates that there is a potential for exposure of people or the environment to 1,4-dioxane in personal care and cleaning products and that such exposure has the potential to cause or contribute to significant or widespread adverse impacts.

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<sup>1</sup> California Code of Regulations, Title 22, Division 4.5, Chapter 55, Article 3.

<sup>2</sup> California Code of Regulations. Title 22, section 69503.2(a).

<sup>3</sup> <https://dtsc.ca.gov/scp/personal-care-and-cleaning-products-containing-14-dioxane/>

- **Key Terms**
- **Candidate Chemical:** A chemical that exhibits a hazard trait and is listed on DTSC’s Candidate Chemicals List.
- **Priority Product:** A product-chemical combination as defined in regulation by DTSC that has the potential to contribute to significant or widespread adverse impacts to humans or the environment.
- **Product-Chemical Profile:** A report that explains DTSC’s determination that a proposed Priority Product meets the SCP regulatory criteria for potential exposure and significant or widespread adverse impacts to humans or the environment.

## EXECUTIVE SUMMARY

DTSC has determined that personal care and cleaning products containing 1,4-dioxane meet the Priority Product identification and prioritization criteria outlined in the SCP Regulations:

1. There is potential for human exposure to 1,4-dioxane from personal care and cleaning products.
2. The exposure has the potential to contribute to or cause significant or widespread adverse impacts.

The remainder of this Executive Summary summarizes the evidence to support any future proposals to regulate one or more personal care or cleaning products containing 1,4-dioxane as Priority Products. Citations and additional details to substantiate the content in this Executive Summary can be found in the remainder of the document.

## Potential for Exposure to 1,4-Dioxane in Personal Care and Cleaning Products

Many personal care and cleaning products include ingredients that act as surfactants – chemical compounds that can function as emulsifiers, wetting agents, detergents, foaming agents, or dispersants – and many surfactants must be made less harsh via ethoxylation, a process that involves the reacting the ingredient with ethylene oxide. 1,4-Dioxane is a contaminant generated during the production of ethoxylated surfactants. Product testing and manufacturer-reported data point to a wide range of 1,4-dioxane contamination in personal care and cleaning products. Current approaches to reducing the concentration of 1,4-dioxane or removing it from personal care and cleaning products

include reducing the formation or presence of 1,4-dioxane in the surfactant ingredients or switching to unethoxylated alternatives.

1,4-Dioxane is a persistent, mobile, and toxic (PMT) chemical that is very soluble in water. It is mobile in both the aquatic environment and in soil. While 1,4-dioxane is volatile – readily vaporizable at a relatively low temperature – it is unlikely to volatilize into air once dissolved in water. Most standard forms of wastewater treatment and drinking water treatment do not remove 1,4-dioxane. Once released into the environment, 1,4-dioxane moves rapidly into surface water and groundwater, where it can accumulate.

While consuming contaminated drinking water is the most concerning source of exposure to 1,4-dioxane for the general population, Californians who use personal care and cleaning products contaminated with 1,4-dioxane may have high aggregate exposures,<sup>4</sup> especially if their drinking water or air is also contaminated with the chemical or if they are occupationally exposed. Home use of personal care and cleaning products containing 1,4-dioxane contributes to both inhalation and dermal exposures to this chemical through activities such as dishwashing and bathing. Workers (e.g., janitors) who use cleaning products on a routine basis are expected to have greater exposure to 1,4-dioxane than the general population. The manufacturing of surfactants used in personal care and cleaning products that are contaminated with 1,4-dioxane may further contribute to worker exposures. Elevated concentrations of 1,4-dioxane in ambient air near surfactant manufacturing facilities may also lead to increased exposure to nearby communities.

Modeling supports the assertion that personal care and cleaning products containing 1,4-dioxane contribute to continuous, low-level, widespread contamination of municipal wastewater when these products are washed down the drain after use. Once introduced, 1,4-dioxane is not easily removed from wastewater and is released into the environment via effluent. Data on the presence of 1,4-dioxane in California wastewater treatment plants indicate a constant 1,4-dioxane level of approximately one microgram per liter (1 µg/L) in wastewater treatment plant effluents, suggestive of a widespread source such as consumer products. Residential septic tank effluent data also indicates average 1,4-dioxane concentrations of 1.49 µg/L, with household products identified as the dominant source.

There is potential for widespread exposure to 1,4-dioxane through drinking water, according to data collected across California by the State Water Resources Control Board (State Water Board) and by the U.S. Environmental Protection Agency (U.S. EPA) under the third Unregulated Contaminant Monitoring Rule (UCMR3). While the dominant source of groundwater contamination is historical releases of

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<sup>4</sup> Aggregate exposure is exposure to the same chemical from multiple sources.

1,4-dioxane, including improper disposal of industrial solvents, additional ongoing contamination of both surface water and groundwater can come from treated wastewater containing 1,4-dioxane from personal care and cleaning products. Concern about the presence of 1,4-dioxane in treated wastewater has grown as recycled water is increasingly reused for drinking water production.

## Potential for Significant or Widespread Adverse Impacts

Mobile and persistent chemicals in the wastewater stream – especially those with toxicity concerns, such as 1,4-dioxane – represent a threat to public health, a burden to wastewater treatment facilities, and an impediment to direct reuse of water. Aggregate exposure to 1,4-dioxane across the life cycle of consumer products as well as exposure to the chemical from other sources of environmental contamination may cause or contribute to widespread and significant adverse impacts to Californians, particularly those living in vulnerable communities, those with liver disease, and children.

1,4-Dioxane is classified as likely to be carcinogenic to humans by U.S. EPA. U.S. EPA characterizes 1,4-dioxane as a multi-site carcinogen that may have more than one mode of action. It acts as a carcinogen, most notably in the liver and nasal cavity, but also in the kidney, mammary glands, lung, and peritoneum of laboratory animals. Additionally, several recent studies have shown positive evidence of genotoxicity.

Aggregate exposure to 1,4-dioxane from use of consumer products, consumption of drinking water, and in some instances inhalation of air, may be significant. Residents of California's vulnerable communities have lower tolerance for exposure to chemical stressors such as 1,4-dioxane than residents of other communities. These vulnerable communities – which are subject to the cumulative effects of factors such as barriers to health care, unemployment, and linguistic isolation – may also have levels of 1,4-dioxane in their drinking water above the State Water Board's Notification Level (NL).

Because 1,4-dioxane functions as a carcinogen affecting the liver, people with compromised liver function are another sensitive population that may be significantly impacted by exposure to the chemical in consumer products. Reduced liver function may slow the breakdown and excretion of 1,4-dioxane. In addition, many liver diseases increase the chance of developing liver cancer. Thus, 1,4-dioxane exposure may create greater risk for liver cancer in humans with impaired liver function. Vulnerable and environmentally burdened communities may have higher rates of liver diseases, including hepatitis and nonalcoholic fatty liver disease, and risk factors for liver diseases, such as obesity and consumption of a high-fat diet.

Children exposed to 1,4-dioxane through use of contaminated personal care products may also have a higher potential for adverse impacts than the population at large. Children's product use patterns,



which are different from those of adults, may lead to longer-duration and higher-level exposures to 1,4-dioxane. For example, children are more likely to take baths and have different behaviors, such as drinking bath water. In addition, early life exposure to carcinogens may have more significant long-term health implications than exposure to the same chemicals later in life.

The presence of 1,4-dioxane in California's wastewater and drinking water supplies is also concerning. U.S. EPA's 2013-2015 UCMR3 survey detected 1,4-dioxane in drinking water in 10 California counties at concentrations above the reference concentration of 0.35 µg/L, which represents a one in one million (1,000,000) cancer risk as determined by U.S. EPA's Integrated Risk Information System (IRIS) Program. While these exceedances were found in a minority of California's 58 counties, they were concentrated in highly populated counties that represent about half of the state's population.

In light of California's arid climate and the propensity for climate change to make droughts more severe, previous risk assessments may have underestimated the potential for exposure to 1,4-dioxane from wastewater-impacted drinking water. Traditional risk assessments assume dilution of wastewater effluent that is generally several orders of magnitude higher than is typical in California watersheds. Release of effluents containing PMT compounds, such as 1,4-dioxane, to surface waters used as drinking water sources is especially concerning. When 1,4-dioxane is not removed from wastewater before release to the environment, the chemical continues to accumulate in the water cycle. In these cases, dilution is critical to reducing the concentration of 1,4-dioxane in receiving waters to acceptable levels. However, when water is scarce, relying on dilution to mitigate 1,4-dioxane concerns is not a viable option. In fact, state policies actively promote direct potable reuse of recycled water to meet California's water demands, due to the state's high population, water-intensive agriculture, and chronic drought conditions.

The presence of 1,4-dioxane in wastewater also contributes to adverse impacts to water agencies that produce recycled water and must meet permit requirements related to 1,4-dioxane. Multiple water agency stakeholders have expressed concern about their ability to consistently produce potable recycled water that meets the standard for 1,4-dioxane. These agencies may need to implement costly additional treatment measures to reduce 1,4-dioxane concentrations, and these expenses could be passed on to their customers. While consumer products are not always the largest contributor of 1,4-dioxane to wastewater, they represent a constant and significant fraction and are a nonpoint source that treatment facilities cannot address through typical industrial source control and pretreatment efforts. The presence of 1,4-dioxane in wastewater influent and effluent may impair the State Water Board's ability to meet its policy goals for recycled water. Source reduction, a potential outcome of listing a personal care or cleaning product containing 1,4-dioxane as a Priority Product, would be an effective way to reduce the presence of 1,4-dioxane in wastewater and therefore assist California in meeting policy goals for recycled water.

## Proposed Action

Based on the criteria in the Safer Consumer Products regulations, we have determined that personal care and cleaning products containing 1,4-dioxane have the potential to cause significant and widespread exposure and adverse impacts to Californians – particularly those living in vulnerable communities, those with liver disease, workers, and children – as well as to agencies that produce recycled water. We have also found that there are no applicable state or federal laws or regulations, nor any international treaties or agreements with the force of domestic law, that currently protect Californians or the environment from such potential exposure or adverse impacts.

Therefore, we plan to propose one or more Priority Products within two product categories included in DTSC’s [Three Year Priority Product Work Plan \(2021-2023\)](#) – the Beauty, Personal Care, and Hygiene Products category and the Cleaning Products category. Because 1,4-dioxane is an impurity in these products, any rulemaking related to the chemical in personal care products or cleaning products, including those defined in this Profile, will include an Alternatives Analysis Threshold (AAT) value, tentatively proposed to be one part per million (ppm). Manufacturers of Priority Products with 1,4-dioxane concentrations below the AAT value can choose to submit an Alternatives Analysis Threshold Notification in lieu of conducting an Alternatives Analysis or other means of complying with the Safer Consumer Products Regulations.

## 1. PRODUCT DEFINITIONS AND SCOPE

*This section describes the types of products, as part of a product-chemical combination, that DTSC may propose as a Priority Product. This section also outlines the proposed Alternatives Analysis Threshold value.*

1,4-Dioxane is often present as a contaminant within two product categories included in DTSC’s [Three Year Priority Product Work Plan \(2021-2023\)](#): Beauty, Personal Care, and Hygiene Products and Cleaning Products. The definitions below highlight some of the products that we may designate as Priority Products within the larger Beauty, Personal Care, and Hygiene Products category and the Cleaning Products category. These definitions are representative but not exclusive of the types of Priority Products we may propose based on this Technical Document. For the purposes of this Profile, the Beauty, Personal Care, and Hygiene Products category will be referred to as simply “personal care products.” We intend to designate one or more 1,4-dioxane-containing products within this category as Priority Products.

We will provide the exact Priority Product definition in future rulemakings. Because 1,4-dioxane is an impurity in these products, any rulemaking related to the chemical in personal care products or



cleaning products, including those defined in this Profile, will include an Alternatives Analysis Threshold (AAT) value, as explained below.

## Laundry Detergent

Laundry detergent includes any product intended to clean or remove soil or unwanted deposits from clothes and textile products, such as bedding and tablecloths, during laundering. This includes laundry detergents of any form, such as granules, liquids, powders, tabs, crystals, liquid laundry packets, or other types of pods/pacs used in washing machines, for hand washing, or as part of a laundry system. Detergents intended for use as a presoak or pre-spotter, or with fabric or color protection properties, are also included. These products may be categorized as Global Product Classification (GPC) laundry detergents identified by the following Global Standards One (GS1) codes (GS1 2020):

- Segment 47000000 – Cleaning/Hygiene Products
  - Family 47100000 – Cleaning Products
    - Class 47101700 – Laundry
      - ⇒ Brick 10000424 – Laundry Detergents

## Surface Cleaners

Surface cleaners for tables, appliances, and other objects at home and work are available to consumers in a variety of forms, such as spray liquid, gel, and wipes. Multipurpose surface cleaners can be applied to many types of surfaces for general cleaning. These products may be categorized as GPC cleaning products identified by the following codes (GS1 2020):

- Segment 47000000 – Cleaning/Hygiene products
  - Family 47100000 – Cleaning Products
    - Class 47101600 – Cleaners
      - ⇒ Brick 10000405 – Surface Cleaners

## Dish Detergent

Dish detergents include any products that may be described as automatic or manual/hand dishwashing detergent preparations specifically designed to clean dishes, assist in the drying process, or prevent filming or lime scale. This includes but is not limited to products in tablet, liquid, gel, or powder form. These products may be categorized as GPC dish cleaning/care detergents identified by the following codes (GS1 2020):

- Segment 47000000 – Cleaning/Hygiene Products
  - Family 47100000 – Cleaning Products

- Class 47101600 – Cleaners
  - ⇒ Brick 10000406 – Dish Cleaning/Care - Automatic
  - ⇒ Brick 10000636 – Dish Detergents - Hand

## Shampoo

Shampoos include hair care products, typically in the form of a viscous liquid, that are used for cleaning hair and scalp. Shampoo is used by applying it to wet hair, massaging the product into the hair, then rinsing it out. These products may be categorized as GPC shampoos identified by the following codes (GS1 2020):

- Segment 53000000 – Beauty/Personal Care/Hygiene
  - Family 53140000 – Hair products
    - Class 53141100 – Hair care products
      - ⇒ Brick 10000368 – Shampoo

The definition of this class of consumer products excludes prescription drugs and devices as defined by Section 4022 of the Business Profession Code.

## Body Washes and Hand Soaps

Body washes are specialized liquid or semiliquid products used for cleaning the body during showers or baths. These products use synthetic detergents derived from either petroleum or plant sources. Examples include but are not limited to combination “X in 1” washes that provide multifunctionality, as well as bubble baths and scrubs. Hand soaps are cleaning soaps designed to be used routinely on the skin to clean or remove typical or common dirt and soils. Examples include but are not limited to foaming hand washes and squirt dispenser sink gels. Body washes and hand soaps may be categorized in the GPC system and identified by the following codes (GS1 2020):

- Segment 53000000 – Beauty/Personal Care/Hygiene Products
  - Family 53130000 – Skin Products
    - Class 53131300 – Body Washing
      - ⇒ Brick 10000330 – Cleansing/Washing/Soap-Body

The definition of this class of consumer products excludes prescription drugs and devices as defined by Section 4022 of the Business Profession Code.

## Face Wash

The scope of face washes covered in this Profile includes cleaners or soaps designed primarily to clean the facial area and then be rinsed off. Face washes include but are not limited to facial cleansing

creams, semisolids, liquids, lotions, and beard washes. These products may be categorized as GPC skin products identified by the following codes (GS1 2020):

- Segment 53000000 – Beauty/Personal Care/Hygiene Products
  - Family 53130000 – Skin Products
    - Class 53131100 – Skin Care
      - ⇒ Brick 10000424 – Cleansers/Cosmetics Removers (non-powdered)
      - ⇒ Brick 10000342 – Exfoliants/Masks

The definition of this class of consumer products excludes prescription drugs and devices as defined by Section 4022 of the Business Profession Code.

## Alternatives Analysis Threshold Definition

The Alternatives Analysis Threshold (AAT) is the maximum concentration of a Chemical of Concern that a Priority Product may contain without triggering a requirement that the manufacturer perform an Alternatives Analysis (see California Code of Regulations, Title 22, section 69505.3). If the Chemical of Concern is a contaminant, the AAT is assumed to be the Practical Quantitation Limit (PQL)<sup>5</sup> unless we decide to set an AAT above the PQL. We will specify the PQL in the Priority Product listing regulation. In products covered by this Profile, 1,4-dioxane is present only as a contaminant. As of the publication date of this document, we intend to set the AAT at one part per million (ppm) for any future Priority Products containing 1,4-dioxane. The justification for an AAT of 1 ppm is provided in [Appendix D: Alternatives Analysis Threshold Rationale](#). If, in the future, we determine that a different AAT is appropriate for a Priority Product containing 1,4-dioxane, we will provide our rationale for the alternate AAT value at the time the regulation to list the Priority Product is proposed.

## 2. CANDIDATE CHEMICAL DEFINITION AND PROPERTIES

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

1,4-Dioxane is a Candidate Chemical under the SCP Program due to its presence on the following authoritative lists (DTSC 2020a; DTSC 2021):

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<sup>5</sup> The Practical Quantification Limit is defined as “the lowest concentration of a chemical that can be reliably measured within specified limits of precision and accuracy using routine laboratory operating procedures” (California Code of Regulations, Title 22, section 69501.1(a)(52).

- California Office of Environmental Health Hazard Assessment's (OEHHA's) Proposition 65 list of carcinogens
- Chemicals with Notification Levels as established by the California State Water Resources Control Board
- Chemicals with Reference Exposure Levels (RELs) established by OEHHA
- Chemicals Identified as Toxic Air Contaminants (TACs) by the California Air Resources Board (CARB)
- Clean Water Act section 303(d) List
- European Commission Annex VI Carcinogen, Category 1B carcinogen
- International Agency for Research on Cancer (IARC), Group 2B carcinogen
- National Toxicology Program 13th Report on Carcinogens, Reasonably Anticipated to be a Human Carcinogen
- United States Environmental Protection Agency's (U.S. EPA's) Integrated Risk Information System (IRIS) Carcinogens, Likely to Be Carcinogenic to Humans
- U.S. EPA's IRIS Neurotoxicants

The concerns outlined in this Profile focus on those related to the presence of 1,4-dioxane as a contaminant in personal care and cleaning products. The formation of 1,4-dioxane as a contaminant in these products is discussed below. 1,4-Dioxane is also a solvent that has been intentionally used in multiple commercial and industrial applications, although many of these uses have decreased (U.S. EPA 2020a).

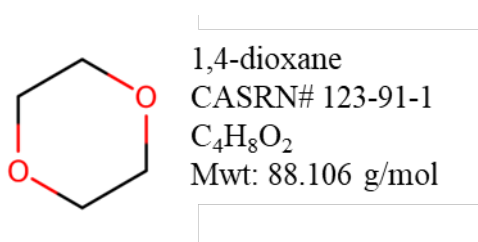


Figure 1. Identifying information for 1,4-dioxane including structure, CASRN (123-91-1), molecular formula (C<sub>4</sub>H<sub>8</sub>O<sub>2</sub>), and molecular weight (88.106 g/mol).

Synonyms for 1,4-dioxane (PubChem 2021):

- 1,4-diethylene dioxide
- 1,4-dioxacyclohexane
- 1,4-diethyleneoxide
- di(ethylene oxide)
- diethylene dioxide
- diethylene ether

- dioxane
- dioxane-1,4
- dioxyethylene ether
- glycol ethylene ether
- p-dioxane
- p-dioxin, tetrahydro-
- tetrahydro-1,4-dioxin
- tetrahydro-p-dioxin

Other identifiers for 1,4-dioxane (PubChem 2021):

- European Community Number = 204-661-8
- InChI = 1S/C4H8O2/c1-2-6-4-3-5-1/h1-4H2
- InChIKey = RYHBNJHYFVUHQT-UHFFFAOYSA-N
- Distributed Structure-Searchable Toxicity (DSSTox) Substance ID = DTXSID4020533

## Relevant Physicochemical Properties

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

*Physicochemical properties can be helpful in predicting a chemical's behavior. A chemical's behavior in humans, wildlife, ecosystems, and the environment may indicate potential adverse public health and environmental impacts.*

Relevant physicochemical properties of 1,4-dioxane are listed in Table 1. 1,4-Dioxane is highly soluble in water (PubChem 2021). It is volatile, highly flammable, and very mobile in soils. When released to soil, 1,4-dioxane moves into groundwater (U.S. EPA 2020a). Its solubility in water, combined with its moderate vapor pressure, gives 1,4-dioxane a low Henry's Law constant,<sup>6</sup> indicating that it is unlikely to volatilize into the air from water. 1,4-Dioxane's low organic carbon-water partition coefficient (log K<sub>oc</sub>) indicates that it is unlikely to be absorbed by and/or adsorbed to sediments or soils. Its low octanol-water partition coefficient (log K<sub>ow</sub>) indicates that it is unlikely to accumulate in fatty tissues; therefore, bioconcentration is not expected to be a concern.

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<sup>6</sup> Henry's Law states that the amount of dissolved gas in a liquid is directly proportional to its partial pressure above the liquid. The proportionality factor is called Henry's law constant.

Table 1. Physicochemical properties of 1,4-dioxane (PubChem 2021). Log  $K_{oc}$  represents the log of the organic carbon-water partition coefficient, and log  $K_{ow}$  represents the log of the octanol-water partition coefficient.

Physicochemical Property	Value	Citation
Log $K_{oc}$	0.4-1.46	(U.S. EPA 2020a; PubChem 2021)
Log $K_{ow}$	-0.27	(PubChem 2021)
Henry's Law constant (atm·m <sup>3</sup> /mole)	4.8x10 <sup>-6</sup>	(PubChem 2021)
Vapor pressure, mm Hg at 25°C	38.1	(PubChem 2021)
Boiling point (°C)	101.2	(PubChem 2021)
Melting point (°C)	11.75	(PubChem 2021)
Density g/cm <sup>3</sup> at 20°C	1.0337	(PubChem 2021)
Water solubility, g/L at 25°C	>800	(PubChem 2021)
Flash point (°C)	12-18.3	(PubChem 2021)

## Environmental Fate

Reference: California Code of Regulations, TITLE 22, section 69503.3(a)(1)(E).

*Environmental fate describes a chemical's mobility in environmental media, transformation (physical, chemical, or biological), or accumulation in the environment or biota. A chemical's environmental fate in air, water, soil, and living organisms relates to its exposure potential hazard traits, as defined in the California Code of Regulations, Title 22, Chapter 54.*

Four key properties determine the fate of 1,4-dioxane in the environment: persistence, solubility, mobility, and volatility (U.S. EPA 2018d; U.S. EPA 2020a). These characteristics indicate that if 1,4-dioxane is released to the environment, it will preferentially migrate to water, where it will persist. Its volatility indicates that it will also be found in the air. Environment Canada and Health Canada (2010) presented modeling results for 1,4-dioxane suggesting that 99.6% of the chemical will reside in water if 1,4-dioxane is released in water. When 1,4-dioxane is released to air, 44.8% will remain in air; 34.4% and 20.8% will partition to water and soil, respectively. Given 1,4-dioxane's distribution patterns in environmental media and its persistence in water, the contamination of water is the predominant concern.

### Water

1,4-Dioxane is highly soluble in water and has a very low Henry's Law constant (U.S. EPA 2020a). Given these parameters, 1,4-dioxane tends to remain dissolved in water or aqueous solutions rather than



volatilize (U.S. EPA 2020a). 1,4-Dioxane also has very low log  $K_{oc}$  and log  $K_{ow}$  values, indicating that it will remain mobile in water rather than partition to sediment, sludge, or biological material. However, it can remain associated with wastewater sludge given the high-water content of most wastewater sludges.

Once in water, 1,4-dioxane is persistent. Biodegradation and sorption are the most typical ways chemicals are removed from water and 1,4-dioxane does neither. 1,4-Dioxane is characterized as persistent in water pursuant to California Code of Regulations, Title 22, section 69405.3 because its half-life in water exceeds 60 days, based on standard Organisation for Economic Cooperation and Development (OECD) tests (U.S. EPA 2015b) (see more details in the [Exposure Potential Hazard Traits](#) section).

### **Wastewater**

Nominal amounts of 1,4-dioxane are removed during wastewater treatment. U.S. EPA predicts that about 98% of the 1,4-dioxane in wastewater influent is released in the treated effluent (U.S. EPA 2020a). Models generated by the Estimation Programs Interface (EPI) Suite predict that 1.75% of 1,4-dioxane from effluent will sorb to solids and 0.27% will volatilize (U.S. EPA 2018d). Standard biodegradation tests indicate that wastewater bacterial cultures do not biodegrade 1,4-dioxane (ECHA 2011; U.S. EPA 2020a). Data from the Los Angeles County Sanitation District (LACSD) provide further evidence for 1,4-dioxane's recalcitrance to biodegradation. The district measured the concentration of 1,4-dioxane in influent and during each of the three main stages of wastewater treatment and found that even the intense biodegradation processes used in secondary and tertiary treatment did not remove the chemical (Heil 2019). Collectively, these data demonstrate that there are few effective treatment methods for removing 1,4-dioxane from wastewater.

### **Surface Water**

In many cases, treated wastewater is discharged to surface water (Simonich et al. 2013). As noted earlier, 1,4-dioxane mixes readily with water. While that allows the chemical to dilute in the body of water it is discharged to, 1,4-dioxane's poor biodegradability allows it to persist. National-scale monitoring data from the National Water Information System demonstrate that 1,4-dioxane is detected in about 6% of surface water samples (U.S. EPA 2020a). In a 2016 study of the Cape Fear River watershed in North Carolina, Sun et al. (2016) measured 1,4-dioxane concentrations in effluent from wastewater treatment plants as high as 1,405  $\mu\text{g/L}$ . In another study of 1,4-dioxane in the Cape Fear River watershed, the North Carolina Department of Water Resources (NCDWR) (2016) found the highest concentrations, as high as 1,030  $\mu\text{g/L}$ , generally occurred near wastewater treatment plant discharges, while concentrations were lower near the river's mouth. While biodegradation may play a

role in downstream environments (Pollitt et al. 2019), U.S. EPA characterizes the biodegradation in surface water as “slow” (U.S. EPA 2020a).

## Groundwater

If 1,4-dioxane is present in soils, it rapidly spreads and percolates into groundwater. Because 1,4-dioxane is polar, it is unlikely to sorb to organic matter, soils, or dissolved solids and will instead migrate with the water in the soil. Because of its persistence, 1,4-dioxane contamination in groundwater can last for many years. Removal of 1,4-dioxane from groundwater has proven challenging, given its long half-life and its propensity to spread from its source (Adamson et al. 2015; reviewed in Pollitt et al. 2019). Additional information on the presence of 1,4-dioxane in California groundwater is included in the [Indicators of Potential Exposures to the](#) Candidate Chemical section below.

## Air

1,4-Dioxane has a vapor pressure of 38.1 mm Hg (mercury) and is, therefore, classified as volatile. It is designated as a hazardous air pollutant (HAP) under the federal Clean Air Act and as a TAC in California. Despite its volatility, long-range transport of 1,4-dioxane in the air is unlikely (Environment Canada and Health Canada 2010).

Once in the air, 1,4-dioxane reacts with hydroxyl radicals and breaks down (U.S. EPA 2020a). The rate of this reaction depends in part on the presence of other pollutants in the air, such as nitric oxide, as well as on weather conditions and the intensity of sunlight (Mohr 2010). We are conservatively classifying 1,4-dioxane as persistent in air, as discussed in greater detail in the Exposure Potential Hazard Traits section.

While 1,4-dioxane is volatile, its low Henry’s Law constant indicates that it is more likely to remain in water rather than partition to air (Health Canada 2018). Enhanced volatilization may occur when water is misted, as occurs in settings such as wastewater treatment plants, where U.S. EPA estimates that 0.27% of the 1,4-dioxane in wastewater will volatilize (U.S. EPA 2018d). Volatilization may also occur as water evaporates from rivers and lakes (Health Canada 2018). 1,4-Dioxane is also likely to volatilize from soil, as well as from sludge that is applied to land (when it is typically referred to as *biosolids*) and allowed to dry (U.S. EPA 2018d).

## Soil

1,4-Dioxane’s low log  $K_{OC}$  and log  $K_{OW}$  values suggest it is unlikely to sorb to organic matter and will, therefore, remain mobile in soils. This mobility can facilitate the chemical’s migration to groundwater (Health Canada 2018).

1,4-Dioxane also resists degradation in soils (U.S. EPA 2015b). In an aerobic soil microcosm study, none of the 1,4-dioxane present degraded after 120 days (U.S. EPA 2018d). Furthermore, the U.S. EPA model, BIOWIN, generally predicts that 1,4-dioxane will degrade slowly or negligibly in either aerobic or anaerobic soil conditions (U.S. EPA 2018d). Because its half-life in soil exceeds 180 days in soil microcosm tests (U.S. EPA 2015b), 1,4-dioxane is characterized as persistent in soil, pursuant to section 69405.3 of Title 22 of the California Code of Regulations.

### ***Sediment and Sludge***

1,4-Dioxane does not preferentially sorb to sediment or sludge (i.e., a slurry of solids and liquids). In most cases, the pore water contained in sediments or sludges is expected to be in equilibrium with the overlying water column (U.S. EPA 2020a). Consequently, 1,4-dioxane concentrations in sediments are predicted to be low, based on the generally low concentrations of 1,4-dioxane in surface water (Adamson et al. 2017). In sludge, which is about 95% water even when prepared for land application as *biosolids*, any 1,4-dioxane will generally remain in the water fraction of the sludge and at the same concentration as in the treated effluent.

### ***Environmental Transformation and Transformation Products***

1,4-Dioxane can be degraded in the atmosphere through indirect photolysis; the dominant transformation product is ethylene glycol diformate (CASRN 629-15-2) (reviewed in ATSDR 2012). In the past 20 years, much research has been conducted to identify specific bacteria, consortia, or other microorganisms that can grow on 1,4-dioxane and be used as a tool for groundwater bioremediation (Nakamiya et al. 2005; Kim et al. 2009; Mohr 2010; Pugazhendi et al. 2015; Inoue et al. 2016; Tusher et al. 2019). Biodegradation of 1,4-dioxane is generally quite limited because of the strength of the ether bonds in the compound (Mohr 2010); bacteria generally prefer carbon sources that break down more easily. Because 1,4-dioxane is so resistant to biodegradation, microbes may require special conditions to encourage them to feed on it, such as ensuring 1,4-dioxane is the only carbon source or acclimating the microbes to the presence of 1,4-dioxane. The biotransformation products reported include ethylene glycol (CASRN 107-21-1) (Nakamiya et al. 2005; Kim et al. 2009; Mohr 2010), 1,4-dioxane-2-ol (CASRN 22347-47-3) (Kim et al. 2009), and oxalic acid, which can feed into the Krebs cycle (the chain reaction in cells that use oxygen to produce energy) (Mohr 2010; Pugazhendi et al. 2015). Ethylene glycol is a Candidate Chemical based on developmental, kidney, and neurotoxicity in animal models and is a respiratory and eye irritant (Pharos 2020; DTSC 2020b).

## **Hazard Traits and Environmental or Toxicological Endpoints**

*Reference: California Code of Regulations, Title 22, section 69503.3(a)(1)(A).*

*The hazard traits and environmental or toxicological endpoints summarized in this section are defined in the SCP regulations sections 69501.1(a)(36) and (33), respectively, both of which refer to the Office of Environmental Health Hazard Assessment's (OEHHA's) Green Chemistry Hazard Trait regulations (California Code of Regulations, Title 22, Chapter 54). These include exposure potential, and toxicological and environmental hazard traits.*

### **Toxicological Hazard Traits**

Carcinogenicity is 1,4-dioxane's hazard trait of greatest concern. There is sufficient evidence from studies in laboratory mammals for authoritative bodies to conclude that 1,4-dioxane could cause cancer in humans. Importantly, cancer arises in animal studies of both ingestion and inhalation. The following authoritative bodies list carcinogenicity as a hazard trait of 1,4-dioxane:

- IARC – Possible human carcinogen (Group 2B) (IARC 1987; IARC 1999a)
- U.S. EPA IRIS – Likely to be carcinogenic to humans (U.S. EPA 2013a)
- National Toxicology Program (NTP) (15th ed.) – Reasonably anticipated to be a human carcinogen (NTP 2021)
- National Institute for Occupational Safety and Health (NIOSH) Center for Disease Control (CDC) – Potential Occupational Carcinogen (CDC 2019a)
- European Chemicals Agency – May cause cancer (class 1B) (ECHA CLP 2021)
- California's Office of Environmental Health Hazard Assessment – Proposition 65 Carcinogen (OEHHA 2020)

In addition to carcinogenicity, 1,4-dioxane is toxic to various organs. OEHHA and U.S. EPA list 1,4-dioxane as having the following toxicities:

- Hepatotoxicity and digestive system toxicity (OEHHA 2000)
- Nephrotoxicity and urinary system toxicity (OEHHA 2000)
- Respiratory toxicity (OEHHA 1999)
- Ocular toxicity (OEHHA 1999)
- Neurotoxicity (U.S. EPA 2013a)
- Hematotoxicity (OEHHA 2000)

### **Carcinogenicity**

Authoritative bodies such as U.S. EPA and IARC have concluded that animal studies provide sufficient evidence of 1,4-dioxane's carcinogenicity. Hepatic tumors (adenomas and carcinomas) are the type most frequently induced in animal studies; they were induced in guinea pigs, four strains of rats, and two strains of mice (U.S. EPA 2018d). While 1,4-dioxane is most likely to affect the liver, carcinogenicity is not limited to that organ. Other tumor types induced by 1,4-dioxane in animal studies include

carcinomas in the kidney (rats and mice); mesotheliomas of the peritoneum (male rats); and tumors in the mammary gland (female rats), nasal cavity (rats and mice), gallbladder (guinea pigs), and Zymbal gland; as well as subcutaneous tumors (IARC 1999a). A reexamination of pathology slides from a 1978 National Cancer Institute (NCI) study also found an increase in leukemia and lymphoma in 1,4-dioxane-exposed mice (Dourson et al. 2014).

1,4-Dioxane-induced tumors far from the primary site of exposure or the site of metabolism.

### ***Laboratory Studies***

In a two-year drinking water study, male and female rats were administered drinking water with 1,4-dioxane concentrations of 0, 200, 1,000, and 5,000 ppm (Kano et al. 2009). Both male and female rats in the mid-dose group (1,000 ppm) and the high-dose group (5,000 ppm) each experienced an increase in two types of liver cancers (hepatocellular adenoma and carcinoma). Even though the mid-dose results were not statistically significant, Kano et al. (2009) determined that they were meaningful because the incidence of tumors was above the historical averages observed in many other cancer studies at the Japanese Bioassay Research Center (JBRC). Additionally, altered hepatocellular foci (precancerous lesions of liver tumors) were significantly increased in males in the 1,000-ppm group. These are likely to represent preneoplastic lesions. The high dose group had additional tumors in the nasal cavity, dermis, mammary gland, and peritoneum. Among the nasal tumors, Kano et al. (2009) observed three rare types never before seen in any of JBRC's 43 previous cancer studies on other chemicals. The occurrence of these rare tumors suggests that 1,4-dioxane may have one or more unique modes of action (MOA).

Concurrently with their rat study, Kano et al. (2009) administered drinking water with 0, 500, 2,000, and 8,000 ppm 1,4-dioxane to mice. Male and female mice dosed with 1,4-dioxane experienced statistically significant increases of hepatocellular adenomas and carcinomas, the same types of liver cancers seen in the rats. In the high-dose groups, Kano et al. (2009) also identified two rare tumors in the nasal cavity – esthesioneuroepithelioma and nasal adenocarcinoma – which they attributed to 1,4-dioxane exposure.

In an inhalation study, Kasai et al. (2009) exposed groups of rats to 0, 50, 250, and 1,250 ppm 1,4-dioxane for six hours per day, five days per week for 104 weeks. IRIS notes a statistically significant dose response trend for the following tumor locations: liver, nose, kidney, abdomen, mammary gland, Zymbal gland (glands at the base of the ear in rodents), and below the skin (Kasai et al. 2009; U.S. EPA 2013a).

### ***Epidemiological Studies***

There is limited evidence of 1,4-dioxane-induced carcinogenicity from epidemiological studies. Studies of exposed workers typically have small sample sizes or are confounded by workers' exposure to other known carcinogens. Buffler et al. (1978) conducted a prospective 20-year mortality study on workers exposed to low levels of 1,4-dioxane, and found no differences between observed and expected incidences of cancer (reviewed in ATSDR 2012).

Thiess et al. (1976) conducted a cross-sectional study of workers exposed to 1,4-dioxane concentrations between 0.006 and 14.3 ppm for an average of nearly 25 years. Twelve deaths were reported; of those, two deaths were attributed to cancer. The rate of cancer and the overall death rate in the workers were not significantly different from rates observed in the general population (reviewed in ATSDR 2012).

A Danish comparative mortality study found that male employees of companies where 1,4-dioxane was used had a 64% higher incidence of liver cancer than male employees of other companies (Hansen, J. 1993 as reviewed by WHO 2004). This increase could not be explained by differences in alcohol consumption. However, the study did not control for co-exposure to other chemicals nor for the dose or duration of exposure (reviewed in WHO 2004 by Hansen, 1993 (in Danish)). The number of female workers in these industries was too low for meaningful statistics.

Garcia et al. (2015) investigated the relationship between ambient concentrations of hazardous air pollutants (HAPs) and the incidence of multiple types of breast tumors. The study found no correlation between exposure to 1,4-dioxane in ambient air and breast cancer incidence (Garcia et al. 2015). The breast cancer data were collected through the California Teacher Study; the exposures to 1,4-dioxane in industrial air emissions were modeled by the National Air Toxics Assessment (NATA). In a similar analysis, Hart et al. (2018) also found no correlation between 1,4-dioxane exposure and breast cancer incidence in a cohort of female nurses.

Given the available evidence, 1,4-dioxane exhibits the hazard trait of carcinogenicity (CCR, Title 22, section 69402.1).

### ***Mutagenicity or Genotoxicity***

U.S. EPA (2013b; 2020a) and IARC (1987; 1999a) concluded that 1,4-dioxane is weakly genotoxic at high doses. The results of genotoxicity studies are mixed; nevertheless, 1,4-dioxane meets the Globally Harmonized System (GHS) criteria for "moderate" genotoxicity, namely that it has "evidence of mutagenicity supported by *in vivo* or *in vitro* somatic cells of humans or animals" (U.S. EPA 2011b).



Some evidence indicates that high doses of 1,4-dioxane may be clastogenic, meaning it can cause breaks in the DNA backbone. This can result in the mis-segregation of chromosomes during mitosis and can generate micronuclei (Roy, Thilagar and Eastmond 2005; Itoh and Hattori 2018).

Neither 1,4-dioxane nor its metabolites have been found to cause point mutations in DNA in bacteria, as evidenced by negative results in a variety of microbial reverse mutation assays, such as the Ames test, with and without activation (summarized in IARC 1999b; Environment Canada and Health Canada 2010). Similar evidence suggests that 1,4-dioxane does not cause point mutations in mammalian cells. However, a recent study by Gi et al. (2018) found that high doses of 1,4-dioxane can cause point mutations in transgenic rats used to examine the mutagenicity of chemicals.

The IARC (1999b) cites 14 genotoxicity studies on mammalian cells, and 1,4-dioxane produced positive results or weakly positive results in five of those assays. These five positive studies, along with several newer positive studies published after the release of the IARC monograph (1999b), are summarized in Table 2.

Table 2. Genotoxicity assays that produced positive results.

Positive Genotoxicity Assay	Animal or Cell-type	Type of Experiment	Reference	Included in IARC Evaluation?
DNA strand breaks, cross-links, or related damage	Rat hepatocytes	<i>in vitro</i>	Sina et al., 1983 (reviewed in IARC 1999b)	Y
Sister chromatid exchange (weak)	Chinese hamster ovary CHO cells	<i>in vitro</i>	Galloway et al., 1987 (reviewed in IARC 1999b)	Y
Cell transformation	BLAB/c 3T3 mouse cells	<i>in vitro</i>	Sheu et al., 1988 (reviewed in IARC 1999b)	Y
DNA strand breaks	Sprague-Dawley rat liver cells	<i>in vivo</i>	Kitchin & Brown, 1990 (reviewed in IARC 1999b)	Y
Micronucleus test	Male and female C57BL/6 mouse bone marrow cells	<i>in vivo</i>	Mirkova, 1994 (reviewed in IARC 1999b)	Y
Micronucleus test	Mouse bone marrow erythrocytes and hepatocytes	<i>in vivo</i>	Roy et al., (2005)	N
Meiotic nondisjunction	Mature and immature <i>Drosophila</i> oocytes	<i>in vivo</i>	Muñoz and Barnett (2002)	N

Positive Genotoxicity Assay	Animal or Cell-type	Type of Experiment	Reference	Included in IARC Evaluation?
Micronucleus test	Rat hepatocytes, with and without hepatectomy	<i>in vivo</i>	Itoh et al. (2018)	N
Point mutations	F344 <i>gpt</i> delta transgenic rats	<i>in vivo</i>	Gi et al., (2018)	N

The results of more recent genotoxicity studies of 1,4-dioxane are mixed. A recent *in vivo* study used ribonucleic acid (RNA) sequencing to compare the transcriptomes of liver cells treated with four different carcinogens: two genotoxic hepatocarcinogens (*N*-nitrosodiethylamine and 3,3'-dimethylbenzidine-2HCl); a non-genotoxic hepatocarcinogen, di(2-ethylhexyl) phthalate (DEHP); and 1,4-dioxane. The RNA profile of cells treated with 1,4-dioxane was intermediate to those of the genotoxic and non-genotoxic chemicals (Furihata et al. 2018). This suggests that 1,4-dioxane may share some characteristics with genotoxic carcinogens or that it may act in a unique manner compared to DEHP. U.S. EPA's Toxicity Forecaster found that 1,4-dioxane induced the transcription of the tumor suppressor gene p53 in a human colon cancer cell line; this may indicate that 1,4-dioxane can induce DNA damage (U.S. EPA 2018a). Therefore, 1,4-dioxane meets the criteria for genotoxicity in in CCR, Title 22, section 69403.5.

### Mode of Action for Carcinogenicity

A chemical's mode of action (MOA) explains how it causes its toxic effects; in this case, cancer. While the carcinogenicity of 1,4-dioxane has been well-characterized, its MOA(s) have not been elucidated. In general, genotoxicity is a potential MOA for a carcinogen. In the assays that implicate 1,4-dioxane as genotoxic, positive results are seen only at higher doses, which may correlate with the saturation of the metabolic pathways that work to eliminate the chemical from the body. However, natural variation in these metabolic pathways and other uncertainties regarding 1,4-dioxane's genotoxicity and MOA(s) indicate that exposures must have wide safety margins to be protective.

### Hepatotoxicity (Digestive System Toxicity) and Nephrotoxicity

Toxicity to the liver and kidney (hepatotoxicity and nephrotoxicity, respectively) are among 1,4-dioxane's most sensitive chronic endpoints, and the response seems to be common in animal models via both oral and inhalation routes. These are also the organs that are most severely affected in workers with lethal exposures (reviewed in U.S. EPA 2005; ATSDR 2012; U.S. EPA 2020a). Both rats and mice experience kidney and liver toxicity at similar ranges in subchronic and chronic exposure studies; therefore, these endpoints are discussed together.

Occupational exposure studies indicate that 1,4-dioxane can be acutely toxic to the liver and kidney at extremely high doses (ATSDR 2012). Several reports from the early part of the 20th century document cases where workers died after being exposed to 1,4-dioxane. Barber reported that five workers died after inhaling unknown concentrations of 1,4-dioxane vapors, although dermal absorption could not be ruled out as a contributing factor (Barber, 1934 reviewed in ATSDR 2012). These workers showed liver and kidney toxicity, hypertension, increased white blood cell count, and cerebral edema. Kidney damage, hemorrhagic nephritis, was the likely cause of death (Barber, 1934 reviewed in ATSDR 2012; U.S. EPA 2013b). Johnstone (1959) reported that a worker died after a week of inhaling 1,4-dioxane vapors at a calculated average concentration of 470 ppm, with a maximum concentration in excess of 650 ppm (Johnstone, 1959 reviewed in ATSDR 2012). In addition, the worker also had significant dermal exposure (reviewed in ATSDR 2012). The autopsy revealed damage to the liver, kidneys, lungs, and brain (U.S. EPA 2020a); however, some of these effects may be attributable to the worker's high intake of alcohol (OEHHA 2000).

The liver and kidney are targets of toxicity when lab animals are exposed to 1,4-dioxane in inhalation and ingestion studies. In the liver, animals had single cell necrosis (Mattie et al. 2012), altered liver enzymes, and delayed recovery from anesthesia (Pilipyuk et al. 1977). Kociba et al. found lesions indicating necrosis, degeneration, and evidence of focal proliferation (1974). Two studies observed tubular degeneration in the kidney (Kociba, McCollister and Park 1974; Mattie et al. 2012). In addition, Kasai et al. found enlarged nuclei and hydropic changes in the proximal tubule of the kidney (2009). A recent 90-day subchronic study by Lafranconi (2021) of mice that were administered 1,4-dioxane in drinking water indicates that 1,4-dioxane can cause early events in liver tumor development such as enlargement of hepatocytes located next to the central vein and apoptosis in the liver.

These studies demonstrate that 1,4-dioxane meets SCP's criteria for hepatotoxicity (CCR, Title 22, section 69403.7) and nephrotoxicity (CCR, Title 22, section 69403.10).

### **Respiratory Toxicity**

1,4-Dioxane is a respiratory toxicant. The National Institute for Occupational Safety and Health (NIOSH) has designated 1,4-dioxane as a respiratory irritant (CDC 2019b), while the European Union (ECHA 2019), Australia, and Malaysia (Pharos 2019) require that 1,4-dioxane carry the H335 warning, "may cause respiratory irritation." These classifications as a respiratory irritant and toxicant are based on results from short-term studies in human volunteers and longer-term studies in animals.

Two studies conducted in the first half of the twentieth century found that relatively brief inhalation of 1,4-dioxane can have noticeable effects on humans. In a 1946 study, Silverman found that a 15-minute exposure to 300 ppm (1,080 mg/m<sup>3</sup>) 1,4-dioxane via inhalation caused nose and throat irritation in volunteers (Silverman, 1946 as reviewed in ATSDR 2012). Similarly, a 1930 study of five individuals

found that a one-minute exposure to a high dose (5,500 ppm) of 1,4-dioxane produced burning sensations in the throat and nose (Yant, 1930 as reviewed in ATSDR 2012).

Animal studies indicate 1,4-dioxane may act as a respiratory toxicant through both inhalation and ingestion exposure routes (NCI 1978; Kano et al. 2008; Kasai et al. 2009). In a study of rats that inhaled 1,4-dioxane, Kasai et al. (2009) observed inflammation, nuclear enlargement, and atrophy in the respiratory epithelium, as well as hardening of the layer beneath the mucous membranes. Rats and mice exposed to 1,4-dioxane in drinking water had enlarged nuclei in various epithelia in the upper respiratory tract and, at high doses, the mice exhibited degeneration in the bronchial epithelium (Kano et al. 2008). Additionally, mice in a 90-week drinking water study developed rhinitis and pneumonia in a dose-dependent manner (NCI 1978).

Given this available evidence, 1,4-dioxane meets the criteria in CCR, Title 22, section 69403.16 for respiratory toxicity.

### **Neurotoxicity**

1,4-Dioxane is classified as a neurotoxicant by U.S. EPA because it can damage the olfactory epithelium, which is a neural structure (U.S. EPA 2013a). Olfactory receptor neurons that detect odorants transmit the signal to the olfactory bulb and then to the central nervous system. Kasai et al. reported nuclear enlargement, inflammation, and atrophy in the olfactory epithelium of rats in response to 1,4-dioxane inhalation (2009).

1,4-Dioxane may cause neurotoxic effects in humans exposed to high doses of the chemical. Barber described workers killed in 1934 within two-weeks of high exposure to 1,4-dioxane (reviewed in ATSDR 2012). They displayed symptoms of central nervous system depression and ataxia (impaired coordination). Three of the five workers also had edema of the brain; Barber hypothesized the swelling to be secondary to kidney failure (reviewed in ATSDR 2012). Johnstone (1959) describes another worker who died after being exposed to an average concentration of 470 ppm 1,4-dioxane for a week (reviewed in ATSDR 2012). The worker had demyelination and small lesions in the basal nuclei; it is unclear whether these were the result of exposure (reviewed in ATSDR 2012).

1,4-Dioxane meets the criteria for neurotoxicity based on the criteria outlined in CCR, Title 22, section 69403.12.

### **Ocular Irritation**

1,4-Dioxane is an eye irritant (OEHHA 1999; U.S. EPA 2005; ATSDR 2012; CDC 2019b) in humans and animals. 1,4-Dioxane carries the H319 hazard warning, “causes serious eye irritation” in the European

Union. Based on data from ECHA, 1,4-dioxane can be classified as a Category 2 eye irritant (ECHA 2011).

1,4-Dioxane meets SCP's criteria for ocular toxicity as outlined in CCR, Title 22, section 69403.13.

### **Hematotoxicity**

OEHHA (2000) identified hematologic changes (changes in blood cell counts) as a critical effect in its derivation of the chronic Reference Exposure Level (REL) for 1,4-dioxane. OEHHA developed the REL based on a two-year inhalation study by Torkelson et al. (1974), in which exposed rats had decreased white blood cell counts and increased red blood cell counts (OEHHA 2000). A 1934 study by Barber suggested that chronic worker exposure to 1,4-dioxane might result in increased white blood cell counts (reviewed in OEHHA 2000; ATSDR 2012). OEHHA notes that these observed changes were inconsistent and that hematologic changes were not reported in a Kociba et al. (1974) ingestion study cited earlier under [Hepatotoxicity \(Digestive System Toxicity\) and Nephrotoxicity](#). OEHHA suggests the hematotoxicity may be dependent on the route of exposure (OEHHA 2000).

This evidence indicates that 1,4-dioxane meets the criteria in CCR, Title 22, section 69403.6 for hematotoxicity.

### ***Exposure Potential Hazard Traits***

#### **Environmental Persistence**

Based on the data discussed below, 1,4-dioxane is characterized as persistent in all environmental media, pursuant to California Code of Regulations, Title 22, section 69405.3. Additionally, U.S. EPA's Safer Choice (formerly, Design for the Environment) criteria would categorize 1,4-dioxane as very persistent (U.S. EPA 2011b), and Environment Canada's Domestic Substance List (DSL) identifies 1,4-dioxane as being persistent (Environment and Climate Change Canada 2021). Table 3 highlights the evidence for 1,4-dioxane's persistence in all environmental media; the evidence is strongest for water and soil.

Table 3. 1,4-Dioxane's persistence in environmental media.

Media	Criteria for Persistence (P) § 69405.3	Result	Reference
Water	$t_{1/2} > 40-60$ d	< 5% degraded after 60 days in fresh water, OECD TG 310	(ECHA 2011; U.S. EPA 2015a)
		< 10% of 1,4-dioxane degraded after 29 days, OECD TG 301F	ECHA (2011)
		$t_{1/2} \sim 31$ months in groundwater	Adamson et al. (2015)
		$t_{1/2} \sim 2-5$ years in groundwater	Pollitt et al. (2019)
		$t_{1/2} \sim 6.1$ years in groundwater	Adamson et al. (2017)
Soil	$t_{1/2} > 60$ d	0% degrades in 120 days in an aerobic soil microcosm	Kelley et al. 2001 as reviewed in U.S. EPA (2020a)
		No degradation in anaerobic soil microcosm study	Steffan 2006 as reviewed in Mohr (2010)
Air	$t_{1/2} > 2$ d	$t_{1/2} = 1-3$ d	ATSDR (2012)

Evidence from multiple sources indicates that biodegradation of 1,4-dioxane is negligible, including Standard Organisation for Economic Cooperation and Development (OECD) freshwater biodegradation tests compiled in Table 3 and further evidence presented in the *Environmental Fate* section above.

Further evidence of persistence in water is provided by monitoring studies. Adamson et al. (2015) evaluated 1,4-dioxane attenuation in groundwater based on the State Water Board (GeoTracker) and U.S. Air Force monitoring records and estimated that the median half-life of 1,4-dioxane is about 31 months. Similarly, data from the Los Angeles County Sanitation District demonstrate that 1,4-dioxane levels do not decrease after three stages of wastewater treatment (Heil 2019).

The range of estimates for the half-life of 1,4-dioxane is quite broad. ATSDR reports the chemical's half-life in air as one to three days (ATSDR 2012). EPI Suite estimates that the half-life may be as low as several hours and that 1,4-dioxane will be broken down by reacting with hydroxyl radicals in the air (U.S. EPA 2020a). Environment Canada predicts a half-life of 35 hours (Health Canada 2018). The range of half-lives is dependent upon other factors including weather conditions, time of day, season, and other air pollutants (Mohr 2010). California Green Chemistry Regulations (California Code of Regulations, Title 22, chapter 54, section 69405.3) categorize a chemical as persistent if the half-life in the air is greater than two days. Given the range estimates of 1,4-dioxane's half-life, we are conservatively classifying 1,4-dioxane as persistent in air, but with lower confidence than in other media.



There is increasing awareness of the need to regulate persistent chemicals to prevent their release into the environment. Cousins and colleagues (2019) assert that continuous release of a persistent chemical will “lead to continuously increasing contamination irrespective of the chemical’s physical-chemical properties” (Cousins et al. 2019). The persistence of 1,4-dioxane is well-characterized and the potential for adverse impacts increases as it is continuously released into the environment.

### **Mobility in Environmental Media**

California’s Green Chemistry Regulations (California Code of Regulations, Title 22, section 69405.6) define mobility quite broadly as the “capacity of a chemical substance for rapid movement in the environment.” Reemtsma et al. (2016) further define an aquatically mobile substance as one that is highly soluble in water and generally polar so that it does not sorb to organic or other nonpolar substances. Mobility in water and soils is primarily determined by a chemical’s log  $K_{oc}$ . 1,4-Dioxane’s estimated and measured log  $K_{oc}$  values range from 0.4 (U.S. EPA 2015b) to 1.23 (ATSDR 2012), which indicates that 1,4-dioxane will not sorb to soils, will move with water through soils, and can infiltrate groundwater. These values further indicate that 1,4-dioxane will not sorb to sand or carbon filters, which are two of the most common methods for preparing source water to become drinking water.

Mobility of water pollutants is increasingly being recognized as a property of concern, since highly mobile chemicals are extremely difficult to remove from water. In the past, concerns about a chemical’s mobility in the environment were often dismissed, based on the assumption that it would be diluted in the receiving water upon release from a wastewater treatment plant. However, as California and other arid regions continue to experience drought and increasingly reuse processed wastewater, there is substantially less dilution. Reemtsma and colleagues (2016) liken the situation with mobile chemicals to bioaccumulation, except that persistent mobile chemicals accumulate in water rather than in biological tissues (Reemtsma et al. 2016). Doherty et al. (2023) note that chemicals that are both persistent and mobile “are considered to pose an intrinsic risk to drinking water sources.”

To address the challenge of persistent mobile organic compounds, the European Union has approved defining criteria for these hazard traits under Registration, Evaluation, Authorisation, and Restriction of Chemical substances (REACH), Europe’s comprehensive chemical management policy. The criteria are:

A substance that fulfils the persistent (P) or very persistent (vP) criteria also fulfils the mobile (M) criterion in any of the following situations:

- a) the lowest log  $K_{oc} \leq 4.0$  over the environmentally relevant potential hydrogen (pH) range of 4-9
- b) in the absence of log  $K_{oc}$  data, the lowest octanol/water distribution coefficient (log  $D_{ow}$ )  $\leq 4.0$  over the environmentally relevant pH range of 4-9

A substance that fulfils the P or vP criterion also fulfils the “very mobile” (vM) criterion in any of the following situations:

- a) the lowest  $\log K_{OC} \leq 3.0$  over the environmentally relevant pH range of 4-9
- b) in the absence of  $\log K_{OC}$  data, the lowest  $\log D_{OW} \leq 3.0$  at the environmentally relevant pH range of 4-9. (Arp 2018; Arp and Hale 2019; Rüdél et al. 2020)

1,4-Dioxane’s estimated and measured  $\log K_{OC}$  values range from 0.4 (estimated, U.S. EPA 2015) to 1.23 (ATSDR 2012), and biodegradation is negligible based on OECD tests and data from wastewater treatment plants (U.S. EPA 2015b; Heil 2019). Therefore, 1,4-dioxane would be characterized as persistent and very mobile (PvM) using the REACH criteria (Arp and Hale 2019) or vPvM using GreenScreen criteria for persistence (Clean Production Action 2018). The most sustainable way of protecting water resources from persistent and mobile chemicals is avoiding their use and subsequent release (Reemtsma and Berger 2019). Preventing the release of these chemicals is of even greater importance when the chemicals are persistent, mobile, and toxic (PMT), as is the case with 1,4-dioxane, a known carcinogen (Reemtsma and Berger 2019).

### 3. POTENTIAL FOR EXPOSURES TO THE CANDIDATE CHEMICAL IN PRODUCTS

*Reference: California Code of Regulations, Title 22, section 69503.3(b).*

*The SCP regulations direct DTSC to evaluate the potential for public or aquatic, avian, or terrestrial animal or plant organism exposure to the Candidate Chemical(s) in a product by considering one or more factors for which information is reasonably available.*

#### Presence of the Candidate Chemical in Products

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

*This subsection summarizes available information indicating the Candidate Chemical’s presence in and release from the product.*

Because 1,4-dioxane is a contaminant rather than an intentional ingredient, its presence in personal care and cleaning products is difficult to determine. 1,4-Dioxane is not included on product labels unless it exceeds a specific threshold value (see [Other Regulatory Programs](#), section 5). As such, two approaches have been used to predict or determine whether 1,4-dioxane is in personal care and cleaning products:

1. Assessing the presence of ethoxylated ingredients in the product
2. Lab testing for the presence of 1,4-dioxane in the product

### **Lab testing for the presence of 1,4-dioxane in the product.**

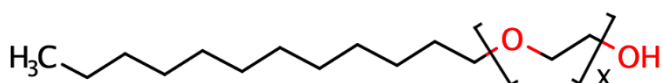
The first approach is less certain, as 1,4-dioxane concentrations in ethoxylated surfactants are inconsistent (see the section [Generation of 1,4-Dioxane as a Contaminant](#) below). The second approach provides a more definitive indication of the concentration of 1,4-dioxane in products, but few studies are available and those that are do not provide a comprehensive assessment of 1,4-dioxane in personal care and cleaning products. These studies are summarized in the [Detection in Products: Lab Studies](#) section below.

### **Generation of 1,4-Dioxane as a Contaminant**

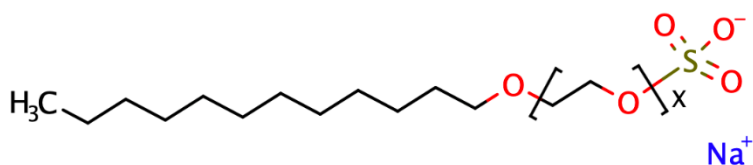
1,4-Dioxane is a known contaminant in one of the most common classes of active cleaning ingredients in many personal care and cleaning products, ethoxylated surfactants, as well as in other ethoxylated ingredients. Surfactants are chemicals added to products to remove soils and solid particles, enhance foaming, and thicken a product to make it more viscous (Cornwell 2018). Ethoxylation is the chemical process of adding one or more units of the chemical group ethylene oxide (C<sub>2</sub>H<sub>4</sub>O) to a chemical substrate, such as an alcohol, a process that imparts at least two desirable characteristics to the chemical: increased water solubility and biodegradability. Additionally, ethoxylated ionic surfactants are less irritating to the skin than unethoxylated ionic surfactants.

Alcohol ethoxylates (AEs) and alcohol ethoxysulfates (AESs) are some of the most common ethoxylated surfactants used in personal care and cleaning products (Figure 2).

**Alcohol ethoxylates (nonionic)**  
e.g. Laureth-X



**Alcohol ethoxysulfates (anionic)**  
e.g. Sodium laureth-X sulfate



*Figure 2. Examples of two common ethoxylated surfactants in personal care and cleaning products. X can be a number or a range that represents the degree of ethoxylation present in the chemical.*

AEs are nonionic ethoxylated surfactants composed of an alcohol substrate, usually with a carbon chain length of 8 to 18, and a varying number of ethylene oxide units attached to the tail. The number of units is referred to as the degree of ethoxylation and is abbreviated as EO or DO (we will use EO in

this document). An example of a common AE is laureth-10, where “laur-” describes the alcohol substrate (lauryl alcohol, a 12-carbon alcohol), “-eth” denotes that the compound is ethoxylated, and “10” is the average EO (denoted as “-X” in the example in Figure 2). AESs are ionic ethoxylated surfactants composed of an AE that has been sulfated, with an example being sodium laureth-3 sulfate (SLES, Figure 2). Other types of ethoxylated ingredients commonly found in personal care and cleaning products include alkylphenol ethoxylates, fatty amine ethoxylates, polyethylene glycols, and sorbitan ester ethoxylates (polysorbates). Not all these ingredients act as surfactants, but they have the potential to contain 1,4-dioxane because they are ethoxylated.

1,4-Dioxane can form during ethoxylation through unwanted side reactions. When two consecutive ethylene oxide units are cleaved from a chain of ethylene oxides, they can form a ring of 1,4-dioxane. Additionally, when ethylene oxide, in its original ring form, is added during the ethoxylation reaction, the ethylene oxide can open to form ethylene glycol. 1,4-Dioxane can then form when two ethylene glycols dimerize (come together) (Figure 3) (Environment Canada and Health Canada 2010).

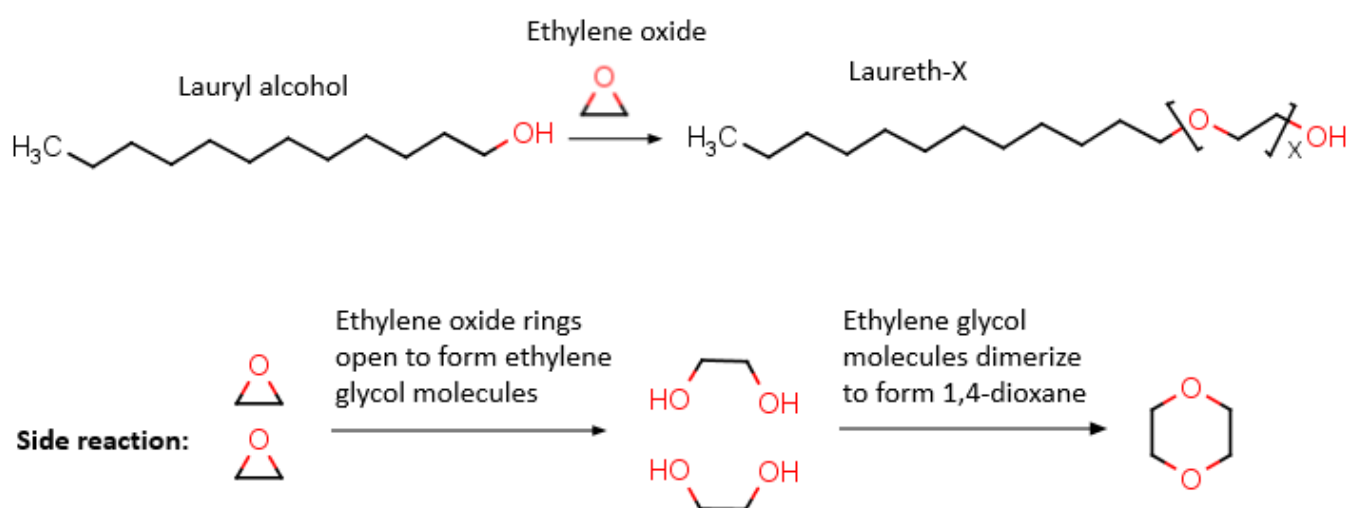


Figure 3. Ethoxylation of lauryl alcohol to produce an alcohol ethoxylate and inadvertently generated 1,4-dioxane. X can be a number or a range that represents the degree of ethoxylation present in the chemical.

1,4-Dioxane can also form during the sulfation step in the synthesis of AESs. AESs are generally made by sulfating an AE. Large-scale sulfation of AEs for the manufacture of detergents is most often conducted using sulfur trioxide (SO<sub>3</sub>) gas in a film reactor (Foster 1997). If not well controlled, excess SO<sub>3</sub> gas can react with the AES to cleave off consecutive ethylene oxides, forming more 1,4-dioxane. This tends to be the most common pathway through which 1,4-dioxane is inadvertently generated during the manufacture of ethoxylated surfactants.

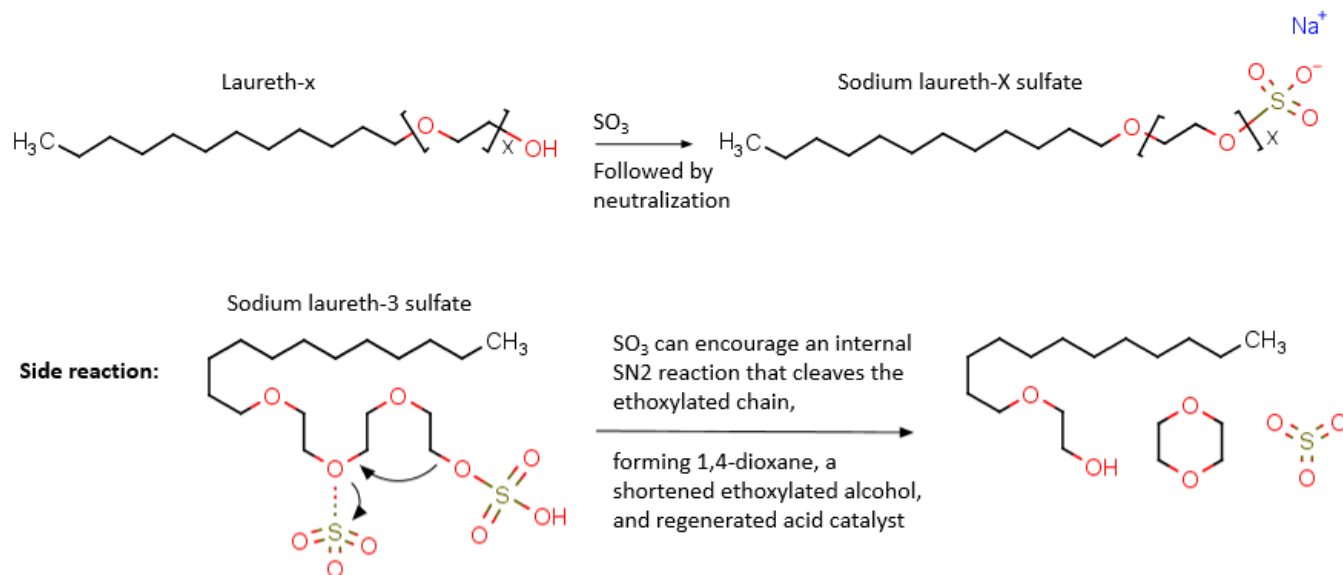


Figure 4. Sulfation of an alcohol ethoxylate to produce an alcohol ethoxysulfate and inadvertently generated 1,4-dioxane. X can be a number or a range that represents the degree of ethoxylation present in the chemical.

## Product Level

Variability in several factors during synthesis leads to a large range in how much 1,4-dioxane contamination is found in an ethoxylated ingredient. Most of these factors involve controls on the reaction chemistry, and these factors are discussed in more detail in section 5: [“Alternatives and Potential 1,4-Dioxane Reduction Approaches.”](#) For example, the sulfation chemistry used to produce AESs is difficult to control and, therefore, tends to result in higher 1,4-dioxane contamination than other synthesis reactions. The production of 1,4-dioxane depends on minor deviations from ideal reaction conditions in the sulfation of alcohol ethoxylates. Absent any removal processes, an AE will likely contain less 1,4-dioxane than its subsequently sulfated AES counterpart. AEs with high EO are also believed to be more susceptible to 1,4-dioxane generation when sulfated than AEs with low EO (Narasimhan 2017). As described by Doherty et al. (2023), “(in) a study that measured 1,4-dioxane in different products containing one or more of five different types of surfactants, Tanabe and Kawata (2008) found statistically significant higher concentrations of 1,4-dioxane in products that contained AESs relative to those that contained other surfactants (AEs, alkyl sulfates, alkylamine oxides, or alpha-olefin sulfonates) but no AESs.”

## Ingredient Level

The amount of 1,4-dioxane in a product is dictated by the number of ingredients contaminated with 1,4-dioxane and the percentage of the product those ingredients make up. The likelihood that a

product contains 1,4-dioxane increases if the product contains any ethoxylated ingredients. Products containing AESs are more susceptible to 1,4-dioxane contamination than those that do not contain AESs. In the absence of product-level testing data, the amount of 1,4-dioxane contamination could likely be estimated with relatively low uncertainty using formulation information and testing data at the ingredient level. It is worth noting that, as discussed below, water can be contaminated with 1,4-dioxane and is often the main ingredient in the products considered in this Profile; however, water's contribution of 1,4-dioxane to a final product is expected to be insignificant relative to the contribution from contaminated ethoxylated ingredients. U.S. EPA estimates maximum concentrations of 1,4-dioxane in California drinking water are around 8 ppb (U.S. EPA 2017a), whereas ethoxylated ingredients found in products sold in the U.S. likely contain the chemical at the ppm level (Black, Hurley and Havery 2001).

Because 1,4-dioxane is generated as a contaminant during ethoxylation, and ethoxylated ingredients are used in many personal care and cleaning products, it is reasonable to assume that the chemical is present as a contaminant in many personal care and cleaning products, unless processes have been employed to reduce 1,4-dioxane from the ethoxylated ingredients to undetectable levels. Products containing ethoxylated ingredients are more likely to contain 1,4-dioxane contamination than those not containing ethoxylated ingredients, and products that contain sulfated ethoxylated surfactants are more likely to contain higher levels of contamination than products that do not.

### ***Detection in Products: Lab Studies***

There are relatively few reports on the analysis of 1,4-dioxane in personal care and cleaning products sold in the United States. Doherty et al. (2023) provide a summary of the distribution of measured 1,4-dioxane concentrations in personal care and cleaning products reported worldwide in scientific literature, noting a distinct difference in products reported before and after 2005. While products reported after 2005 typically have lower 1,4-dioxane concentrations, it is still frequently detected (Doherty et al. 2023). This section focuses on publicly available reports on tested products that were sold in the United States, were published in 2009 or later, and provided quantitative data above the report's own reporting or detection limits (DLs). Three studies met all these qualifications and are summarized in Figure 5. 1,4-Dioxane in products from studies conducted since 2009. The orange dotted line represents the proposed AAT value of 1 ppm, the black dots denote individual measurements in products, and the open diamonds show the average value for each product category. Detailed data are available in Table 4 and are further described below (Sarantis, Malkan and Archer 2009; Citizens Campaign for the Environment 2019; Zhou 2019). These datasets are provided in full by Dawson et al. (2022).



In generating Figure 5 and Table 4, we excluded a product type if fewer than four data points were available. When 1,4-dioxane was not detected in a sample, we used a value of one half the DL in preparing summary statistics and data visualizations. Because Sarantis et al. (2009) did not report DLs, we ran summary statistics at both a high (0.25 ppm) and low (0.025 ppm) DL. We chose these values because the lowest reported value in the Sarantis study was 0.27 ppm, and the lowest DL among the three studies was 0.025 ppm. Use of the higher DL resulted in a slight increase in the calculated mean concentration for baby wipes (0.1 ppm) and lotion (0.1 ppm) relative to the mean calculated with the lower DL (Table 4).

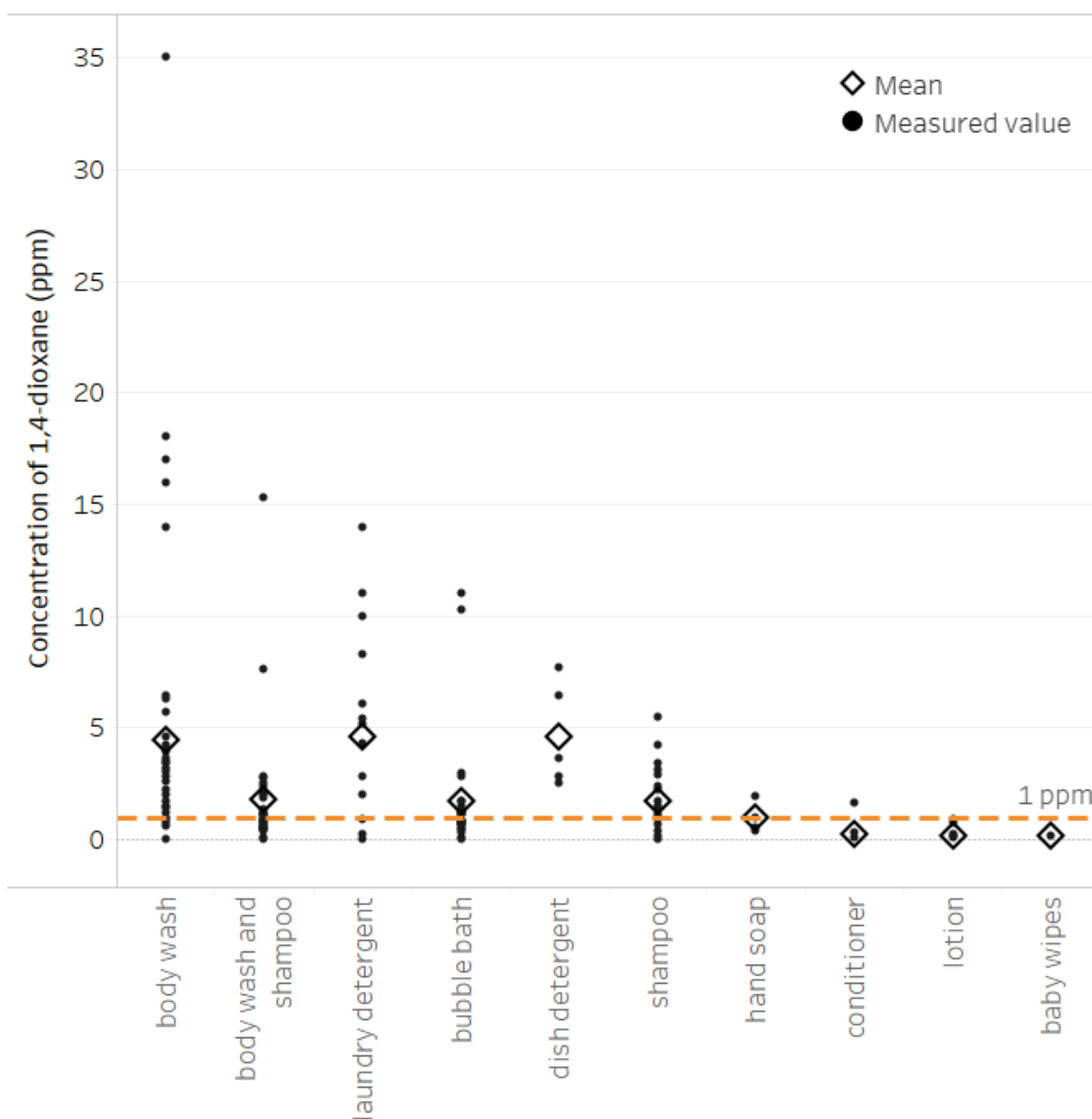


Figure 5. 1,4-Dioxane in products from studies conducted since 2009. The orange dotted line represents the proposed AAT value of 1 ppm, the black dots denote individual measurements in products, and the open diamonds show the average value for each product category. Detailed data are available in Table 4.

Table 4. Summary of 1,4 dioxane concentrations detected in personal care and cleaning products sold in the United States since 2009 (Sarantis, Malkan and Archer 2009; Citizens Campaign for the Environment 2019; Zhou 2019).

Product Type	n	Percent of Products < 1 ppm	Max (ppm)	Mean (ppm)
Laundry detergent	18	33	14.0	4.6
Dish detergent	5	0	7.7	4.6
Body wash	42	19	35.0	4.4
Body wash and shampoo	32	53	15.3	1.8
Bubble bath	29	55	11.0	1.7
Shampoo	23	39	5.5	1.7
Hand soap	4	75	1.9	0.9
Conditioner	14	93	1.7	0.2
Lotion	27	100	0.9	0.2
Baby wipes	5	100	0.1	0.1

This data set does not contain data from industrial and institutional (I&I) products, whose 1,4-dioxane concentrations may differ from those used by consumers. Additionally, two of the three studies included in this data set were focused on children’s products, which may have different 1,4-dioxane concentrations than products not intended for children.

The most recent product testing data available for many personal care and cleaning products subcategories come from Citizens Campaign for the Environment. Its 2019 data cover 80 personal care and cleaning products. 1,4-Dioxane was found above DLs (0.025 ppm) in all subcategories tested, including baby products (eight of 11), body washes and gels (15 of 19), dish soaps (five of five), hand soaps (three of three), laundry detergents (13 of 18), men’s products (seven of seven), and shampoos (14 of 17). Maximum concentrations were highest in body washes and gels (17 ppm), laundry detergents (14 ppm), and baby products (10 ppm) and lowest in hand soaps (1.9 ppm) and men’s products (3.1 ppm) (Citizens Campaign for the Environment 2019).

In 2019, the U.S. Food and Drug Administration published a study that tested 82 cosmetic products marketed toward children (Zhou 2019). These included bath products, hair treatments, lotions, beauty bars, washes, and shampoos. Of the products tested, 47 had detectable levels of 1,4-dioxane above the limit of quantitation (0.5 ppm), with an average concentration of 1.54 ppm and a range of 0.23-15.3

ppm. Rinse-off and wash products were more likely to contain 1,4-dioxane, including bath products (19 of 21) and washes such as bath soap, baby wash, and shampoo (23 of 24). In contrast, leave-on products, including hair treatments such as conditioners, detanglers, style gels (two of 14) and lotions (two of 20) were less likely to contain 1,4-dioxane.

The Campaign for Safe Cosmetics released a report in 2009 highlighting results of 1,4-dioxane testing in 48 children's bath and personal care products (Sarantis, Malkan and Archer 2009). Results indicated 32 of these products contained 1,4-dioxane, with concentrations ranging from 0.27 to 35 ppm. The maximum 1,4-dioxane concentrations were found in liquid shower soap (35 ppm), bath wash (6.4 ppm), and bubble bath (11 ppm). Lotion, shampoo, baby wipes, hair relaxer, hand soap, sun block, and toothpaste all had results at or below 1.1 ppm. While no reporting limits or DLs are provided, reported concentrations were as low as 0.27 ppm, suggesting that the reporting limit was below that value.

Two additional product testing data sets are available but are not summarized above or included in Figure 5 or Table 4. Women's Voices for the Earth released a report outlining results from product testing for 20 cleaning products conducted in 2011; the analyte list included 1,4-dioxane, but the DL for the chemical was reported to be 250 ppm. All measurements reported (0.32-89 ppm) were well below this DL (Scranton 2011), providing cause for concern about the study. Similarly, the Washington State Department of Ecology's (WS DoE) Product Testing Database provides results from tests the department conducts on various children's products (Washington Department of Ecology 2021a). Ecology tests children's products to ensure that manufacturers follow limits on 1,4-dioxane and other chemicals of high concern to children and that they report accurate information about chemicals in their children's products (Washington State Legislature 2017). In the results reported in WS DoE's Product Testing Database, 1,4-dioxane was not detected above the method quantitation limit, which ranged from 19 ppm to 390 ppm (Washington Department of Ecology 2021a). These reporting limits are higher than the maximum values reported in Table 5 except for shampoo, but the lowest reporting limit for shampoo or body wash in WS DoE's Product Testing Database was 39 ppm (versus a maximum of 35 ppm for shampoo reported in Table 5). As a result, these studies are not reviewed here. Similarly, a separate data set reported to WS DoE by manufacturers includes no reports of 1,4-dioxane in personal care or cleaning products and is, therefore, not included here (Washington Department of Ecology 2021b).

SCP has completed our own analysis of 1,4-dioxane in personal care and cleaning products using the analytical method developed by DTSC (Castor et al. 2021b; Grant 2022). The first stage of this testing analyzed 156 products. The median, mean, and maximum concentrations of 1,4-dioxane across all these products was 1.14 ppm, 4.42 ppm, and 132 ppm, respectively. One laundry detergent had the highest concentration of 1,4-dioxane (132 ppm) across all products, while hand soap had the highest detection of the chemical among personal care products, at 111 ppm. Most samples in the study had concentrations of 1,4-dioxane below 10 ppm; however, categories like laundry detergents, manual dish soap, body wash, bubble bath, hand soap, and shampoo had samples at or above 10 ppm. The study indicated that products marketed to Latinx or Hispanic consumers (Latinx products) had higher levels of 1,4-dioxane than products marketed to other communities, however it was difficult to obtain a truly representative sample set (Grant 2022).

In the second stage of this project, we worked with students from Huntington Park Institute of Applied Medicine, a high school in the Los Angeles Unified School District, to gather additional products used specifically in their communities, resulting in data for an additional 45 personal care and cleaning products. These additional data solidified concerns that there may be relatively higher concentrations of 1,4-dioxane in Latinx products. The median 1,4-dioxane concentration in the six Latinx products sampled in this second stage (62.2 ppm) was more than 30 times higher than the median for those not marketed to the Latinx community (2.5 ppm). These additional data points also elevated concern about the presence of 1,4-dioxane in personal care products. While the median concentration of the chemical in all (first and second phase) cleaning products marketed to the Latinx community was 5.0 ppm, the median of personal care products marketed to this community was 19.4 ppm, with one data point over 220 ppm (Grant 2022). We are still evaluating data from this testing effort and are developing a more extensive report.

### ***Detection in Products: Manufacturer-Reported Data***

Additional data on the concentration of 1,4-dioxane in consumer products has recently become available as a result of a New York law prohibiting the sale of personal care and cleaning products with 1,4-dioxane concentrations exceeding 1 ppm after December 31, 2023 (see the [Additional Considerations](#) section) (NY ENV Article 35 2020). If a product manufacturer anticipates not being able to meet this limit, they may submit a waiver to New York to request additional time to come into compliance (NY DEC 2023). In their submittal, manufacturers are required to report the current concentration of 1,4-dioxane in the products for which they are submitting a waiver. We downloaded the most recent data available on the New York Department of Environmental Conservation's website as of March 2023, sorted by product category. Table 5 reports summary statistics for this dataset. We reported these data separately from the lab studies noted above because we lack information about the methods used for determining 1,4-dioxane concentrations in these products. Additionally, these

data only include products with concentrations of 1,4-dioxane above 1 ppm. Of note, the dataset likely contains duplicated data due to the same product being reported in different sizes or multiple concentrations being reported for a single product.

*Table 5. Summary of manufacturer-reported 1,4 dioxane concentrations in various categories of personal care and cleaning products from the New York State Department of Conservation. Manufacturers only reported products with 1,4 dioxane concentrations above 1 ppm.*

Product Type	n	Max (ppm)	Mean (ppm)	Median (ppm)
all-purpose cleaner	25	99	17.8	6
body wash and shampoo	37	7.9	3.7	3.2
body washes and scrubs	437	24	4.6	4.6
bubble bath	28	7	4.1	4.5
conditioner	3	6.8	4.7	3.7
degreaser	3	5.4	3.5	2.5
dish detergent	29	57.6	9.3	7.9
fabric softener	1	177.1	177.1	177.1
face washes and scrubs	14	15	5.5	5.35
hand soap	74	154.3	8.2	3.5
laundry detergent	20	177.1	28.0	8.91
miscellaneous	6	65.3	15.0	5.35
other hair products	19	6.1	4.6	4.6
shampoo	415	34.9	5.6	6.1
shaving gel	2	3	3.0	3
toilet cleaner	12	75.7	10.5	5.76

On average, concentrations in this dataset are greater than those reported in Table 4. This is in part because these data only include products with 1,4-dioxane concentrations above 1 ppm. Also, these data likely represent a larger and more thorough assessment of products than those included in the currently available lab studies referenced above. These data clearly indicate that there are products present in the New York market, and likely the California market, with relatively high concentrations of 1,4-dioxane. The average concentrations of shampoo in this dataset (mean 5.6 ppm, median 6.1 ppm) are 3-4 times the mean concentration of this same product category in Table 4 (1.7 ppm). For products that serve as both body washes and shampoos, their reported concentration in Table 5 (mean 3.7 ppm, median 3.2 ppm) are roughly twice the mean concentration of their counterparts in Table 4. Notably, the maximum reported concentrations of laundry detergents (177.1 ppm), dish detergents (57.6 ppm), hand soap (154.3 ppm), body washes and scrubs (24 ppm), and shampoo (34.9 ppm) in Table 5, all product categories considered in this document, are considerably higher than the maximum reported concentrations in the lab studies presented in Table 4. The findings from both datasets otherwise corroborate each other. Laundry and dish detergents tend to have higher 1,4-dioxane levels than personal care products such as shampoo, hand soap, and combined shampoo and body wash. This manufacturer-reported dataset does not include any leave-on products, suggesting that 1,4-dioxane concentrations in leave-on products generally do not exceed 1 ppm. This aligns with the similarly low

detection frequencies and concentrations of 1,4-dioxane in leave-on products reported in other studies from Table 4.

## Market Presence and Trends

*Reference: California Code of Regulations, Title 22, sections 69503.3(b)(1)(A-C).*

*Product market presence information may be used as a surrogate to assess potential exposures to the Candidate Chemical in a product. This information may include statewide sales by volume or number of units, the intended use(s) of the product, and characteristics of the targeted customer base.*

Two North American Industry Classification Systems (NAICS) codes represent broad sectors that manufacture a variety of goods, including personal care and cleaning products – 325611: “soap and other detergent manufacturing” and 325612: “polish and other sanitation good manufacturing.” These two NAICS sectors experienced a slight decline in the number of manufacturing facilities between 2007 and 2017 – from 1,257 to 1,133 (U.S. Census Bureau 2007; U.S. Census Bureau 2017a; U.S. Census Bureau 2017b). National annual sales revenues also declined during this same period – by 11.9% for 325611 and by 42.6% for 325612 (U.S. Census Bureau 2007; U.S. Census Bureau 2017a; U.S. Census Bureau 2017b).

Several additional data sources provided insights into the relevant business sectors. One of these sources, Dun & Bradstreet, collects data (e.g., sales revenues, numbers of employees) on companies across the globe and compiles the information into a searchable database. However, this database aggregates dissimilar businesses into the NAICS codes 325611 and 325612. In these cases, researchers must manually examine individual companies to identify their areas of business more specifically. We found that the laundry and dish detergent industry comprises 400 manufacturers nationally, 32 of which are headquartered in California (D&B 2020). However, substantial market data gaps remain, and readily accessible data sources have limited information on manufacturers for specific product types in the personal care and cleaning industries.

Although national sales revenues experienced an overall decline in both NAICS sectors (325611 and 325612), a separate market database reports that retail market sales for a variety of personal care and cleaning products including body care, dishwashing, fabric care, household cleaners, shampoo/conditioners, and soap, bath, and shower products increased by 31.4% from 2015 through 2021 (Mintel 2023). A self-reported consumer expense report suggests Americans increased their housekeeping supply spending by 15.8% from 2013 to 2018, with laundry and cleaning products accounting for 24% of the expenses (U.S. Bureau of Labor Statistics 2019). Americans altogether spend about \$9.1 billion annually on laundry detergent alone (Smartklean 2011; Mars 2016). Declining sales revenues for companies within NAICS sectors despite increasing sales for these products highlights the



emergence of alternative sources of product supply. These sources may include foreign imports and more domestic manufacturers making personal care and cleaning products but operating under different NAICS codes.

Data on the sales of personal care and cleaning products in California can be used as an indicator of how widely consumers use various products within these two categories. The results of the California Air Resources Board's (CARB's) most recent Consumer Product Survey (2015) provide data on the number of companies, products, and sales for common personal care and cleaning products. As shown in Table 6, laundry detergents have the highest daily sales volumes (1,012.88 tons/day) – more than the total for all other evaluated personal care and cleaning products combined (897.53 tons/day). One manufacturer reported that the average family of five purchases laundry detergent every 3-4 weeks and washes at least 300 loads of laundry annually Smartclean (2011; CARB 2015). High sales volumes of laundry detergent imply high product use within households. However, comparing the sales of specific laundry detergent products with those of individual personal care products can be misleading. Product categories that are sold in smaller volumes, such as shampoos and general-use hand and body soaps, have far more product lines. For example, laundry detergents include 1,763 types of products, while there are 6,612 types of shampoos and 4,620 types of general-use hand and body soaps. In addition, these products are likely to be used more frequently (daily vs. approximately weekly) and at different volumes than laundry detergents.

Historical market data for cleaning products may not reflect more recent trends. Notably, the COVID-19 pandemic may have led to an increase in the use of cleaning products, as well as in injuries and illnesses caused by exposure to these products. According to the Centers for Disease Control and Prevention (CDC), 45,550 cleaning- and disinfectant-related exposure calls were reported during January to March 2020, an increase of 20.4% from the same timeframe in 2019 (Chang et al. 2020). While the correlation may not be causal, increased media coverage of the pandemic, consumer product shortage, restricted retail purchasing rules, and workplace sanitizing efforts, along with stay-at-home orders, could account for the sharp increase in cleaning and disinfecting product purchase and use (NPR 2020).

Table 6. Amount of products sold in California in 2013–2015 in tons per day (CARB 2015)

Product	Reporting Companies	Reported Products	Sales in tons per day
Laundry detergent	93	1,763	1,012.88
Dish detergent/soap manual	93	897	253.20
Shampoo	288	6,612	197.97
General-use hand/body cleaner/soap	240	4,620	169.76
Body wash/mousse/gel/soap/foam/scrub	286	7,959	164.21
Hand and body conditioner, cream, lotion	419	16,977	104.63
Heavy-duty hand soap	48	321	7.76

## Workplace Presence of the Products

*Reference: California Code of Regulations, Title 22, sections 69503.3(b)(3).*

*The potential for exposure to the Candidate Chemical in the product relates to how common the product is in households and workplaces. The household and workplace presence of other products that contain the same Candidate Chemical may increase the potential for aggregate effects.*

While U.S. Census Bureau reports indicate a national decline in the number of manufacturing facilities in 325611 and 325612 NAICS sectors (2007; 2017a; 2017b), employment has risen in occupations that manufacture personal care and cleaning products, especially in California. Nationally, the number of employees in both NAICS sectors increased by 9.5% between 2012 and 2017, while these sectors saw a 20.3% increase in California during the same period (U.S. Census Bureau 2012a; U.S. Census Bureau 2012b; U.S. Census Bureau 2017a; U.S. Census Bureau 2017b). In addition to manufacturing, workers in a wide range of other occupations regularly use personal care and cleaning products that are likely to contain 1,4-dioxane. For example, many or most dishwashers, maids and housekeeping cleaners, hairdressers, shampooers, personal care aides, and laundry workers (Standard Occupation Classification codes 35-9021, 37-2012, 39-5012, 39-5093, 39-9021, and 51-6011 respectively) rely on products containing 1,4-dioxane to perform their work. In 2016, these sectors employed 909,400 people in California. By 2026, California’s Employment Development Department (Cal EDD) projects that there will be 1,191,500 employees in these sectors (Cal EDD 2018). The high employment growth in both manufacturing and occupations where these products are regularly used to perform job functions suggests that a larger proportion of California’s workforce may be exposed to 1,4-dioxane.

## Potential Exposures to the Candidate Chemical During the Products' Life Cycle

*Reference: California Code of Regulations, Title 22, sections 69503.3(b)(3); 69503.3(b)(4)(A-H).*

*Potential exposures to the Candidate Chemical or its degradation products may occur during various product life cycle stages, including manufacturing, use, storage, transportation, waste, and end-of-life management practices. Information on existing regulatory restrictions, product warnings, or other product-use precautions designed to reduce potential exposures during the product's life cycle may also be discussed here.*

Potential exposure to 1,4-dioxane in personal care and cleaning products is largely determined by the chemical's physicochemical properties and the products' life cycles. The four physicochemical properties that most determine 1,4-dioxane's exposure potential are its solubility, volatility, persistence, and mobility, as defined in Table 1. 1,4-Dioxane is highly soluble in water and other aqueous solutions, such as shampoos and detergents. The vapor pressure of 1,4-dioxane is 38.1 mm Hg at 25° Celsius, which is moderate, indicating it will readily volatilize from dry surfaces such as dry soil or a freshly cleaned countertop. However, its low Henry's Law constant of  $4.8 \times 10^{-6}$  atm-m<sup>3</sup>/mol indicates that volatilization from water and personal care and cleaning products will be low. As discussed above, 1,4-dioxane is a PMT compound, so any 1,4-dioxane washed down the drain after product use will result in additional potential for exposure when that wastewater is treated and subsequently becomes drinking water.

1,4-Dioxane has been measured in personal care and cleaning products, including laundry detergents, manual dishwashing detergents, hand soap, shampoo, and bodywash (Table 4 and Figure 5). These types of products are widely sold and frequently used in households and workplaces throughout California, creating the potential for exposure during the use phase. Janitors, custodians, and other workers involved in cleaning in industrial and institutional settings may face additional exposures from commercial-grade products, such as detergents and surface cleaners. Similarly, workers in salons and spas may have additional exposures to both personal care and cleaning products as they clean their workspace between clients. There is potential for exposure to 1,4-dioxane found in personal care and cleaning products through inhalation, dermal absorption, and ingestion, during the products' use and end-of-life stages.

## ***Manufacturing, Storage, and Transportation***

The production of many personal care and cleaning products involves the use of ethoxylated ingredients, usually surfactants, that are often contaminated with 1,4-dioxane (see [Generation of 1,4-Dioxane as a Contaminant](#) section, above). Information is not readily available on discharges and emissions of 1,4-dioxane by surfactant manufacturers. However, CARB collects emission data on 1,4-dioxane from all of California's Air Quality Management Districts (AQMDs) and Air Pollution Control Districts (APCDs) for its Toxic Hotspots program, which includes industrial emissions that could potentially be associated with the production of personal care and cleaning products. The total amount of 1,4-dioxane emissions in 2019 was 13,854.8 pounds (lbs)(CARB 2021).

People working in the manufacturing, storage, and transportation of personal care and cleaning products can be exposed to 1,4-dioxane on the job, whether or not they work directly with the chemical. Inhalation and dermal exposures could happen under various relevant exposure scenarios, including during drumming/bottling of consumer products as well as from spills and fugitive emissions. The dose received by a worker will depend on several variables, including the use of personal protective equipment (PPE), the size of the room, the adequacy of ventilation and air flow, the quantity and concentration of 1,4-dioxane released, ambient temperature, and proximity of the worker to the source. The extent of actual exposure is expected to vary significantly under these scenarios.

The use of gloves made of unsuitable materials or the incorrect use of appropriate gloves could lead to increased exposures. For example, 1,4-dioxane can degrade gloves made of certain materials (U.S. EPA 2020a). Once a glove is compromised, its interior becomes a reservoir for potential exposure. These PPE-use details need to be considered while characterizing exposures (U.S. EPA 2019a; U.S. EPA 2020a).

All current occupational exposure limits for 1,4-dioxane are focused on inhalation. The U.S. Occupational Safety and Health Administration's permissible exposure limit is 100 ppm averaged over an 8-hour time period (time weighted average (TWA)); the NIOSH recommended exposure limit is 1 ppm as a 30-minute ceiling (i.e., 1,4-dioxane concentrations may not exceed 1 ppm at any point during a 30 minute period); and the American Conference of Government Industrial Hygienists Threshold Limit Value is 20 ppm over an 8-hour TWA (U.S. EPA 2017c). However, because no monitoring data are publicly available on occupational exposures to 1,4-dioxane during the manufacturing, storage, or transportation of personal care and cleaning products, we are unable to determine the existence, frequency, or extent of any exceedances of these occupational limits.

U.S. EPA has concluded that 1,4-dioxane represents an "unreasonable risk of injury to health or the environment" under certain, specific conditions of use (U.S. EPA 2020a):

- Manufacturing (e.g., domestic manufacturing and import/repackaging).

- Processing (i.e., repackaging, recycling, non-incorporative processing, and processing as a reactant).
- Industrial/commercial use (e.g., intermediates, processing aids, laboratory chemicals, adhesives and sealants, film cement, printing and printing compositions).
- Disposal.

The Toxic Substances Control Act Science Advisory Committee on Chemicals has concurred with these conclusions (U.S. EPA 2019a).

Workers who manufacture, store, or transport personal care and cleaning products rarely handle pure 1,4-dioxane. To our knowledge, the health impacts associated with occupational exposures to 1,4-dioxane during manufacturing of personal care and cleaning products have not been characterized through short-term or long-term exposure monitoring or modeling.

The concentration of 1,4-dioxane in surfactants can be reduced during the manufacture of ethoxylated ingredients (see the [Ethylene Oxide Concerns During Surfactant Manufacturing](#) section). 1,4-Dioxane that is recovered during these processes is often condensed and used as fuel for on-site boilers or other energy-recovery operations (Mohr 2010). As an alternative to combustion, 1,4-dioxane can be destroyed using different techniques based on how the chemical was formed. 1,4-dioxane that is formed in the production of lauryl ether sulfate can be destroyed using specialized equipment specifically designed for this purpose. Other destruction methods for 1,4-dioxane in condensate include a “catalyzed reaction with hydrogen peroxide to oxidize 1,4-dioxane, producing carbon dioxide and water” (Mohr 2010). While these methods are helpful for reducing the concentration of 1,4-dioxane in surfactants, the potential for worker exposure remains.

### **Product Use**

Consumers can be exposed to 1,4-dioxane through dermal absorption or inhalation during product use. More research is needed to better characterize the exposures from the use of products considered in this Profile. The intended use of many of the products highlighted in the [Product Definitions and Scope](#) section involves direct dermal contact. Additionally, improper use (e.g., insufficient dilution) of concentrated products (e.g., dishwashing detergents) may lead to increased 1,4-dioxane exposure, either through dermal absorption or inhalation.

### **Dermal Absorption**

Dermal absorption is a major route of 1,4-dioxane exposure during the use of many personal care and cleaning products; however, there is a lack of experimental data to quantify typical human dermal exposure during product use. The one available study – an *in vitro* experiment using excised human

skin – showed that 1,4-dioxane penetrated the skin under both occluded conditions<sup>7</sup> (3.2% of the applied dose) and unoccluded conditions (0.3% of the applied dose) 205 minutes after the application of a lotion containing 1,4-dioxane (Bronaugh 1982). This study suggests very low 1,4-dioxane penetration, although this conclusion is questionable due to a few major uncertainties associated with the study. First, this conclusion was drawn based on secondary data published in a conference abstract with limited experimental details (e.g., the details of the lotion that acted as the vehicle). Second, the experimental protocol (e.g., testing duration) is not consistent with the OECD *in vitro* testing method for skin absorption (OECD Test No. 428). Third, the results were expressed as the percentage of administered agent being absorbed by the skin without clear context as to the amount (or concentration) of lotion applied or how it was applied. This percentage (known as the fractional absorption of a chemical) is usually not constant and generally depends on how much of the substance is initially applied to the skin; this is often an inverse relationship (Kissel 2011; Frasch et al. 2014). Normally, for environmental exposures like those that might occur while using dishwashing detergents, the fractional absorption is high for small amounts of dermal application (Frasch et al. 2014). More detailed information about this study's experimental conditions would be needed to properly interpret the findings.

In contrast to Bronaugh's (1982) results, modeled data suggest that dermal uptake of 1,4-dioxane is rapid. The permeability coefficient for 1,4-dioxane is  $3.3 \times 10^{-4}$  cm/h, as documented by U.S. EPA in the Risk Assessment Guidance for Superfund (RAGS, Part E) (U.S. EPA 2004). To confidently estimate the dermal uptake of 1,4-dioxane, it would be necessary to conduct *in vitro* skin absorption tests in accordance with standard testing guidelines (e.g., OECD test methods for skin absorption).

Estimating dermal exposure to 1,4-dioxane during product use is further complicated by incomplete information about the use patterns of cleaning and personal care products. These data gaps prevent the determination of accurate exposure factors (e.g., the amount of product used for each event and how the product is applied).

Notably, some children's products, including body wash, bubble bath, and shampoos, contain detectable levels of 1,4-dioxane (Citizens Campaign for the Environment 2019; Zhou 2019). Several exposure factors specific to children suggest they may experience a higher exposure to 1,4-dioxane than adults. For example, children are more likely to take baths and ingest bath water. In addition, 1,4-dioxane may diffuse through infants' and children's skin more readily than through the skin of adults, due to their skin structure (Mancini 2004). Even if their dermal absorption were the same as

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<sup>7</sup> In occluded conditions, the skin is covered after the 1,4-dioxane is applied.

adults, children's higher ratio of skin surface area to body weight will lead to a larger body weight-normalized dose (U.S. EPA 2011a).

### **Inhalation Exposure**

1,4-Dioxane is a volatile organic compound that partitions between water and air during product use. Although the Henry's law constant for 1,4-dioxane is relatively low due to its high solubility in water, some factors associated with dishwashing and bathing/showering – including high water temperature and potential for increased volatilization from aerosolized water droplets – may increase the amount of 1,4-dioxane that evaporates during product use. 1,4-Dioxane can also volatilize from products allowed to air-dry after being used for wiping down surfaces. In addition, a person who is using these products (e.g., a janitor using cleaning products on a routine basis or a person washing dishes) is usually very close to the evaporating 1,4-dioxane, potentially leading to exposure via inhalation. A recent intervention study of 49 Latina women in California using household cleaning products reported significant inhalation exposure to 1,4-dioxane (Harley et al. 2021). The study measured 1,4-dioxane exposure as personal air concentrations when workers used standard cleaning products and again after they switched to “green” products. (Harley et al. 2021). After the switch, they reported a 46% mean reduction in 1,4-dioxane exposure – from 0.57  $\mu\text{g}/\text{m}^3$  to 0.31  $\mu\text{g}/\text{m}^3$ .

### **Exposure Estimated by Authoritative Bodies**

Several regulatory agencies have estimated dermal and inhalation exposures to 1,4-dioxane from the use of personal care and cleaning products contaminated with the chemical (i.e., surface cleaner, dish soap, dishwasher detergent, and laundry detergent). U.S. EPA's Final Risk Evaluation for 1,4-Dioxane (U.S. EPA 2020a) used U.S. EPA's Consumer Exposure Model to assess certain cleaning products (Table 7). In addition, several international regulatory agencies have estimated dermal and inhalation exposures to 1,4-dioxane from both personal care and cleaning products (ECHA 2002; Environment Canada and Health Canada 2010). The European Chemical Bureau used the ConsExpo exposure model to estimate direct inhalation and dermal exposures to 1,4-dioxane from the use of dishwashing liquids and shampoos (ECHA 2002). Environment and Health Canada took a similar approach, using the same model, to estimate dermal and inhalation exposures to 1,4-dioxane from the use of a larger variety of personal care and cleaning products (Environment Canada and Health Canada 2010). Modeling results are detailed in Table 7.



Table 7. Exposure modeling results for 1,4-dioxane exposure during product use. OEHHA's NSRL is 30 µg/day for a 10<sup>-5</sup> lifetime risk of cancer, or 0.43 µg/kg bw/day, assuming an average body weight of 70 kg.

Product Type	Use	Assumed Concentration (ppm unless otherwise noted)	Pathway	Average Exposure (µg/kg bw/day)	High-end Exposure (µg/kg bw/day)
Household Cleaning Products	Manual dishwashing detergent	0.7 – 204 [a] 30-100 [b] 0.033% [c]	Dermal	0.00011 [a] 0.002 [b] 0.065 [c]	0.00026 [a] 0.0347 [b]
		0.7 – 204 [a] 30-100 [b] 0.033% [c]	Inhalation	0.094 (reported as 3.3 × 10 <sup>-4</sup> mg/m <sup>3</sup> ) [a, d] 0.13 [b] 0.22 [c]	0.20 (reported as 7.1 × 10 <sup>-4</sup> mg/m <sup>3</sup> ) [a, d] 2.17 [b]
	Surface cleaner	0.36-9 [a]	Dermal	0.0023 [a]	0.0056 [a]
		0.36-9 [a]	Inhalation	0.16 (reported as 5.6 × 10 <sup>-4</sup> mg/m <sup>3</sup> ) [a, d]	0.29 (reported as 1.0 × 10 <sup>-3</sup> mg/m <sup>3</sup> ) [a, d]
	Laundry detergent	0.05-14 [a]	Dermal	0.000062 [a]	0.00015 [a]
		0.05-14 [a]	Inhalation	0.020 (reported as 7.1 × 10 <sup>-5</sup> mg/m <sup>3</sup> ) [a, d]	0.037 (reported as 1.3 × 10 <sup>-4</sup> mg/m <sup>3</sup> ) [a, d]
Personal Care Products	Shampoo (adults)	50-300 [b] 45.5 [c]	Dermal	0.9 [b] 9.1 × 10 <sup>-5</sup> [c]	5.4 [b]
		50-300 [b] 45.5 [c]	Inhalation	0.02 [b] 8.0 × 10 <sup>-6</sup> [c]	0.125 [b]
	Shampoo (children)	10 [c]	Dermal	2.9 × 10 <sup>-6</sup> [c]	n/a
		10 [c]	Inhalation	1.4 × 10 <sup>-7</sup> [c]	n/a
	Body wash (adults)	23 [c]	Dermal	2.5 × 10 <sup>-6</sup> [c]	n/a
		23 [c]	Inhalation	2.2 × 10 <sup>-6</sup> [c]	n/a
Body wash (children)	5.3 [c]	Dermal	9.9 × 10 <sup>-7</sup> [c]	n/a	
	5.3 [c]	Inhalation	4.9 × 10 <sup>-7</sup> [c]	n/a	

[a] (U.S. EPA 2020a);

[b] (ECHA 2002);

[c] (Environment Canada and Health Canada 2010);

[d] Inhalation exposure was reported in the unit of mg/m<sup>3</sup>, which was converted to µg/kg bw/day, assuming average body weight of 70 kg and an average amount of air inhaled being 20 m<sup>3</sup> per day (U.S. EPA 2011a).

Many of the scenarios specified in Table 7 are relatively low, particularly when compared with OEHHA's Proposition 65 No Significant Risk Level (NSRL) for a 10<sup>-5</sup> lifetime risk of cancer (30 µg/day or 0.43 µg/kg bw/day, assuming an average body weight of 70 kg) (OEHHA 2021). While many exposures are anticipated to be relatively low, there are some instances where exposure to 1,4-dioxane due to the use of specific consumer products may exceed OEHHA's NSRL (Table 7). Most notably, these include high-end exposures due to manual dishwashing as well as both average and high-end dermal exposures from shampoo as estimated by the ECHA (2002). In generating these estimates, ECHA assumed manual dishwashing detergent concentrations between 30 and 100 ppm and shampoo concentrations between 50 and 300 ppm. While these concentrations are high, particularly based on the lab studies summarized in Table 4, the manufacturer data submitted to New York State indicates concentrations of dishwashing detergent as high as 57.6 ppm and shampoo as high as 34.9 ppm (Table 5), both close to or within the range of assumed concentrations. Therefore, the use of products such as shampoo and manual dishwashing detergent may result in exposures that meet or exceed OEHHA's No Significant Risk Level. Additionally, even if exposures during a product's use phase are relatively low individually, they contribute to aggregate exposure to 1,4-dioxane.

The exposure estimates in Table 7 are limited to the product-use stage. They do not account for potential contributions from drinking water pathways, which are important for California residents. These have not been adequately considered and will be discussed in the next section. The exposure estimates in Table 7 also do not account for workers like janitors or hairdressers who may be exposed to these products for eight or more hours per day. For these and other sensitive subpopulations, as defined in California Code of Regulations, Title 22, section 69501.1, exposures during the product use phase may be significantly higher than those of the average consumer, but data is lacking to confirm this or to quantify how much higher their exposures may be.

## ***End-of-Life Disposal***

### **General Description of End-of-life Exposure Pathways**

As described in Doherty et al. (2023), the use of 1,4-dioxane-containing personal care and cleaning products generates at least two waste streams: solid waste and wastewater. 1,4-Dioxane subsequently enters environmental media from these waste streams via either landfills (solid waste) or wastewater effluent (wastewater), leading to subsequent human and environmental exposures.

The physicochemical properties of 1,4-dioxane (i.e., its miscibility with water, persistence and mobility in water, and high volatility) determine its fate and transport in the environment and govern its

potential exposures. Figure 6 illustrates the transport of 1,4-dioxane across major environmental media and potential exposure pathways, with a focus on the end-of-life stage of personal care and cleaning products, which is the primary concern for this Profile. Although potential end-of-life exposure pathways are complex, they can be grouped in two major pathways: drinking water-related pathways and air-related pathways. Some activities and operations, such as landfill and wastewater treatment, contribute to both exposure pathways. The discussion below will first focus on the drinking water pathway as the primary concern, followed by the inhalation pathway and some other, minor pathways.

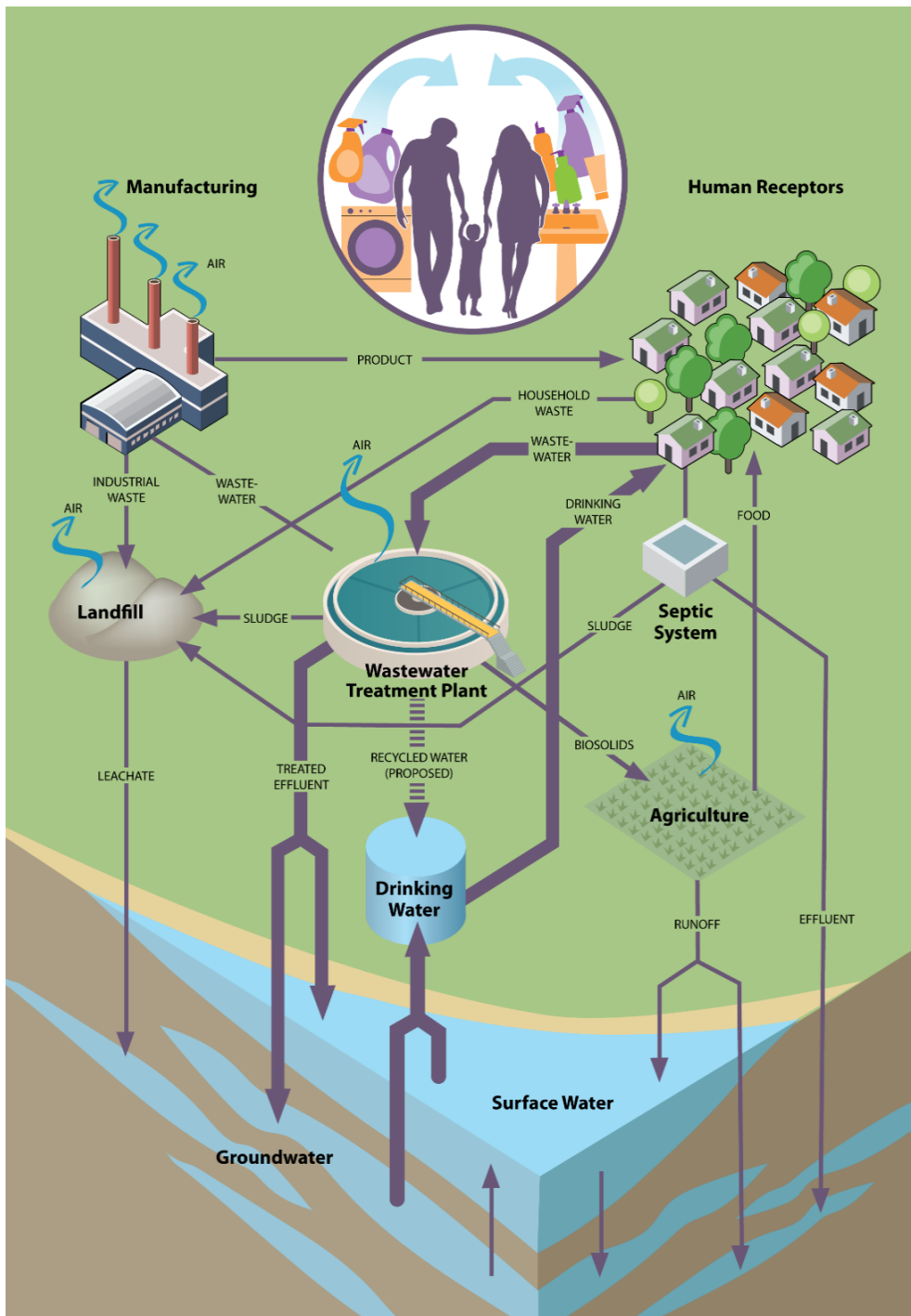


Figure 6. A conceptual model of exposure to 1,4-dioxane from personal care and cleaning products, as presented by Doherty et al. (2023). Arrows represent the flow of 1,4-dioxane throughout the life cycle of potential Priority Products. The thick arrows represent the drinking water pathway of 1,4-dioxane exposure, which is emphasized in this Profile. Not included in this diagram are exposures due to improper disposal of 1,4-dioxane from industrial use (such as use as a stabilizer for the solvent trichloroethane); these represent a significant input to groundwater that is not related to Priority Product use or disposal.

### Drinking Water Exposure Pathways

As described by Doherty et al. (2023), drinking water sources can become contaminated by 1,4-dioxane in personal care and cleaning products through several pathways. Surface water and groundwater can be contaminated from the discharge of wastewater down the drain (Dawson et al. 2022), the migration

of leachate from landfills, or the improper disposal of products containing 1,4-dioxane. The application of 1,4-dioxane-containing-biosolids as agricultural fertilizer may also contribute to groundwater and surface water contamination.

### *Down the Drain Wastewater*

Doherty et al. (2023) outlines the transfer of 1,4-dioxane from consumer products to wastewater treatment plants (WWTPs) from sinks, showers, and washing machine drains, via sewer systems. 1,4-Dioxane has been detected at approximately 1 µg/L in the influent of wastewater treatment plants in Southern California (Heil 2019). This level is consistent across many plants and is relatively constant over time, indicating widespread, ongoing releases of 1,4-dioxane from residential sources, consistent with the use of consumer products.

1,4-Dioxane is resistant to routine wastewater treatment techniques, including the highest standard level of treatment, tertiary treatment. U.S. EPA's EPI Suite model predicts that about 98% of the 1,4-dioxane that enters WWTPs will be released to the receiving waters (U.S. EPA 2020a). The Los Angeles County Sanitation Districts (LACSD) routinely detect 1,4-dioxane in the effluent of multiple WWTPs at levels around 1 µg/L (Heil 2019). This finding is consistent with a nationwide study that reported a mean 1,4-dioxane concentration of  $1.11 \pm 0.60$  µg/L in effluents collected from 40 WWTPs that primarily received domestic wastewater (Simonich et al. 2013). The consistency of these results across many locations and times suggests that the source is personal care and cleaning products used in homes and workplaces, rather than industrial or legacy inputs that may cause localized high concentrations. 1,4-Dioxane can be removed from wastewater using costly advanced treatment processes (see the [Removal Technologies](#) section).

The release of treated municipal wastewater effluent to surface water or groundwater can contribute to 1,4-dioxane contamination in drinking water derived from these sources (Dawson et al. 2022; Doherty et al. 2023). 1,4-Dioxane was one of the most frequently detected chemicals in drinking water in the third round of U.S. EPA's Unregulated Contaminant Monitoring Rule (UCMR3) (U.S. EPA 2017a). Samples from 21% of the 4,864 public drinking water systems measured between 2013 and 2015 contained the chemical, at concentrations between 0.07 µg/L (minimum reporting limit) and 0.35 µg/L; 6.9% contained 1,4-dioxane at levels greater than 0.35 µg/L (Adamson et al. 2017).<sup>8</sup>

Simonich et al. (2013) conducted a risk estimate focused on the potential for 1,4-dioxane from wastewater effluent to contaminate drinking water derived from surface water. This study measured

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<sup>8</sup> The U.S. EPA's reference concentration of 0.35 µg/L represents a one in one million cancer risk, as determined by the U.S. EPA's Integrated Risk Information System (IRIS) Program, (U.S. EPA 2013a; U.S. EPA 2017a).

1,4-dioxane concentrations in effluents from 40 WWTPs and modeled surface water dilution factors of 1,323 drinking water intakes across the United States. Simonich et al. (2013) estimated that drinking water intake concentrations of 1,4-dioxane would exceed U.S. EPA's reference concentration of 0.35 µg/L only 0.31% of the time. However, the estimated dilution factors used in this study, which range from 2.6 to 48,113 (with a mean of 875), may not represent low-flow conditions where they may be less than 2 (Rice and Westerhoff 2017). Due to long-term drought conditions across California, low-flow conditions in some California waterways would be expected. The Rice and Westerhoff study suggests that Simonich et al. (2013) may have significantly underestimated the potential magnitude of 1,4-dioxane contamination from down-the-drain disposal of personal care and cleaning products to contaminate drinking water.

The difference in estimates between Simonich et al. (2013) and UCMR3 (U.S. EPA 2017a) may be the result of the different sources they sampled. Simonich et al. measured only effluent from WWTPs, while UCMR3 reports detections of 1,4-dioxane in both surface water and groundwater drinking sources, which include contamination from both wastewater effluents and legacy industrial sources.

Direct potable reuse of treated municipal wastewater is a long-term goal for California's water sustainability efforts and represents an additional pathway for contamination of drinking water, despite the advanced treatment employed in these applications. While California is not yet utilizing direct potable reuse, *de facto* potable reuse<sup>9</sup> of wastewater effluent is already occurring in California and other states as a result of low dilution of wastewater and the proximity of wastewater outfalls to drinking water intakes (Rice and Westerhoff 2015). Direct potable reuse will likely result in little to no dilution of 1,4-dioxane, leading to much higher exposures via drinking water than under most current scenarios.

It is worth noting that, due to infrastructure deterioration, many municipal sewage pipelines in the U.S. leak wastewater before it can be treated (U.S. EPA 2000b). Given that 1,4-dioxane is very soluble in water and is widespread in municipal wastewater, pipeline leakage likely contributes to the contamination of drinking water sources.

1,4-Dioxane in personal care and cleaning products could also enter groundwater and surface water through septic systems, given its mobility in soils and water. Nationally, about 20% of household wastewater is processed by septic systems (U.S. EPA 2020b). In California, that number is roughly 10%, or approximately 1,200,000 individual housing units, based on a 1998-1999 survey of on-site wastewater practices in California (CSU-Chico California Wastewater Training and Research Center and

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<sup>9</sup> *De facto* potable reuse "occurs when treated wastewater is discharged into surface waters upstream of potable drinking water treatment plant uptakes" (Rice and Westerhoff 2015).

US. EPA 2003). With more than 500,000 private drinking water wells in California (CSU-Chico California Wastewater Training and Research Center and US. EPA 2003), contamination from septic systems is a concern. High levels of nitrate in groundwater is often used as an indicator of septic system failure (CSU-Chico California Wastewater Training and Research Center and US. EPA 2003). Nitrate hotspots in California have been attributed to on-site wastewater treatment systems in the following areas: Antelope area (Tehama County), Baywood-Los Osos (San Luis Obispo County), Chico (Butte County), Livermore Valley (Alameda County), Oxnard Plain (Ventura County), and Yucca Valley (San Bernardino County) (CSU-Chico California Wastewater Training and Research Center and US. EPA 2003). Schaidler et al. (2017) reported that many organic wastewater compounds, including chemicals in personal care products, may not be effectively removed by septic systems, causing groundwater and surface water contamination. 1,4-Dioxane has been detected in groundwater sampling wells (0.26-3.8 ppb) near septic systems in New Hampshire (Regan 2015). This is consistent with the findings published by Lee et al. (2021), who reported that 1,4-dioxane concentrations in residential septic tank effluents ranged from 0.07-8.45 µg/L (0.07-8.45 ppb) with a mean of 1.49 µg/L (1.49 ppb) on Long Island, New York. Lee et al. (2021) concluded that 1,4-dioxane observed in septic tank effluents primarily came from the use of household products. Additionally, septic tank waste containing 1,4-dioxane can be shipped to sewage treatment facilities and landfills (Sonoma County 2020), contributing to subsequent 1,4-dioxane contamination of surface water and groundwater.

### *Disposal of Waste in Landfills*

Landfill leachate containing 1,4-dioxane may also contaminate groundwater and surface water, which are drinking water sources (Doherty et al. 2023). Most of the 1,4-dioxane in landfills is likely a result of improper disposal of hazardous waste in the past; however, discarded personal care and cleaning products in household waste may also contribute. As noted above, septic tank waste, which may contain 1,4-dioxane, can also be shipped to landfills.

Between 2005 and 2021, a total of 39 municipal solid waste landfills in California reported the 1,4-dioxane concentrations in their leachates to the State Water Resources Control Board (State Water Board 2021a). 1,4-Dioxane was measured above reporting limits in 20 of the 39 sites (State Water Board 2021a), with detected levels ranging between 1 and 1,100,000 µg/L, with a mean of 21590.7 µg/L and a median of 150 µg/L (State Water Board 2021a).

1,4-Dioxane has also been detected in groundwater located beneath landfills in California. In groundwater samples collected beneath 53 landfills (also reported by the State Water Board between 2005 and 2020), maximum 1,4-dioxane concentrations ranged from 0.22 µg/L to 12,800 µg/L (State Water Board 2021b).



## ***Agriculture***

Two agricultural practices can contribute to 1,4-dioxane contamination in groundwater and surface water – the use of wastewater to irrigate crops and the application of biosolids for fertilizer. Waste from septic tanks and sludge from wastewater treatment facilities (Sonoma County 2020) can be treated and subsequently applied as biosolids for agricultural activities (NC Policy Watch 2019). Despite their name, biosolids have between 70% and 97% water content (U.S. EPA 2000a) and may contain 1,4-dioxane. Treated wastewater can also be recycled for crop irrigation (State Water Board 2019d). Both effluent and biosolids from WWTPs and septic systems can contain 1,4-dioxane (see details in the [Indicators of Potential Exposures to the](#) Candidate Chemical section). Since 1,4-dioxane has low sorption to soil, it is expected to migrate downward through soils to groundwater or to surface water through runoff.

## **Inhalation Exposure Pathways**

Although 1,4-dioxane is primarily emitted to the air through industrial releases, inhalation exposure to 1,4-dioxane associated with personal care and cleaning products could be important in some scenarios. For example, estimated 1,4-dioxane emissions from landfills and wastewater treatment facilities have been reported to the California Air Resources Board, which may be attributable to down-the-drain releases and landfill disposals of personal care and cleaning products. According to these estimates, landfills emitted a total of 24.7 pounds of 1,4-dioxane in 2019, and wastewater treatment facilities emitted a total of 846.3 pounds the same year (Table 19) (CARB 2021).

Additionally, applying biosolids to farmlands, which is commonly done in arid regions, could also generate 1,4-dioxane air emissions. Given that 1,4-dioxane is found in the liquid portion of biosolids, high temperatures may facilitate volatilization of the chemical as the water evaporates. Similarly, lawn watering using tap water or groundwater might generate a constant low-level emission of gas-phase 1,4-dioxane as the water evaporates. These types of air emissions might be highly localized and, thus, more important to workers and residents and less likely to be captured by ambient air monitoring networks.

## **Other Pathways for Human Exposure**

Ingestion of contaminated food is a potential exposure pathway for 1,4-dioxane (Lin et al. 2017), but data gaps and confounding factors make it difficult to characterize the importance of this source relative to others (e.g., drinking water). Food crops themselves could be contaminated via uptake of 1,4-dioxane from contaminated groundwater or irrigation water, or fruits and vegetables could contain residue from detergents used to wash them. The uptake of 1,4-dioxane by food crops is not well characterized. Produce washes that are sometimes used to clean fruits and vegetables may (like other

cleaning products) be contaminated with 1,4-dioxane and could potentially contribute to dietary exposure (Lin et al. 2017).

### **Ecological Exposure**

Aquatic organisms and terrestrial wildlife are exposed to 1,4-dioxane in surface water, but the concentrations to which they are exposed can vary by many orders of magnitude. According to U.S. EPA modeling, the 1,4-dioxane concentration in a low-flow stream receiving 1,4-dioxane discharge from a top 10 facility in the U.S. EPA's Toxic Release Inventory database may range from as low as  $2.4 \times 10^{-8}$  µg/L to as high as 11,500 µg/L at the point of release (U.S. EPA 2020a). In national-scale monitoring data in the National Water Information System, 1,4-dioxane was measured in surface water at concentrations ranging from 0.568 to 100 µg/L in samples collected over the past 10 years (U.S. EPA 2020a). Although aquatic toxicity of 1,4-dioxane is generally considered to be low, the data on which this conclusion was based contains gaps and uncertainties. For example, while 1,4-dioxane would not be assumed to bioconcentrate to a significant degree (Franke et al. 1994), toxicity data are lacking for organisms at different trophic levels, and the diversity of species used to determine 1,4-dioxane's aquatic toxicity is limited, especially in chronic toxicity studies.

## **Indicators of Potential Exposures to the Candidate Chemical**

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

*The SCP regulations consider various data that indicate potential for exposure to the Candidate Chemical or its degradation products, including: monitoring data indicating the Candidate Chemical's presence in the indoor and outdoor environment, biota, humans, human food, drinking water, and other media; and evidence of persistence, bioaccumulation, and lactational and transplacental transfer.*

### **Introduction**

Various data reliably demonstrate the occurrence, or potential occurrence, of exposures to 1,4-dioxane from personal care and cleaning products (California Code of Regulations, Title 22, section 69503.3(b)(2)). These data include exposure attributes of 1,4-dioxane (i.e., persistence, mobility); environmental emission data; environmental monitoring data in air, water, and soil; biomonitoring data; and exposure modeling results. Exposure attributes have already been discussed (see the [Hazard Traits and Environmental or Toxicological](#) Endpoints section), but environmental monitoring and biomonitoring data are discussed below.

## ***Emission and Discharge of 1,4-Dioxane***

### **Emission of 1,4-Dioxane**

1,4-Dioxane is designated as a hazardous air pollutant (HAP) under the federal Clean Air Act and as a Toxic Air Contaminant (TAC) in California because of its carcinogenicity (see the [Hazard Traits and Environmental or Toxicological Endpoints](#) section). California's Air Toxic Hot Spots program (AB 2588) requires point<sup>10</sup> and area sources,<sup>11</sup> including landfills and WWTPs, to estimate and report their 1,4-dioxane emissions to CARB. Table 19 in [Appendix E: Indicators of Exposure Data](#) Tables provides the 2019 emissions data for eight landfills and 15 WWTP facilities, which are relevant pathways for personal care and cleaning products. The total amount of 1,4-dioxane emitted from the eight landfills was 24.7 lbs/yr in 2019, while the 15 wastewater treatment facilities emitted 846.3 lbs/yr (CARB 2021). Table 20 in [Appendix E: Indicators of Exposure Data](#) Tables summarizes the total 1,4-dioxane emissions for 13 regional Air Quality Management Districts (AQMD) and Air Pollution Control Districts (APCD). The total amount of 1,4-dioxane emissions was 13,854.8 lbs in 2019 across all of these AQMDs and APCDs (CARB 2021). The four AQMD/APCDs with the highest 1,4-dioxane emissions, as well as the dominant facilities contributing to those emissions, are listed below:

- Santa Barbara County APCD with total emissions of 8,760.7 lbs/year, dominated by a membrane manufacturer that accounted for 99.99% of the emissions
- San Joaquin Valley APCD with total emissions of 3,704.0 lbs/year, dominated by a company producing natural gas from landfill gas that accounted for 99.9% of the emissions
- San Diego County APCD with total emissions of 754.9 lbs/year, dominated by wastewater treatment facilities that accounted for 97.8% of the emissions
- Bay Area AQMD with total emissions of 422.5 lbs/year, dominated by a vehicle and clean energy company that accounted for 70.4% of the emissions.

The specific sources or processes responsible for 1,4-dioxane in each of these emissions are uncertain, but data in Table 19 and Table 20 both suggest that WWTPs may be an important source of the presence of 1,4-dioxane in air.

### **Wastewater Effluent and Recycled Water**

#### ***California Integrated Water Quality System***

Data on 1,4-dioxane in wastewater effluent and recycled water from 2010 to 2023 come from the State and Regional Water Quality Control Boards' California Integrated Water Quality System Project (CIWQS)(State Water Board 2023). Although CIWQS contains data from all stages of wastewater

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<sup>10</sup> A point source is a stationary source of air pollution (e.g., factory smoke stack).

<sup>11</sup> Area sources are sources whose emissions are estimated by a methodology (e.g., gas stations) (CARB 2023).

processing in California's nine Water Board regions, this report focuses on detections of 1,4-dioxane in wastewater effluent and recycled water, which is summarized in Table 21. 1,4-Dioxane concentrations ( $\mu\text{g/L}$ ) in municipal wastewater effluent and recycled water as reported by the State Water Board's CIWQS database, 2010-2023 (State Water Board 2023).

While statewide monitoring for 1,4-dioxane in wastewater is not mandated, facilities that are engaged in generation of recycled water are required to monitor for 1,4-dioxane. As of March 2023, this includes Water Board Regions 3, 4, 8, and 9. However, CIWQS does not prescribe the 1,4-dioxane analytical method used by these facilities, and the method detection limits (MDLs) varied considerably in the CIWQS data. Many of the MDLs were very high – appropriate for detecting industrial discharges or a contaminated groundwater plume but not for much lower levels resulting from the use and disposal of consumer products. In some cases, the MDL was 20 times higher than the California Notification Level (NL) of  $1 \mu\text{g/L}$  and more than 50 times higher than U.S. EPA's reference concentration of  $0.35 \mu\text{g/L}$ .

Only three Regional Water Boards reported detections of 1,4-dioxane in wastewater above MDLs to CIWQS (Table 21) (State Water Board 2023) – the Los Angeles Regional Water Quality Control Board (Region 4); the Central Valley Regional Water Quality Control Board, Fresno (Region 5F); and the Colorado River Basin Regional Water Quality Control Board (Region 7). Region 4 reports the most data (418 samples), most likely due to the relatively high number of recycled water facilities in the area. More than 84% of the effluent samples in Region 4 had 1,4-dioxane concentrations above the MDL (Table 21). Detected concentrations of 1,4-dioxane (355 samples) ranged from  $0.026 \mu\text{g/L}$  to  $4.0 \mu\text{g/L}$ , with the mean being 0.93 and the median being 0.88 – values that are both close to the NL of  $1 \mu\text{g/L}$ . The mean 1,4-dioxane concentrations in the Central Valley ( $0.23 \mu\text{g/L}$ ) and Colorado River Basin regions ( $0.01 \mu\text{g/L}$ ) are lower than those reported for Region 4; however, the number of samples in these regions is also much lower (36 and 15 samples, respectively, compared to 418 for Region 4).

Of note, Region 4 was the only region to report 1,4-dioxane concentrations in recycled water. The observed mean concentration of  $1.31 \mu\text{g/L}$ , with a 100% detection frequency, is in line with the mean reported for the wastewater effluent data in that region ( $0.93 \mu\text{g/L}$ ). While the data do not indicate which wastewater effluent was the source of the recycled water, the similarity in values suggests that 1,4-dioxane in wastewater is making its way into recycled water. This concern is further explored in the [Adverse Waste and End-of-Life Effects](#) section below.

More detailed data on 1,4-dioxane concentrations in wastewater from Los Angeles County Sanitation Districts (LACSD) was presented at DTSC's June 2019 public workshop (Heil 2019). The presence of 1,4-dioxane at WWTPs within LACSD is of particular concern because of the large amount of recycled water they produce, a significant portion of which is used for groundwater recharge. In eight LACSD treatment plants that are unimpacted by industrial sources, the concentrations of 1,4-dioxane in the wastewater are remarkably similar. These levels, approximately  $1 \mu\text{g/L}$ , have remained relatively stable

over time and are not significantly impacted even by tertiary treatment of the wastewater. These consistent concentrations over time and across WWTPs suggest a widespread, domestic (non-industrial) source such as consumer products (Heil 2019). Additionally, these levels are of concern because they are at the California NL of 1 µg/L. Depending on the permit and final use of the effluent, WWTPs may be asked by the Division of Drinking Water (DDW) to meet the NL standard.

Region 5S Central Valley (Sacramento) has no municipal wastewater data on 1,4-dioxane but does include measurements from a single industrial/Superfund facility taken at various stages of the facility's wastewater treatment process. This site was responsible for the highest concentrations of 1,4-dioxane in the CIWQS, including 62 readings that qualify as outliers ranging from 3.1 to 6.3 µg/L (more than 1.5 times the interquartile range (IQR)). Data from Region 5R Central Valley (Redding) and Region 9, San Diego, were also excluded from further analysis because the MDLs reported for those datasets range from 8.8 µg/L to 20.2 µg/L, considerably higher than the 1 µg/L NL for drinking water.

### ***Orange County Sanitation District***

The Groundwater Replenishment System (GWRS) in Orange County provided the State Water Board with 1,4-dioxane data collected from 2008 to 2017 (Kawamoto 2019). The GWRS is an internationally known joint project of the Orange County Water District (OCWD) and the Orange County Sanitation District (OCSD) that receives treated wastewater from OCSD. The treated wastewater is further purified using a three-step advanced treatment process, including ultraviolet light with hydrogen peroxide to target 1,4-dioxane. This purified water is then pumped to recharge basins, where it naturally percolates into the Orange County Groundwater Basin and supplements Orange County's drinking water supplies. In 2015, the GWRS produced 100 million gallons of recycled water per day (OCWD and OCSD 2018).

The fairly consistent level of 1,4-dioxane in municipal wastewater (around 1 µg/L, as reported by LACSD (Heil 2019), OCSD (Kawamoto 2019), and nationally by Simonich et al. (2013)) suggests a widespread, constant source, such as the residential use of consumer products and their release down the drain. The only options to reduce the concentration of 1,4-dioxane in treated and untreated wastewater are subsequent dilution, advanced oxidation processes (AOPs), and source reduction. Subsequent dilution is increasingly unlikely given California's increasingly frequent droughts and movement toward potable reuse of wastewater, leaving AOPs and source reduction as the only likely viable options.

### **Leachates from Land Disposal Sites**

1,4-Dioxane also enters the environment through leachates from land disposal sites. Between 2005 and 2021, the State Water Board analyzed 1,795 leachate samples collected from 39 California municipal solid waste (MSW) landfills for 1,4-dioxane (State Water Board 2021a). Of these, 332

samples representing 20 landfills contained 1,4-dioxane above reporting limits (2021a). 1,4-Dioxane concentrations in these samples ranged from 1 – 1,100,000 µg/L, with a median of 21,590.7 µg/L and a mean of 150 µg/L. The 39 MSW landfills had a wide range of reporting limits of 1,4-dioxane — from 0.0001 µg/L to as high as 100,000 µg/L — indicating that the presence of 1,4-dioxane in MSW leachate may be underestimated, especially for those “non-detects” from landfills with high reporting limits.

## ***Environmental Monitoring Data***

### **1,4-Dioxane in Groundwater**

#### ***The California Groundwater Ambient Monitoring and Assessment Program***

The California Groundwater Ambient Monitoring and Assessment (GAMA) Program was created in 2000 and is managed by the State Water Board (State Water Board 2018a). This program is used to assess water quality in the groundwater basins that account for 95% of the state’s groundwater use. Ninety percent of California’s drinking water systems rely on groundwater for some portion of their water supply (State Water Board 2018a). Data for the GAMA Program are collected by the State and Regional Water Quality Control Boards and other state or federal agencies, in cooperation with local water agencies and well owners.

Three of the nine GAMA data sets available for the 10-year period from 2008 through 2017 indicate the presence of 1,4-dioxane – the GAMA Priority Basin Project, GAMA Monitoring Wells, and Public Water System Wells. All samples are of untreated groundwater (State Water Board 2018a). Data for the Public Water System Wells are included in the drinking water data presented below. Data from the other two data sets are summarized in Table 22 in [Appendix E: Indicators of Exposure Data](#) Tables. 1,4-Dioxane was detected in groundwater from almost all regions, with Region 6 Lahontan and Region 7 Colorado River Basin being the only exceptions. While a significant portion of this is undoubtedly related to industrial and legacy inputs, the ubiquity of 1,4-dioxane in California’s groundwater reflects its widespread distribution.

The GAMA Priority Basin Project data set also includes well testing results collected by the U.S. Geological Survey and the Lawrence Livermore National Laboratory (State Water Board 2018b). Most wells sampled are public water system wells; the rest are irrigation or monitoring wells, or private domestic wells. As shown in Table 22, Region 4 Los Angeles ( $0.9 \pm 2.1$  µg/L for mean  $\pm$  standard deviation) and Region 8 Santa Ana ( $0.1 \pm 0.3$  µg/L) both had 1,4-dioxane concentrations higher than the State Water Board’s NL (1.0 µg/L) in 31% and 4% of their samples, respectively (State Water Board 2018a).

GAMA monitoring wells data are submitted to the State Water Board by a number of regulatory programs, such as the U.S. Department of Defense, DTSC, and the Central Coast Regional Water

Quality Control Board's Irrigated Lands Regulatory Program (State Water Board 2018a) and provide a general overview of groundwater quality across the state, whether or not it will be used as drinking water. 1,4-Dioxane was found in a variety of sites, including cleanup sites, land disposal sites, military sites, and those monitored under waste discharge requirements (WDRs). As Table 22 shows, in the nine Water Board regions reporting 1,4-dioxane concentrations in their groundwater, the highest mean concentrations were found in Region 2 San Francisco (808.2 µg/L), followed by Region 4 Los Angeles (478.5 µg/L) and Region 8 Santa Ana (407.5 µg/L), while the highest median concentrations were found in Region 8 Santa Ana (1.7 µg/L) and Region 4 Los Angeles (1.3 µg/L). These very high mean 1,4-dioxane concentrations observed in Regions 2, 4, and 8 are associated with wells at cleanup sites (State Water Board 2018a).

### **Data from Contaminated Sites (GeoTracker)**

GeoTracker is the State Water Board's database system, developed in 2000, to 1) monitor authorized or unauthorized discharge to land from sites and facilities, 2) monitor unauthorized releases of hazardous substances from underground storage tanks, and 3) assess regulatory compliance through analyses of the collected monitoring data. The discharge and release of wastes can impact various environmental media, especially groundwater, air, and soil. GeoTracker includes data from sites overseen by DTSC's Site Mitigation & Restoration Program (e.g., brownfields, State Superfund, and military facilities), from unregulated projects, from permitted facilities (e.g., land disposal sites, irrigated lands, waste discharge requirement sites), and from other sites and facilities.

Table 23 presents the most recent data from GeoTracker for 1,4-dioxane levels in groundwater beneath contaminated sites (State Water Board 2020a). In the most recent sampling (October 25, 2000, to January 21, 2020), mean levels of 1,4-dioxane in groundwater beneath cleanup sites ranged from 0.1 µg/L to 765.5 µg/L, while mean levels beneath land disposal sites ranged from non-detects to 440 µg/L.

### **1,4-Dioxane in Drinking Water**

#### ***U.S. EPA's Third Unregulated Contaminant Monitoring Rule***

Treated wastewater can contribute to 1,4-dioxane contamination of both surface water and groundwater, both of which may serve as sources of drinking water. Drinking water data collected across California during U.S. EPA's third Unregulated Contaminant Monitoring Rule (UCMR3, detailed below) between 2013 and 2015 are presented in Table 8 and Figure 7.

*Table 8. Summary statistics of 1,4-dioxane concentration (µg/L) in California drinking water (U.S. EPA 2017a).*



Drinking Water Source Characterization	n	% above DL [a]	Mean	Std Dev	Median	95th Percentile	Max
Groundwater under influence of surface water	16	0	0.07	0	0.07	0.07	0.07
Groundwater	4828	16	0.17	0.55	0.07	0.47	7.80
Groundwater + surface water	295	18	0.10	0.09	0.07	0.31	0.93
Surface water	1335	4	0.08	0.07	0.07	0.07	1.14
Overall	6474	13	0.15	0.47	0.07	0.36	7.80

[a] DL: Detection limit, which is 0.07 µg/L. Samples with concentrations below the DL are reported as DL in the original data set.

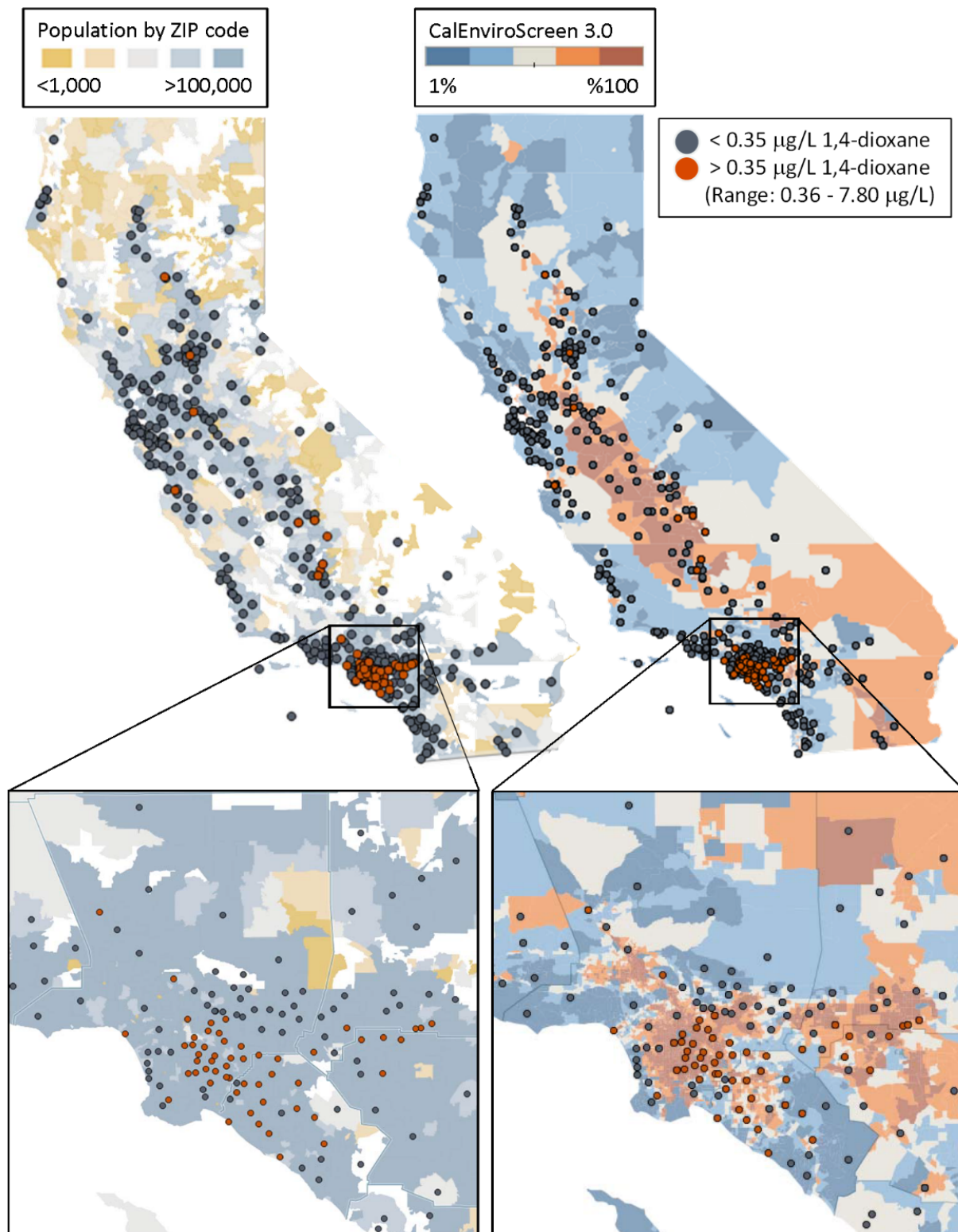


Figure 7. 1,4-Dioxane concentrations in California drinking water from U.S. EPA’s UCMR3 survey (U.S. EPA 2017a). Background maps show population by zip code on the left and CalEnviroScreen environmental justice communities on the right. Visualizations were created using Tableau 2019.3.

The UCMR3 data illustrate Californians’ widespread exposure to 1,4-dioxane through drinking water (Figure 7). 1,4-Dioxane was detected above U.S. EPA’s reference concentration of 0.35 µg/L in 10 California counties (U.S. EPA 2017a). Exceedances were concentrated in highly populated counties that represent about half of the state’s population. While much of this drinking water contamination is likely a result of historical releases of 1,4-dioxane to groundwater, elevated levels of 1,4-dioxane in samples taken from surface water point to wastewater effluent and consumer products as potential sources. Additionally, groundwater may be contaminated with 1,4-dioxane from personal care and cleaning products through injection of treated wastewater into groundwater.

**California State Water Board Division of Drinking Water (DDW) Data**

U.S. EPA has supplemented the UCMR3 data with data from the State Water Board – 27,770 measurements of 1,4-dioxane in drinking water. The data were collected from 1996 to 2018 across 41 California counties (State Water Board 2019b). As shown in Table 10, 97% of the data were collected from six of these counties – Los Angeles County, Orange County, Riverside County, Sacramento County, San Bernardino County, and San Diego County – which account for 57.8% of California’s population, according to 2019 census estimates (Table 10) (U.S. Census Bureau 2019).

The overall mean, standard deviation, 95th percentile, and median concentrations of 1,4-dioxane in treated and untreated drinking water are shown below in Table 9.

*Table 9. 1,4-Dioxane concentrations (µg/L) in California’s drinking water (1996-2018 data, State Water Board 2019b).*

Dataset	n	Mean	Std Dev	Median	95 <sup>th</sup> Percentile	Max
Original source data [a]	27,766	1.5	3.9	1.0	4.4	100.0
Detection limit (DL) replacement [b]	27,766	0.7	2.0	0.1	4.0	53.0
Above DL data only [c]	6,913	2.7	3.3	1.8	8.3	53.0
Data collected after 2012 [d]	14,558	1.2	1.9	1.0	3.5	100.0
Above DL data collected after 2012 [e]	4,827	2.1	2.5	1.5	6.0	36.0

[a] All the data in the data set except for four invalid data points marked as invalid in the downloaded data set. Below DL data were replaced with zero or the corresponding DL, ranging from 0 µg/L to 100 µg/L. The maximum 1,4-dioxane concentration indicated for the original source data is representative of a DL and not an actual concentration of 1,4-dioxane detected in a drinking water sample.

[b] Below DL data were replaced with U.S. EPA UCMR3’s DL, i.e., 0.07 µg/L.

[c] Data above DL were included in the analyses.

[d] Data collected in and after 2012 were included in the analyses.

[e] Above DL data collected in and after 2012 were included in the analyses.

According to State Water Board data, the counties with the highest 1,4-dioxane concentrations in their drinking water were Santa Barbara, Los Angeles, Monterey, San Diego, and Orange (Table 10). These counties represent almost half of the California population, indicating the potential for widespread 1,4-dioxane exposure through drinking water (Table 10).

*Table 10. Counties with the highest detections of 1,4-dioxane in drinking water, according to data from the State Water Board (2003-2018 data, State Water Board 2019b), with accompanying 1,4-dioxane drinking water concentration data in µg/L. Data used for generating summary statistics are above-detection-limit data collected after 2012.*

County	n	Mean (µg/L)	Std Dev	Median (µg/L)	95 <sup>th</sup> Percentile (µg/L)	Max. detect (µg/L)	% of CA Population [a]
SANTA BARBARA	22	12.4	4.1	13.5	16.0	16.0	1.1
LOS ANGELES	3120	2.5	2.5	1.7	6.3	36.0	25.4
MONTEREY	27	1.5	0.4	1.5	1.8	3.0	1.1
SAN DIEGO	1	1.2	N/A [b]	1.2	1.2	1.2	8.4
ORANGE	1635	1.1	1.8	N.D.	5.2	9.7	8.0

[a] Based on 2019 census data.

[b] Not applicable.

Due to a large number of non-detect samples (i.e., >75% of samples were below detection limits) and the inconsistency of DLs (0-100 µg/L) across different counties, we calculated the summary statistics for the State Water Board data in five different ways (Table 9), to explore different methods for handling the DLs when evaluating the data. The results indicate that, when detected, the mean and median 1,4-dioxane concentration in California’s drinking water is almost always higher than U.S. EPA’s reference concentration of 0.35 µg/L and higher than the California drinking water NL of 1 µg/L, regardless of how the samples below the DL are handled.

As shown in Table 11 and Figure 8, 1,4-dioxane concentrations in drinking water data from the State Water Board are comparable regardless of treatment classification. Additionally, the data indicate that levels of 1,4-dioxane in the State Water Board’s drinking water data are frequently higher than both U.S. EPA’s health-based concentration and the State of California’s drinking water NL. For more than 35% of the data, the extent of treatment was not characterized. While definitive conclusions cannot be drawn, the data do reveal that treated drinking water can have 1,4-dioxane concentrations that are just as high as untreated drinking water.

Table 11. 1,4-Dioxane concentrations ( $\mu\text{g}/\text{L}$ ) in California drinking water, stratified by treatment (Data used to calculate summary statistics are above-detection-limit data from the State Water Board collected after 2012 (State Water Board 2019b)).

Treatment [a]	n	Mean	Std Dev	Median	95 <sup>th</sup> Percentile	Max
Not Treated	106	1.5	2.3	1.1	7.8	11
Treated	3,938	2.1	2.5	1.6	6.2	36
N/A [b]	783	1.8	2.3	1.5	4.0	32

[a] N = sample description indicates no treatment, T = sample description indicates some level of treatment.

[b] N/A = sample description does not indicate whether sample has been treated.

Table 12 and Figure 8 show 1,4-dioxane concentrations in California’s drinking water, stratified by the source type (groundwater or surface water). Consistent with the national UCMR3 data, the median 1,4-dioxane concentration in groundwater is slightly higher than that in surface water. The mean, 95th percentile, and some median concentrations are above U.S. EPA’s reference concentration (0.35  $\mu\text{g}/\text{L}$ , solid red line in Figure 8 ) and the State Water Board NL (1.0  $\mu\text{g}/\text{L}$ , dotted red line in Figure 8) for drinking water from both source types. Combined, the mean 1,4-dioxane concentration for 19 of the state’s 58 counties was above U.S. EPA’s reference concentration.

Table 12. 1,4-Dioxane concentration ( $\mu\text{g/L}$ ) in California's drinking water by source ( data from the State Water Board State Water Board 2019b)).

Data Set	Source Water Type	n	Mean	Std Dev	Median	95 <sup>th</sup> Percentile	Max
Original source data [a]	Groundwater	26,244	1.5	3.8	1	4.4	100
	Surface water	715	1.4	5.0	1	3	100
Detection limit replacement [b]	Groundwater	26,244	0.7	1.9	0.07	4	46.2
	Surface water	715	0.1	0.1	0.07	0.07	1.2
Above DL data only [c]	Groundwater	6,712	2.6	3.1	1.7	8	46.2
	Surface water	22	0.4	0.5	0	1.23	1.2
Data collected after 2012 [d]	Groundwater	13,747	1.2	1.9	1	3.6	100
	Surface water	533	1.0	0.2	1	1	1.2
Above DL data collected after 2012 [e]	Groundwater	4,748	2.0	2.3	1.5	6	36
	Surface water	20	0.4	0.6	0	1.23	1.2

[a] All the data (including data collected before, in, and after 2012) in the data set except for four invalid data points. Below DL data were replaced with zero or the corresponding DL, ranging from 0  $\mu\text{g/L}$  to 100  $\mu\text{g/L}$ .

[b] Below DL data were replaced with U.S. EPA UCMR3's DL, i.e., 0.07  $\mu\text{g/L}$ .

[c] Only data above DL were included in the analyses.

[d] Data collected in and after 2012 were included in the analyses. Below DL data were replaced with the corresponding DL, ranging from 0  $\mu\text{g/L}$  to 100  $\mu\text{g/L}$ .

[e] Above DL data collected in and after 2012 were included in the analyses.

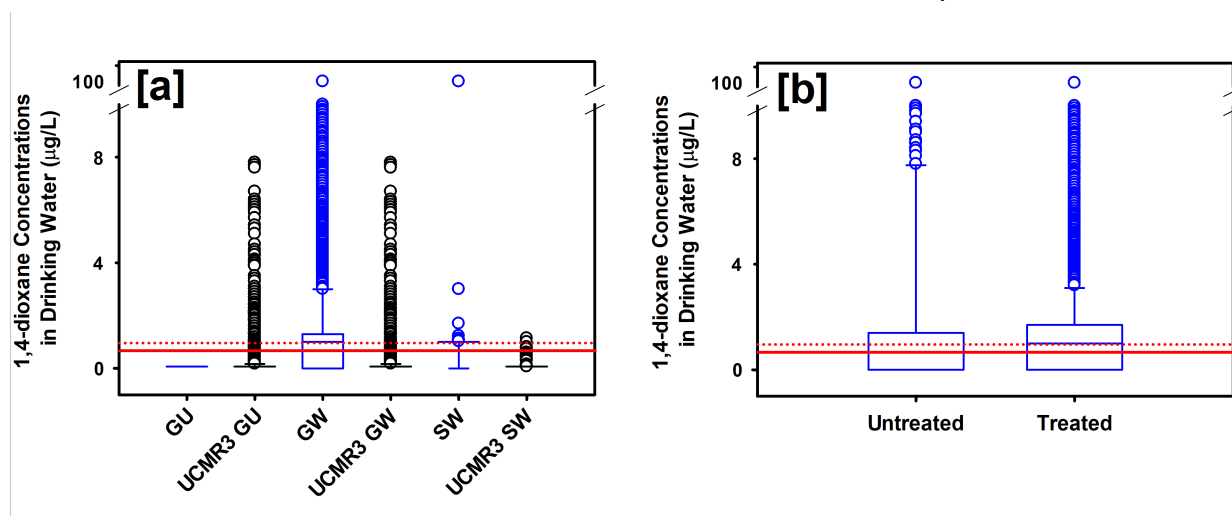


Figure 8. [a] Distributions of 1,4-dioxane concentrations in drinking water from groundwater under the influence of surface water (GU), groundwater (GW), and surface water (SW) for State Water Board data (blue) and UCMR3 data (black) (U.S. EPA 2017a; State Water Board 2019b). The boxes represent the 25th, 50th, and 75th percentiles, the top lines indicate the 95th percentiles, and data points above the 95th percentiles are indicated by circles. U.S. EPA's reference concentration (0.35  $\mu\text{g/L}$ ) is indicated by the solid red line, and the State Water Board notification level (NL) (1.0  $\mu\text{g/L}$ ) is indicated by the

dotted red line. [b] Box plot distributions of drinking water concentrations in untreated and treated California drinking water (State Water Board 2019b). The boxes represent the 25th, 50th, and 75th percentiles, the top lines indicate the 95th percentiles, and data points above the 95th percentiles are indicated by circles. U.S. EPA's reference concentration ( $0.35 \mu\text{g}/\text{L}$ ) is indicated by the solid red line, and the State Water Board NL ( $1.0 \mu\text{g}/\text{L}$ ) is indicated by the dotted red line.

## 1,4-Dioxane in Ambient Air

U.S. EPA's National Air Toxics Assessment (NATA) provides census tract-level estimates of 1,4-dioxane concentrations in ambient air, based on facility emissions throughout the continental United States (U.S. EPA 2018b). In contrast, GeoTracker data focus on measuring emissions from various contaminated sites, such as cleanup, military, land disposal, and waste discharge requirement sites throughout California. Both data sets are used to assess the potential for exposure to 1,4-dioxane through ambient air. While both modeled and measured data indicate that ambient air concentrations alone are below levels of concern, these exposures contribute to aggregate 1,4-dioxane exposures.

### *The National Air Toxics Assessment*

1,4-Dioxane is regulated as a hazardous air pollutant (HAP) under the U.S. Clean Air Act and a toxic air contaminant (TAC) under California Health and Safety Code section 39657 (CARB 2011; U.S. EPA 2015e).

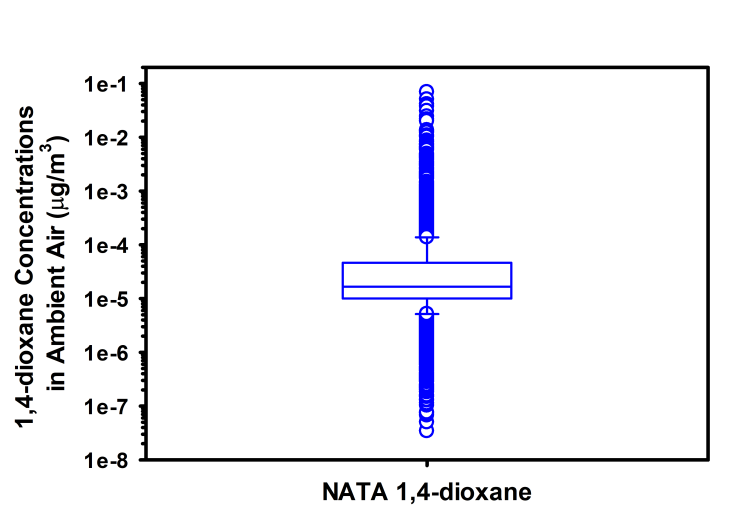


Figure 9. NATA modeled 1,4-dioxane ambient air concentrations in California. The box represents the 25th, 50th, and 75th percentiles; the top line indicates the 95th percentile, and data points above the 95th percentile are indicated by circles; the bottom line indicates the 5th percentile, and data points below the 5th percentile are also indicated by circles.

Based on NATA's modeling of National Emissions Inventory (NEI) data, the ambient air concentrations of 1,4-dioxane in the California census tracts with the highest concentrations are 10 times lower than the U.S. EPA residential screening value ( $0.56 \mu\text{g}/\text{m}^3$ ) (U.S. EPA 2015d). NATA indicates that regions of



Santa Barbara, San Joaquin, and San Diego counties, as well as census tracts in a few other counties, have the highest concentrations of 1,4-dioxane in the air (U.S.EPA 2018). Some of these census tracts have estimated levels of 1,4-dioxane 5,000 times higher than the median concentration in California ( $1.66 \times 10^{-5} \mu\text{g}/\text{m}^3$ ). Roughly 11% of census tracts have concentrations of 1,4-dioxane that qualify as upper-limit outliers (defined as  $1.5 \times \text{IQR}$ ); some of these areas may be considered disproportionately impacted communities. The mean concentration,  $1.4 \times 10^{-4} \mu\text{g}/\text{m}^3$  for census tracts in California is considerably higher than the median. NATA is intended to provide screening-level information about HAPs (U.S. EPA 2018).

### ***Air Monitoring Results at Locations Near Contaminated Sites***

Higher 1,4-dioxane ambient air concentrations near contaminated sites may result in elevated exposures, above EPA residential screening value, to on-site workers and nearby residents. Table 19 in [Appendix E: Indicators of Exposure Data](#) Tables presents the most recent GeoTracker data for ambient 1,4-dioxane levels near contaminated sites (data from December 22, 2002 to January 15, 2020). The mean airborne 1,4-dioxane concentrations range from  $0.08 \mu\text{g}/\text{m}^3$  to  $3.5 \mu\text{g}/\text{m}^3$  for cleanup sites and from  $9 \mu\text{g}/\text{m}^3$  to  $140,000 \mu\text{g}/\text{m}^3$  from military sites (State Water Board 2020a).

### **1,4-Dioxane in Indoor Air**

1,4-Dioxane levels in indoor air are influenced by concentrations of the chemical in outdoor air, by indoor sources of 1,4-dioxane, by room volume, and by air flow and ventilation. Historical data from the mid-1980s indicates that the average indoor air 1,4-dioxane concentration in the U.S. was approximately  $4 \mu\text{g}/\text{m}^3$  (ATSDR 2012). Residential homes near outdoor 1,4-dioxane sources (e.g., cleanup sites and WWTPs) are likely to have high levels of the chemical in indoor air. The use of 1,4-dioxane-containing consumer products in the indoor environment, such as dishwashing detergents and spray-and-wipe-type cleaners (see the [Potential Exposures to the Candidate Chemical](#) During the Products' Life Cycle section), could also release the chemical into the indoor environment.

### **1,4-Dioxane in Soil**

In contaminated soils, dissolved 1,4-dioxane can readily migrate to groundwater and surface water, and vapor-phase 1,4-dioxane can contaminate indoor air via vapor intrusion. Table 26 presents the most recent GeoTracker data for 1,4-dioxane measurements in soil gas at contaminated sites; mean values range from not detected to  $12,000 \mu\text{g}/\text{kg}$  (State Water Board 2020a). The data on soil included in this Profile were collected between October 15, 2001, and January 14, 2020.

### ***Biomonitoring Data***

Although the presence of 1,4-dioxane is widespread in consumer products and environmental media, data from the National Health and Nutrition Examination Survey (NHANES) indicate that most Americans do not have measurable concentrations of the chemical in their blood – the 95th percentile



of the measured-blood 1,4-dioxane concentrations were below the DL of 0.5 ng/ml for all age groups (CDC 2018). However, these results do not mean people are not being exposed. Biomonitoring for 1,4-dioxane is a challenge because of the chemical's short half-lives in the human body (59 min in plasma and 48 min in urine (ATSDR 2012)). After entering the human body, more than 99% of the absorbed 1,4-dioxane is metabolized to  $\beta$ -hydroxyethoxyacetic acid (HEAA) and rapidly excreted in urine (ATSDR 2012).

Göen et al. (2016) measured HEAA levels in urine in a study of the toxicokinetics of 1,4-dioxane in humans. Blood samples were collected after four and eight hours of inhalation exposure to 1,4-dioxane, and urine samples were periodically collected over the 24 hours immediately after exposure. HEAA concentrations in urine were largely above the limit of quantification (LOQ = 0.6 mg/L) and increased during exposure, peaking at  $9.8 \pm 1.9$  hours after the beginning of exposure; meanwhile, the levels of 1,4-dioxane in blood and urine were barely above the LOQ (0.3 mg/L). These results indicate that HEAA in urine is a better measure of 1,4-dioxane exposure than 1,4-dioxane in blood is. Additional biomonitoring efforts focused on HEAA may provide a better understanding of aggregate human exposure to 1,4-dioxane.

## Aggregate Exposure

*Reference: California Code of Regulations, Title 22, section 69503.3(a)(1)(B) and sections 69503.3(b)(3).*

*Multiple sources of exposure to the Candidate Chemical may increase the potential for significant or widespread adverse impacts.*

### **Aggregate Exposure to 1,4-Dioxane Due to the Use of Multiple Consumer Products**

Many personal care and cleaning products on the market include ethoxylated ingredients and, therefore, potentially contain 1,4-dioxane as a contaminant (see the [Generation of 1,4-Dioxane as a Contaminant](#) section). For example, the Environmental Working Group's Skin Deep Cosmetics Database reports 2,400 personal care products that contain the AES sodium laureth sulfate, including 660 shampoos, 629 body washes, 354 liquid hand soaps, and many other personal care products (searched on 12/14/2021, Environmental Working Group 2018). The levels of 1,4-dioxane in personal care and cleaning products are summarized in Table 4, and Figure 5 ([Detection in Products: Lab Studies](#)).

As described above, personal care (e.g., shampoos, body cleaners, and face washes) and cleaning products (e.g., laundry and dishwashing detergents) are extremely prevalent in homes and workplaces nationwide, including in California. (DTSC 2018)

Consumers use both personal care and cleaning products daily (i.e., product co-use). Wu et al. (2010) reported moderate correlations among use frequencies for personal care products in California homes. Within the category of general hygiene products, people are likely to use multiple products (e.g., shampoo, hair conditioner, and bath gel), leading to aggregate exposures to 1,4-dioxane.

Although methods have been developed to characterize aggregate exposures from multiple consumer products (Delmaar et al. 2015; Brandon et al. 2020) information on product co-use patterns, which is critical for calculating aggregate exposure during the product-use stage, is extremely limited (ECETOC 2016). Further, product co-use patterns may be linked to the user's gender, age, and ethnicity (Manov? et al. 2013), further complicating the calculation. Adding to the challenge, there are no available aggregate exposure estimates for workers who use cleaning products (e.g., housecleaners, janitors) or personal care products (e.g., salon workers) for the entire workday.

Despite these challenges, the European Chemicals Agency (ECHA) has estimated the aggregate exposure to 1,4-dioxane from the use of shampoos, body lotions, and dishwashing detergents. Using the ConsExpo model (ECHA 2002), ECHA estimated the average combined total internal dose of 1,4-dioxane to be 3.3  $\mu\text{g}/\text{kg bw}/\text{d}$  and, under the worst-case scenarios, to be 10.0  $\mu\text{g}/\text{kg bw}/\text{d}$ . These values are considerably higher than OEHHA's 1,4-dioxane NSRL of 30  $\mu\text{g}/\text{day}$  (equivalent to 0.43  $\mu\text{g}/\text{kg bw}/\text{day}$  for a 70-kg adult). For more detailed information on estimated exposures to 1,4-dioxane during product use, please refer to Table 7. ECHA's high predicted level of exposure is attributable, in part, to the high levels of 1,4-dioxane the ECHA evaluation assumed (e.g., 50 ppm to 300 ppm in shampoo) (ECHA 2002). While ECHA's assumed concentrations are higher than many of the reports of 1,4-dioxane concentrations in consumer products discussed above in the [Detection in Products: Lab Studies](#) section, recent data submitted by manufacturers to New York State indicate concentrations of 1,4-dioxane in shampoo and dishwashing detergent close to or exceeding the lower bound of ECHA's assumptions – as high as 34.9 ppm in shampoo (ECHA assumption 50 ppm) and as high as 57.6 ppm in dishwashing detergent (ECHA assumption 30 ppm) (Table 5). Despite the recent data from New York State, the concentrations of 1,4-dioxane across all products currently on the market are poorly understood, especially products marketed toward sensitive subpopulations. Preliminary product testing data from DTSC indicate that concentrations of 1,4-dioxane were as high as 225 ppm in recently purchased products intended for contact with the skin (Grant 2022). Therefore, ECHA's predictions indicate the potential for significant aggregate exposures.

Using a similar modeling approach, Environment Canada and Health Canada (2010) estimated adult women's aggregate exposure to 1,4-dioxane from the use of hair conditioners, hair shampoos, skin moisturizers, and body washes to be 3.0 µg/kg bw/d. For infants under 6 months old, the estimated aggregate exposure from the use of skin moisturizers, hair shampoos, and body washes was 0.44 µg/kg bw/d (Environment Canada and Health Canada 2010). Accidental ingestion was not incorporated into the aggregate exposure calculation for children. These estimates indicate that aggregate exposure to 1,4-dioxane from multiple consumer products may result in significant adverse impacts. Further, these exposures contribute to larger aggregate exposures to 1,4-dioxane from contaminated environmental media and down-the-drain contamination of drinking water, as detailed below.

### ***Aggregate Exposure to 1,4-Dioxane Due to Product End-of-Life Disposal and Other Emissions***

As discussed throughout this Profile, exposure to 1,4-dioxane from personal care and cleaning products extends beyond the use phase, because these products are released down the drain and 1,4-dioxane is mobile and persistent in the environment. Exposures to 1,4-dioxane in personal care and cleaning products can occur through any of the pathways laid out in section 4 above; however, the disposal (end-of-life) phase of the product life cycle has the greatest potential for widespread exposures outside of the use phase.

Personal care and cleaning products are not the only source of 1,4-dioxane exposures. The chemical is also emitted or discharged from industrial processes and from historically contaminated sites. All contribute to aggregate exposures to 1,4-dioxane. Elevated levels of 1,4-dioxane are found in drinking water, groundwater, air, and soil in certain geographic regions (e.g., groundwater in Southern California) and are often associated with certain human activities (e.g., landfilling of waste), as described above (section 3, [Indicators of Potential Exposures to the](#) Candidate Chemical).

Figure 10 illustrates the levels of 1,4-dioxane contamination of water, air, and soil throughout California. Superimposed on the map are locations where the drinking water contains 1,4-dioxane at concentrations above U.S. EPA's UCMR3 reference concentration (0.35 µg/L). Data underlying Figure 10 primarily come from the State Water Board's GeoTracker database. Information about GeoTracker and summary statistics associated with the data used for generating this figure are detailed in section 3, [Indicators of Potential Exposures to the](#) Candidate Chemical.

Figure 10 shows that the regions in California with the highest potential for 1,4-dioxane exposure due to environmental contamination are clustered in two highly populated areas: the San Francisco Bay Area and the Los Angeles region. Within these regions are many disadvantaged communities with CalEnviroScreen scores of more than 75%, indicating they are already experiencing adverse health impacts due to pollution and other health-based factors (OEHHA 2019a). Table 12, along with figures

and tables presented in the [Indicators of Potential Exposures to the](#) Candidate Chemical section, illustrate that elevated levels of 1,4-dioxane are found in multiple environmental media across California. The combination of environmental contamination, and exposures from the use of personal care and cleaning products contributes to total 1,4-dioxane exposures for local residents and for those working to clean up contaminated sites.

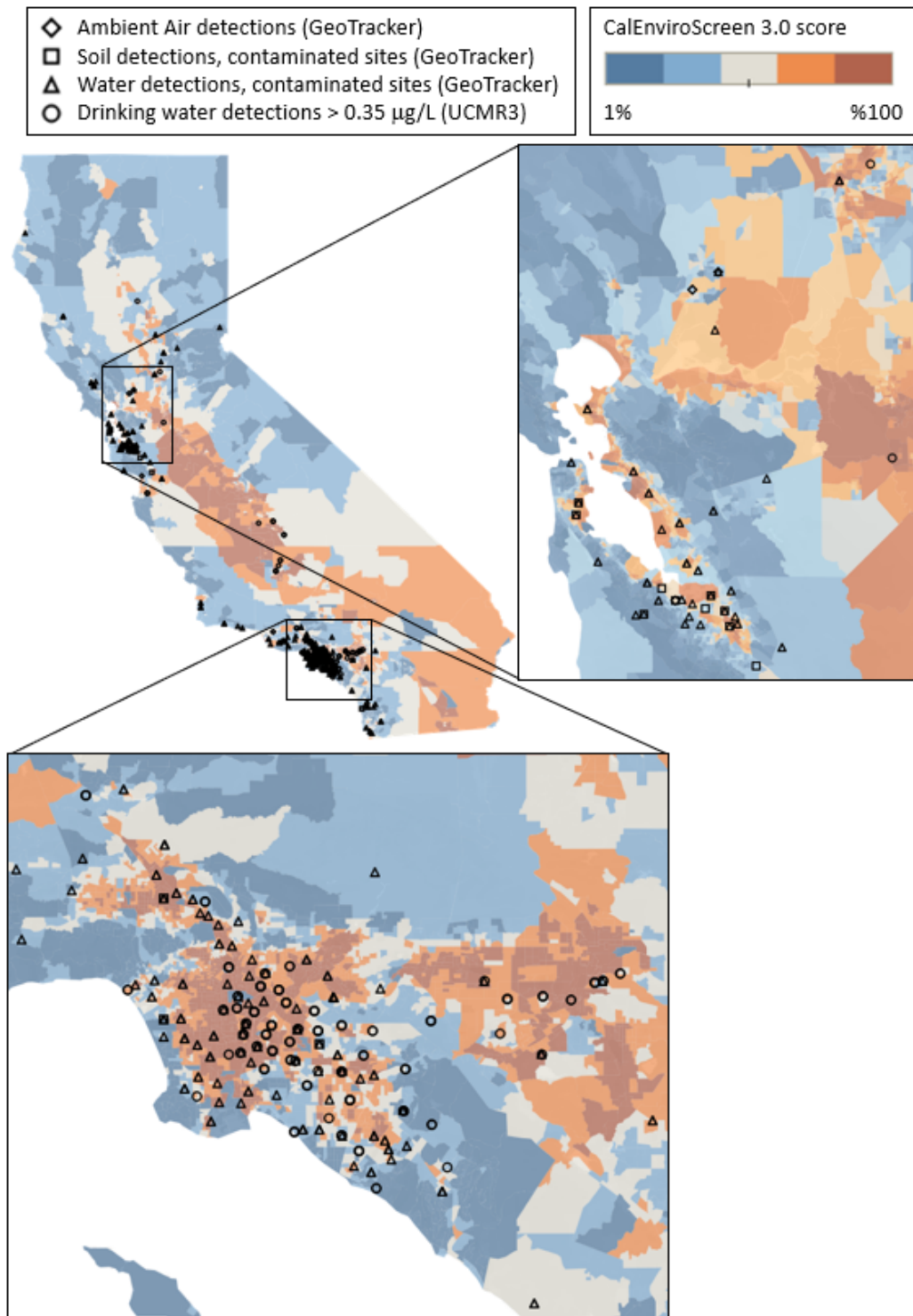


Figure 10. 1,4-Dioxane in contaminated water, air, and soil documented in GeoTracker (State Water Board 2020a) and in drinking water with 1,4-dioxane concentrations above 0.35  $\mu\text{g/L}$  (U.S. EPA 2017a) overlying the Cal-EnviroScreen data showing disadvantaged communities (OEHHA 2019a). The top right inset provides a detailed view of the San Francisco Bay Area, while the lower left inset details the Los Angeles region.

Indoor air can also be contaminated with 1,4-dioxane through vapor intrusion from contaminated soil, representing additional 1,4-dioxane exposures in addition to those discussed above. Although Brenner (2010) did not find clear evidence that vapor intrusion is a major contributor to 1,4-dioxane in indoor air, it cannot be conclusively ruled out as a significant source in certain cases. Many factors can affect the magnitude of vapor intrusion or even whether vapor intrusion is an issue, including depth and concentration of the contaminant underlying the ground surface, soil structure, building structure, and preferential pathways (U.S. EPA 2015a). Table 25 in [Appendix E: Indicators of Exposure Data](#) Tables presents the most recent 1,4-dioxane levels in soil gas measured at contaminated sites documented in GeoTracker (State Water Board 2020a).

## 4. POTENTIAL FOR SIGNIFICANT OR WIDESPREAD ADVERSE IMPACTS

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

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

1,4-Dioxane is a persistent, mobile carcinogen. It is resistant to degradation, can spread quickly in water and soil, and cannot be removed by standard wastewater or drinking water treatments. All of this allows 1,4-dioxane to accumulate in surface water and groundwater. The discharge of 1,4-dioxane found in personal care and cleaning products represents a threat to public health, a burden to wastewater treatment facilities, and an impediment to direct reuse of water. The most efficient method to reduce the concentration of 1,4-dioxane and other persistent, mobile chemicals in water is to eliminate the source (Reemtsma and Berger 2019).

### **Adverse Impacts linked to the Candidate Chemical's Hazard Traits**

*Reference: California Code of Regulations, Title 22, section 69503.3(a).*

*The SCP regulations direct the Department to evaluate the potential for the Candidate Chemical to contribute to or cause adverse impacts by considering several adverse impact factors for which information is reasonably available.*

As described in section 3, 1,4-dioxane is a carcinogen according to various authoritative bodies (IARC 1999a; U.S. EPA 2013a; NTP 2021; OEHHA 2021). The carcinogenic potential of 1,4-dioxane has been demonstrated across multiple species of laboratory animals (IARC 1999; ATSDR 2012; U.S. EPA 2019). The chemical induces multiple tumor types, affecting specific organs and metabolic pathways shared between lab animals and humans, raising the possibility that the mechanisms of carcinogenicity may

be applicable to humans. 1,4-Dioxane also has demonstrated toxic effects in humans, notably affecting the liver, kidney, respiratory tract, and eye (OEHHA 2000; ATSDR 2012). However, its carcinogenicity is the toxicological hazard that requires the greatest margin of safety.

When aggregate exposures from product use, drinking water, air emissions, and occupational exposures are taken into account, the resulting exposures may be high enough for concern. This may be particularly true for sensitive subpopulations. Foremost among these are workers in industries where 1,4-dioxane is used as a solvent; these workers face “unreasonable risk” based on U.S. EPA criteria (U.S. EPA 2020a). Other categories of workers, such as janitors and hair stylists or shampooers, may also be exposed to concerning levels of 1,4-dioxane from consistent use of contaminated products.

Furthermore, UCMR3 data reveal that drinking water in 10 counties, representing about half of California’s population, had 1,4-dioxane detections above U.S. EPA’s reference concentration of 0.35 µg/L. The UCMR3 data reflect the concentration of 1,4-dioxane in water at a specific point in time and do not provide information about the frequency or duration of the exceedances, nor the exact number of people impacted, but the data demonstrate that the presence of 1,4-dioxane in drinking water is widespread. In areas where drinking water contamination is already at or above levels of concern, any additional exposures to 1,4-dioxane further exacerbate the risk of adverse impacts. People living in areas designated as disadvantaged communities by CalEnviroScreen (Figure 7) are more vulnerable to adverse health impacts because of cumulative exposures to pollutants and other health-based factors. Figure 8 demonstrates that many of these communities have drinking water with 1,4-dioxane levels above U.S. EPA’s reference concentration.

In addition to its toxicological hazard traits, 1,4-dioxane has two traits that increase the likelihood, level, and duration of exposure: persistence and mobility. 1,4-Dioxane does not readily break down in surface water, ground water, or soil, nor during typical water treatment processes. Its persistence, coupled with its mobility, ensure that 1,4-dioxane continues to circulate in the environment long after its release (Reemtsma et al. 2016; Reemtsma and Berger 2019) and remains a concern for drinking water (Doherty et al. 2023).

## Populations that May Be Adversely Impacted

*Reference: California Code of Regulations, Title 22, sections 69503.3(a)(1)(F) and 69503.3(a)(2).*

*This section identifies specific populations of humans and environmental organisms that may be harmed if exposed to the Candidate Chemical in the product. Sensitive subpopulations, environmentally sensitive habitats, endangered and threatened species, and impaired environments in California have special consideration, as they may be more vulnerable.*



## ***General Population***

1,4-Dioxane has been detected in many personal care and cleaning products that are widely used in California. Most of the 1,4-dioxane present in these products enters municipal wastewater after the product is used. People are exposed to 1,4-dioxane from consumer products by multiple pathways – both directly, when they use products that contain 1,4-dioxane, and indirectly, when they drink water that has been contaminated by consumer products via domestic wastewater (Dawson et al. 2022). In particular, estimates of exposure to 1,4-dioxane from product use, indicated in Table 7, can exceed OEHHA’s NSRL, suggesting that product use alone may contribute to adverse impacts. When considered along with indirect exposure from drinking water, personal care and cleaning products have the potential to expose Californians to 1,4-dioxane at levels that may result in widespread adverse impacts.

## ***Infants and Children***

Infants and children constitute a sensitive subpopulation that may be more vulnerable to exposures to 1,4-dioxane. Early life exposure to carcinogens, including both mitogens and mutagens, may have more significant long-term health implications than exposure to the same chemicals later in life (OEHHA 2009). Cancer is a multi-step disease process, so early exposure to a carcinogen may start the progression toward the disease at an earlier age. In addition, the dynamic processes of growth and development create a greater opportunity for DNA damage and other changes that can be replicated during subsequent cell divisions (OEHHA 2009). Lastly, children’s physiological systems are different than those of adults in regards to immunological responses for eliminating damaged cells and in regards to the metabolism or transport of a toxicant, which may result in a greater internal dose or in different metabolites (OEHHA 2009). 1,4-Dioxane has been detected in children’s and babies’ personal care products. Due to their higher ratio of skin surface area to body weight (U.S. EPA 2011a), children with the same dermal absorption of 1,4-dioxane will have a higher body weight-normalized dose than adults. Additionally, the skin structure of infants and children may allow 1,4-dioxane to diffuse more easily into the body than in adults, exacerbating 1,4-dioxane exposures. Further complicating the issue of children’s exposure, their product-use patterns differ from those of adults.

## ***Populations that May Experience Higher Exposures to 1,4-Dioxane***

Some groups may experience higher aggregate 1,4-dioxane exposures than the general population due to their product use. They include individuals who use products with higher 1,4-dioxane concentrations and those who use personal care and cleaning products more frequently. Product use could also contribute to high aggregate exposures to 1,4-dioxane for subpopulations that drink water with elevated 1,4-dioxane levels, live near a 1,4-dioxane emission source, or work with 1,4-dioxane as a



solvent. Indeed, workers in industries that use 1,4-dioxane as a solvent are a sensitive subpopulation that U.S. EPA considers to be at “unreasonable risk” from exposure (U.S. EPA 2020a).

As noted in Section 4 above, several types of personal care and cleaning products contain concentrations of 1,4-dioxane above 1 ppm. Products with especially high levels may include imported products, industrial and institutional cleaning products, and products marketed toward specific cultural subpopulations. For example, in 2020 we conducted two studies of 1,4-dioxane in personal care and cleaning products and found significantly higher concentrations in those marketed to the Latinx community. Specifically, the median for all products tested in one study was 1.14 ppm, with a maximum concentration of 132 ppm in laundry detergent and 111 ppm in hand soap. Our second study, which featured products marketed to the Latinx community, found concentrations in personal care products as high as 225 ppm. These data provide evidence that specific cultural subpopulations may experience higher exposures to 1,4-dioxane (Grant 2022). Additionally, while exposure data are limited, there is potential for disproportionate adverse effects on tribal communities whose cultural and subsistence practices may lead to increased contact with contaminated environmental media. People who use products containing high concentrations of 1,4-dioxane experience higher exposures during use, which contributes to aggregate exposures and associated adverse impacts.

The risk of exposure to 1,4-dioxane faced by workers who use personal care and cleaning products as an integral part of their job is largely unstudied but remains a concern, even if these products are contaminated with relatively low levels of 1,4-dioxane. People who use these products on the job for an extended period of time are likely exposed to higher levels of 1,4-dioxane than nonoccupational users. These exposures may be amplified if nearby coworkers are also using 1,4-dioxane-containing products that may volatilize into the room. These workers also experience the same exposures to 1,4-dioxane as the general population, in addition to their occupational exposures.

Drinking water is another key source contributing to aggregate exposure to 1,4-dioxane for many sensitive subpopulations across California, yet data are lacking for many drinking water sources across the state. This is particularly true for smaller drinking water systems that are not subject to UCMR3 requirements. As noted earlier, 1,4-dioxane has been measured in drinking water above U.S. EPA’s reference concentration of 0.35 µg/L in 10 California counties (U.S. EPA 2017a). The population of these 10 counties represents about half of the state’s population. Additionally, 1,4-dioxane concentrations were even higher in drinking water samples collected by the State Water Board in five populous California counties (Los Angeles, Orange, Monterey, San Diego, and Santa Barbara) – above the State Water Board’s NL (1 µg/L) (Table 10). More data on the presence of 1,4-dioxane in Californians’ drinking water would provide a more comprehensive understanding of how much of the population is at risk of higher exposures to the chemical from this source, in addition to exposures anticipated from product use. Other people may experience elevated inhalation exposures to

1,4-dioxane on top of their exposures from drinking water – those who live close to landfills, farmland, wastewater treatment plants, or surfactant manufacturers and other industrial facilities that use 1,4-dioxane.

### ***People with Compromised Liver Function***

Differences in physiology may make some people more vulnerable to adverse impacts from 1,4-dioxane, and in some cases those physiological conditions or diseases may be disproportionately found in disadvantaged communities as defined by CalEnviroScreen. From a hazard perspective, perhaps the most sensitive sub-population is people with compromised liver function. Some of the risk factors for liver disease may be overrepresented in impacted communities. Diseases such as hepatitis and nonalcoholic fatty liver disease (NAFLD) can damage the liver (Li, Zhang and Zhan 2018). Risk factors for NAFLD and hepatocellular carcinoma include obesity and/or consumption of a high-fat diet (ASCO 2012; Karin and Dhar 2016; Li, Zhang and Zhan 2018; NIDDK 2021). In addition, exposures to over-the-counter medications, pharmaceuticals, alcohol, and toxicants from other consumer products can result in hepatocyte injury and inflammation (Mayo Clinic 2021). The cumulative effect of these exposures could prime the liver for other toxic effects (Callahan and Sexton 2007), including cell death from 1,4-dioxane.

People metabolizing high loads of other toxicants may experience a greater internal dose of 1,4-dioxane because of competition for the enzymes needed for detoxification of these substances. Rats given both anesthesia and 1,4-dioxane took about twice as long to recover from anesthesia as rats that were not coexposed (Pilipyuk et al. 1977). This indicates that the detoxification pathways that eliminate 1,4-dioxane may become saturated by other compounds, allowing 1,4-dioxane to persist in the body for a longer period. If so, people with an overall higher body burden of pollutants may be at greater risk of experiencing toxicological impacts from 1,4-dioxane.

### **Adverse Waste and End-of-Life Effects**

*Reference: California Code of Regulations, Title 22, sections 69503.2(b)(1)(B) and 69501.1 (a)(8).*

SCP's framework regulations require us to consider end-of-life impacts, and any special handling needed to mitigate them, when prioritizing product-chemical combinations for regulation. End-of-life impacts are particularly important for 1,4-dioxane, which is a persistent and mobile carcinogen widespread in personal care and cleaning products. These products contribute to a low but constant flux of 1,4-dioxane to wastewater when they eventually go down the drain (Dawson et al. 2022). Special handling is required to remove 1,4-dioxane during wastewater treatment; insufficient removal can result in direct releases to drinking water sources (see section 4 [Potential for Significant or Widespread Adverse](#) Impacts). These releases may threaten California's ability to increase recycled

water generation as part of an overall plan to supply safe and clean drinking water, which is a priority for the state (CDWR 2020).

The importance of California's water recycling efforts is underscored by the growing global recognition that recycled water is a critical facet of sustainable water management, particularly in regions where water is scarce (Lazarova et al. 2001; Asano 2002; Miller 2006; Tortajada 2020). Recycled water generated from wastewater effluent is an essential component of California's water resources. To secure this resource, the State Water Board's Water Quality Control Policy for Recycled Water includes goals to increase recycled water use from 714,000 acre-feet per year (afy) in 2015 to 1.5 million afy in 2020 and 2.5 million afy in 2030 (State Water Board 2019d). Meeting these goals will rely on the continued ability to use wastewater effluent to generate recycled water that can be efficiently treated and used for drinking water sources and other purposes.

### ***Contribution of 1,4-Dioxane from Personal Care and Cleaning Products to Wastewater***

The impact of down-the-drain personal care and cleaning products on 1,4-dioxane concentrations in wastewater can be significant (Dawson et al. 2022), despite declines in its concentration in consumer products over the last few decades.

#### **Estimates of 1,4-dioxane from personal care and cleaning products to wastewater influent**

To estimate the down-the-drain contribution of personal care and cleaning products to 1,4-dioxane levels in wastewater influent, four data elements are required per product type:

1. The concentration of 1,4-dioxane in the product.
2. The frequency of the activity that uses the product (e.g., running a load of laundry or taking a shower).
3. The volume of water used for that activity.
4. The amount of product typically used for that activity.

Section 3 ([Presence of the Candidate Chemical in Products](#)) covered the first data element, and several resources were used to estimate the remaining three data elements. Data for these elements were available for only three product types – laundry detergent, shampoo, and body wash. These data are outlined in Table 13.

Table 13. Volume and frequency estimates for product use and activity for laundry detergent (Sanderson et al. 2006; U.S. EPA 2008; Alliance for Water Efficiency 2019a), shampoo (U.S. EPA 2011a; Daily Infographic 2015; Alliance for Water Efficiency 2019b), and body wash (U.S. EPA 2011a; Daily Infographic 2015; Alliance for Water Efficiency 2019b).

Product Type (Activity)	Product Used per Activity (g)	Water Used Per Activity (L)	Number of Times Performed per Person Per Year
Laundry detergent (load of residential laundry)	98.5 [a]	189 [b]	100 [c]
Shampoo (shower) [d]	13.1 [e]	65 [f]	312 [g]
Body wash (shower) [d]	15.5 [h]	65 [f]	312 [g]

[a] These data come Sanderson et al. (2006), Table 2, Product Amount Used per Use in North America. Table cites range of 76-121 g laundry detergent per use; 98.5 g reflects the median.

[b] These data are based on an average of 50 gallons (189 L) used per laundry cycle for a traditional washing machine in the United States (U.S. EPA 2008).

[c] The Alliance for Water Efficiency estimates that an average U.S. household runs >300 loads per year (Alliance for Water Efficiency 2019a). The average size of a California household is 2.96 people (U.S. Census Bureau 2019), which we rounded up to 3 to estimate use per person.

[d] It is much more common for Americans to shower than to take a bath (Daily Infographic 2015). We assumed all bathing was done via shower and did not account for baths in this estimation.

[e] The EPA Exposure Factors Handbook, Chapter 17 (U.S. EPA 2011a) estimates shampoo use. The per use mean of 11.76 g applied 1.11 times per day equals 13.1 g per day. Original data come from Loretz et al. (2006).

[f] According to the Alliance for Water Efficiency, "The average American shower uses 17.2 gallons (65.1 liters) and lasts for 8.2 minutes at an average flow rate of 2.1 gallons per minute (gpm) (7.9 lpm)" (Alliance for Water Efficiency 2019b).

[g] In 2015, the average person in the United States took six showers per week (Daily Infographic 2015). Six showers times 52 weeks equals 312 showers per person per year.

[h] The EPA Exposure Factors Handbook, Chapter 17 (U.S. EPA 2011a) estimates body wash use. The per use mean of 11.3 g applied 1.37 times per day equals 15.5 g. Original data from Loretz et al. (2006).

We calculated the diluted down-the-drain concentration in  $\mu\text{g/L}$  of 1,4-dioxane in water used for an activity ( $C_a$ ) using the following equation and information outlined in Table 4 and in Table 13:

$$C_a = \frac{C_p \times m_{pa}}{V_a}$$

where  $C_p$  is the concentration of 1,4-dioxane in the product (1 ppm = 1  $\mu\text{g/g}$ , Table 4),  $m_{pa}$  is the mass (g) of product used during a given activity (Table 13), and  $V_a$  is the total volume (L) of water used for a

given activity (Table 13). Table 14 shows the results of this calculation using the maximum and mean values from Table 4. Additionally, Table 14 shows the results of this calculation if all products were assumed to have a 1,4-dioxane concentration of 1 ppm, given the proposed Alternatives Analysis Threshold value of 1 ppm.

*Table 14. Down-the-drain concentrations of 1,4-dioxane in water for a given activity ( $C_o$ ,  $\mu\text{g/L}$ ) resulting from the use of different products. Each column shows the results of the calculation for three product concentration scenarios: the data set max, data set mean, and 1 ppm.*

Product Type (Activity)	Symbol	$C_p = \text{Max}$	$C_p = \text{Mean}$	$C_p = 1 \text{ ppm}$
Laundry detergent (Load of residential laundry)	$C_{lw}$	7.30	2.40	0.52
Shampoo + body wash (shower)	$C_{sw}$	9.44	1.39	0.44
Shampoo only (shower)		1.10	0.33	0.20
Body wash only (shower)		8.34	1.06	0.24

To understand the overall contribution of the use of these products to 1,4-dioxane concentrations detected in wastewater influent, we need to know how much of the total wastewater influent comes from each of these activities. To learn this, we used available data from three water reclamation plants (WRPs) on population served and volume of residential water processed per day (millions of gallons per day (MGD)). These three plants are all in Southern California and all generate recycled water (Table 15): Whittier Narrows Water Reclamation Plant (WN WRP) (LACSD 2019a; LACSD 2019c), Orange County Sanitation District (OCSD) (OCSD 2013; OCSD 2019), and San Jose Creek Water Reclamation Plant (SJC WRP) (LACSD 2019b; LACSD 2019c). Using the population served (Table 15), the rate of frequency of activity per person (Table 13), and the water use per activity (Table 13), we can estimate the percentage of the total wastewater influent volume due to showering and laundering. These estimates are reasonably aligned with residential water use estimates for showering and laundering cited by The American Water Works Association (AWWA) Research Foundation (Mayer et al. 1998).

Table 15. Data and estimates for three water reclamation plants in Southern California (OCSD 2013; LACSD 2019a; LACSD 2019b; OCSD 2019; LACSD 2019c) and comparison to estimates from the AWWA Research Foundation (Mayer et al. 1998). The DTSC estimates represent averages across the WRPs weighted by population served.

Parameter	WN WRP	OCSD	SJC WRP	DTSC Estimate	AWWA Estimate
Population served	150,000	2,600,000	1,000,000	–	–
Million gallons of residential water processed per day	7.8 [a]	176 [b]	58.4 [c]	–	–
Estimated % influent water from laundering	26.2 [d]	20.2 [d]	23.4 [d]	21.3 [e]	21.7 [f]
Estimated % influent water from showering	28.1 [d]	21.7 [d]	25.2 [d]	22.9 [e]	16.8 [f]

[a] WN WRP 2017 influent flow is reported as 9.26 MGD (LACSD 2019a), with 15.4% reported to be industrial. The remaining 84.6% (7.83 MGD) is estimated to be the residential component.

[b] In Part II on page 5.2 (pdf p. 4), the domestic contribution is computed as “88% of the average combined influent flow of 200 MGD” in Table 5.1. (i.e., 176 MGD) (OCSD 2013).

[c] There are two SJC WRPs. Influent flow at SJC-East WRP was 39.81 MGD, with 10.5% being industrial (Sanitation Districts of Los Angeles County (LACSD): 2018 Pretreatment Program Annual Report, Table 1-1 on pdf pg 17 (LACSD 2019c)). We estimate the remaining 89.5% (35.63 MGD) to be residential. Influent flow at SJC-West WRP 2017 was 23.53 MGD, with 3.4% being industrial. We estimate the remaining 96.6% (22.73 MGD) to be residential. Therefore, the total SJC WRP influent residential flow is estimated to be 58.36 MGD (35.63 + 22.73).

[d] Estimates were made using the “Water used per activity” (in millions of gallons (MG)) and “Number of times activity performed per year” values in Table 13 combined with other values in this table. For example:

*MG influent water used to shower*

$$= \frac{L \text{ water use}}{1 \text{ shower}} \times \frac{\# \text{ showers}}{\text{person} \times \text{year}} \times \frac{\text{population served}}{WWTP} \times \frac{1 \text{ MG}}{3785411.78 \text{ L}}$$

$$\% \text{ influent water from a given activity} = \frac{MG \text{ water used to shower}}{MG \text{ total water processed}}$$

[e] To estimate the percentage of influent (%infl.) as a weighted average of population served (pop.srvd) for each treatment facility:

*DTSC Estimate*

$$= \frac{(\text{pop. srvd}_{WN \text{ WRP}} \times \% \text{infl.}_{WN \text{ WRP}}) + (\text{pop. srvd}_{OCSD} \times \% \text{infl.}_{OCSD}) + (\text{pop. srvd}_{SJC \text{ WRP}} \times \% \text{infl.}_{SJC \text{ WRP}})}{\text{pop. srvd}_{WN \text{ WRP}} + \text{pop. srvd}_{OCSD} + \text{pop. srvd}_{SJC \text{ WRP}}}$$

[f] (Mayer et al. 1998) Figure 5.5 pg 87.

Using these percentage volume estimates, the total 1,4-dioxane concentration of influent water ( $C_{wwtp}$ ) can be characterized by the sum of laundry, shower, and other water inputs:

$$C_{wwtp} = f_{lw}(C_{lw}) + f_{sw}(C_{sw}) + f_{ow}(C_{ow})$$

where the fractions of influent from laundering ( $f_{lw}$ , 0.213) and showering ( $f_{sw}$ , 0.229) combine with the remaining influent water from other residential water use ( $f_{ow}$ , 0.56) to make up the total residential wastewater processed by the water reclamation plant. Multiplying the fractions ( $f_{lw}$ ,  $f_{sw}$ ) by their respective down-the-drain concentration estimates ( $C_{lw}$ ,  $C_{sw}$ , Table 14), we can estimate the contribution of 1,4-dioxane from laundry detergent, body wash, and shampoo to the overall wastewater influent (Table 16). This is likely an underestimate of the contribution from all personal care and cleaning products because only three product types were used in this calculation and because industrial and institutional (I&I) products were not considered.

*Table 16. Estimated contribution of 1,4-dioxane to wastewater influent resulting from product use, assuming three different concentrations of 1,4-dioxane in products ( $C_p$ , ug/L).*

Influent Contribution Source	$C_p = \text{Max}$	$C_p = \text{Mean}$	$C_p = 1 \text{ ppm}$
Laundry water influent, $f_{lw}(C_{lw})$	1.55	0.51	0.11
Shower water influent, $f_{sw}(C_{sw})$	2.16	0.32	0.10
Contribution due to total product use	3.71	0.83	0.21

To understand how much the use of these products contributes to the total amount of 1,4-dioxane found in wastewater, we can compare these estimated values to measured values of 1,4-dioxane in wastewater influent ( $C_{wwtp}$ ). The Los Angeles County Sanitation Districts have indicated that 1,4-dioxane is consistently present in influent to its WRPs at concentrations around 1  $\mu\text{g/L}$  (Heil 2019; O’Keefe 2019). Simonich et al. (2013) have similarly reported an average consistent concentration of 1  $\mu\text{g/L}$  1,4-dioxane in wastewater effluent across the country. Taken together these findings indicate a widespread residential source of 1,4-dioxane across the nation.

The mean contribution of 1,4-dioxane from the use of laundry detergent, shampoo, and body wash calculated above (0.83  $\mu\text{g/L}$ ) (Table 16) suggests that personal care and cleaning products may be responsible for a large portion of this input. This finding is supported by the findings by Dawson et al. (2022) that down-the-drain personal care and cleaning products represent a significant addition of 1,4-dioxane to municipal wastewater effluent. Additionally, recent data from residential septic tanks



indicate similar concentrations of 1,4-dioxane in septic tank effluent (mean 1.49 µg/L), and research attributes household products as the dominant source (Lee et al. 2021).

Standard wastewater treatment processes are unable to remove 1,4-dioxane (Doherty et al. 2023), as shown by LACSD influent and effluent data (Heil 2019). As a result, the influent concentration of 1,4-dioxane is often approximately equal to the effluent concentration from the same WRP, absent additional, specialized treatment. Effluent may be subject to the State Water Board NL of 1 µg/L, depending on how it will be used (see the [Recycled Water](#) section below). WRPs may need to install costly treatment processes if their effluent concentrations are not below 1 µg/L, and optimally below U.S. EPA's reference concentration of 0.35 µg/L (U.S. EPA 2013a).

Based on the estimates above in Table 15 and their alignment with WRP influent data, it appears that the mean concentration of 1,4-dioxane in laundry detergent, shampoo, and body wash of approximately 4.5 ppm (Table 4) places a burden on WRPs that approaches the NL.

Table 16 also presents the estimated contribution from personal care and cleaning products under a hypothetical scenario in which manufacturers reduce the 1,4-dioxane concentration in all three of these product types to 1 ppm. In this scenario, the 1,4-dioxane burden on WRPs from personal care and cleaning product use could be reduced by 75%, to below both the State Water Board NL and the U.S. EPA health reference concentration. This could also reduce the need for WRPs to install additional costly treatment equipment specifically designed to mitigate 1,4-dioxane.

## Uncertainty

Uncertainties associated with the above estimates come primarily from 1,4-dioxane concentrations in products and from product-use patterns. Product use patterns, such as the frequency of showering or doing laundry and the amount of product used per shower or laundry load, vary widely across the population (e.g., by gender and age group). Other factors may also influence the water-to-product ratio, such as the use of a high-efficiency versus standard washing machine or a standard versus low-flow showerhead. While the water usage data may not be aligned with current water use rates, it was the best available information at the time these calculations were made.

Although the U.S. EPA Exposure Factors Handbook concluded that, “very little information is available about the exact way the different kinds of products are used by consumers” (U.S. EPA 2011a), we have used the most reliable and readily available data to estimate product-use patterns. A full probability distribution model could capture the variability of product use but was outside the scope of this effort. Also, 1,4-dioxane concentrations in products vary widely, and there is uncertainty inherent in using a small sample data set (~200 products) to represent a very large set of products that potentially contain 1,4-dioxane (>30,000 products, see the [Market Presence and Trends](#) section). Additionally, we did not



consider I&I products in our estimates, nor are they represented in the 1,4-dioxane product concentration sampling data set. This likely leads to an overall underestimate of the contribution that personal care and cleaning products have made to 1,4-dioxane levels in wastewater influent.

Data were available for the frequency of use (Weegels and van Veen 2001; RIVM 2018; Porras et al. 2020), volume of water used (Stamminger et al. 2007; Berkholz, Kobersky and Stamminger 2013; Porras et al. 2020), amount of product used (Weegels and van Veen 2001; Stamminger et al. 2007; Ramirez-Martinez et al. 2014; RIVM 2018; Porras et al. 2020), and 1,4-dioxane concentration in manual dishwashing detergent (Citizens Campaign for the Environment 2019). However, the reported data were highly variable, particularly when compared to the other products used in this calculation. Estimations describing product use may vary based on access to an automatic dishwasher (Weegels and van Veen 2001; Porras et al. 2020), package opening dimensions (Weegels and van Veen 2001), and even uses of dishwashing detergent for other purposes (Weegels and van Veen 2001; Schneider et al. 2019). Additionally, much of the available data on dishwashing detergent are not focused on product use within the United States. As a result, the product-use estimates for dishwashing detergent were not included in this assessment, despite their availability.

## ***Wastewater and Water Treatment Challenges and Impact on Agencies***

### **Removal Technologies**

The presence of 1,4-dioxane in wastewater, recycled water, and drinking water is of particular concern because most conventional wastewater and drinking water treatment practices do not remove the chemical (Doherty et al. 2023). 1,4-Dioxane's small molecular size, high water solubility, low partition coefficients (i.e.,  $K_{ow}$  and  $K_{oc}$ ), and low biodegradability prevent it from being appreciably removed via conventional treatment, which often relies on physical treatment through adsorption and filtration or biodegradation (Mohr 2010). In addition, many advanced treatments such as reverse osmosis have variable efficacy and may be largely ineffective (Bell et al. 2019; Doherty et al. 2023), while others such as granular activated carbon (GAC) have only limited efficacy (Mohr 2010 Chapter 7; Bell et al. 2019).

It is possible for water treatment facilities to break down 1,4-dioxane by employing advanced oxidation processes (AOPs) that utilize ultraviolet light (UV) and hydrogen peroxide to generate hydroxyl radicals (Mohr 2010). In California, AOPs have proven effective in reducing 1,4-dioxane concentrations in wastewater (Kawamoto 2019; O'Keefe 2019). An AOP system can be demonstrated to be functioning properly if it accomplishes a 0.5 log(n) removal (around 69%) of 1,4-dioxane (California Code of Regulations, Title 22, section 60320.201). However, facilities that add AOPs incur significant costs, including capital investment and operation and maintenance (e.g., chemical costs and high energy costs for UV) (OCWD and OCSD 2018; O'Keefe 2019). The types of facilities most likely to add this

treatment are advanced wastewater facilities that generate recycled water, which could use AOPs to meet 1,4-dioxane regulatory requirements for both potable reuse and groundwater recharge.

In January 2019, the State Water Board requested that OEHHA establish a Public Health Goal (PHG) for 1,4-dioxane (State Water Board 2019e) as a first step in setting a maximum contaminant level (MCL) for California. If California adopts an MCL for 1,4-dioxane, all drinking water systems throughout the state may have to develop monitoring plans for the chemical to ensure compliance (California Code of Regulations, Title 22, sections 60320.312(a) and 64445). Plants found in violation of the 1,4-dioxane MCL would be required to alert the State Water Board about these exceedances and take all required actions as directed by the regulations (California Code of Regulations, Title 22, section 64445.1). These required actions could include the installation of costly advanced treatment processes (California Code of Regulations, Title 22, section 64445).

Without source reduction, many if not most public water systems in California could be required to add AOPs to remove 1,4-dioxane from drinking water in order to comply with an MCL, and the costs would be significant. For example, large groundwater treatment projects in Southern California that incorporated AOPs incurred capital costs between \$8.3 and \$36 million each, in addition to high operation and maintenance costs (O’Keefe 2019). Similarly, the state of New York has estimated that installation of a single treatment system to remove 1,4-dioxane, such as an AOP, would require \$3.57 million in capital costs and \$150,000 in annual operations and maintenance costs (NYDH 2020).

We calculated that only about five percent of California’s 7,898 public water systems voluntarily monitor drinking water for 1,4-dioxane and report results to the State Water Board (State Water Board 2019b; State Water Board 2020b). DDW reported that 57 of these reporting facilities had 1,4-dioxane concentrations above the NL of 1 µg/L (O’Keefe 2019). Similarly, U.S. EPA’s UCMR3 assessment covered approximately six percent of California’s public water systems and found 73 systems with detections above U.S. EPA’s reference concentration of 0.35 µg/L; 33 of those had detections above 1 the NL of µg/L (U.S. EPA 2017a). These counts almost certainly underrepresent the number of water systems in California that would need to install AOP treatment equipment if California were to adopt an MCL.

The available testing data likely does not reflect the extent of 1,4-dioxane contamination in drinking water systems across the state, particularly in private and smaller systems. The State Water Board estimates that more than 90% of California’s public water systems are small systems<sup>12</sup> (State Water

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<sup>12</sup> A small public water system has more than 5 and less than 14 service connections and does not regularly supply drinking water to a daily average of more than 25 people for more than 60 days in a year (Health and Safety Code, Section 116275).

Board 2019a). Data gaps make it difficult to estimate the number of AOPs that would need to be installed, and emphasize the fact that mitigating 1,4-dioxane contamination in drinking water would most certainly impose significant cost burdens on California’s water treatment agencies. Given the large proportion of small systems, widespread installation of advanced treatment for 1,4-dioxane would likely disproportionately impact smaller drinking water systems with limited resources for costly specialized treatment.

The State Water Board’s many remediation projects illustrate just how costly it is to reduce 1,4-dioxane contamination in drinking water sources (State Water Board 2020d). These projects have typically involved the construction of highly complex treatment systems tailored for each site based on a unique combination of factors, including the ultimate purpose of treatment (e.g., drinking water) and the quality and quantity of the influent. Construction costs ranged from \$8.3 million to \$36.9 million each (O’Keefe 2019). Once built, these treatment systems are also expensive to operate and maintain, because the two critical aspects of AOP treatment are UV generation, which involves high energy demand, and the use of costly chemicals (e.g., hydrogen peroxide) at amounts higher than those used in a typical potable reuse treatment system (O’Keefe 2019).

### **Unintended Byproducts**

While AOP has been useful in removing 1,4-dioxane from water as described above, there are concerns related to potentially toxic byproducts. When hydroxyl radicals are produced during the process of combining strong chemical oxidants (e.g., hydrogen peroxide) with UV (O’Keefe 2019; Venkatesan 2019), they react with 1,4-dioxane and other chemicals in the water and can generate unintended byproducts. These byproducts are relatively understudied, although research suggests some may be toxic (Li et al. 2018; Venkatesan 2019; Lee et al. 2020). As a result, treatment systems that employ AOP may need to install additional treatment steps, such as GAC, to remove these byproducts as well as any excess hydrogen peroxide (Toor and Mohseni 2007; O’Keefe 2019; Venkatesan 2019). Further complicating this process, excess hydroxyl radicals generated during AOP can impact the performance of the GAC filters (Venkatesan 2019).

Source control that reduces the concentration of 1,4-dioxane in wastewater flowing into treatment plants – one possible outcome of a Priority Product designation – would reduce the need for AOP and the costs associated with this additional treatment.

### ***1,4-Dioxane End-of-Life Impacts on Drinking Water and Recycled Water Generation***

The presence of 1,4-dioxane in wastewater may directly impact drinking water agencies’ ability to provide drinking water, and it can also impede water recycling agencies’ ability to generate recycled water that meets State Water Board requirements.

## Drinking Water

The State Water Board adopted its notification level (NL) of 1 µg/L based on *de minimis* risk and analytical constraints (State Water Board 2019e). The NL is not an enforceable standard and does not require monitoring for 1,4-dioxane in California drinking water systems. However, if the chemical is measured at a concentration above the NL, the drinking water system is required to notify the local agency's governing body and is encouraged to notify consumers (State Water Board 2020c). The State Water Board has also established a response level of 35 µg/L for 1,4-dioxane, which represents the point at which the State Water Board recommends that the source of the contaminated water be removed from service (State Water Board 2020c). While there is no 1,4-dioxane MCL for California, the State Water Board requested in January 2019 that OEHHA re-evaluate the public health goal (PHG) for 1,4-dioxane (State Water Board 2019c), the first step toward establishing an MCL. Any future MCL the State Water Board proposes for 1,4-dioxane would represent an enforceable regulatory standard. It would be set as close to the PHG as possible, considering technological and economic feasibility (State Water Board 2019e). If an MCL were set for 1,4-dioxane, drinking water agencies across the state could be forced to install costly treatment or to terminate service.

## Recycled Water

The State Water Board convened a Science Advisory Panel (Panel) in July 2017 to provide guidance on which chemicals should be monitored in recycled water (Drewes et al. 2018). The Panel identified indicator compounds that would represent a wide range of chemicals and provide certainty in the treatment process. As a part of this effort, the Panel reviewed concentration data for chemicals, including 1,4-dioxane, in samples of wastewater effluent collected at different points in the recycled water treatment process, as well as in final recycled water products. The review reported a 90th percentile concentration value of 7.16 µg/L for 1,4-dioxane, which was seven times higher than the Panel's established monitoring trigger level of 1 µg/L. Based on this value, the Panel recommended monitoring 1,4-dioxane as an indicator compound for recycled water (Drewes et al. 2018).

The State Water Board has adopted regulatory criteria for recycled water that is intended for groundwater replenishment or for augmentation of surface water reservoirs that are used as sources of drinking water (California Code of Regulations, Title 22, sections 60301 through 60355, 64668). Contaminant monitoring criteria are based on recommendations from the Panel. Water recycling agencies that generate water for surface water augmentation must test their effluent monthly and their final recycled water product quarterly for all contaminants with MCLs or NLs (California Code of Regulations, Title 22, sections 60320.302, subd. (h) and 60320.320, subd. (b)). Similarly, agencies generating recycled water for groundwater replenishment are required to monitor 1,4-dioxane concentrations quarterly in both recycled municipal water and groundwater (California Code of Regulations, Title 22, section 60320.120, subd. (b)). In both instances, if the NL is consistently

exceeded, the agency must stop using the recycled water. If the State Water Board were to adopt an MCL below 1 µg/L, or if the NL were lowered in the future, water recycling facilities may be unable to provide recycled water that meets the criteria for 1,4-dioxane.

A reduction in the availability of recycled water would have a particularly profound impact on Southern California, given the critical role it plays in meeting the region's water sustainability goals. The Orange County and Los Angeles County Sanitation Districts are two of the largest recycled water suppliers in the United States, generating a combined 180 million gallons per day (200,750 afy) of recycled water (DTSC 2019a). These agencies have expressed concern about their ability to consistently meet the 1,4-dioxane regulatory requirements for the recycled water they generate (DTSC 2019a).

While consumer products may not always be the dominant source of 1,4-dioxane to these facilities, they represent a constant and significant source that treatment plants are unable to address through industrial source control or pretreatment efforts (DTSC 2019a; Heil 2019; Kawamoto 2019). These and other recycled water producers may have to invest significant resources to upgrade their treatment processes to keep 1,4-dioxane at acceptable levels and ensure the continued viability of using recycled water to help meet customers demand (Heil 2019).

## 5. OTHER REGULATORY PROGRAMS

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

We have assessed all applicable state and federal laws and regulations as well as all international treaties or agreements that have the force of domestic law related to personal care and cleaning products or to 1,4-dioxane in those products. We have determined that these programs do not overlap or conflict with this proposal to list personal care and cleaning products containing 1,4-dioxane as a Priority Product, nor do they overlap or conflict with any subsequent regulation that may result from such listing.

### Presence in Products

U.S. EPA has updated its evaluation of 1,4-dioxane after reevaluating its initial determination. In December 2016, U.S. EPA listed 10 chemicals, including 1,4-dioxane, for initial risk evaluation under the newly amended Toxic Substances Control Act (TSCA, U.S. EPA 2016b). Risk evaluations are intended to assess the hazards of and exposure to a chemical during various use scenarios. If the agency determines that a scenario poses unreasonable risk, the evaluation provides the basis for U.S. EPA to "propose actions to address those risks" (U.S. EPA 2019b; U.S. EPA 2020a). While its May 2018 problem formulation for 1,4-dioxane indicated that the presence of the chemical as a contaminant in consumer products would not be considered (U.S. EPA 2017b; U.S. EPA 2018d), U.S. EPA's 2020 Draft

Supplemental Analysis to the Draft Risk Evaluation for 1,4-Dioxane expanded the scope such that it included certain cleaning products (surface cleaners, dish soap, dishwasher detergent, and laundry detergent). In that report, U.S. EPA determined there was no unreasonable risk due to the presence of 1,4-dioxane in those products (U.S. EPA 2020c). U.S. EPA released the Final Risk Evaluation for 1,4-Dioxane (U.S. EPA 2020a) confirming its finding of no unreasonable risk for the included cleaning products. However, in 2021, U.S. EPA announced plans to reopen the previous risk evaluation and its intent to revisit the findings and consider additional exposure pathways and conditions of use (U.S. EPA 2021). U.S. EPA's 2023 Draft Supplement to the Risk Evaluation of 1,4-Dioxane and revised TSCA Risk Determination for 1,4-Dioxane were released in July 2023, after we finished writing this Profile. U.S. EPA's updated evaluation does not change our overall conclusion about the potential for exposure and potential for significant and widespread adverse impacts associated with personal care and cleaning products containing 1,4-dioxane.

The Food and Drug Administration (FDA) Center for Food Safety and Applied Nutrition's Office of Cosmetics and Colors investigates the presence of chemicals such as 1,4-dioxane in cosmetics, which includes shampoos and other products applied to a person to "cleanse or beautify" (U.S. FDA 2018; Zhou 2019; U.S. FDA 2020). The FDA currently has no regulations governing the presence of 1,4-dioxane in personal care products but does encourage manufacturers to use vacuum stripping to reduce 1,4-dioxane concentrations (U.S. FDA 2019).

## Product Ingredient Disclosure

While there are no current California or federal regulations that restrict the presence of 1,4-dioxane in personal care and cleaning products, in California there are product ingredient disclosure requirements, either proposed or enacted, that may result in additional information about 1,4-dioxane being available to consumers.

California's Cleaning Products Right to Know Act (Lara 2017) applies to all cleaning products (household, institutional, commercial) and defines 1,4-dioxane as a nonfunctional constituent that is required to be included on the label if "it is present in the finished designated product at a concentration at or above 0.001% (10 ppm)" (Lara 2017). This legislation became effective for online disclosures on January 1, 2020, and went into effect for on-label disclosures on January 1, 2021 (Lara 2017).

1,4-Dioxane is also included on OEHHA's Proposition 65 list as a chemical known to the state to cause cancer (OEHHA 2021). As a result, manufacturers must determine whether their product contains 1,4-dioxane at levels that would result in exposure above the established NSRL of 30 µg/day to determine whether a warning label is required (OEHHA 2019b; OEHHA 2021). As of January 2023, 172 60-day notices related to 1,4-dioxane have been filed by third parties (California Attorney General

2023), with at least one settlement related to levels of 1,4-dioxane in laundry detergents (California Attorney General 2011).

## 6. ALTERNATIVES AND POTENTIAL 1,4-DIOXANE REDUCTION APPROACHES

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

*This section summarizes information available to DTSC regarding approaches to mitigate the presence of 1,4-dioxane in personal care and cleaning products and regarding alternatives that may or may not be safer than the Candidate Chemical. DTSC does not need to ensure that these alternatives are safer, and we may summarize their associated hazards to illustrate readily available information. The sections below may include information such as how readily available an alternative is, product functions addressed by the alternative, and implications for manufacturers using the alternative (e.g., use limitations, product reformulation, different equipment needs).*

### Mitigation Controls on Ethoxylated Ingredients

1,4-Dioxane is inadvertently generated during the synthesis of ethoxylated ingredients, and this is widely recognized as a problem (Black, Hurley and Havery 2001; Mohr 2010; Chemithon Corporation 2014). Decades of research have been dedicated to improving techniques for reducing and removing 1,4-dioxane from these ingredients (Chemithon Corporation 2014).

Ethoxylated ingredients are generally complex mixtures of the unethoxylated ingredient and the ethoxylated ingredient, where the ethoxylated ingredient is present at a varying range of ethylene oxide (EO) units. During ethoxylation, different catalysts are used to achieve different desired properties of ethoxylated ingredients by dictating the range and average degree of ethoxylation in the final mixture (Narasimhan 2017). The range of ethoxylation for an alcohol ethoxylate, for example, can be thought of as a bell curve distribution of these compounds from the free alcohol to a highly ethoxylated alcohol. The curve can be broad (e.g., EO units = 1-20) or narrow (e.g., EO units = 8-12), with the average EO describing the ethoxylated substrate at the peak of that distribution curve.

Different degrees of ethoxylation give surfactants different functional properties in products, and a narrow range in the number of EO units tends to best serve the desired function (Narasimhan 2017). Ingredients with a broader EO range and more impurities tend to be less expensive than ingredients where the distribution of EO units is much more controlled; the latter require advanced technology and removal processes to prevent or remove impurities.



The catalyst used in ethoxylation affects the amount of 1,4-dioxane that is inadvertently generated. Potassium hydroxide (KOH) is a basic catalyst used for conventional ethoxylation processes that produces broad-range, high-EO ethoxylates with relatively lower levels of 1,4-dioxane contamination (Narasimhan 2017).  $\text{BF}_3$  is an acidic catalyst commonly used to generate narrow-range ethoxylates; it creates acidic conditions that favor the inadvertent generation of 1,4-dioxane. The synthesis processes, catalysts, and other factors employed in ethoxylation are evolving and improving. Some manufacturers can now produce AEs with 1,4-dioxane at less than 1 ppm, although the chemistry behind these processes is confidential (Sasol North America Inc. 2009).

Alcohol ethoxysulfates (AESs), which are commonly found in shampoos, tend to have a low number of EO units (1 to 3) (HERA 2004; Cornwell 2018). By comparison, AEs in household products tend to have a higher degree and broader range of ethoxylation (EO between 3 and 12 units) and may have less 1,4-dioxane than AESs when synthesized using a conventional KOH catalyst (HERA 2009; Narasimhan 2017). However, AEs with a higher number of EO units are thought to be more susceptible to 1,4-dioxane generation if they are subsequently sulfated (Narasimhan 2017).

To minimize the formation of 1,4-dioxane during the sulfation of AEs, the mole ratio of  $\text{SO}_3$  gas to feedstock is of critical importance; 1,4-dioxane generation increases dramatically at mole ratios above 1.03 (Foster 1997). 1,4-Dioxane is thought to be formed during sulfation only when the ethoxylated alcohol being sulfated has three EOs or more (Chemithon Corporation 2014). The challenges involved in controlling 1,4-dioxane generation in an AES are fundamentally different from those in an AE (DTSC 2019b), and it is likely harder to reduce 1,4-dioxane in AESs to levels comparable to those possible for AEs, at least without additional removal processes. Temperature and pH, among other factors, influence 1,4-dioxane formation during synthesis of AESs and need to be monitored and controlled to reduce the amount generated. Advanced technologies currently appear able to produce AESs with 1,4-dioxane at less than 5 ppm (BASF 2020), though again with manufacturing processes that are confidential.

1,4-Dioxane can also be removed from ingredients via vacuum stripping, the efficacy of which depends on the amount of 1,4-dioxane initially present. A stripping method's efficacy can be described by its "dioxane reduction ratio" – the ratio of the 1,4-dioxane concentrations in the AES prior to and after stripping. 1,4-Dioxane reduction ratios are preferably at least 7:1, but some technologies boast the ability to reduce the chemical at ratios of 40:1 to as high as 100:1 after a single pass through a stripper/dryer system (Chemithon Corporation 2014). While stripping is commonly employed today in sulfonation/sulfation plants (Mohr 2010), manufacturers may not be able to reduce 1,4-dioxane to the desired level without sufficient controls on the chemistry prior to stripping. Surfactants can be run through a stripper/dryer system multiple times, but this option is time-consuming and costly.

The above reduction techniques generally involve approaches at the ingredient supplier level; thus, product manufacturers who do not plan to reformulate would need to work with their ethoxylated ingredient suppliers to reduce the introduction of 1,4-dioxane into their products.

## Unethoxylated Alternatives

Some product formulators have eliminated 1,4-dioxane by avoiding ethoxylated ingredients altogether (Wolf 2019). While unethoxylated alternatives exist, their limited availability and higher cost, the time required to reformulate, and consumer perception are barriers to product manufacturers' adoption of these alternative surfactants (DTSC 2019b). Current alternatives include, but are not limited to, alkyl sulfates and their salts (ASs), alkylpolyglucosides, acyl glycamides, sulfonates, and biosurfactants.

ASs are the unethoxylated versions of AESs. Together, ASs and AESs make up the most widely used surfactant classes in shampoos (Cornwell 2018). Sodium lauryl sulfate (SLS), which has a 12-carbon chain, is likely the most cost-effective AS and the most frequently used in personal care and cleaning products. A variety of other ASs alkyl chain lengths, organic derivatives, complex alkyl mixtures, and other salt counterions can also be used. Some examples of ASs are listed below:

- Sodium lauryl sulfate, also known as sodium dodecyl sulfate, dodecyl sulfate sodium salt, and SLS
- Sodium cocosulfate (this mixture is derived from coconut oil fatty acids and contains generally about 50% SLS)
- Ammonium lauryl sulfate
- Sodium cetyl sulfate

There has been growing concern regarding potential skin and eye irritation and drying effects of ASs, which has led to an increasing market of sulfate-free products (Cornwell 2018), including "SLS-free" compounds.

Alkylpolyglucosides and acyl glycamides may be possible substitutes for nonionic ethoxylated surfactants. While these compounds are touted as having reasonable foaming properties, they are weaker surfactants than AESs and may require additional ingredients to meet product performance requirements (Cornwell 2018).

Sulfonates, which include several subclasses, may be good alternatives to alkyl sulfates and alkyl ether sulfates, although it is unlikely that a single sulfonate on its own would perform as well. Some examples of sulfonates include taurates, sulfosuccinates (frequently found in baby shampoos), and isothionates (frequently found in bar soaps) (Cornwell 2018).

Biosurfactants are produced by microorganisms such as yeast, fungi, and bacteria from a variety of substrates, including plant biomass, sugars, vegetable oils, and waste materials (Makkar, Cameotra and Banat 2011; Vecino et al. 2017). They are split into subclasses based on chemical composition and molecular weight. Low molecular weight compounds, such as glycolipids, include rhamnolipids and sophorolipids; high molecular weight biosurfactants tend to be polymeric (Vecino et al. 2017). These compounds can serve many of the same functions as traditional surfactants and may have added benefits, including increased biodegradability, decreased toxicity and skin irritancy, and stability at high temperatures (Makkar, Cameotra and Banat 2011; Fracchia et al. 2014; Vecino et al. 2017). Despite potential benefits, widespread use in consumer products has been hampered by cost, limited supply, and the tendency for biosurfactants to be produced as mixtures rather than pure formulations (Syldatk and Hausmann 2010; Makkar, Cameotra and Banat 2011; Vecino et al. 2017).

While unethoxylated alternatives exist, the differences in their performance, cost, and availability might require product reformulation rather than a drop-in replacement in order to maintain the product performance or price point. The time and resources necessary to reformulate a product may make this option less attractive than finding cleaner sources of ingredients for use in existing formulations. Responsible entities may need to educate surfactant manufacturers about their need for more tightly controlled surfactant synthesis and/or improved removal processes.

## 7. ADDITIONAL CONSIDERATIONS

*This section summarizes other relevant information not captured under the adverse impact and exposure factors named in section 69503.3 of the Safer Consumer Products regulations.*

### Product Legislation in Other States

In December 2019, New York Governor Andrew Cuomo signed into law a bill significantly restricting the level of 1,4-dioxane allowed in personal care products, including shampoos and body washes, and household cleansing products (NY ENV Article 35 2020). Specifically, personal care and household cleansing products sold in New York may not contain 1,4-dioxane at concentrations above 2 ppm after December 31, 2022, and 1 ppm after December 31, 2023. The New York law also limits 1,4-dioxane levels in cosmetics to 10 ppm or less after December 31, 2022. The law also directs the New York State Department of Environmental Conservation to evaluate, every two years (starting no later than May 1, 2025), whether these thresholds should be lowered.

Additionally, the state of Oregon lists 1,4-dioxane as a high priority chemical of concern under its Toxic Free Kids Act (Oregon Secretary of State 2022). Manufacturers of children's products sold in Oregon must report products that contain 1,4-dioxane above a *de minimis* level of 100 ppm and, in these instances, ultimately remove 1,4-dioxane from the product or seek a waiver (Oregon 2023).

## Ethylene Oxide Concerns During Surfactant Manufacturing

Because the Safer Consumer Products Program was created as a result of California's Green Chemistry Initiative, the principles of green chemistry are at SCP's core. These principles consider the entire chemical life cycle and urge use of the least toxic, most efficient chemical reactions (Anastas and Warner 1998). Identifying the safest option from a group of potential chemical ingredients requires an evaluation of the impacts of the commercial synthesis of each chemical. In that light, ethylene oxide emerges as a reagent that should be scrutinized when evaluating ethoxylated surfactants' potential for adverse impacts.

Ethylene oxide (EtO) is an IARC Group 1 carcinogen and a known mutagen. U.S. EPA's 2016 reassessment of EtO revised its cancer potency estimate by a factor of 30. Some studies have questioned the accuracy of U.S. EPA's potency evaluation while affirming that EtO is a known class 1 carcinogen that causes multiple types of genotoxic insults due to its actions as an alkylating agent (IARC 2012; U.S. EPA 2016a). Specifically, U.S. EPA recognizes EtO as causing cancers of the lymphohematopoietic systems (leukemias and lymphomas) and, in females, breast cancer. In addition, chronic exposure is linked with neurological damage, developmental toxicity, and reproductive toxicity, including increased miscarriages and testicular degeneration (U.S. EPA 2018c).

EtO is a gas used as an intermediate for innumerable chemical processes, including production of ethoxylated surfactants, antifreeze, polyurethane foam, medicines, and solvents. EtO is also used to sterilize medical equipment and spices (IARC 2012). There has been recent concern in Illinois and Georgia over elevated cancer risks from emissions from sterilization facilities using EtO. However, sterilization facilities annually use just 0.05% of the EtO that is produced globally (IARC 2012) – far less than petrochemical facilities that produce and use EtO as an intermediate in chemical reactions (Saiyid 2019). The amount of EtO that is used to produce ethoxylated surfactants used in personal care and cleaning products is not readily available.

It is estimated that 90% of the cancer risk from air pollutants in the U.S. comes from just three chemicals – EtO, formaldehyde, and chloroprene (U.S. EPA 2018b; Lerner 2019). In 48 of the 50 census tracts with the highest cancer risk from air pollutants, the majority of the risk is from EtO (U.S. EPA 2014a; as reviewed in Lerner 2019). Most EtO is released by petrochemical plants; many of these are clustered along the Gulf Coast of Texas and Louisiana, in an area that is often referred to as "Cancer Alley" (Saiyid 2019). The residents in this area are generally people of color, and their average income is below the U.S. average. In addition, fourteen of the top 20 census tracts for air pollution-derived cancer risk are in this area. A census tract within St. John the Baptist Parish, Louisiana, has the highest air pollution cancer risk in the U.S. Its residents face a cancer risk of 1,505 per million – 15 times the U.S. EPA's threshold for concern (Lerner 2019). The average cancer risk across the U.S. from exposure

to air toxics is about 30 per million; U.S. EPA considers cancer risk concerning when it exceeds 100 per million (U.S. EPA 2018b). The elevated risk along the Gulf Coast is due in part to EtO, as well as other emissions from these petrochemical plants (Lerner 2019).

The impact of EtO emissions from petrochemical plants in California is less clear than in these areas along the Gulf Coast. In 2017, there were 15 California facilities that released between one and 411 pounds of EtO in 2017 (NEI 2017), while just one plant in Louisiana – the Union Carbide plant in St. Charles Parish – reported 15 tons of emissions in 2014 (Saiyid 2019).

Since EtO is a gas, exposure from consumer products is less of a concern than occupational exposure and exposures to those who live near emission sources, because any residual EtO remaining in consumer products would be expected to volatilize before the consumer could be exposed (U.S. EPA 2016a; Lerner 2019; Saiyid 2019). While the risk from EtO may be lower in California than on the Gulf Coast, a true green chemistry solution to reducing 1,4-dioxane should carefully evaluate the safety of the chemicals used to produce surfactants, including EtO.

## 8. CONCLUSIONS

DTSC has determined that personal care and cleaning products containing 1,4-dioxane meet the key prioritization criteria for listing a Priority Product (California Code of Regulations, Title 22, section 69503.2(a)):

- (1) There is potential public and/or aquatic, avian, or terrestrial animal or plant organism exposure to the Candidate Chemical(s) in the product; and
- (2) There is the potential for one or more exposures to contribute to or cause significant or widespread adverse impacts.

The use of personal care and cleaning products contaminated with 1,4-dioxane is widespread across California homes and workplaces, with most Californians using many of these products on a daily basis. This is particularly true for occupational uses of products contaminated with 1,4-dioxane. Californians can be exposed to 1,4-dioxane from personal care and cleaning products during product use or through the end-of-life contamination of environmental media, including drinking water and air. Exposure estimates and manufacturer-reported 1,4-dioxane concentrations in consumer products indicate that the use of products that contain 1,4-dioxane, including dishwashing detergents and shampoo, may result in exposures above OEHHA's No Significant Risk Level (NSRL). Additionally, available monitoring data indicate that 1,4-dioxane concentrations in drinking water in some parts of California exceed U.S. EPA and State Water Board health-based reference levels. These exposures are part of a larger aggregate exposure to 1,4-dioxane that some Californians experience, which has the potential to result in significant and widespread adverse impacts.

1,4-Dioxane is a carcinogen that is persistent and mobile in the environment. Disadvantaged communities, children, and those with compromised liver function may be particularly impacted by aggregate exposure to 1,4-dioxane from product use, drinking water, and in some instances, air. Standard forms of water treatment do not remove 1,4-dioxane, meaning difficult and costly measures are needed to remove it from wastewater and drinking water. As a result, 1,4-dioxane may interfere with California's ability to produce recycled water for long-term, sustainable water management and may result in significant cost impacts to water agencies.

Further studies on the presence of 1,4-dioxane in products and the potential for aggregate exposure may help inform our future decision-making. Nevertheless, we have sufficient information about the potential for several personal care and cleaning products to expose humans to harmful levels of 1,4-dioxane to designate one or more of these products as a Priority Product.

## ACRONYMS AND ABBREVIATIONS

### Abbreviations Used in This Document

AA	Alternatives Analysis
AAT	Alternatives Analysis Threshold
AEs	alcohol ethoxylates
AESs	alcohol ethoxysulfates
AOP	advanced oxidation processes
APCD	Air Pollution Control District
AQMD	Air Quality Management District
AS	alkyl sulfates and their salts
ATSDR	Agency for Toxic Substances and Disease Registry
AWWA	American Water Works Association
CARB	California Air Resources Board
Cal EDD	California Employment Development Department
CCR	California Code of Regulations
CDC	Centers for Disease Control and Prevention
CIWQS	California Integrated Water Quality System Project
DDW	Division of Drinking Water
DNA	deoxyribonucleic acid
DEHP	di(2-ethylhexyl) phthalate
DL	detection limit
D <sub>ow</sub>	octanol/water distribution coefficient
DSL	Domestic Substance List
DTSC	Department of Toxic Substances Control
ECHA	European Chemicals Agency
ECOSAR	Ecological Structure Activity Relationships



EO	degree of ethoxylation (by measure of ethylene oxide units)
EPI	Estimation Programs Interface
EtO	ethylene oxide
FDA	Food and Drug Administration
GAC	granular activated carbon
GAMA	Groundwater Ambient Monitoring and Assessment
GHS	Globally Harmonized System
GPC	Global Product Classification
GS1	Global Standards One
GWRS	Groundwater Replenishment System
HAP	hazardous air pollutant
HEAA	$\beta$ -hydroxyethoxyacetic acid
I&I	industrial and institutional
IARC	International Agency for Research on Cancer
IQR	interquartile range
IRIS	Integrated Risk Information System
JBRC	Japanese Bioassay Research Center
KOH	potassium hydroxide
K <sub>oc</sub>	organic carbon-water partition coefficient
K <sub>ow</sub>	octanol-water partition coefficient
LACSD	Los Angeles County Sanitation Districts
LC	lethal concentration
LOQ	limit of quantification
M	mobile
MCL	maximum contaminant level
MDL	method detection limit
MG	millions of gallons

MGD	millions of gallons per day
MOA	mode of action
MSW	municipal solid waste
NAICS	North American Industry Classification Systems
NAFLD	nonalcoholic fatty liver disease
NATA	National Air Toxics Assessment
NCI	National Cancer Institute
NCDWR	North Carolina Department of Water Resources
NEI	National Emissions Inventory
NHANES	National Health and Nutrition Examination Survey
NIOSH	National Institute for Occupational Safety and Health
NL	notification level
NSRL	No Significant Risk Level
NTP	National Toxicology Program
OCSD	Orange County Sanitation District
OCWD	Orange County Water District
OE	olfactory epithelium
OECD	Organization for Economic Cooperation and Development
OEHHA	Office of Environmental Health Hazard Assessment
P	persistent
PvM	persistent and very mobile
PEG	polyethylene glycols
pH	potential hydrogen
PHG	Public Health Goal
PMT	persistent, mobile, toxic
PPE	personal protective equipment
PQL	practical quantitation limit

RAGS	Risk Assessment Guidance for Superfund
REACH	Registration, Evaluation, Authorisation, and Restriction of Chemical substances
REL	reference exposure level
RNA	ribonucleic acid
SCP	Safer Consumer Products
SJC WRP	San Jose Creek Water Reclamation Plant
SLES	sodium laureth-x sulfate
SLS	sodium lauryl sulfate
SO <sub>3</sub>	sulfur trioxide
TAC	toxic air contaminant
TSCA	Toxic Substances Control Act
TWA	time weighted average
UCMR	Unregulated Contaminant Monitoring Rule
U.S. EPA	United States Environmental Protection Agency
UV	ultraviolet
vM	very mobile
vP	very persistent
vPvM	very persistent and very mobile
WDR	waste discharge requirement
WN WRP	Whittier Narrows Water Reclamation Plant
WRP	water reclamation plant
Ws DOE	Washington State Department of Ecology
WWTP	Wastewater Treatment Plant

## Units

atm-m <sup>3</sup> /mol	(atmospheres of air)/(moles per cubic meter of water).
cm <sup>3</sup>	cubic centimeter
d	days
d/wk	day per week
g	gram
g/cm <sup>3</sup>	gram per cubic centimeter
g/L	gram per liter
g/mol	gram per mol
hr/d	hour per day
kg	kilogram
L	liter
mg	milligram
mg/kg	milligram per kilogram
mg/kg-d	milligram per kilogram of body weight per day
mg/L	milligram per liter
mm Hg	millimeter of mercury
ppb	parts per billion
ppm	parts per million
μg	microgram
μg/L	micrograms per liter

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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) process to make a focused and meaningful comparison of adverse impacts between the Priority Product and an alternative over the product's life cycle. This Profile has identified potential adverse impacts in the following categories:

- Adverse environmental impacts
- Adverse public health impacts
- Adverse waste and end-of-life effects
- Environmental fate
- Physical chemical hazards
- Physicochemical properties
- Associated exposure pathways and life cycle segments
  - Resource inputs and consumption
  - Intermediate process materials
  - Manufacture
  - Use
  - Waste generation and management
  - End-of-life disposal

At a minimum, all AAs submitted for this product-chemical combination must include a discussion of these impacts and how they compare between the Priority Product and whatever alternatives have been identified at the relevant points in the life cycle. This list is not intended to be comprehensive. Also, alternatives evaluated in the AA report will likely have additional adverse impacts that don't 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 Profile.

## APPENDIX B: REPORT PREPARATION

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## APPENDIX C: EXAMPLES OF ETHOXYLATED INGREDIENTS

Ingredient class	Examples (synonyms separated by semicolons)
Alkyl ether sulfates; AESs; Alcohol ethoxysulfates	<ul style="list-style-type: none"> <li>• Sodium laureth-X sulfate; SLES; Sodium dodeceth-X sulfate</li> <li>• Ammonium laureth-X sulfate</li> <li>• Ammonium myreth-X sulfate</li> <li>• Magnesium coceth-X sulfate</li> <li>• Magnesium deceth-X sulfate</li> <li>• Sodium coceth-X sulfate</li> <li>• Sodium deceth-X sulfate</li> <li>• Sodium C12-15 pareth-X sulfate</li> </ul>
Alcohol ethoxylates; AEs; Alkyl polyethers; Ethoxylated alcohols; Alkoxyated alcohols	<ul style="list-style-type: none"> <li>• Laureth-X; Dodecyl alcohol, ethoxylated; Polyethylene glycol (PEG) monododecyl ether; PEG-X Lauryl ether</li> <li>• C8-C12 Alcohol ethoxylates; Alcohols, C8-C12, ethoxylated</li> <li>• Coceth-X; Coconut oil alcohol, ethoxylated; Polyethylene glycol cocoyl ether; PEG-X cocoyl ether; Alcohols, coco, ethoxylated</li> <li>• C12-13 Pareth-X</li> <li>• Ceteareth-X</li> <li>• Deceth-X</li> <li>• Isoceteth-X</li> </ul>
Polyetheylene glycols; PEGs; Polyoxyethylene glycols	<ul style="list-style-type: none"> <li>• PEG-X; polyethylene glycol; polyoxyethylene; polyethylene oxide; PEO</li> </ul>
Polysorbates	<ul style="list-style-type: none"> <li>• Sorbeth-X cocoate; sorbitol, ethoxylated, esters with coconut acid</li> <li>• Sorbeth-X laurate; Ethoxylated sorbitol, laurate</li> <li>• Polysorbate-80; Tween 80</li> <li>• Polysorbate-20; Polyoxyethylene (20) sorbitan monolaurate; Tween 20; PEG-20 sorbitan monolaurate</li> </ul>

Alkoxylated amides; Ethoxylated amides	<ul style="list-style-type: none"> <li>• PEG-X Stearamide</li> <li>• PEG-X Cocamide</li> <li>• PEG-X Lauramide</li> </ul>
Alkoxylated amines	<ul style="list-style-type: none"> <li>• PEG-X Cocamine</li> <li>• PEG-X Lauramine</li> <li>• PEG-X Soyamine</li> <li>• Diethylaminoethyl PEG-X Cocoate</li> </ul>
Alkoxylated carboxylic acids	<ul style="list-style-type: none"> <li>• PEG-X Stearate</li> <li>• PEG-X Cocoate</li> <li>• PEG-X Laurate</li> <li>• PEG-X Soyate</li> <li>• PEG-X Distearate</li> <li>• Jojoba Wax PEG-120 esters</li> <li>• Isosteareth-X Carboxylic Acid</li> </ul>
Alkyl ether phosphates	<ul style="list-style-type: none"> <li>• Dilaureth-X phosphate</li> <li>• Isosteareth-X Phosphate</li> <li>• Deceth-X phosphate</li> </ul>
Alkylphenol ethoxylates	<ul style="list-style-type: none"> <li>• Nonylphenol ethoxylate</li> <li>• Octylphenol ethoxylate</li> </ul>

## APPENDIX D: ALTERNATIVES ANALYSIS THRESHOLD RATIONALE

### Alternatives Analysis Threshold Explanation

DTSC's Safer Consumer Products Regulations mandate that an Alternatives Analysis Threshold (AAT) be set for Chemicals of Concern that are contaminants, such as 1,4-dioxane, in proposed Priority Products. Pursuant to section 69505.3 of Title 22, when a Chemical of Concern is present in a Priority Product only as a contaminant, at a concentration below the Alternatives Analysis Threshold (AAT), the product's manufacturer is exempted from submitting an Alternatives Analysis and must instead submit a Priority Product Notification (PPN) along with an AAT Notification. Subsection (a)(12) of section 69501.1 of Title 22 defines the AAT as either the Practical Quantitation Limit (discussed below) or some higher value specified by DTSC.

Subsection (a)(52) of section 69501.1 of Title 22 defines the Practical Quantitation Limit (PQL) as "the lowest concentration of a chemical that can be reliably measured within specified limits of precision and accuracy using routine laboratory operating procedures."

However, even if a Chemical of Concern is present only as a contaminant, if its concentration in the Priority Product exceeds the AAT, the manufacturer must submit a PPN and either (1) a Preliminary and then Final Alternatives Analysis (CCR, Title 22, section 69505.1) or (2) one of these notifications (CCR, Title 22, section 69505.2):

- Chemical Removal Intent and Confirmation Notifications;
- Product Removal Intent and Confirmation Notifications; or
- Product-Chemical Replacement Intent and Confirmation Notification.

If the contaminant is present in a Priority Product at a concentration at or below the AAT, the manufacturer of that product must submit a Priority Product Notification (PPN) along with an AAT Notification. As part of their AAT notifications, manufacturers are required to submit information to demonstrate and certify that their products do not contain the Chemical of Concern at concentrations above the AAT (CCR, Title 22, section 69505.3(a)(8)).

### Alternatives Analysis Threshold Value

DTSC has determined that 1,4-dioxane can be reliably measured at 1 ppm in consumer products by qualified analytical testing laboratories. We propose to set the AAT for all Priority Products adopted through rulemaking based on this Profile at 1 ppm. Any future regulations for a Priority Product containing 1,4-dioxane that set an AAT other than 1 ppm will include justification for that value at the time that the regulations are proposed.

As discussed in sections 4 and 6, down-the-drain discharge of consumer products that contain 1,4-dioxane at concentrations close to 1 ppm has the potential to threaten water recycling in California. We consider setting the AAT at 1 ppm to be appropriate and consistent with our framework regulations and New York's legislation in restricting the level of 1,4-dioxane in household cleansing products and personal care products to below 1 ppm by December 31, 2023 (see Section 7).

### ***Concentrated Products***

Concentrated cleaning products covered by this profile may contain higher levels of 1,4-dioxane. However, concentrated products have well recognized environmental benefits, including reduced packaging material needs and reduced transportation impacts per functional unit of product delivered because they contain less water. DTSC will consider these factors in determining if separate AAT considerations are needed for concentrated products on a product-by-product basis at the time regulations are proposed.

### **Analytical Methods**

Analytical methods have been developed since 1979 to measure the concentration of 1,4-dioxane in consumer products and raw materials for cosmetics (Table 17). These methods utilize a variety of technologies and techniques for sample preparation and quantification of 1,4-dioxane; all can achieve a quantitation limit of 1 ppm or lower. Gas chromatography coupled to mass spectrometry has become a common and preferred instrument for quantitation. Mass spectrometry offers the advantage of a determinative technique to uniquely identify a compound based on its retention time and the mass to charge ratios ( $m/z$ ) of the fragment ions.

Commercial laboratories that are developing their own analytical methods to test for 1,4-dioxane need to ensure such methods meet the performance criteria specified in the Requirements and Reporting section.

Table 17. 1,4-Dioxane Analytical Method Research Studies

Sample Material	Sample Preparation Procedure	Quantitation Procedure	MDL (ppm)	Reference
Alcohol ethoxylates (C <sub>9</sub> /C <sub>10</sub> /C <sub>11</sub> /C <sub>14</sub> /C <sub>15</sub> )	Dilute sample in chlorobenzene	Direct injection into GC-FID with dual column	0.5	Stafford et al. (1980)
Cosmetic raw materials and finished products	Azeotropic atmospheric distillation	Direct injection into GC-FID	1	Black, Hurley, and Havery (2001)
	Solid phase extraction (SPE)			
Nonionic surfactants (polyethylene oxide, poly(ethylene/propylene) oxide, polyhydric alcohol), shampoo, liquid soap, and dish washing detergent	SPME-GC-FID		0.3	Fuh et al. (2005)
	SPME-GC-MS with THF ISTD with and without standard addition approach		0.06	
Personal care products, household detergents, and cleaners	SPE with surrogate 1,4-dioxane-d <sub>8</sub> for isotope dilution approach	GC-MS (SIM) with 4-bromofluorobenzene IS	0.05 (LOQ)	Tanabe and Kawata (2008)
Shampoos, hand soaps, body cleansers, and dishwashing liquids	Headspace-GC-MS with standard addition approach and fluorobenzene and 1,4-dioxane-d <sub>8</sub> as IS		1 (LOQ)	Tahara, Obama and Ikarashi (2013)
Household detergents	Headspace-SPME-GC-MS (SIM) with standard addition approach		0.03	Lin et al. (2017)
Sodium lauryl ether sulphate, sodium lauryl sulphate (SLS), shampoos, hand washing liquids, and dish washing liquids	Headspace single-drop microextraction (HS-SDME)	Direct injection into GC-FID	0.4	Saraji and Shirvani (2017)

Bath products, hair treatment, lotions, beauty bars, washes and shampoos	Ultrasound-assisted extraction (UAE)	Direct injection into GC-MS-MS	0.2	Zhou (2019)
	Solid phase extraction (SPE)			
Cosmetics, liquid soaps, shampoos, and cleaning products	Headspace GC-MS (SIM) with isotope dilution approach		0.007	Fernando (2019)
Cosmetics, liquid soaps, shampoos, and cleaning products	SPME-GC-MS-MS (MRM) with isotope dilution approach		0.001	Castor et al. (2021a)
Dish soap, laundry detergent, industrial and institutional laundry detergent	Headspace GC-MS with standard addition approach and 1,4-dioxane-d <sub>8</sub> as IS		<0.1	Palumbo, Conrad-Vlasak and Stanton (2023)

*GC-FID: gas chromatography with flame ionization detection; SPE: solid phase extraction; SPME: solid phase microextraction; GC-MS: gas chromatography coupled with single quadrupole mass spectrometry; IS: internal standard; SIM: selected ion monitoring; GC-MS-MS: gas chromatography couple with triple quadrupole mass spectrometry; MRM: multiple reaction monitoring.*

## Requirements and Reporting

A manufacturer submitting an AAT Notification in lieu of a full Alternatives Analysis must demonstrate and certify that the concentration of 1,4-dioxane in its product or products is at or below the AAT, for the products to be exempt from the Alternatives Analysis requirements (California Code of Regulations, Title 22, section 69505.3(a)). Options to demonstrate that the AAT exemption has been met include providing data from laboratory analysis of the manufacturer's Priority Products or providing documentation received from suppliers of the ingredients in the Priority Product along with calculations of the concentration of 1,4-dioxane in the final, formulated product. Any trade secret or confidential business information that might need to be submitted for compliance certification can be submitted through the [CalSAFER](#) website, which is equipped to receive and securely handle such information. Manufacturers must also provide the laboratory analytical testing methodology and quality control and assurance protocols that are followed to measure each Chemical of Concern in the Priority Product and must identify the testing laboratory used.

In addition, per the Safer Consumer Product Regulations (California Code of Regulations, Title 22, section 69503.5(a)), each AAT Notification should also include a demonstration that the manufacturer will continue to meet the AAT threshold value. If at any point the concentration of 1,4-dioxane in the

Priority Product no longer falls below the AAT (e.g., due to reformulation or a change in raw material suppliers), the manufacturer is required to notify DTSC within 30 days of the change and submit a Preliminary AA Report or an applicable Intent and/or Confirmation Notification within 180 days of the change (CCR, Title 22, section 69503.5(d)).

## Sample Preparation Criteria

- 1) Each sample shall be homogenous prior to taking an aliquot of the product to ensure the aliquot is representative of the contents in the container.
- 2) A sample may be introduced into the analytical instrument by various techniques including, but not limited to, purge-and-trap, automated static headspace, solid phase microextraction (SPME), and direct injection, provided that all other performance criteria are met.

## Analytical Method Criteria

- 1) It is recommended to use a gas chromatograph/mass spectrometer (GC/MS) method designed for analysis of 1,4-dioxane in solid and aqueous samples. Any other analytical technique that meets the method performance criteria may be used for sample analysis and determination of 1,4-dioxane in personal care and cleaning products.
- 2) The method must use isotope dilution with 1,4-dioxane-d8 as an internal standard (IS). The IS shall be added to each sample, prior to introduction into the analytical instrument, at a concentration within the range of the initial calibration range for 1,4-dioxane.
- 3) The Limit of Quantitation (LOQ) shall be at or below one-third of the Alternative Analysis Threshold of 1 ppm.

## Instrument and Calibration Criteria

- 1) All study samples shall be analyzed on a properly calibrated instrument that meets instrument manufacturer specifications. If the instrument calibrations or other instrument check requirements (for example, mass spectrometer tune, mass calibration check, or qualitative identification criteria) are outside the acceptable criteria, standard measures to correct the problem shall be implemented prior to analyzing samples.
- 2) The use of a gas chromatograph/mass spectrometer is recommended for the separation and fragmentation of analytes for identification. The ratios of qualifier ions to quantitation ions shall be established during calibration and shall be maintained throughout sample analysis to verify the identity of 1,4-dioxane and ensure that there are no interfering peaks.
  - a) Laboratories may use mass spectrometer full scan, selected ion monitoring, or multiple reaction monitoring scanning modes to analyze samples and meet the limit of quantitation requirement.



- b) The method shall incorporate, at a minimum, one quantitation and one qualifier ion for 1,4 dioxane.
  - (i) The quantitation ions for 1,4 dioxane are found in Table 18.
- c) The method shall incorporate, at minimum, one quantitation ion for internal standards and surrogates. Further, the method may include one or more qualifier ions for internal standards and surrogates.

*Table 18. Mass Spectrometer Ions for Compounds of Interest*

Compound	Full Scan and SIM	MRM
1,4-Dioxane	Quantitation Ion: 88	Quantitation Ion: 88 --> 57
	Qualifier Ions: 57, 58	Qualifier Ion: 88 --> 58
1,4-Dioxane-d <sub>8</sub>	Quantitation Ion: 96	Quantitation Ion: 96 --> 62
	Qualifier Ions: 62, 64	Qualifier Ion: 96 --> 64

- 3) The instrument tune checks shall be done prior to calibration and at the beginning of each 12-hour analytical period. For analysis run by full scan GC/MS, it is recommended to use 4-bromofluorobenzene (BFB) as the tune verification standard. For selected ion monitoring or multiple reaction monitoring scanning modes, it is recommended to follow the manufacturer's instrument tuning criteria. All samples, including quality control and calibration standards, shall be introduced into the GC/MS for analysis within 12 hours of the analysis of the tune verification standard. Samples and quality control standard solutions that are not analyzed within the 12-hour time window cannot be reported.
- 4) For each analyte and surrogate of interest, prepare an initial calibration from standards containing 1,4 dioxane, at a minimum of five different non-zero concentrations, and an appropriate solvent.
  - a) The fitted line of the initial calibration shall meet one of these criteria:
    - (i) The relative standard deviation of the average response of the target analyte, expressed as a percentage, shall not exceed 20%. This is the ratio of the standard deviation to the mean of the response factor for 1,4 dioxane; or
    - (ii) The linear fit shall have a correlation coefficient (r) greater than or equal to 0.995 or a coefficient of determination (r<sup>2</sup>) greater than 0.99.
- 5) The concentration of 1,4 dioxane in the lowest calibration standard solution shall be accurate within 50% of its true concentration value, meaning the percentage of recovery shall be within 50% to 150% of the expected concentration, and all other 1,4 dioxane calibration levels must be

within 30% of their true value, meaning the percentage of recovery shall be within 70% to 130% of the expected concentration.

- 6) After the initial calibration, the retention time of each internal standard shall be within 30 seconds of the retention time of the internal standard at the midpoint of the initial calibration.
- 7) An initial calibration verification standard solution shall be prepared from a different source than the initial calibration standard solution, with a 1,4 dioxane concentration at or near the mid-point of the calibration range and analyzed immediately following the initial calibration. The calculated concentration of 1,4 dioxane and the surrogate in the initial calibration verification standard solution shall be within 30% of its their true concentration values, meaning the percentage of recovery shall be within 70 to 130 of the expected concentration. No samples shall be run until the initial calibration verification standard solution is analyzed.
- 8) A continuing calibration verification standard solution shall be analyzed, prepared from the same source as the initial calibration standard solution, with a 1,4 dioxane concentration at or near the midpoint of the calibration range. The continuing calibration verification standard solution shall be analyzed before the samples at the beginning of each 12-hour analytical period. The measured concentration of the continuing calibration verification standard solution shall be within 20% of its true concentration value, meaning the percentage of recovery shall be 80 to 120% of the expected concentration. If the calibration verification does not meet the acceptance criteria, standard measures to correct the problem shall be implemented, and another aliquot of the continuing calibration verification standard solution shall be analyzed. If the response of the continuing calibration verification standard solution is still not within 20% of its true concentration value, then a new initial calibration shall be conducted.

## Sample Analysis Criteria

- 1) An instrument blank shall be analyzed after the continuing calibration verification standard solution, and before the samples, to demonstrate that the total analytical system is free from contaminants. A sufficient number of instrument blanks shall also be inserted between samples to verify no carryover or cross contamination of 1,4-dioxane from one sample to the next.
- 2) The response of the internal standard for all samples shall be within 50% to 200% of the midpoint of the initial calibration or the continuing calibration verification.
- 3) The retention time of the analyte of interest shall be within 10 seconds of retention time of the midpoint of the initial calibration or within 10 seconds of the continuing calibration verification standard solution analyzed at the beginning of the 12-hour analytical period.

## Quality Control Criteria

- 1) All data shall adhere to a quality control protocol for each batch of 20 samples and each type of nail product analyzed:
  - a) Preparation and analysis of a method blank. The concentration of 1,4-dioxane in each method blank shall not exceed one half of the lower limit of quantitation.
  - b) Preparation and analysis of a duplicate sample.
  - c) Preparation and analysis of a matrix spike and matrix spike duplicate containing a spiked concentration of 1,4-dioxane in the middle range of the initial calibration.
  - d) Preparation and analysis of a laboratory control sample and laboratory control sample duplicate containing a spiked concentration of 1,4-dioxane in the middle range of the initial calibration.
- 2) Each product sample, method blank, sample duplicate, matrix spike, matrix spike duplicate, laboratory control sample, and laboratory control sample duplicate shall be spiked with a surrogate standard solution prior to extraction and analysis.
- 3) Each matrix spike, matrix spike duplicate, laboratory control sample, and laboratory control sample duplicate shall demonstrate a relative percent difference (RPD) less than or equal to 20% for duplicate samples, and each spiked quality control sample shall have a spike recovery between 70% and 130% of the true value of the spiked concentrations.
- 4) A laboratory may establish more rigorous internal control limits but shall demonstrate an RPD less than or equal to 20% for duplicate samples and a 70% to 130% recovery range for known spiked concentrations.
- 5) The measured concentration of the surrogate standard solution in each product sample, method blank, sample duplicate, laboratory control sample, laboratory control sample duplicate, and matrix spike duplicate undergoing analysis shall be within 70% to 130% of the spiked concentration.

## Definitions

Partially adapted from Chapter One of the SW-846 Compendium for Hazardous Waste Test Methods (U.S. EPA 2014b).

“Aliquot” is a measured portion of a total amount of a larger sample solution or suspension.

“Certificate of Analysis (COA)” is a quality assurance document that provides the results of laboratory tests or other analyses performed on a product or ingredient. A COA shall contain information on the name of the product or ingredient, including the batch number, and the release date for each batch tested. The COA shall list each test performed including the quality control acceptance limits, the method quantitative limits, and the numerical results obtained. Certificates shall be dated and signed

by authorized personnel and shall include the name, address, and telephone number of the original product or ingredient manufacturer.

“Coefficient of Determination ( $r^2$ )” is a statistical measure of the strength of the relationship between two variables and is the squared value of the correlation coefficient.

“Continuing Calibration Verification (CCV) Standard” is a mid-range concentration standard analyzed before, during, and at the end of an analytical batch and verifies that the instrument response has not drifted from the initial calibration response. This standard solution contains a known concentration of the target analyte and is typically derived from the same source as the initial calibration standards.

“Correlation Coefficient ( $r$ )” is a statistical measure of the strength of relationship between two variables.

“Duplicate Sample” is a quality control sample which is identical to one of the analytical samples and undergoes the same sample preparation and analytical procedures as the analytical sample.

“Initial Calibration (ICAL)” is a determination of the instrument response over a range of known concentrations of an analyte or analytes. A series of standard solutions is prepared from a certified reference material and analyzed on the instrument prior to any samples. Five or more standard solutions containing progressively higher concentrations of the analytes of interest are generally prepared.

“Instrument Blanks” are typically analyzed before the sample analysis and following high concentration samples. These blanks are used to assess background contamination or carryover in the analytical system that may lead to reporting of false positives in the subsequent sample analyses.

“Initial Calibration Verification (ICV) Standard” is a certified solution from a source other than used for the initial calibration standards and is used to verify the accuracy of the initial calibration.

“Internal Standard (IS)” is a chemical substance that is similar but not identical to the target analyte and is added to each sample at a known concentration. The internal standard mimics the behavior of the target analyte but has a different signal than the analyte. An internal standard is used for quantitation of target analytes and to account for matrix effects and/or variability in instrument response by normalizing the response of the target analytes and surrogates, thereby decreasing measurement bias.

“Laboratory Control Sample/Laboratory Control Sample Duplicate (LCS/LCSD)” is a clean matrix which has been spiked with a known concentration of the target analyte. It is prepared and analyzed in the same analytical batch and in exactly the same manner as the other samples. The laboratory control

sample and laboratory control sample duplicate are used to assess general method performance based on the ability of the laboratory to successfully recover target analytes.

“Limit of Quantitation (LOQ)” is the lowest measured concentration of the analyte that has gone through extraction or dilution and analysis and meets defined accuracy and precision criteria.

“Matrix Spike/Matrix Spike Duplicate (MS/MSD)” are quality control samples that contain known concentrations of target analytes which have been added before extraction and analysis.

“Method Blank” is a clean matrix quality control sample that is carried through the entire dilution or extraction and analytical process. Concentrations of the target analyte shall not exceed one half of the lower limit of quantitation. If concentrations exceed this value, it is an indication of contamination of the reagents, glassware, or any part of the extraction and analysis process.

“Multiple Reaction Monitoring (MRM)” is a highly sensitive analytical method using a triple quadrupole mass spectrometer. The target analyte is ionized in the ion source which creates specific ions that are characteristic of the target analyte. Selected ions are allowed through the first quadrupole and are then subsequently fragmented into product (quantitation and qualifier) ions in the collision cell. These product ions are selectively passed through the final quadrupole, where they are detected. Multiple product ions can be detected at once.

“Relative Percent Difference (RPD)” is the absolute difference between two measurements divided by their average and converted to a percentage.

“Relative Standard Deviation (RSD)” is the standard deviation of a group of measurements in a data set divided by their average and converted to a percentage. Relative standard deviation is an indicator of how a group of measurements in a data set are scattered around the mean.

“Response Factor (RF)” is the ratio between a signal produced by an analyte, and the concentration of analyte which produced the signal.

“Selected Ion Monitoring (SIM)” is a mass spectrometry technique in which a limited set of ions with specific mass-to-charge ( $m/z$ ) ratios is monitored by the instrument. This technique typically results in increased sensitivity relative to full scan mass spectrometry.

## APPENDIX E: INDICATORS OF EXPOSURE DATA TABLES

### Air Emissions of 1,4-Dioxane

Table 19. 1,4-Dioxane air emissions (lbs/year) in landfills and wastewater treatment plants reporting emission data to CARB (CARB 2020; CARB 2021).

Facility or Location	n	Mean	Std Dev	Median	95 <sup>th</sup> percentile	Max	Total
Landfills	8	3.1	6.7	0.0	14.3	18.9	24.7
Wastewater Treatment Plants	15	56.4	75.8	5.9	194.2	249.1	846.3

The wastewater treatment plants included are Bakersfield City Wastewater #2; Camarillo Wastewater Plant; City of Escondido; City of Oceanside Water Utilities Department San Luis Rey Wastewater Treatment Plant; City of San Diego Metro Wastewater Biosolids Center; City of San Diego Metropolitan Wastewater Department; Encina Wastewater Authority; Inland Empire Utilities Agency Regional Water Recycling Plant Nos. 1, 2, and 3; North City Water Reclamation Plant; and Oxnard Wastewater Treatment Plant.

Table 20. 1,4-Dioxane air emissions in lbs/year from 69 facilities reporting emission data to CARB, grouped and reported by regional Air Quality Management Districts (AQMD) and Air Pollution Control Districts (APCD) (CARB 2021).

Facility or Location under regional air districts	n	Total
Antelope Valley AQMD	1	0.14
Bay Area AQMD	12	422.5
Mojave Desert AQMD	2	0.1
Placer County APCD	1	18.7
Sacramento Metropolitan AQMD	2	4.0
San Diego County APCD	10	754.9
San Joaquin Valley APCD	7	3704.0
San Luis Obispo County APCD	1	5.1
Santa Barbara County APCD	7	8760.7
Shasta County AQMD	1	0.4
South Coast AQMD	20	85.5
Ventura County APCD	4	98.8
Yolo-Solano AQMD	1	0.0
Total	69	13,854.8

## 1,4-Dioxane in Wastewater Effluent and Recycled Water

Table 21. 1,4-Dioxane concentrations ( $\mu\text{g/L}$ ) in municipal wastewater effluent and recycled water as reported by the State Water Board's CIWQS database, 2010-2023 (State Water Board 2023).

Region	Sample Type	n [a]	Method Detection Limit ( $\mu\text{g/L}$ )	Percent above DL	Mean [d]	Std Dev	Median [d]	95 <sup>th</sup> Percentile	Max
R1 North Coast	effluent	0 [b]	-	-	-	-	-	-	-
R2 San Francisco Bay	effluent	0 [b]	-	-	-	-	-	-	-
R3 Central Coast	effluent	0 [b]	-	-	-	-	-	-	-
R4 Los Angeles	effluent	418	0.04-7.4 for 346 samples	84.9%	0.93	0.62	0.88	2.05	4.0
	recycled water	21	0.04-0.17	100%	1.31	0.38	1.2	2.1	2.1
R5R Central Valley (Redding)	effluent	2	8.8	0%	0.00	0.00	0.00	0.00	0.00
R5S Central Valley (Sacramento) [a]	effluent	512 [c]	-	-	-	-	-	-	-
R5F Central Valley (Fresno)	effluent	36	0.32-1.1	30.6	0.23	0.41	0	0.79	1.9
R6 Lahontan	effluent	0 [b]	-	-	-	-	-	-	-
R7 Colorado River Basin	effluent	15	0.59-20 for 14 samples	6.67%	0.01	0.04	0.00	0.064	0.19
R8 Santa Ana	effluent	0 [b]	-	-	-	-	-	-	-
R9 San Diego	effluent	51	18.5-20.2 for 13 samples	0%	0.00	0.00	0.00	0.00	0.00

[a] Data with validation code "B" (analyte in blank) and "R" (Data Rejected) were excluded from the analysis.

[b] No data reported in the system.

[c] Data from Region 5S was purely industrial and as such is not reported here.

[d] Means and medians are given for the entire data set, including data below the RL but above the MDL and assigning the non-detects (a Qual value = "ND" or "<" in the dataset) a value of 0.



## 1,4-Dioxane in Groundwater

Table 22. 1,4-Dioxane concentrations ( $\mu\text{g/L}$ ) in untreated groundwater, recorded in the State Water Board's Groundwater Ambient Monitoring and Assessment (GAMA) dataset (State Water Board 2018a).

Year	Region	n	Percent above DL	Mean	Std Dev	Median	95 <sup>th</sup> Percentile	Max	%>1.0 $\mu\text{g/L}$
<b>GAMA Priority Basin Project - Statewide (n=649) [a]</b>									
2014-2015	R1 North Coast	17	0%	0	0	0	0	0	0%
2014-2016	R2 San Francisco Bay	21	0%	0	0	0	0	0	0%
2008-2016	R3 Central Coast	34	0%	0	0	0	0	0	0%
2010-2017	R4 Los Angeles	26	34.6%	0.92	2.12	0	2.35	10.5	30.8%
2013-2017	R5 Central Valley	483	0.4%	0.004	0.07	0	0	1.37	0.2%
2015-2016	R6 Lahontan	16	0%	0	0	0	0	0	0%
2007	R7 Colorado River Basin	4	0%	0	0	0	0	0	0%
2010-2017	R8 Santa Ana	28	10.7%	0.08	0.26	0	0.58	1.17	3.6%
2014-2016	R9 San Diego	20	0%	0	0	0	0	0	0%
<b>GAMA Monitoring Wells – Statewide (n=52,377) [b]</b>									
2008-2018	R1 North Coast	374	66.3%	3.24	7.42	0.94	12.0	78	49.2%
2008-2018	R2 San Francisco Bay	4,826	44.7%	808	7,280	0	970	277,000	36.3%
2008-2018	R3 Central Coast	2,375	29.9%	92.9	1,050	0	170	31,000	24.5%
2008-2018	R4 Los Angeles	25,205	54.7%	478	4,520	1.30	650	310,000	46.6%
2008-2018	R5 Central Valley	4,590	38.6%	16.0	44.8	0	100	629	22.7%
2008-2018	R6 Lahontan	15	0%	0	0	0	0	0	0%
2008-2018	R7 Colorado River Basin	80	0%	0	0	0	0	0	0%
2008-2018	R8 Santa Ana	10,547	56.0%	408	4,550	1.70	350	130,000	51.1%
2008-2018	R9 San Diego	4,365	45.3%	101	628	0	250	17,000	43.3%

- [a] DLs are not explicitly documented in the original data. If the “QUALIFER” value in the original document is “<”, a measurement is considered below detection limit and the value is replaced as zero for calculation. Otherwise, a measurement is considered above detection limit and the value is used as is for calculation. The speculated DLs in the dataset ranged from 0.5 – 0.7 µg/L.
- [b] DLs are not explicitly documented in the original data. However, the “QUALIFER” variable does indicate values below detection limit using a symbol “ND”. For ND data, concentrations are replaced with zero (the majority of ND data are reported as zero in the original data set). Otherwise the concentrations are used as is for calculation. The RL ranged from 0.0001 µg/L to 500000 µg/L.

Table 23. 1,4-Dioxane levels in groundwater under contaminated sites in California Counties from GeoTracker database ( $\mu\text{g/L}$ ) (State Water Board 2020a). Most recent data from each site are used for calculating the statistics. Standard deviation (Std Dev) cannot be calculated when there is only one data point ( $n=1$ ).

County	Site Type [a]	Field Sampling Point Description	n	Percent Above DL [b]	Mean	Std Dev	Median	95 <sup>th</sup> Percentile	Max
Alameda	LUST Cleanup Site	Remediation/Ground water Monitoring Well	2	50	85.0	120.2	85.0	170.0	170.0
	Cleanup Program Site	Above Ground Tank Location	1	100	4.2	-	4.2	4.2	4.2
	Cleanup Program Site	Remediation/Ground water Monitoring Well	9	67	18.6	28.0	1.6	82.8	82.8
Contra Costa	Land Disposal Site	Monitoring Well in Leachate	1	100	3100.0	-	3100.0	3100.0	3100.0
Los Angeles	LUST Cleanup Site	Temporary Well	1	100	440.0	-	440.0	440.0	440.0
	Cleanup Program Site	Vapor Extraction Well	2	50	16.0	22.6	16.0	32.0	32.0
	Cleanup Program Site	Remediation/Ground water Monitoring Well	28	61	408.0	1834.9	3.8	1200.0	9700.0
	Cleanup Program Site	Temporary Well	1	100	1.4	-	1.4	1.4	1.4
	Land Disposal Site	Effluent Sample	1	100	0.7	-	0.7	0.7	0.7
	Cleanup Program Site	Monitoring Gas Well	1	100	0.7	-	0.7	0.7	0.7
	* WDR Site	Piezometer	1	100	0.4	-	0.4	0.4	0.4
	* WDR Site	Remediation/Ground water Monitoring Well	11	45	10.6	25.1	0.0	84.0	84.0
Orange	Cleanup Program Site	Influent Sample	1	100	62.0	-	62.0	62.0	62.0

County	Site Type [a]	Field Sampling Point Description	n	Percent Above DL [b]	Mean	Std Dev	Median	95 <sup>th</sup> Percentile	Max
	Cleanup Program Site	Remediation/Ground water Monitoring Well	11	55	79.7	198.2	1.4	650.0	650.0
	* WDR Site	Remediation/Ground water Monitoring Well	1	100	0.5	-	0.5	0.5	0.5
Placer	Land Disposal Site	Lysimeter Sampling Point	1	100	0.0	-	0.0	0.0	0.0
	Land Disposal Site	Surface Sampling Point	1	100	0.0	-	0.0	0.0	0.0
	Land Disposal Site	Remediation/Ground water Monitoring Well	3	67	0.0	0.0	0.0	0.0	0.0
	Land Disposal Site	Leachate Sampling Point	2	100	0.0	0.0	0.0	0.0	0.0
Riverside	Cleanup Program Site	Remediation/Ground water Monitoring Well	1	100	367.0	-	367.0	367.0	367.0
	Land Disposal Site	Remediation/Ground water Monitoring Well	2	100	24.0	12.7	24.0	33.0	33.0
	Cleanup Program Site	Surface Sampling Point	1	100	1.0	-	1.0	1.0	1.0
Sacramento	Cleanup Program Site	Borehole	1	100	13.6	-	13.6	13.6	13.6
	Cleanup Program Site	Influent Sample	1	100	1.8	-	1.8	1.8	1.8
	Cleanup Program Site	Effluent Sample	1	100	1.5	-	1.5	1.5	1.5
	Cleanup Program Site	Remediation/Ground water Monitoring Well	1	100	0.3	-	0.3	0.3	0.3
San Benito	Land Disposal Site	Effluent Sample	1	100	360.0	-	360.0	360.0	360.0
San Bernardino	Land Disposal Site	Transient Subsurface Sampling Point (i.e. direct-push)	4	25	775.0	1,550.0	0.0	3,100.0	3,100.0

County	Site Type [a]	Field Sampling Point Description	n	Percent Above DL [b]	Mean	Std Dev	Median	95 <sup>th</sup> Percentile	Max
San Diego	Cleanup Program Site	Transient Subsurface Sampling Point (i.e. direct-push)	1	100	66.6	-	66.6	66.6	66.6
	Cleanup Program Site	Influent Sample	1	100	31.0	-	31.0	31.0	31.0
	Cleanup Program Site	Borehole	1	100	20.1	-	20.1	20.1	20.1
	Cleanup Program Site	Remediation/Ground water Monitoring Well	4	50	17.6	33.6	1.3	68.0	68.0
San Mateo	Cleanup Program Site	Influent Sample	2	100	765.5	982.2	765.5	1,460.0	1460.0
	Cleanup Program Site	Remediation/Ground water Monitoring Well	4	50	295.8	576.3	11.5	1,160.0	1,160.0
	Cleanup Program Site	Transient Subsurface Sampling Point (i.e. direct-push)	1	100	5.1	-	5.1	5.1	5.1
	Cleanup Program Site	Borehole	2	100	3.3	2.6	3.3	5.1	5.1
	Cleanup Program Site	Piezometer	1	100	2.0	-	2.0	2.0	2.0
	Cleanup Program Site	Stream or Creek Sampling Point	1	100	0.2	-	0.2	0.2	0.2
	Cleanup Program Site	Midway Treatment Sampling Point	2	50	0.1	0.1	0.1	0.2	0.2
Santa Barbara	Land Disposal Site	Leachate Sampling Point	1	100	718.0	-	718.0	718.0	718.0
	Cleanup Program Site	Remediation/Ground water Monitoring Well	3	100	21.4	29.2	6.3	55.0	55.0
	Military UST Site	Borehole	1	100	5.6	-	5.6	5.6	5.6

County	Site Type [a]	Field Sampling Point Description	n	Percent Above DL [b]	Mean	Std Dev	Median	95 <sup>th</sup> Percentile	Max
	Military UST Site	Remediation/Ground water Monitoring Well	3	67	0.7	0.8	0.6	1.6	1.6
Santa Clara	Land Disposal Site	Monitoring Well in Leachate	1	100	521.0	-	521.0	521.0	521.0
	Land Disposal Site	Leachate Sampling Point	1	100	100.0	-	100.0	100.0	100.0
	Cleanup Program Site	Influent Sample	2	50	37.0	52.3	37.0	74.0	74.0
	Cleanup Program Site	Midway Treatment Sampling Point	1	100	13.0	-	13.0	13.0	13.0
	Cleanup Program Site	Effluent Sample	4	75	12.2	13.6	12.4	24.0	24.0
	Cleanup Program Site	Remediation/Ground water Monitoring Well	5	60	10.3	22.7	0.0	50.9	50.9
	Land Disposal Site	Remediation/Ground water Monitoring Well	3	33	0.6	1.0	0.0	1.7	1.7
	Santa Cruz	Cleanup Program Site	Remediation/Ground water Monitoring Well	1	100	210.0	-	210.0	210.0
Cleanup Program Site		Borehole	1	100	36.0	-	36.0	36.0	36.0
Solano	Land Disposal Site	Leachate Sampling Point	1	100	130.0	-	130.0	130.0	130.0
Sonoma	Cleanup Program Site	Injection Well	1	100	19.0	-	19.0	19.0	19.0
	Cleanup Program Site	Remediation/Ground water Monitoring Well	2	100	18.6	20.3	18.6	32.9	32.9
	Cleanup Program Site	Borehole	1	100	3.2	-	3.2	3.2	3.2
Ventura	WDR Site	Influent Sample	2	100	95.5	119.5	95.5	180.0	180.0
	Cleanup Program Site	Injection Well	1	100	15.0	-	15.0	15.0	15.0

County	Site Type [a]	Field Sampling Point Description	n	Percent Above DL [b]	Mean	Std Dev	Median	95 <sup>th</sup> Percentile	Max
	Cleanup Program Site	Influent Sample	1	100	11.0	-	11.0	11.0	11.0
	Cleanup Program Site	Remediation/Ground water Monitoring Well	4	75	11.1	19.3	2.3	40.0	40.0
	WDR Site	Remediation/Ground water Monitoring Well	3	100	13.9	22.6	0.9	40.0	40.0

[a] LUST = leaking underground storage tanks, WDR = waste discharge requirements

[b] DL = detection limit; a value is considered above DL if the PARVQ has a value of “=”; otherwise, a value is considered below DL. Below DL data (NDs) are reported as zeros in the original data. Summary statistics reported in this table are for the cases that “Percent above DL” is greater than 0; in other words, if all data points for a combination of county, site type, and field sampling point are below DL, the summary statistics are not reported here.

## Gas Monitoring Results at Locations Close to Contaminated Sites

Table 24. 1,4-Dioxane levels in ambient air near contaminated sites in California Counties from GeoTracker database ( $\mu\text{g}/\text{m}^3$ ) (State Water Board 2020a). Most recent data from each site are used for calculating the statistics.

County	Site Type [a]	Field Sampling Point Description	n	Percent Above DL [b]	Mean	Std Dev	Median	95 <sup>th</sup> Percentile	Max
Alameda	Cleanup Program Site	Indoor Air	1	100	0.61	-	0.61	0.61	0.61
	Cleanup Program Site	Ambient Air	6	67	0.20	0.30	0.09	0.79	0.79
Humboldt	Cleanup Program Site	Soil Gas	1	100	3.50	-	3.50	3.50	3.50
San Francisco	LUST Cleanup Site	Indoor Air	1	100	0.09	-	0.09	0.09	0.09
	LUST Cleanup Site	Ambient Air	1	100	0.02	-	0.02	0.02	0.02



County	Site Type [a]	Field Sampling Point Description	n	Percent Above DL [b]	Mean	Std Dev	Median	95 <sup>th</sup> Percentile	Max
San Mateo	LUST Cleanup Site	Ambient Air	1	100	0.36	-	0.36	0.36	0.36
San Mateo	LUST Cleanup Site	Indoor Air	1	100	0.27	-	0.27	0.27	0.27
Santa Barbara	Military UST Site	Soil Gas	1	100	140000.00	-	140000.00	140000.00	140000.00
	Military Cleanup Site	Vapor Extraction Well	1	100	13.00	-	13.00	13.00	13.00
	Military Cleanup Site	Borehole	2	100	9.00	0.00	9.00	9.00	9.00
Santa Clara	Cleanup Program Site	Indoor Air	1	100	0.17	-	0.17	0.17	0.17
	Cleanup Program Site	Ambient Air	1	100	0.08	-	0.08	0.08	0.08

[a] LUST = leaking underground storage tanks, WDR = waste discharge requirements

[b] DL = detection limit; a value is considered above DL if the PARVQ has a value of “=”; otherwise, a value is considered below DL. Below DL data (NDs) are reported as zeros in the original data. Summary statistics reported in this table are for the cases that “Percent above DL” is greater than 0; in other words, if all data points for a combination of county, site type, and field sampling point are below DL, the summary statistics are not reported here.

Table 25. 1,4-Dioxane levels in soil gas in California Counties from GeoTracker database ( $\mu\text{g}/\text{m}^3$ ) (State Water Board 2020a). Most recent data from each site are used for calculating the statistics.

County	Site Type [a]	Field Sampling Point Description	n	Percent Above DL [b]	Mean	Std Dev	Median	95 <sup>th</sup> Percentile	Max
Alameda	Cleanup Program Site	Soil Gas	37	3	0.30	1.81	0.00	0.00	11.00
	Cleanup Program Site	Borehole	6	17	0.20	0.49	0.00	1.20	1.20
Sacramento	LUST Cleanup Site	Influent Sample	2	50	48.62	68.76	48.62	97.24	97.24
San Mateo	Cleanup Program Site	Midway Treatment Sampling Point	2	50	1.45	2.05	1.45	2.90	2.90
	Cleanup Program Site	Effluent Sample	6	17	0.87	2.12	0.00	5.20	5.20
	LUST Cleanup Site	Subslab Soil Vapor	5	20	0.19	0.43	0.00	0.97	0.97
Santa Clara	LUST Cleanup Site	Soil Gas	7	14	0.13	0.35	0.00	0.92	0.92
Santa Cruz	LUST Cleanup Site	Ambient Air Sample	1	100	1.60	-	1.60	1.60	1.60
Sonoma	Cleanup Program Site	Soil Gas	2	50	0.75	1.06	0.75	1.50	1.50
Yuba	Military Cleanup Site	Remediation/ Groundwater Monitoring Well	8	25	2.88	5.39	0.00	12.97	12.97
	Military Cleanup Site	Vapor Extraction Well	9	22	0.19	0.40	0.00	1.12	1.12

[a] LUST = leaking underground storage tanks, WDR = waste discharge requirements

[b] DL = detection limit; a value is considered above DL if the PARVQ has a value of “=”; otherwise, a value is considered below DL. Below DL data (NDs) are reported as zeros in the original data. Summary statistics reported in this table are for the cases that “Percent above DL” is greater than 0; in other words, if all data points for a combination of county, site type, and field sampling point are below DL, the summary statistics are not reported here.

Table 26. 1,4-Dioxane levels in contaminated soil in California counties ( $\mu\text{g}/\text{kg}$ ) (State Water Board 2020a). Most recent data from each site are used for calculating the statistics.

County	Site Type	Field Sampling Point Description	n	Percent Above DL [a]	Mean	Std Dev	Median	95 <sup>th</sup> Percentile	Max
Los Angeles	Cleanup Program Site	Leachate Sampling Point	1	100	0.20	-	0.20	0.20	0.20
	Cleanup Program Site	Piezometer	2	50	0.02	0.03	0.02	0.04	0.04
	Cleanup Program Site	Remediation/Groundwater Monitoring Well	16	6	0.01	0.05	0.00	0.20	0.20
	Cleanup Program Site	Stockpile Sample	5	20	0.03	0.05	0.00	0.11	0.11
	Cleanup Program Site	Borehole	43	7	0.01	0.03	0.00	0.02	0.20
Orange	Cleanup Program Site	Borehole	5	40	1.14	2.55	0.00	5.70	5.70
	Cleanup Program Site	Remediation/Groundwater Monitoring Well	7	14	0.01	0.03	0.00	0.07	0.07
San Diego	Cleanup Program Site	Vapor Extraction Well	1	100	0.17	-	0.17	0.17	0.17
	Cleanup Program Site	Borehole	3	33	0.03	0.06	0.00	0.10	0.10
San Mateo	Cleanup Program Site	Stockpile Sample	1	100	12.00	-	12.00	12.00	12.00
	Cleanup Program Site	Transient Air Sample	2	50	0.10	0.14	0.10	0.20	0.20
	Cleanup Program Site	Remediation/Groundwater Monitoring Well	4	50	0.08	0.14	0.01	0.29	0.29
	Cleanup Program Site	Borehole	6	17	0.00	0.00	0.00	0.00	0.00

County	Site Type	Field Sampling Point Description	n	Percent Above DL [a]	Mean	Std Dev	Median	95 <sup>th</sup> Percentile	Max
	Cleanup Program Site	Transient Subsurface Sampling Point (i.e. direct-push)	2	50	0.00	0.00	0.00	0.00	0.00
Santa Cruz	Cleanup Program Site	Composite Sample	1	100	0.00	-	0.00	0.00	0.00

[a] DL = detection limit; a value is considered above DL if the PARVQ has a value of “=”; otherwise, a value is considered below DL. Below DL data (NDs) are reported as zeros in the original data. Summary statistics reported in this table are for the cases that “Percent above DL” is greater than 0; in other words, if all data points for a combination of county, site type, and field sampling point are below DL, the summary statistics are not reported here.