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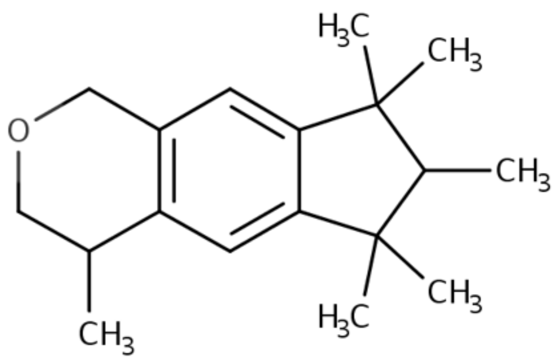
Draft Physical Chemistry, Fate and Transport, Environmental Release, and Environmental Exposure Assessment for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)

Technical Support Document for the Draft Risk Evaluation

CASRN 1222-05-5



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KEY ABBREVIATIONS AND ACRONYMS

7Q10	Lowest 7-day flow (on average) in a 10-year period
30Q5	Lowest 30-day flow (on average) in a 5-year period
ADD	Average daily dose
ADME	Absorption, distribution, metabolization, and excretion
ADR	Acute dose rate
BAF	Bioaccumulation factor
BSAF	Biota-sediment accumulation factor
BCF	Bioconcentration factor
CBI	Confidential business information

CDR	Chemical Data Reporting (rule)
ChemSTEER	Chemical Screening Tool for Exposures and Environmental Releases
COU	Condition of use
CT	Central tendency
CWNS	Clean Watershed Needs Survey
DEP	Diethyl phthalate
DOE	Department of Energy (U.S.)
DMR	Discharge Monitoring Report
DOC	Dissolved organic carbon
DTD	Down-the-drain
dw	Dry weight
ECHA	European Chemicals Agency
ECHO	EPA's Enforcement and Compliance History Online Database
E-FAST	Exposure and Fate Assessment Screening Tool
EPA	Environmental Protection Agency (U.S.)
EROM	Enhanced Runoff Method
ESD	Emission scenario document
EU	European Union
FCA	Fragrance Creators Association
FFDCA	Federal Food, Drug, and Cosmetic Act
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
GS	Generic scenario
HE	High-end
HHCB	1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran
HM	Harmonic mean
KABAM	K_{OW} (based) Aquatic BioAccumulation Model
K_{OA}	Octanol:air coefficient
K_{OC}	Organic carbon:water partition coefficient
K_{OW}	Octanol:water partition coefficient
K_p	Dermal permeability coefficient
LOD	Limit of detection
MDL	Method detection limit
MOE	Margin of exposure
NAICS	North American Industry Classification System
NESHAPS	National Emission Standards for Hazardous Air Pollutants
NPDES	National Pollutant Discharge Elimination System
OAQPS	Office of Air Quality Planning and Standards (EPA)
OCSPP	Office of Chemical Safety and Pollution Prevention (EPA)
OES	Occupational exposure scenarios
OECD	Organisation for Economic Co-operation and Development
OPP	Office of Pesticide Programs (EPA)
OPPT	Office of Pollution Prevention and Toxics (EPA)
OSHA	Occupational Safety and Health Administration (U.S.)
P95	95th Percentile
P50	50th Percentile
POTW	Publicly owned treatment works
PSC	Point Source Calculator
RCRA	Resource Conservation and Recovery Act
RIFM	Research Institute for Fragrance Materials

RIVM	National [Netherlands] Institute for Public Health and the Environment
RS	Release Scenario
SDS	Safety data sheet
SHEDS-HT	Stochastic Human Exposure and Dose Simulations-High Throughput
STP	Sewage treatment plant
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
TSD	Technical support document
UF	Uncertainty factor
U.S.	United States
WQP	Water Quality Portal
w/w	Weight by weight
ww	Wet weight
WWT	Wastewater treatment
WWTP	Wastewater treatment plant

SUMMARY

This technical support document (TSD) is part of the *Draft Risk Evaluation for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (also called the "draft HHCB risk evaluation") (see also public docket, EPA-HQ-OPPT-2018-0430) (U.S. EPA, 2026j), a fragrance ingredient in cleaning, laundry, and air care products. This TSD focuses on environmental exposure and includes a physical chemistry and fate and transport assessment (Section 2), an environmental release assessment (Section 3), and an environmental exposure assessment (Section 4).

HHCB is a colorless, viscous liquid with a strong musk odor at room temperature; it is a key ingredient in fragrances, commonly added to cleaning, laundry, and air care products. The synthetic musk is frequently distributed as Galaxolide. From 1 to 10 million pounds (lb) are domestically produced each year. HHCB is expected to be moderately persistent in surface water and sediments but not in outside air, especially if released during the day. It is expected to bind to soil, resulting in minimal leaching. HHCB has been shown to concentrate in fish, particularly non-edible tissues, and is present in human milk.

HHCB is released into the environment through surface water discharges, land disposal, and air emissions from industrial and commercial facilities. Releases to surface waters are expected to be mostly through down-the-drain disposal from commercial and consumer releases. Once released to surface water, HHCB is expected to bind to sediment, limiting exposure in the water column, but increasing exposure to sediment dwelling or sediment consuming organisms. Environmental concentrations for both surface water and sediment are evaluated in this draft TSD using available environmental monitoring data and through modeling of expected releases. Releases are evaluated for industrial releases, down-the-drain releases from both commercial and consumer releases, as well as their aggregation. Soil concentrations are calculated using reported monitoring data and modeling of land-applied biosolids. Available HHCB air monitoring data were reviewed, but due to its rapid degradation in this media, concentrations were not modeled.

Based on the available evidence, it is expected that populations of aquatic and terrestrial receptors will be exposed to environmental concentrations of HHCB. HHCB poses potential hazards from acute and chronic exposures to vertebrates, invertebrates, and algae in the water column (*e.g.,* aquatic organisms); chronic exposure to sediment-dwelling animals; chronic soil exposure to terrestrial invertebrates and terrestrial plants; and chronic dietary exposure to terrestrial mammals via trophic transfer (U.S. EPA, 2026i)

Physical Chemistry and Fate and Transport Assessment Summary

- HHCB is semi-volatile, susceptible to photolysis and not expected to persist in outdoor air.
- HHCB has low water solubility, does not hydrolyze, and degrades slowly via biotic processes (anaerobic and aerobic metabolism) under some environmental conditions. It partitions to sediment and bioaccumulates in aquatic biota and is metabolized to form more polar, excretable compounds. HHCB has been detected in surface water, sediments, soil, and aquatic tissues—consistent with fate and transport data. Overall, HHCB can persist for weeks to months in water leading to exposure and bioaccumulation in aquatic organisms.
- Wastewater treatment removes most HHCB via sorption to sludge; land application of treated sludge ("biosolids") can introduce HHCB to soils. Soil-dwelling organisms like earthworms can bioaccumulate HHCB from biosolid-amended soils, but plants do not. HHCB may persist for weeks to months in soil and anaerobic environments.

Environmental Release Assessment Summary

- Environmental concentrations were estimated for (1) industrial and down-the-drain (commercial and consumer) releases to surface water and sediment, (2) biosolid land application to soil, and (3) bioconcentration in aquatic organisms. Expected exposure pathways include surface water and sediment downstream of wastewater treatment (WWT) facility discharges and soil following biosolid application.
- HHCB is a Toxics Release Inventory (TRI)-reportable substance, but not reportable under the National Emissions Inventory (NEI) or Discharge Monitoring Report (DMR). Water release estimates were derived from 2023 TRI data and supplemented with standard modeling approaches.
- Based on TRI data in 2023, 3,331 kg (7,344 lb) of HHCB were released to publicly owned treatment works (POTWs) and 1,225 kg (2,700 lb) to (WWT) facilities from industrial uses.
- Industrial laundry has the highest per site daily releases among commercial uses, but other commercial and consumer products contribute more HHCB to POTWs overall because multiple use sites release to the same facility.

Environmental Exposure Assessment Summary

- A tiered assessment approach was used combining screening-level methods with more refined analyses, based on the evaluated population and relevant exposure pathways.
- Upper-bound environmental exposure concentrations were estimated for industrial and down-the-drain releases to surface water, sediment, and fish tissues. Land pathway exposures were considered and assessed using measured exposure concentrations in surface water because this assessment's conditions of use (COUs) under the Toxic Substances Control Act (TSCA) do not directly link to soil concentrations. Exposures in air were considered but not assessed due to both rapid HHCB degradation in air and the absence of air inhalation hazard effects.
- The highest potential HHCB exposure concentration estimated for screening occurred in surface water and sediment from combined (commercial + consumer) down-the-drain releases, though the high-end of this scenario is not widespread and depends on specific and rarely occurring conditions (Table S-1).
- The highest estimated fish tissue concentration used for screening was also from the combined (commercial + consumer) down-the-drain releases, though the high-end of this scenario is not widespread and depends on specific and rarely occurring conditions (Table S-1).
- Soil exposure concentrations estimated for screening were modeled from the highest measured biosolid concentration (Table S-1).

Table S-1. HHCB Conditions of Use, Release Media, Route of Exposure, and Upper Bound Estimated Environmental Exposure Concentrations or Doses Used in the Screening Risk Assessment

Screening Exposure Scenario	Release Medium	Pathway of Exposure	Upper Bound Estimated HHCB Concentration
Industrial Release (Highest) (Manufacturing/Domestic Manufacturing) [a]	Water	Surface water	0.57 µg/L
		Sediment	171 µg/kg
		Whole fish[a]	902 µg/kg
Combined Commercial Plus Consumer Down-the-Drain (P95 POTW) [b]		Surface water	25.4 µg/L
		Sediment	7,741 µg/kg
		Whole fish[a]	6,071 µg/kg
N/A	Biosolids	Soil[b]	1,629 µg/kg
		Earthworm[c]	58,644 µg/kg

[a] HHCB in large fish (1.0 kg) estimated using K_{OW} (based) Aquatic BioAccumulation Model) (KABAM) (U.S. EPA, 2009) with high-end surface water inputs and calculated within-fish metabolic transformation.
[b] Highest soil concentration modeled from highest reported biosolid concentration 554,000 µg/kg (Kinney et al., 2006).
[c] Highest earthworm concentration estimated using highest modeled soil concentration and highest reported earthworm bioaccumulation factor (36).

Overall, the Agency has moderate-to-robust confidence in the scenarios that represent potential upper-bound exposure concentrations for screening assessments in the draft HHCB risk evaluation.

1 INTRODUCTION

This technical support document (TSD) presents the draft environmental exposure assessment, also referred to as the "draft HHCB environmental exposure TSD," part of the TSCA *Draft Risk Evaluation for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (see also public docket, EPA-HQ-OPPT-2018-0430) (U.S. EPA, 2026j). A basic diagram of the draft HHCB risk evaluation is shown Figure 1-1, with this TSD shaded blue. This TSD focuses on environmental exposure and includes three supporting assessments: (1) physical chemistry and fate and transport (Section 2), (2) environmental release (Section 3), and (3) environmental exposure (Section 4). The accompanying HHCB TSDs share underlying models and assumptions; overlaps are noted and not redundantly detailed across multiple TSDs.

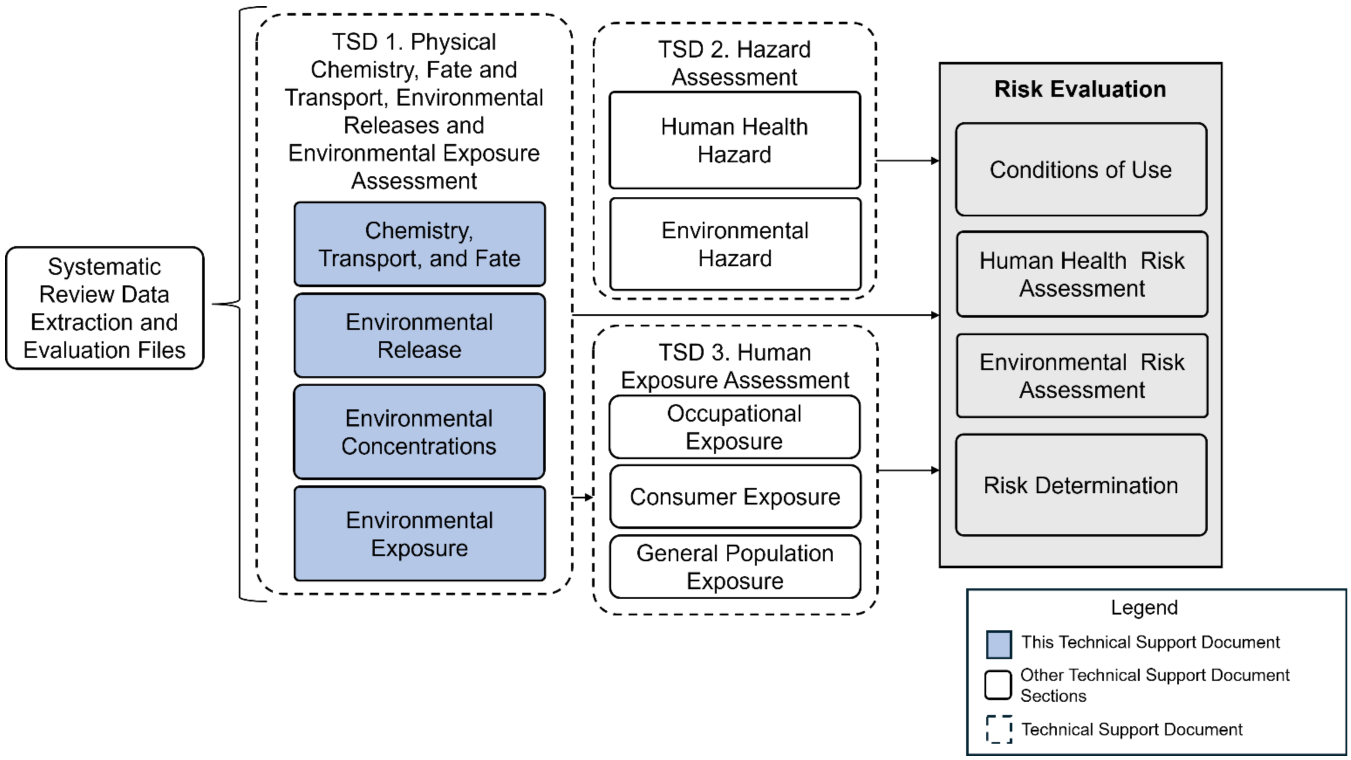

Figure 1-1. Draft HHCB Risk Evaluation Document Map

1.1 Conditions of Use

Between 1 and 10 million pounds (lb) of HHCB are produced annually in the United States (see U.S. EPA (2020a) for further detail}). It is primarily imported for processing into air care, cleaning, laundry, dishwashing and plastic products, and can also be incorporated into fragrance oils sold directly to consumers. HHCB-containing products are regulated under the TSCA, the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), and the Federal Food, Drug, and Cosmetic Act (FFDCA). EPA's Office of Pesticide Programs (OPP) oversees products making pesticidal claims that contain HHCB, while personal care products that contain HHCB are overseen by the U.S. Food and Drug Administration. In this assessment, these are termed "other sources of HHCB."

Table 1-1 presents the COUs under TSCA that are subject to risk evaluation, updated with information submitted to the Agency after the publication of the *Final Scope of 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-Hexamethylcyclopenta[γ]-2-Benzopyran (HHCB; CASRN 1222-05-5) as a High-Priority Substance for Risk Evaluation* (also called the "final scope document for HHCB") (U.S. EPA, 2020b).

533 **Table 1-1. Conditions of Use Table**

Life Cycle Stage	Category	Subcategory
Manufacturing	Domestic manufacturing	Domestic manufacturing
Manufacturing	Importing	Importing
Processing	Incorporation into formulation, mixture or reaction product	Odor agent in: All other chemical products and preparation manufacturing; Miscellaneous manufacturing; Soap, cleaning compound, and toilet preparation manufacturing; other: Fragrance mixtures and fragrance raw materials
Processing	Incorporation into articles	Odor agent in: Plastic materials and resin manufacturing
Processing	Repackaging	Odor agent in: All other chemical product and preparation manufacturing
Processing	Recycling	Recycling
Distribution in commerce	Distribution in commerce	Distribution in commerce
Commercial use	Air care products	Air fresheners for motor vehicles
Commercial use	Air care products	Continuous action air fresheners
Commercial use	Air care products	Instant action air fresheners
Commercial use	Cleaning and furnishing care products	All-purpose foam spray cleaner; All-purpose liquid cleaner/polish; All-purpose liquid spray cleaner; All-purpose waxes and polishes; Appliance cleaners; Drain and toilet cleaners (liquid); Powder cleaners (floors); Powder cleaners (porcelain)
Commercial use	Laundry and dishwashing products	Laundry detergent (liquid); Laundry detergent (unit dose/granule); Fabric enhancers; Stain removers; Dishwashing detergent (liquid/ gel); Dishwashing detergent (unit dose/granule); Dishwashing detergent liquid (hand-wash)
Commercial use	Plastic and rubber articles not covered elsewhere	Plastic and rubber articles
Commercial use	Other use Laboratory Chemicals	Laboratory chemicals
Consumer use	Air care products	Air fresheners for motor vehicles
Consumer use	Air care products	Continuous action air fresheners
Consumer use	Air care products	Instant action air fresheners
Consumer use	Cleaning and furnishing care products	All-purpose foam spray cleaner; All-purpose liquid cleaner/polish; All-purpose liquid spray cleaner; All-purpose waxes and polishes; Appliance cleaners; Drain and toilet cleaners (liquid); Powder cleaners (floors); Powder cleaners (porcelain)

Life Cycle Stage	Category	Subcategory
Consumer use	Laundry and dishwashing products	Laundry detergent (liquid); laundry detergent (unit dose/granule); fabric enhancers; stain removers; dishwashing detergent (liquid/gel); dishwashing detergent (unit dose/ granule); dishwashing detergent liquid (hand-wash)
Consumer use	Plastic and rubber products not covered elsewhere	Plastic and rubber articles
Consumer use	Chemical substances in treatment products	Ion exchangers; Liquid water treatment products; solid powder water treatment products
Disposal	Disposal	Disposal

1.2 Source Data and Evaluation

EPA applies best available science using a weight-of scientific evidence approach (see *Draft Systematic Review Protocol for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran [HHCB]*) (U.S. EPA, 2026l). Data used in this exposure assessment were identified through a search for sources with relevant information on HHCB. These sources were evaluated per the strategies laid out in the *Draft Systematic Review Protocol Supporting TSCA Risk Evaluations for Chemical Substances, Version 1.0: A Generic TSCA Systematic Review Protocol with Chemical-Specific Methodologies* (U.S. EPA, 2021). The documentation of the evaluation of these sources is included in the following supplemental documents for the draft HHCB risk evaluation (package):

- *Draft Data Quality Evaluation and Data Extraction Information for Physical and Chemical Properties for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026f)
- *Draft Data Quality Evaluation and Data Extraction Information for Environmental Fate and Transport for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026d)
- *Draft Data Quality Evaluation and Data Extraction Information for Environmental Release and Occupational Exposure for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026e)
- *Draft Data Quality Evaluation Information for General Population, Consumer, and Environmental Exposure for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026g)
- *Draft Data Extraction Information for General Population, Consumer, and Environmental Exposure for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026c)

Generally, sources with data quality ratings of medium or higher were considered; however, lower scoring sources are considered and were used and noted in rare cases. Additionally, relevant data that may have been submitted directly to the Agency, submitted to the docket during public comment periods, or identified through internet searches were considered.

2 PHYSICAL CHEMISTRY AND FATE AND TRANSPORT ASSESSMENT

2.1 Background

This section outlines the approach and methods, summarizes key findings on chemical properties and transport behavior, and presents the overall weight of scientific evidence conclusions.

2.2 Approach and Methodology

As described in Section 1.2, high-quality studies were used when selecting physical and chemical properties. Medium- and high-quality studies were also considered for selecting transport and fate characteristics as not all parameters had reasonably available, high-quality studies.

2.3 Physical and Chemical Properties

HHCB is a colorless viscous liquid with a strong musk odor at room temperature. Sometimes referred to as Galaxolide, the synthetic musk consists of four diastereomers (*i.e.*, an isomer that differs in the spatial arrangement of atoms in the molecule but is not a mirror image). Two (-)/4S isomers (4S, 7R & 4S, 7S) have the characteristic odor, and the other two (+)/4R isomers (4R, 7R & 4R, 7S) have little to no odor (see Figure 2-1). HHCB is on the TSCA Inventory with CASRN 1222-05-5. In addition, Galaxolide is often combined with diethyl phthalate (DEP) to enhance fragrance longevity and serve as a fixative. The mixture of isomers or combination with diethyl phthalate can affect some physical and chemical properties. Information for every endpoint on whether it is a mixture or a neat compound is not available.

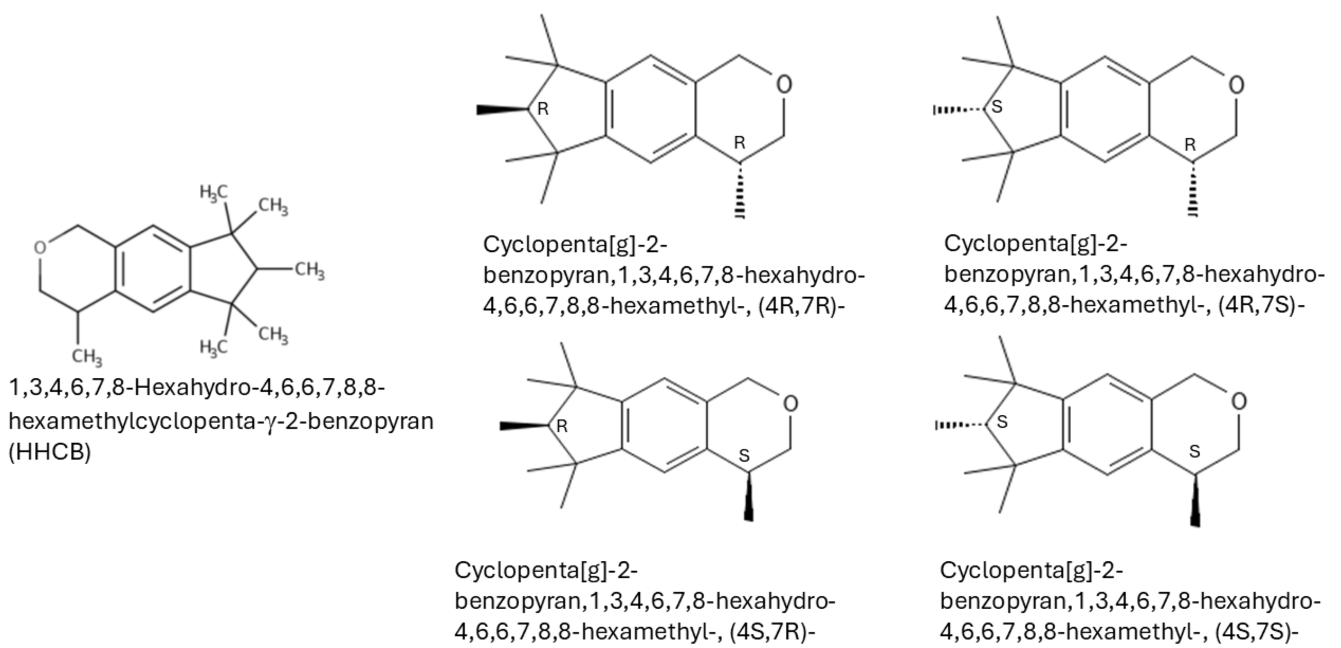

Figure 2-1. HHCB Isomers: Chemical Structure Noting Chiral Centers

Table 2-1 provides information on selected physical and chemical properties based on reported values available through 2019. These properties are mostly consistent with those presented in the final scope document (U.S. EPA, 2020b); however, water solubility and vapor pressure have been updated with information submitted to the Agency during the public comment period and through stakeholder engagement. Key properties are described in the subsections below. Results of assessment of HHCB through EPISuite™ are provided in 0.

Table 2-1. Selected Physical and Chemical Properties for HHCB

Property	Value[a b]	Reference	Data Quality Rating
Molecular formula	$C_{18}H_{26}O$	N/A	N/A
Molecular weight	258.41 g/mol	N/A	N/A
Physical state	Viscous liquid	(NLM, 2018)	High
Physical properties	Colorless, strong musk odor	(NLM, 2018)	High
Melting point	Less than or equal to −20 °C	(IFF, 2009)	High
	57–58 °C	(U.S. EPA, 2019a)	High
Boiling point	325 °C	(U.S. EPA, 2019a)	High
Density	1.0054 g/cm^3 at 20 °C	(O'Neil et al., 2013)	High
Vapor pressure	5.45×10^{-4} mm Hg at 25 °C	(MacGillivray, 1996)	High
	1.99×10^{-3} mm Hg at 47 °C	(Wootitunthipong and Chickos, 2019)	High
Water solubility	1.75 mg/L at 25 °C	(Edwards, 1996)	High
Octanol/water partition coefficient (log K_{OW})	5.9 (unitless)	(U.S. EPA, 2019c)	High
Henry's Law constant	1.06×10^{-4} atm·m^3/mole at 25 °C	(U.S. EPA, 2012)	High
Viscosity	12,914 cP	(NLM, 2018)	High
Refractive index	1.5342	(O'Neil et al., 2013)	High

cP = centipoise
[a] Measured unless otherwise noted
[b] Composition of tested substance is not always provided in the study and can result in wide variation in value.

2.3.1 Physical State

HHCB is a viscous liquid (NLM, 2018). The systematic review identified two sources on physical state; because only one (National Library of Medicine) was rated high quality, the Agency selected viscous liquid as the physical state.

2.3.2 Physical Properties

Two high-quality studies describe HHCB as colorless; one notes a strong musk odor. The Agency selected clear, colorless liquid with a strong musk odor as the physical description with high confidence based on concordance with other regulatory sources (NLM, 2018).

2.3.3 Melting Point

Six high-quality studies assessed HHCB melting point, either as a pure isomer or mixture of isomers (*i.e.*, as Galaxolide). For the pure isomer, the reported melting point varied (≤ −20 to 0 °C). The Agency selected less than or equal to −20 °C based on a modified OECD (Organisation for Economic Co-operation and Development) Guideline 102 study (IFF, 2009). For isomer mixtures, high-quality studies consistently report a melting point range of 57 to 58 °C. The Agency selected this range, with high confidence given concordance across sources.

2.3.4 Boiling Point

Six high-quality studies report HHCB boiling points at 760 mmHg ranging from 318.6 to 325 °C. The Agency selected 325 °C based on inclusion in a peer-reviewed and recognized database (PHYSPROP) (U.S. EPA, 2019a). Because it is not clear whether this represents pure HHCB or an isomer mixture, confidence is moderate.

One high-quality study reports a boiling point of 129 °C at 0.8 mm Hg. Given the single source, the confidence is moderate.

2.3.5 Density

Four high-quality studies reported densities of 1.0054 and 1.015 g/cm^3. The Agency selected 1.0054 g/cm^3 based on consensus across sources and inclusion in a peer-reviewed and recognized database (PHYSPROP), with high confidence (O'Neil et al., 2013).

2.3.6 Vapor Pressure

Several high-quality studies report HHCB vapor pressure of 0.019 to 0.082 Pa (1.4×10^{-4} to 6.1×10^{-4} mmHg). An OECD Guideline 104 study (MacGillivray, 1996) determined 0.0727 Pa (5.45×10^{-4} mmHg) at 25 °C, consistent with most other high-quality studies. A non-guideline study conducted by Okeme (2020) reported 0.0380 to 0.0562 Pa (2.85×10^{-4} to 4.22×10^{-4} mmHg). These values indicate low volatility under typical environmental conditions. The OECD value was selected with high confidence.

A high-quality, non-guideline study conducted by Wootitunthipong (2019) estimated 0.265 Pa (1.99×10^{-3} mm Hg) at 47 °C. Because this is a single, estimated non-guideline study, the Agency has moderate confidence.

2.3.7 Water Solubility

HHCB water solubility is low and decreases slightly with increasing pH. An OECD 105 Guideline shake-flask study (Edwards, 1996) reported 1.99 mg/L (pH 5), 1.65 mg/L (pH 7), and 1.60 mg/L (pH 9). The value selected for this evaluation is the overall average, 1.75 mg/L, reflecting typical pH variability in surface water. Other high-quality studies report a range of 1.26 to 2.09 mg/L, consistent with this selection, giving the Agency high confidence in the selected value.

2.3.8 Octanol/Water Partition Coefficient (Log K_{OW})

The Agency selected an octanol/water partition coefficient (log K_{OW}) of 5.9 based on consistent findings for several high-quality studies conducted using OECD Test Guideline 117 (U.S. EPA, 2019c). Confidence in this value is high.

2.3.9 Viscosity

The Agency identified two database entries reporting a viscosity of 12,914 cP (centipoise) and has high confidence in this value, as it is reported by the National Library of Medicine, which is a trusted source (NLM, 2018).

2.3.10 Refractive Index

The Agency identified four database entries for the refractive index; the most common value was 1.5342. Although lower values (<1.5) have been reported for pure HHCB, those studies were not found via systematic review. The Agency selected 1.5342 based on its prevalence in trusted sources (*e.g.,* National Library of Medicine) (O'Neil et al., 2013).

2.4 Environmental Transport and Fate Characteristics

Table 2-2 provides the selected fate and transport parameters for the draft risk evaluation based on reported values available through March 2025. Subsequent subsections describe each parameter and its selection rationale, followed by a discussion of HHCB fate across environmental media.

Table 2-2. Selected Environmental Transport and Fate Characteristics

Property or Endpoint	Value[a]	Reference(s)	Data Quality Rating
Direct photodegradation	Half-life ($t_{1/2}$) = 3.7 hours	(U.S. EPA, 2008)	Medium
Indirect photodegradation	Half-life ($t_{1/2}$) = 10.9 hours based on ·OH reaction rate constant of 2.71×10^{-11} cm^3/molecules·second	(Li et al., 2018)	High
Hydrolysis	Stable; HHCB is not expected to hydrolyze in the environment because its structure lacks hydrolytically labile functional groups	(NLM, 2018); (OECD, 2009a)	Not Rated
Biodegradation	Stable; 0% at 28 days CO_2 evolution test (OECD test guideline 301 B) (aerobic water)	(U.S. EPA, 2008)	High
Field degradation study	Half-life ($t_{1/2}$) = 140–144 days in biosolid amended soils	(DiFrancesco et al., 2004)	High
Removal in wastewater treatment	92% total removal (0.8% by biodegradation, 91% by sludge and 0.1% by volatilization to air; estimated) [b]	(U.S. EPA, 2012)	Not Rated
	Between 50% and >95% during biological wastewater treatment and removal	(Clara et al., 2011)	High
Bioconcentration factor	1,584 L/kg (whole fish, ww) bluegill (*Lepomis macrochirus*) OECD Test guideline 305E	(NLM, 2018) citing (Balk and Ford, 1999)	High
	1,624 L/kg (ww); 33,200 L/kg (lipid) zebrafish, (OECD Test guideline 305E	(ECB, 2008b) citing (Butte and Ewald, 1999)	High
Bioaccumulation factor	52,370 L/kg (crucian carp) 66,030 L/kg (common carp) 39,400 L/kg (silver carp)	(Hu et al., 2011a)	High
Soil organic carbon:water partition coefficient (log K_{OC})	4.85 (19% Organic Content)	(RIVM, 1997)	High
	3.6–3.9	(ECB, 2008b) citing (Muller et al., 2002)	Not Rated
	3.8	(ECB, 2008b) citing (Artola-Garciana, 2002)	Not Rated

Property or Endpoint	Value[a]	Reference(s)	Data Quality Rating
[a] Measured unless otherwise noted [b] EPI Suite™ physical property inputs: log K_{OW} = 5.90, boiling point = 325 °C, melting point = −5 °C, vapor pressure = 0.000545 mmHg, water solubility = 1.75 mg/L, biodegradation half-life (in hours) in the primary clarifier of a sewage treatment plant (STP; BioP) = 10,000, biodegradation half-life (in hours) in the aeration vessel of an STP (BioA) = 10,000 and biodegradation half-life (in hours) in the final settling tank of an STP (BioS) = 10,000, Simplified Molecular-Input LineEntry System (SMILES): O(CC(c(c1cc(c2C(C3C)(C)C)C3(C)C)c2)C)C1			

2.4.1 Photolysis

HHCB undergoes direct and indirect photolysis. Two studies report atmospheric half-lives of 3.7 h for direct photolysis (U.S. EPA, 2008) and 3.4 hours via hydroxy radical (·OH) oxidation (2001). The longer half-life (3.7 h) was selected as conservative. These values indicate HHCB is not persistent in air, especially during daylight; and the concordance supports high confidence in the selection.

HHCB reacts with hydroxyl radicals at K_{OH} of 2.71×10^{-11} $cm^3 \cdot molecule^{-1} \cdot sec^{-1}$ with a half-life of 10.9 hours (Li et al., 2018), indicating longer persistence for nighttime releases but overall is nonpersistent. Confidence in these values is moderate as it is from a single study.

2.4.2 Hydrolysis

HHCB lacks hydrolyzable functional groups and is not expected to undergo hydrolysis OECD (2009a). An OECD guideline study reports no transformation over 28 days (U.S. EPA, 2008). No additional studies were identified. These findings indicate HHCB will not hydrolyze in water. There is high confidence in this determination.

2.4.3 Aerobic Biodegradation

Five sources on aerobic biodegradation show variable results. A modified OECD 301B study reported 0% degradation at 28 days (Balk and Ford, 1999). A river water study reported substantial loss (60% degraded; $t_{1/2}$ ≈100 hours after (ECB, 2008a)). A river die-away showed 8.8% at 5 hours to 92.17% at 28 days (Schaefer, 2005). These data indicate aerobic biodegradation can occur under some conditions but is highly system dependent. For a conservative (worst-case) assessment, HHCB was assumed stable (no biodegradation), a choice the Agency supports with high confidence given alignment with other regulatory assessments.

2.4.4 Anaerobic Biodegradation

Several studies indicate HHCB is not readily biodegradable under anaerobic conditions and can persist in soil for more than 60 days. HHCB presence in soil is likely from land application of biosolids from wastewater facilities. Soil studies show concentrations can decrease by up to 90% after 1 year (DiFrancesco et al., 2004).

A microcosm study with oak forest, agricultural, and biosolids-amended agricultural soils found HHCB decreased to 7, 9, and 35% of initial concentration, respectively, after 1 year (average 14%); thin layer chromatography indicated formation of more polar metabolites, and unrecovered radiolabeled was hypothesized to be covalently bound to soil organic compounds (*i.e.*, was immobilized by humification (IFF, 1998)).

DiFrancesco (2004) conducted a 1-year die-away study in four soils (sandy agricultural soil, silty agricultural soil, clayey soil, and highly weathered oxide-rich soil), with and without spiking.

Anaerobically digested, dewatered sludge (100% domestic sewage; 10% solids) from a Georgetown, Delaware, wastewater treatment plant (WWTP) contained 86 mg/kg and 38 mg/kg HHCB (dw). Initial HHCB spiked soil ranged from 5.5 to 13 mg/kg soil; unspiked soils contained 0.1 to 0.27 mg/kg. Concentrations declined rapidly: 30 to 90% of initial concentration after 1 month and 8 to 60% after 90 days. HHCB in frozen soil was stable over months. After 1 year, residues of HHCB were less than 10 to 14% of initial concentration. Dissipation was faster in the soils with lower organic matter. Losses likely included biotransformation and to a lesser extent, volatilization, and leaching.

Studies collectively show that HHCB persists in soils, remaining at low levels after 1 year. Unfrozen soil half-lives consistently exceed 60 days (DiFrancesco et al., 2004). Repeated land application of biosolids can extend the presence of HHCB in soils. As a result, locations with repeated land application of biosolids containing HHCB will consistently have HHCB present at those locations. EPA selected a half-life of 140 to 144 days, with high confidence, reflecting slow degradation across multiple studies.

In sediments, a single study was identified for anaerobic biodegradation that was determined to be uninformative because there was insufficient evidence presented to confirm that parent compound disappearance was not likely due to some other process (*i.e.*, volatilization). Accordingly, the Agency uses a 9,999-day half-life at 25 °C for modeling sediment concentrations. This high, conservative value represents a worst-case scenario; at this half-life, the model effectively treats the chemical as stable (*i.e.,* not subject to degradation).

2.4.5 Soil Organic Carbon:Water Partition Coefficient (Log K_{OC})

Three Log K_{OC} values were identified: 4.85 from a high-quality RIVM (National [Netherlands] Institute for Public Health and the Environment) study in sludge-amended material with high organic content (19%; typical soils contain 0.5% and 5%) (RIVM, 1997), and 3.6 and 3.9 from the European Chemicals Agency (ECHA) dossier (ECB, 2008b). These values indicate strong sorption to soils and sediments. EPA has high confidence in this conclusion.

2.4.5.1 Partitioning

A Level III fugacity model from EPI Suite™ was used to estimate HHCB partition among air, water, soil and sediment). The models assume steady state (not equilibrium) and no chemical transformation. The results are shown below in Figure 2-2.

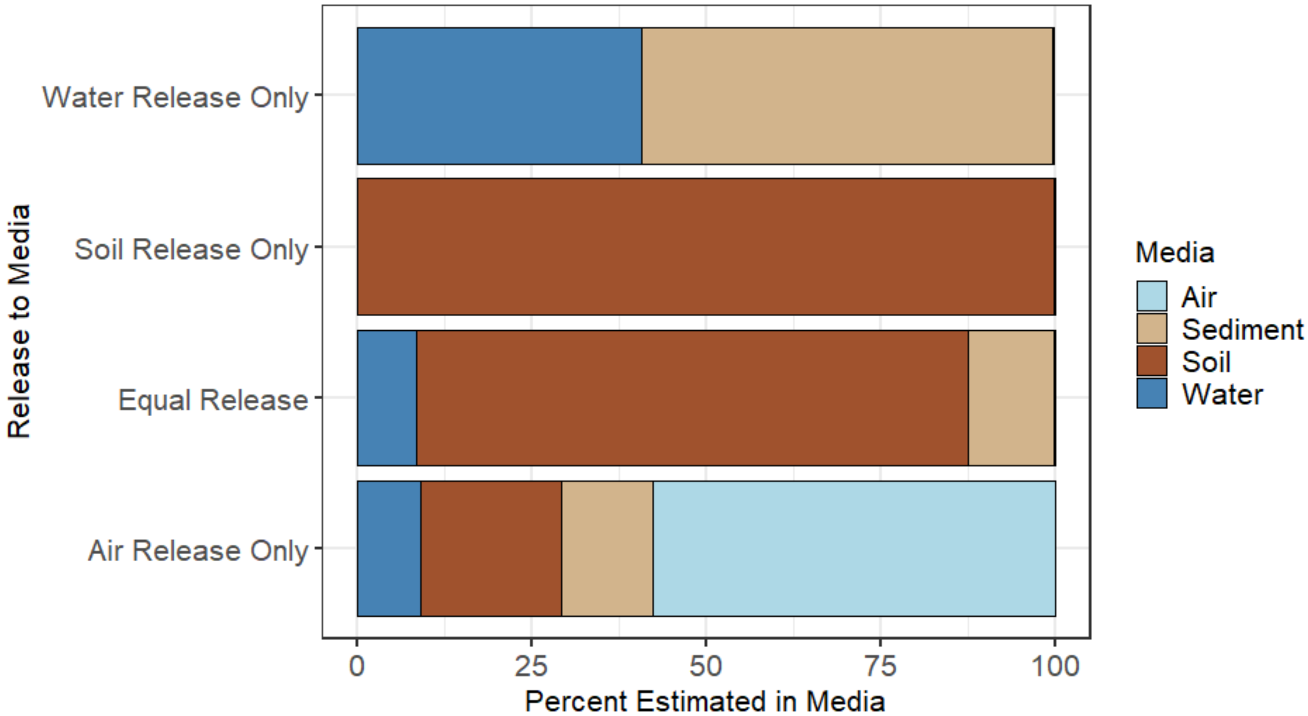

Figure 2-2. Distribution of HHCB in Air, Sediment, Soil, and Water Based on Media of Release According to Level III Fugacity Modeling from EPI Suite™

With equal releases to all media, the model predicts HHCB predominately partitions to soil (dark brown), with lesser amounts in sediment (light brown) and water (dark blue). For soil-only releases, HHCB remains in soil due to strong sorption. For water-only releases, HHCB partitions between water and sediment, with a slight preference to sediment (consistent with low solubility (1.75 mg/L) and log K_{OC} (3.6–4.5). HHCB's density (1.0054 g/cm^3 at 20 °C) may result in the chemical floating on water. For air-only release, HHCB partitions to air (57.8%), with smaller amounts partitioning to soil (20.3%), sediment (13%), and water (8.95%). However, rapid photolysis limits persistence aloft. These results (Figure 2-2) are based on steady-state level III fugacity simulation and are screening-level indicators of multimedia distributions; confidence in the use of EPI Suite™ for HHCB fugacity modeling is high.

2.4.6 Wastewater Removal

Due to low water solubility (1.75 mg/L) and high Log K_{OW} (5.9), HHCB is readily removed from wastewater via sorption. Between 50 and 95% is typically removed by sorption sludge (Table 2-2), with some remaining in effluent. The wide range in this removal efficiency reflects variability in wastewater treatment facility size, served population, treatment technologies, and sludge organic content. Reported activated-sludge half-lives are 69 hours at 5 µg/L and 10 hours at 25 µg/L (lower concentrations persist longer), respectively (OCSPP, 2014; Schaefer and Koper, 2009). The geometric mean of the half-life is 22.5 hours, indicating "moderate-to-slow" biodegradation (OCSPP, 2014). For modeling purposes, 92% removal is assumed based on empirical data representing treatment technologies commonly used.

2.4.7 Bioaccumulation and Bioconcentration

2.4.7.1 Aquatic Bioaccumulation and Bioconcentration in Fish Species

Bioaccumulation metrics (bioaccumulation [BAF], bioconcentration [BCF], and biota-sediment accumulation factors [BSAF]) vary widely by study type (guideline vs. wild catch), species, and water body. For the draft HHCB risk evaluation, an OECD Guideline BCF of 1,584 L/kg was selected as representative given its regulatory use and alignment with international standards. The Agency has high confidence in this value. However, the Agency also recognizes the extensive variation in potential accumulation factors (ranging from 624 L/kg wet weight [ww] in zebrafish to 66,030 L/kg common carp (see Table 2-2). Additional characterization is needed to explain the substantial differences in these values and is provided below and in greater detail in Section 4.3.3.

Several OECD guideline studies have evaluated fish BCF but to different ends. As mentioned above, one OECD Test guideline 305E demonstrates a BCF of 1,584 L/kg in bluegill (*Lepomis macrochirus*) NLM (2018) citing Balk and Ford (1999). A separate OECD Guideline 305 E flow-through fish test conducted in 1996 exposed 220 bluegill for 28 days (Van Dijk, 1996), preceded by a 5-day toxicity pre-test at 0.91 µg/L and 8.84 µg/L. Although the results of this test do not substantially differ from a BCF of 1,584 L/kg, but demonstrate some variability with a BCF of 1,635 L/kg and 1,618 L/kg at 0.91 µg/L and 1,613 L/kg and 1,550 L/kg at 8.84 µg/L. In addition, Van Dijk (1996) partitioned non-edible fractions (*e.g.,* viscera, gills) from edible fractions (muscle). The non-edible fractions had approximately 4 times higher BCFs than edible fraction (muscle) (see Table 2-3), suggesting lower HHCB levels in fillet relative to viscera and gills.

Table 2-3. BCF by Dose in an OECD Guideline 305E Study (Van Dijk, 1996)

Dose	Overall BCF (L/kg)	Edible Fraction (L/kg)	Non-Edible Fraction (L/kg)
0.91 µg/L	1,635, 1,618	498	2,175
8.84 µg/L	1,613, 1,550	546	2,507

Schreurs (2004) measured HHCB in zebrafish exposed to 25.8 and 258 µg/L. After 96 hours, fish tissues contained 18.9 and 135 mg/kg (fresh weight), respectively. Control tanks without fish had water concentrations roughly an order of magnitude higher than tanks with fish, indicating zebrafish acted as net sinks for HHCB.

Fromme (1999) conducted a non-guideline study with wild caught eels in Germany, reporting mean ± 1SD (standard deviation) concentrations of 0.091 ± 0.074 mg/kg (n = 74) in waters with low effluent discharges and 1.364 ± 0.912 mg/kg (n = 48) in waters with high effluent discharges. These results indicate there is a potential for higher HHCB tissue concentrations in eels downstream of wastewater treatment facility discharges.

Table 2-4 summarizes HHCB concentrations in fish and other aquatic species in the United States. Species inhabiting sediment-laden water (*i.e.*, catfish, perch, and carp) tend to have higher concentrations; species with higher lipid content (*i.e.*, eels) also show elevated levels. The highest fish tissue concentration was 2,100 µg/kg and mean of 1,800 µg/kg (n = 6) for common carp found in Phoenix, Arizona, in wastewater effluent dominated streams (Ramirez et al., 2009). In contrast, aquatic mammals (*e.g.*, otters, dolphins) generally have lower concentrations than fish potentially due to differing primary exposure pathways. Mammal exposure is primarily dietary, whereas fish uptake HHCB via their gills and diet, with gills likely representing a primary pathway relative to dietary uptake for HHCB (Appendix G). HHCB is metabolized to more polar HHCB-lactone, which is eliminated through depuration (Schneider et al., 2021) and is predicted to be less toxic than HHCB to algae, daphnia, and fish (Su et al., 2023).

Table 2-4. Species and Concentration in Tissues for Sampling Events in the United States

Species	Year(s)	n	Location	HHCB Concentration (µg/kg)	Reference
Lipid weight					
White perch (liver)	2006	3	Troy, NY Albany, NY Catskill, NY	6.27–19.9 7.58–22.5 13.7–27.9	(Reiner and Kannan, 2011)
Channel catfish (liver)		3 1	Troy, NY Catskill, NY	11.1–39 <1	
Smallmouth bass (liver)		3 3 3	Troy, NY Albany, NY Catskill, NY	<1–11.1 1–31.9 <1	
Largemouth bass (liver)		1 1	Albany, NY Catskill, NY	10.9 8.22	
White catfish (liver)		1 1	Albany, NY Catskill, NY	6.56 5.79	
Brown bullhead (liver)		3	Catskill, NY	<1–51.1	
Zebra mussel		4	Catskill, NY	10.3–19.3	
American eel (whole body)		1	Catskill, NY	125	
Shrimp, wild caught Shrimp, farm raised	2006	6 3	US US	330 max 424 max	(Sapozhnikova et al., 2010)
Tissue concentration					
Largemouth bass	2006	6	Chicago, IL	1,200 mean 1,800 max	(Ramirez et al., 2009)
Smallmouth buffalo fish		6	Dallas, TX	800 mean 1,800 max	
Bowfin		6	Orlando, FL	100 mean 300 max	
Common carp		6	Phoenix, AZ	1,800 mean 2,100 max	
White sucker		6	West Chester, PA	1,800 mean 2,000 max	
Wet weight					
Sea otter (liver)	1993–1999	8	Monterey Bay, CA	<1–3.2	(Kannan et al., 2005)
Harbor seal (liver)	1996–1997	3	Central CA coast	4.4–5.5; 4.8 mean	
California sea lion (liver)	1993–1996	3	Central CA coast	1.5–4.4; 2.8 mean	

Species	Year(s)	n	Location	HHCB Concentration (µg/kg)	Reference
River otter (liver)	1997	3	Central CA coast	2.4–3.0; 2.8 mean	(Kannan et al., 2005)
Bottlenose dolphin (blubber)	1994–2000	4	FL coast	4.2–20.5; 12 mean	
Striped dolphin (blubber)	1995–1997	3	FL coast	8.1–25; 14 mean	
Pygmy sperm whale (blubber)	2000	1	FL coast	6.6	
Atlantic sharpnose shark (liver)	2004	3	FL coast	4.6–5.2; 4.8 mean	
Smallmouth bass (liver)	2003	3	NY	4.3–5.4; 4.8 mean	

2.4.7.2 Terrestrial Bioaccumulation and Bioconcentration Data

HHCB has also been detected in terrestrial and semi-aquatic species, including earthworms, minks, and ducks, generally at lower tissues concentrations than in fish and other aquatic organisms. Kannan (2005) reported liver mean concentration of 3.7 µg/kg in mink, 3.7 µg/kg in common merganser, 2.7 µg/kg in mallard, and 2.3 µg/kg in greater and lesser scaup. These species are closely associated with aquatic environments, suggesting HHCB exposure occurs primarily via aquatic dietary pathways.

Earthworms were found to contain HHCB in their tissues. Kinney (2006) surveyed sites with and without biosolid and manure amended soils and reported unamended soils had detections levels ranging from below the limit of detection (LOD) to 61 µg/kg; biosolid-amended soils had 3,340 µg/kg and 131 µg/kg (31 days and 156 days post-application), and manure-amended soils had less than the LOD to 49 µg/kg. These results indicate HHCB is bioavailable to soil-dwelling organisms, particularly where wastewater-derived biosolids are applied.

Plant uptake data for HHCB are limited. Given its hydrophobicity and strong sorption to soil organic matter, uptake and translocation are expected to be minimal, with residues primarily in the rhizosphere. Macherius (2012) found the highest concentration in carrots peel and a total-plant BCF of 0.86. Fernandes (2022) observed some translocation in pea plants grown in biosolid-amended soils, with average BCF in the shoots 0.02 and 0.003 in edible peas. These BCFs are much lower than those in aquatic organisms, indicating limited uptake and a low potential for substantial exposure via consumption.

The Agency's confidence in these values is moderate because the underlying monitoring data did not quantify external exposure concentrations for the organisms evaluated.

2.5 Overall Chemistry, Transport, and Fate Summary and Weight of Scientific Evidence

HHCB is a nearly colorless, viscous liquid with a pungent odor. It is not expected to be volatile or persistent in air. Air monitoring data are limited, but studies report low concentrations (<5 ng/m^3) or non-detects. More information can be found on HHCB air monitoring in Appendix D.

HHCB has been detected in surface water, sediments, soil, and biota, typically, downstream of wastewater treatment (POTW) discharges. It has low water solubility (1.75 mg/L) and moderate sorption (log K_{OC} 3.6–4.85), favoring partitioning to sediments. Reported sediment concentrations range from 33 to 6,860 μg/kg. HHCB is moderately bioaccumulative (BCF = 1,584 L/kg), with higher levels found in the non-edible fractions (gills, liver) than in muscle/fillet. In fish, HHCB is metabolized to HHCB-lactone and subsequently excreted. HHCB does not readily biodegrade in aerobic aquatic conditions.

Wastewater facilities can remove up to 95% of HHCB by sorption to sludge; nevertheless, downstream sampling indicates HHCB can remain in effluents and be discharged to surface water. HHCB is not readily biodegradable in surface water and can persist. Dredge and land application of sludge as biosolids may contaminate soils; under anaerobic conditions, HHCB degrades slowly and may persist for more than 60 days. Some leaching to groundwater is possible; but migration is limited by sorption-driven retardation. Earthworms can bioaccumulate HHCB, with little evidence of trophic transfer to higher organisms, as summarized within Section 4.3.3.

This assessment integrates multiple lines of evidence to characterize HHCB transport and fate, including physical and chemical properties, measured data from peer-reviewed studies, and available monitoring data. Inter-study consistency and individual study quality were evaluated; where discrepancies occurred, methodological differences were examined and protective endpoint values selected. Overall, this approach provides a robust basis for the draft HHCB risk evaluation (U.S. EPA, 2026j).

3 ENVIRONMENTAL RELEASE ASSESSMENT

3.1 Background

HHCB is released into the environment through surface water discharges, land disposal, and air emissions. For this draft TSD and HHCB risk evaluation, only surface water discharges were considered as HHCB does not persist in air and, though persistent in soils and groundwater, is not expected to be mobile in these media (see Section 1.2).

To analyze HHCB releases to surface water, 16 Release Scenarios (RSs) were identified and assessed. Table 3-1 maps 22 COUs to all 16 RSs. RSs are developed based on similarities and differences in release potential and the availability of data and modeling approaches for the release assessment. The RSs are the same as occupational exposure scenarios (OESs), which are developed based on similarities and differences in occupational exposure potential and the availability of data and modeling approaches for the occupational exposure assessment, except in one scenario as noted in the table.

Table 3-1. Crosswalk of COUs Listed in the Draft Risk HHCB Evaluation to Assessed RSs/OESs

COU			Release Scenarios (RSs)/ Occupational Exposure Scenarios (OESs)
Life Cycle Stage	**Category**	**Number and Subcategory**	
Manufacturing	Domestic manufacturing	(1) Domestic manufacturing	(1) Manufacturing (Section 3.3.1)
	Importing	(2) Importing	(2) Repackaging (Section 3.3.2)
Processing	Processing – Incorporation into formulation, mixture or reaction product	(3) Odor agent in: All other chemical product and preparation manufacturing; Miscellaneous manufacturing; Soap, cleaning compound, and toilet preparation manufacturing; Fragrance mixtures and fragrance raw materials	(3) Formulation of Fragrance Oils (Section 3.3.3)
			(4) Formulation of End-Use Products (Section 3.3.4)
Processing	Processing – Incorporation into articles	(4) Odor agent in Plastics material and resin manufacturing	(4) Formulation of End-Use Products (Section 3.3.4)
Processing	Repackaging	(5) Odor agent in: All other chemical product and preparation manufacturing	(2) Repackaging (Section 3.3.2)
Processing	Recycling	(6) Recycling	(4) Formulation of End-Use Products (Section 3.3.4)
Commercial use	Air care products	(7) Air fresheners for motor vehicles	Not assessed, releases are primarily expected to be to air and landfill
		(8) Continuous action air fresheners	
		(9) Instant action air fresheners	
Commercial use		(10) All-purpose foam spray cleaner; All-purpose liquid cleaner/polish; All-	(5) Use of Liquid Surface Cleaners (Section 3.4.3)

COU			Release Scenarios (RSs)/ Occupational Exposure Scenarios (OESs)
Life Cycle Stage	**Category**	**Number and Subcategory**	
	Cleaning and furnishing care products	purpose liquid spray cleaner; All-purpose waxes and polishes; Appliance cleaners; Drain and toilet cleaners (liquid); Powder cleaners (floors); Powder cleaners (porcelain)	(6) Use of Liquid Toilet Cleaners (Section 3.4.3)
			(7) Use of Liquid Carpet Cleaners (Section 3.4.3)
			(8) Use of Powder Carpet Cleaners (Section 3.4.3)
Commercial use	Laundry and dishwashing products	(11) Laundry detergent (liquid); Laundry detergent (unit dose/granule); Fabric enhancers; Stain removers; Dishwashing detergent (liquid/ gel); Dishwashing detergent (unit dose/ granule); Dishwashing detergent liquid (hand-wash)	(9) Use of Liquid Laundry (Detergent/Softener) [a] Products (Industrial) (Section 3.4.1)
			(10) Use of Liquid Laundry (Detergent/Softener) [a] Products (Institutional) (Section 3.4.1)
			(11) Use of Powder Laundry (Detergent/Softener) [a] Products (Industrial) (See Section 3.4.1)
			(12) Use of Powder Laundry (Detergent/Softener) [a] Products (Institutional) (Section 3.4.1)
			(13) Use of Liquid Dishwasher Detergent (See Section 3.4.2)
			(14) Use of Powder Dishwasher Detergent (Section 3.4.2)
			(15) Use of Hand Dishwashing Soap (Section 3.4.2)
Commercial use	Plastic and rubber articles not covered elsewhere	(12) Plastic and rubber articles	Not assessed, releases are primarily expected to be to landfill
Commercial use	Other use; Laboratory chemicals	(13) Laboratory chemicals	Not assessed as no facilities for use as a laboratory chemical were identified in TRI and releases to down-the-drain are expected to be minimal

COU			Release Scenarios (RSs)/ Occupational Exposure Scenarios (OESs)
Life Cycle Stage	**Category**	**Number and Subcategory**	
Consumer use	Air care products	(14) Air fresheners for motor vehicles	See Consumer down-the-drain (Section 4.2.2.1)
		(15) Continuous action air fresheners	
		(16) Instant action air fresheners	
Consumer use	Cleaning and furnishing care products	(17) All-purpose foam spray cleaner; all-purpose liquid cleaner/polish; All-purpose liquid spray cleaner; All-purpose waxes and polishes; Appliance cleaners; Drain and toilet cleaners (liquid); Powder cleaners (floors); Powder cleaners (porcelain)	
Consumer use	Laundry and dishwashing products	(18) Laundry detergent (liquid); Laundry detergent (unit dose/granule); Fabric enhancers; Stain removers; Dishwashing detergent (liquid/gel); Dishwashing detergent (unit dose/ granule); Dishwashing detergent liquid (hand-wash)	
Consumer use	Plastic and rubber products not covered elsewhere	(19) Plastic and rubber articles	
Consumer use	Chemical substances in treatment products	(20) Ion exchangers; Liquid water treatment products; Solid powder water treatment products	
Disposal	Disposal	(21) Disposal	(16) Waste Handling, Treatment, and Disposal (Section 3.3.5)
Distribution in commerce	Distribution in commerce	(22) Distribution in commerce	Not assessed (Section 3.3.6)

[a] HHCB is in fabric softener dryer sheets and professional stain remover used in laundries and dry cleaning. Fabric softener dryer sheets are not expected to result in water releases as these are added after the washing step. No releases for the stain remover were modeled as no usage data for stain removers at industrial and institutional laundries were found, so this product type was not separately assessed.

This assessment does not include quantitative analysis for the following COUs:

- (7) Commercial use – Air care products – Air fresheners for motor vehicles
- (8) Commercial use – Air care products – Continuous action air fresheners
- (9) Commercial use – Air care products – Instant action air fresheners
- (12) Commercial use – Plastic and rubber articles
- (13) Commercial use – Other use laboratory chemicals – Laboratory chemicals

For the three commercial air care uses listed above, HHCB is released to air either as a vapor or mist/aerosol, which may deposit onto surfaces and could lead to minor down-the-drain releases during activities such as floor or carpet cleaning. This potential is much lower than the activities that lead directly to down-the-drain releases, so these releases were not estimated. For plastic and rubber articles, finished products are ultimately disposed of in landfills. For laboratory chemicals, five products marketed for laboratory use (Table 3-2) were identified, typically sold in milligram (mg) quantities, indicating low daily use. With no laboratory use reported in EPA's Chemical Data Reporting rule (CDR) and the small package sizes, it was inferred that only a small volume of HHCB is used for laboratory use and the daily releases to water or wastewater treatment would be a minor contributor compared to the other uses.

Table 3-2. Laboratory Use Products Containing HHCB

Products	Supplier	Weight Concentration (%)	Package Size	Maximum Amount of HHCB per Container (kg)
Galaxolide (HHCB) in acetonitrile	Accustandard	0.01	1 mL[a]	7.87E−08
HHCB	Sigma Aldrich	≤100	10–50 mg [b]	5.00E−05
Galaxolide (mixture of diastereomers)	Toronto Research Chemicals [Canada]	100 (assumed)	50–500 mg [c]	5.00E−04
Galaxolide (solution 50% in diethyl phthalate)	Toronto Research Chemicals [Canada]	50	100 mg–1,000 g [c]	5.00E−01
Galaxolide-d6 (mixture of diastereomers) (>80%)	Toronto Research Chemicals [Canada]	90–100	1–0 mg [c]	1.00E−05

[a] Product density reported as 0.787 g/cm^3 and converted to 7.87E−04 kg/mL
[b] Product density reported as 0.99–1.01520 per OECD Test Guideline 104 and converted to 1.00E−03 kg/mL
[c] Product density not reported; values calculated based on a density of 1.00E−03 kg/mL

3.2 Approach and Methodology for Industrial and Commercial Releases

3.2.1 Components of Release Assessment

The environmental release assessment of each RS comprised the following components:

- **Process Description:** A description of the RS, including the function of the chemical in the scenario; physical forms and weight fractions of the chemical throughout the process; per site throughputs/use rates of the chemical; and process equipment used during the RS.
- **Facility Estimates:** An estimate of the number of sites that use HHCB for the given RS, the total production volume associated with the RS, and the operating schedules.
- **Environmental Release Assessment**
  - **Environmental Release Sources:** The potential sources of environmental releases in the process and their expected media of release for the RS.
  - **Environmental Release Assessment Results:** Estimates of HHCB released into surface water, POTW, and non-POTW-WWT for the given RS.

3.2.2 Process Descriptions

A literature search was conducted to identify descriptions of processes involved in each RS. Where data were available, the following information was captured in each of the following process descriptions:

- Total production volume associated with the RS;
- Key process steps;
- Physical form and weight fraction of the chemical throughout the process;
- Information on receiving and shipping containers; and
- Ultimate destination of chemical leaving the facility.

Where HHCB-specific process descriptions were unclear or not available, generic process descriptions from literature, including relevant emission scenario documents (ESDs) or generic scenarios (GSs) were used. Sections 3.3 through 3.4 provide process descriptions for each RS.

3.2.3 Environmental Releases

Releases to the environment were assessed using data obtained through direct measurement via monitoring data, calculations based on empirical data, and/or assumptions and models. For each RS, the annual releases, daily releases, and the number of release days per year are provided.

The hierarchy below is used in selecting data and approaches for assessing environmental releases. The objective is to use the best, fit-for-purpose approach for the chemical and the specific scenario of interest.

1. Monitoring and measured data:
    a. Releases calculated from site- and media-specific concentration and flow rate data.
    b. Releases calculated from mass balances or emission factor methods using site-specific measurements.
2. Modeling approaches:
    a. Surrogate release data (based on data for a different chemical or scenario)
    b. Fundamental modeling approaches (based on physical chemical properties and the scenario).
    c. Statistical regression modeling approaches
3. Release limits:
    a. Company-specific limits
    b. Regulatory limits (*e.g.*, National Emission Standards for Hazardous Air Pollutants [NESHAPs] or effluent limitations/requirements).

Final release results are presented as a point estimate (*i.e.*, a single descriptor or statistic, such as central tendency or high-end). No release limits were applied for any scenario; releases were characterized using either measured (*e.g.,* calculated from mass balances or emission factor methods using site-specific measurements.) data or modeled estimates.

3.2.3.1 Toxics Release Inventory

In November 2022, EPA added HHCB to the TRI (U.S. EPA, 2024). This assessment uses the 2023 reporting year data (public release in 2024).[1] In 2023, a total of 65 facilities submitted Form R to TRI. EPA evaluated the reported quantities to surface water, "off-site POTW" treatment, and "off-site wastewater treatment (excluding POTWs; non-metals only)".[2] Facilities must report to TRI if they have

[1] TRI release data was extracted in March 2025. Facilities can make corrections to their TRI submission if needed; therefore, they may differ from the currently available version.
[2] Some of the excluded release categories were other off-site management (M90), offsite transfer to waste broker for disposal (M94), and offsite disposal unknown (M99), which were considered to not be wastewater treatment-related.

10 or more full-time employees; operate under a covered North American Industry Classification System (NAICS) code; and manufacture, processes, or otherwise use the chemical above the reporting threshold. For HHCB, the threshold is 100 lb and HHCB is not eligible for a *de minimis* exemption. Relevant 2023 HHCB release data are provided in *Draft Summary of Toxics Release Inventory (TRI) Water Releases for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026k). Preliminary 2024 data in Appendix B are included only for supplemental comparison to the 2023 data used.

The TRI data does not capture releases from commercial uses of HHCB. For these uses, scenarios were modeled where significant releases to POTWs were expected. Central tendency (50th percentile) and high-end (95th percentile) daily and annual release amounts were estimated via Monte Carlo simulations, assuming most of the product is disposed of down-the-drain. See Section 3.2.3.2 Modeling Approaches for details.

Basis of Estimate

TRI facilities must report the principal estimation method used for each surface water discharge and off-site transfer. The methods are listed below in Table 3-3, with the order as a guide indicating preference from most to least preferred for this risk evaluation.

Table 3-3. Toxics Release Inventory's Basis of Estimate Methods

Basis of Estimate Methods
Continuous monitoring data or measurements for the TRI chemical.
Periodic or random monitoring data or measurements for the TRI chemical.
Mass balance calculations such as calculations of the TRI chemical instreams entering and leaving process equipment.
Site-specific emission factors such as those relating release quantity to throughput or equipment type. This may include emission factors that are developed for a specific piece of equipment.
Published emission factors such as those relating to release quantity to throughput or equipment type. These may include emission factors in a trade associations publication.
Other estimation methods or approaches such as engineering calculations or best engineering judgement.

Production or Activity Ratio

A production or activity ratio is a ratio of reporting year production/activity to prior year's value. TRI reporters calculate the ratio based on production or activity variables that best reflect the outcome of the process using the chemical. The ratio helps interpret year-to-year changes in release and other waste-management quantities in the context of production levels. For chemicals with limited reporting history, the ratios can provide useful insight into past production activity.

Miscellaneous Information

TRI facilities may include optional "miscellaneous" information with their Form R to contextualize data that might otherwise appear unusual or inconsistent. This free-text input can address changes in production levels, calculation methods, and one-time or intermittent events affecting quantities, and can be useful for characterizing facility releases.

TRI Facility Mapping

A "mapping" process is used to assign TRI-identified sites to the release scenarios and COUs in scope. Mapping HHCB TRI facilities to a COU involved a review of multiple information sources—CDR data, industry classification information (NAICS codes), TRI use information, and other sources (*e.g.*, company websites, safety data sheets [SDSs], etc.)—to improve accuracy and confidence. Because a relatively low number of facilities reported HHCB to TRI, each company's website (when available) was reviewed to assign the facility to the most likely exposure scenarios. For several sites, company websites indicated production of personal care products (*e.g.*, hair care or cosmetics). These sites were not mapped to an in-scope release scenario; however, they are listed in Appendix B.2. The rationales for each RS assignment are provided in *Draft Summary of Toxics Release Inventory (TRI) Water Releases for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026k).

3.2.3.2 Modeling Approaches

Models were used to estimate environmental releases for commercial HHCB COUs that lacked TRI data. These models used deterministic, stochastic, or a combination to generate release estimate. The following steps were used to estimate releases:

1. Identify release sources and associated release media for each relevant process.
2. Identify or develop model equations for estimating releases from each source.
3. Identify model input parameter values from relevant literature sources.
4. If a range of input values is available for an input parameter, determine the associated distribution of input values.
5. Calculate annual and daily release volumes for each release source using input values and model equations.
6. Aggregate release volumes by release media and report total releases to each medium from each facility.

For release models employing stochastic calculations, Monte Carlo simulation (100,000 iterations) were performed in Lumivero @Risk software with the Latin Hypercube sampling. Appendix C details the modeling approach for each scenario, including model equations, input parameter values, and associated distributions. EPA also provided supplemental files containing the parameters, calculations, and full results of the modeled scenarios (see *Draft Environmental Release Modeling for Draft Risk Evaluation of 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)*).

The standard release sources assessed for scenarios in this assessment are listed in Table 3-4 below.

Table 3-4. Standard Release Sources Assessed

Standard Release Sources	Model(s)	Potential Release Media	Rationale
Container Residue Losses	EPA/OPPT Small Container Residual Model or EPA/OPPT Drum Residual Model or EPA/OPPT Solid Residual Model	Water (POTW), incineration, or landfill	Generally, some residue is left in a container after final use. Based on the size of the container and/or physical form of the product, this residue may be rinsed down-the-drain or sent for cleaning and disposal (via incineration or landfill).
Transfer Operation Losses	EPA/OPPT Dust Emissions from Transferring Solids Model	Air, water (POTW), incineration, or landfill	During transfer operations, volatile or dust emissions into the air may occur. As HHCB is not considered to be volatile, volatile emissions during transfers are not expected. For solid (powder) products, dust may be

Standard Release Sources	Model(s)	Potential Release Media	Rationale
			emitted into air during unloading and loading operations. The settled dust may be rinsed down-the-drain or disposed via incineration or landfill.
Application/Use of Product	Mass Balance	Water (POTW) or landfill	The commercial products assessed are expected to fully release HHCB into the environment during use. Therefore, mass balance can be used to estimate the amount remaining after accounting for the upstream losses to calculate the loss to down-the-drain or some distribution between POTW and other media.
POTW = publicly owned treatment works			

The key parameters for estimating the daily release amounts per site are detailed in Table 3-5.

Table 3-5. Key Parameters Used

Key Parameter	Parameter Description	Common Sources
Daily Use Rate for the Product Type	Estimated amount of product used per day at the site	Parameters are derived through a variety of sources including specific product instruction information for HHCB-containing products, default parameters from the National [Netherlands] Institute for Public Health and the Environment (RIVM) Consumer Fact Sheet on Cleaning Products, EPA's Building Assessment Survey and Evaluation (BASE) Study, and other sources.
Physical Form	Liquid or solid (*e.g.*, powder/granule)	Liquid products for all product types were assessed. Solid products were separately considered if the use rates of solid products were reasonably available.
Loss Fraction for Release Source	Amount of product released per amount of product handled	Default EPA/OPPT models and engineering judgement.
HHCB Mass Fraction	Mass fraction of HHCB in the product	Weight concentrations are taken from safety data sheets (SDSs). Use of concentrations from products marketed as industrial or commercial use products were prioritized; however, in some cases there were no such products identified and therefore consumer products were used. In addition, no concentration information was identified for HHCB in solid products; therefore, the concentration data for liquids were used.
Container Volume	Container volumes of the products	Container sizes of HHCB-containing products were preferred but, in rare cases, other assumptions may have been made.
Operating Days	Expected number of days that the product is used at a location	See Section 3.2.4

3.2.4 Number of Facilities

Facility counts were estimated by combining bottom-up data from reporting programs with top-down U.S. economic and industry-specific datasets. For this assessment, facility counts estimate the number of facilities where HHCB may be handled or used in industrial or commercial products. The steps to develop facility estimates are summarized below:

1. Identify each facility that reported HHCB in the 2020 CDR and 2023 TRI and assign to their relevant COU based on facility reported industry sectors (typically reported as either NAICS or SIC codes), chemical activity, and processing and use information. The rationale behind these assignments can be found in *Draft Summary of Toxics Release Inventory (TRI) Water Releases for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026k).
2. Based on the reporting thresholds and requirements of each data set,[3] EPA evaluated whether the data in the reporting programs were expected to cover most or all the facilities within the RS. If so, the total number of facilities in the RS is equal to the count of facilities mapped to the RS from each data set.
3. Generic industry data from GSs, ESDs, and other literature sources on typical throughputs/use rates, operating schedules, and the HHCB production volume were used within the RS to estimate the number of facilities. The approach to deriving a production volume for a given RS is provided in the next Section 3.2.4.1.
4. Total establishments for relevant NAICS codes extracted from the Census Bureau Statistics of U.S. Businesses were also considered.

3.2.4.1 Production Volume

Public data quantifying HHCB volume by commercial and consumer product categories in the United States are not available. However, the 2020 CDR requires manufacturers and importers to report the percentage of their production volume associated with each specific consumer and commercial end use (see Table 3-6 below). Submitters indicate whether a category is consumer-only, commercial-only or both. Due to confidential business information (CBI) claims, EPA cannot disclose the production volume from these submissions. Additionally, no product categories were designated as commercial-only in 2020; most submissions indicated consumer-only end-use products.

Table 3-6 lists the categories that manufacturers or importers marked as 'both' indicating products can be used commercially and by consumers. The table shows the percentage of production volume reported each category by the submitting company(ies). For these commercial end uses, the percentage ranged from 1 to 8% of the HHCB production or import volume. Preliminary 2024 CDR indicates increases in these percentages as compared to 2020 CDR, which suggests increased use of HHCB in commercial products (ranges from 1–31%).

Because company-level production volumes were claimed as CBI, an average production volume were calculated using the total production for all manufacturers/importers—1 to 10 million lb (453,592–4,535,923 kg)—and dividing across the eight manufacturer/importers. This yields approximately 56,699 to 566,990 kg per company. Using this average, production volumes for each product category were estimated, which informed the facility-count estimates.

A non-CBI estimate of production volume was provided by the International Fragrance Association whose industry survey indicates HHCB production could be approximately 2,200,000 kg (≈4,900,000 lb) in North America (RIFM, 2025) based on an unknown number of manufacturers and importers in the United States.

[3] For CDR, manufacturers including importer are required to report if they manufacture or import 25,000 lb per site or higher of HHCB during any calendar year for the 4-year reporting period. Note, that there are some exemptions from reporting. For more information about TRI, see reporting requirements in Section 3.2.3.1.

Table 3-6. Production Volume Estimates for Each Commercial End-Use Based on 2020 CDR

Category	Number of Companies that Reported	Percent of Manufacturing/ Import Volume	U.S. Production Volume (kg/year)
Cleaning and Furnishing Care Products			
All-purpose foam spray cleaner	1	8	4,536–45,359
All-purpose liquid cleaner/polish	2	Company A: 8 Company B: 1	5,103–51,029
All-purpose liquid spray cleaner	1	8	4,536–45,359
Drain and toilet cleaners	1	8	4,536–45,359
Laundry and Dishwashing Products			
Dishwashing detergent (liquid/gel)	1	8	4,536–45,359
Dishwashing detergent (unit dose/granule)	1	8	4,536–45,359
Fabric enhancers	1	2	1,134–11,340
Laundry detergent (liquid)	1	8	4,536–45,359
Air Care Products			
Continuous action air fresheners	2	Company A: 8 Company B: 4	6,804–68,039
Instant action air fresheners	1	8	4,536–45,359
Other articles with routine direct contact during normal use including rubber articles; plastic articles (hard)	1	1	567–5,670

A 2008 European Union (EU) Risk Assessment Report on HHCB (ECB, 2008b) cited the distribution of uses for fragrance oils in the EU, providing a useful comparison for how HHCB might be used in the U.S. Table 3-7 presents the percentage of fragrance oil volume used in the EU across different end-use product categories, based on general fragrance oils (not specifically those containing HHCB) (OCSPP, 2014). The table indicates most fragrance oils are formulated into detergents, followed by fabric softeners and then personal care products. However, air fresheners products, including scented plastics and candles, are not specifically included. Additionally, the data does not differentiate between industrial/commercial use (*e.g.,* laundry detergent used in industrial and commercial laundries) and those for consumer use (*e.g.*, household laundry detergent).

Table 3-7. Distribution of Fragrance Oils in the EU

Product Category	Percentage
Detergent	25
Fabric Softeners	14
Personal Care	13
Bath and Shower	10
Hair Care	10
Soaps	9
Industrial and Household Cleaner	8
Other	6
Fine Fragrances	5
Source: (Balk et al., 2001) as referenced in (ECB, 2008b).	

3.2.5 Number of Release Days

The number of release days was assumed to equal the facility's assumed operating days, unless available information indicates otherwise. Table 3-8 lists the number of release days for each scenario assessed and basis for estimate.

Table 3-8. Number of Release Days Used

Scenarios	Release Days	Basis
TRI		
Manufacturing	250	HHCB is a specialty chemical, therefore it is not assumed to be manufactured continuously throughout the year. A value of 250 days per year is used, corresponding to a 5-day work week, operating 50 weeks per year (with 2 weeks down for turnaround).
Repackaging	250	The expected operating days for a repackaging facility range from 174–260 days/yr according to the draft Chemical Repackaging Generic Scenario (U.S. EPA, 2022), with a recommended default value of 260 days/yr. However, other scenarios with chemical-specific data use values of 240 and 250 days per year, a value of 250 days per year, which aligns with the number of release days for formulation of end-use products and similar to GS recommendation and other scenario was used.
Formulation ("Compounding") of Fragrance Oils	240	A 2021 survey by the Fragrance Creators Association (FCA) reported a range of 240–270 operating days per year with an average of 254 days per year and a mode of 250 days per year (FCA, 2021b). With consideration that HHCB may not be used every day, the lower end of the range was used (240 days/year).
Formulation of End-Use	250	A 2021 survey of sites that use fragrance oils reported a

Scenarios	Release Days	Basis
Products		range of 250 to 365 operating days per year with an average of 328 days per year and a mode of 365 days per year (FCA, 2021b). With consideration that HHCB may not be used every day, the lower end of the range was used (250 days/year).
Waste handling, treatment, and disposal	250	Waste management sites operate year-round. However, regardless of the facility operating schedule, a facility is unlikely to manage waste containing HHCB every day. Therefore, a value of 250 days per year was used for this RS.
Modeled scenarios		
Use of Liquid Surface Cleaners	250–365	Assumption based on normal business schedules (5–7 days/week and 50 to 52 weeks). Triangular distribution with a maximum of 365, a minimum of 250, and 260 days/year as the mode.
Use of Liquid Toilet Cleaners	250–365	Assumption based on normal business schedules (5–7 days/week and 50–52 weeks). Triangular Distribution with a maximum of 365, a minimum of 250, and 260 days/year as the mode.
Use of Liquid Carpet Cleaners	1 day/year	Assumption that professional carpet cleaners visit a new site every day, therefore only 1 day per job site.
Use of Powder Carpet Cleaners	1 day/year	Assumption that professional carpet cleaners visit a new site every day, therefore only 1 day per job site.
Use of Liquid Laundry Products (Industrial)	20–365	ESD on the Chemicals Used in Water-Based Washing Operations at Industrial and Institutional Laundries provides the range and average of distribution for 6 separate years for industrial laundries (*i.e.*, 6 ranges and 6 averages provided) (OECD, 2011). No data on institutional laundries was available. The ESD uses the most common average as the default value, which is used as the mode of the distribution. Triangular Distribution with a maximum of 365, a minimum of 20, and 260 days/year as the mode.
Use of Liquid Laundry Products (Institutional)		
Use of Powder Laundry Products (Industrial)		
Use of Powder Laundry Products (Institutional)		
Use of Liquid Dishwashing Detergent	350	Assume use occurs 7 days/week, 50 weeks/year
Use of Powder Dishwashing Detergent	350	Assume use occurs 7 days/week, 50 weeks/year
Use of Hand Dishwashing Soap	350	Assume use occurs 7 days/week, 50 weeks/year

3.2.6 Evidence Integration

Evidence integration in the environmental release assessment involves analyzing and synthesizing information to estimate environmental releases. The analysis considered the likely location, duration, intensity, frequency, and quantity of releases, as well as factors influencing the strength of evidence. Key factors considered include the following:

1. **Data Quality:** High-, medium-, or low-rated data are integrated from the data evaluation phase, excluding data deemed uninformative based on data quality metrics. In general, higher-ranked data are preferred but lower-ranked data may be used as needed. For example, when a lower-ranked dataset may more closely aligns with an RS.
2. **Data Hierarchy:** Measured and modeled data were used to accurately, representative estimates of environmental releases from specific sources, media, and products. Measured data, especially chemical-specific directly representative of the RS/exposure source, are preferred over modeled data. In integrating evidence, both data quality and data hierarchy are considered. For example, high-quality modeled data directly applicable to an RS may be used over low-quality measurement data that are not specific to the RS.

The final integration of environmental release evidence involved evaluating the strength, plausibility, and coherence of information across evidence streams.

3.3 Industrial Releases

For this draft assessment and the draft HHCB risk evaluation, releases associated with COUs under the life-cycle stages of manufacturing, processing, and disposal are categorized as "industrial" releases. This section provides an overview of the key release assessment components for industrial releases. Each subsection will describe

1. The primary activity associated with the RS;
2. The key data elements are used to estimate the number of facilities;
3. The quantity of the chemical released to the environment or transferred off-site for treatment or disposal from the facilities considered in the RS; and
4. The source(s) (*e.g.*, programmatic data, modeling, literature) of data.

3.3.1 Manufacturing

3.3.1.1 Process Description

HHCB is manufactured in a three-step process. First, α-methylstyrene reacts with tertiary amyl alcohol under acidic conditions to form pentamethylindane. Next, pentamethylindane is hydroxyalkylated with propylene oxide via a Friedel-Crafts reaction using aluminum chloride as a catalyst. Finally, the resulting 1,1,2,3,3-pentamethyl-5-(-hydroxyisopropyl)indane (2) undergoes ring closure with paraformaldehyde in the presence of either and either a lower aliphatic alcohol (acetal route) or a carboxylic acid anhydride (acylate route) to yield to 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamethylcyclopenta-γ-benzopyran (HHCB; Galaxolide) (Wiley-VCH, 2002; Zviely, 2002).

Limited information is available on domestic HHCB manufacturing processes, but process details from an EU plant are reported (ECB, 2008b). The facility's production volume (2–10 million lb/yr) is expected to be comparable to U.S. manufacturing facilities. At the EU site, HHCB is produced via an automated process, but with manual opening and closing of the tanker manhole during unloading and loading. Local exhaust ventilation (LEV) is used at product sampling points, due to the use of formaldehyde in the process. The plant processes 14,000 lb per batch, with a batch time of 10 to 15 hours (ECB, 2008b).

3.3.1.2 Facility Estimates

Based on 2020 CDR and 2023 TRI data, there are likely two to three HHCB manufacturers within the United States. In the 2020 CDR, one site withheld its activity type from public disclosure due to CBI claims; therefore, it could be either manufacturing or importing HHCB. This site's identity is also claimed as CBI. In addition, two TRI-sites indicated manufacturing HHCB (see Table_Apx B-6).

In the EU, HHCB operated continuously (24 hours a day, 7 days a week) for 48 weeks a year (approximately 330 days) (ECB, 2008b). The EU manufacturing site reported filling approximately 4 tanker trucks of HHCB per week (ECB, 2008b). For U.S. facilities, an operation schedule of 250 days per year is assumed, aligning more closely with the schedule reported for U.S. processors.

3.3.1.3 Water Release Assessment

Table 3-9 presents data on HHCB releases to surface water, and transfers to POTW and WWT from sites with TRI activity codes indicating manufacturing (U.S. EPA, 2024). None of the manufacturing sites reported on-site discharge of HHCB-containing waste stream (or a waste stream that previously contained HHCB).

One facility reported no transfers of waste to POTWs or off-site WWT facilities. The other facility reported transferring HHCB-containing wastewater to a POTW with no pretreatment. The transferred wastewater was estimated using mass-balance calculations, and the expected treatment method at the receiving POTW was reported as "other or unknown."

Table 3-9. Water Release and Transfer Estimates for Manufacturing

Site Identity and Location	Annual Release to Surface Water (kg/yr-site)	Annual Transfer to POTW (kg/yr-site)	Annual Transfer to WWT (kg/yr-site)	Daily Release or Transfer (kg/day-site)	Number of Release Days
Takasago International Corp. (Harriman, NY)	0	2,226	0	9	250

POTW = publicly owned treatment works; WWT = wastewater treatment
Note: For brevity, only the sites with non-zero release or transfer quantities are provided in this table. For a full list of the sites, see Table_Apx B-6.

The two sites reported TRI production ratios of 1.45 and 2.76, indicating increased HHCB production activity from 2022 to 2023. Despite the increase, the estimated quantities of waste treated off-site was similar in 2022 and 2023.

3.3.2 Repackaging

3.3.2.1 Process Description

As noted earlier, 2016 and 2020 CDR data indicate HHCB is primarily imported into the U.S. from foreign manufacturers. It is imported in liquid form at concentrations of 1%, 1 to 30%, and 90% or greater (U.S. EPA, 2020a, 2016). Imported HHCB may be used at the importation site of record or distributed to use sites. If imported strictly for distribution, it may never be physically present at the importations site of record. In some cases, HHCB may be used both at the importation site of record and at distribution sites. The repackaging scenario covers only those sites that purchase neat HHCB or HHCB-containing products from domestic or foreign suppliers and repackage the HHCB from bulk containers into smaller containers for resale.

Although no HHCB-specific container information is available, commodity chemicals are imported in intermodal bulk containers such as chemical tankers, railcars, and tank trucks (Tomer and Kane, 2015). Bulk chemicals may then be repackaged into smaller containers, with blending and dilution potentially occurring at import locations prior to distribution.

No U.S.-specific data are available on HHCB concentrations following repackaging. However, based on information from an EU plant that dilutes and repackages HHCB, it may be diluted to 65% weight using benzyl benzoate or isopropyl myristate (ECB, 2008b). The diluted HHCB solution is then repackaged into tanker trucks or containers of 50 gallons (200 L) or more (ECB, 2008b).

3.3.2.2 Facility Estimates

According to 2020 CDR, there are approximately seven to eight importers, with a total aggregate volume between 1 to 10 million lb (U.S. EPA, 2020a). Only one importer indicated repackaging HHCB, allocating 50% of its import volume to repackaging. Its submission indicates receipt of HHCB at 90% or greater concentration, with repackaging occurring at 25 to 100 sites (U.S. EPA, 2020a). Based on the TRI reports, only one site indicated repackaging of HHCB.

No information on facility operating schedules was identified. In the absence of such data, a standard operating schedule of 250 days per year (*i.e.*, 5 days/week, 50 weeks/yr) was assumed. See Table 3-8 for more details on the number of release days used.

3.3.2.3 Water Release Assessment

In 2023, a single site, primarily engaged in repackaging, reported HHCB transfer to POTW or WWT (no direct surface water discharges). Table 3-10 shows the reported releases and transfers (U.S. EPA, 2024). The site reported a production ratio of 0.4, indicating an overall decrease in HHCB processing relative to 2022. The facility did not discharge HHCB-associated waste streams to receiving waters on-site (or adjacent). Instead, HHCB-containing wastewater underwent adsorption-based physical treatment (estimated efficiency: 0–50%) prior to transfer to the POTW. The quantity of HHCB transferred was estimated using published emission factors.

The treatment method at the receiving POTW was reported as experimental. Additionally, no waste was transferred to private off-site WWTs.

Table 3-10. Water Release and Transfer Estimates for Repackaging

Site Identity and Location	Annual Release to Surface Water (kg/yr-site)	Annual Transfer to POTW (kg/yr-site)	Annual Transfer to WWT (kg/yr-site)	Daily Release or Transfer (kg/day-site)	Number of Release Days
Tilley Distribution Inc. (Norwood, NJ)	0	21	0	0.1	250

POTW = publicly owned treatment works; WWT = wastewater treatment
Note: For brevity, only the sites with non-zero release or transfer quantities are provided in this table. For a full list of the sites, see Table_Apx B-6.

3.3.3 Formulation of Fragrance Oils

3.3.3.1 Process Description

HHCB, together with other aroma chemicals, is blended during fragrance oil formulation to create specific scent profiles. These fragrance oils are then incorporated into commercial and consumer products such as detergents, cleaning products, air fresheners, and scented plastics (OECD, 2010).

The formulation process begins with transporting HHCB to fragrance oil compounders in tanker trucks or containers of 50 gallons (200 L) or more (ECB, 2008b). HHCB may arrive at formulation sites either at greater than or equal to 90% concentration (as imported) or diluted to about 65% in solvent (OCSPP, 2014; ECB, 2008b). Due to its high viscosity, HHCB is typically transferred at elevated temperatures of 77 to 167 °F (25–75 °C) (ECB, 2008b). A U.S. fragrance oil compounder reported unloading HHCB at 120 °F from drums by pumping or pouring. In the EU, fragrance oils are produced in batch volumes ranging from 2 to 44,000 lb (1–20,000 kg) (ECB, 2008b), although batch size information for U.S. sites is unavailable. For large batches, outdoor storage tanks are used to receive bulk deliveries. After dilution, HHCB may be transferred to an indoor tank within the formulation facility (OCSPP, 2014).

As HHCB is diluted with other fragrance ingredients, its viscosity decreases; accordingly, EPA assumes no heating is required during the blending process. In addition, many aroma chemicals are heat sensitive, so blending typically occurs at ambient temperatures (OECD, 2010). A 2004 Human and Environmental Risk Assessment (HERA) reported HHCB concentrations between 2 to 4%, while an EU risk assessment reported an average concentration of 4% (ECB, 2008b; HERA, 2004). The EPA's review of fragrance oil products found a wide range of HHCB concentration, from 0.25 to 60% (U.S. EPA, 2025b).

Fragrance oils are packaged in transport containers, typically drums or smaller containers, and shipped to facilities where they are incorporated into liquid or powder products and articles (OECD, 2010).

3.3.3.2 Facility Estimates

Seven submitters to the 2020 CDR indicated that HHCB is incorporated into a formulation, mixture, or reaction product (U.S. EPA, 2020a). Of these, 4 reported fewer than 10 sites, 1 reported between 10 and 25 sites, 1 reported at least 250 but fewer than 1,000 sites, and 1 stated that the number of sites was not known or reasonably ascertainable (U.S. EPA, 2016). However, it is unclear whether these responses pertain to fragrance oil formulation, formulation of end-use products, or both.

Using 2023 TRI data for HHCB, a review of publicly available company information identified 12 sites that sell fragrances; these are listed in Section 3.3.3.3. Notably, the two sites that were classified as manufacturing sites in Section 3.3.1.2 also reported formulation processes.

A 2021 Fragrance Creators Association (FCA) survey of fragrance compounders reported annual HHCB usage at two sites: 177,807 kg/yr-site at one and 3 to 7 kg/yr-site at another, suggesting some facilities may operate below the TRI reporting threshold (>100 lb/yr; exceeding ≈45 kg/yr) (FCA, 2021b).

The 2021 FCA survey reported that fragrance compounders operate 240 to 270 days per year (average: 254; mode: 250) (FCA, 2021b). For U.S. release estimates, the lowest bound of 240 days was used to reflect that HHCB may not be used every day.

3.3.3.3 Water Release Assessment

Table 3-11 presents releases to surface water and transfer to POTW or WWT facilities from sites expected to formulate HHCB into fragrance oils (U.S. EPA, 2024). None of the sites discharged HHCB-containing wastewater directly to surface waters at their facility or transferred waste to private off-site WWT facilities. Six of the 12 sites also reported no transfers to POTW, indicating no water releases of HHCB from those sites. The other six sites transferred HHCB-containing wastewater to POTWs. Among these, only Firmenich Inc. reported pretreating the waste prior to transfer, using biological treatment with an estimated efficiency between 50 to 95%.

Table 3-11. Water Release and Transfer Estimates for Formulation of Fragrance Oils

Site Identity and Location	Annual Release to Surface Water (kg/yr-site)	Annual Transfer to POTW (kg/yr-site)	Annual Transfer to WWT (kg/yr-site)	Daily Release or Transfer (kg/day-site)	Number of Release Days
Robertet Inc. (Budd Lake, NJ)	0	340	0	1	240
International Flavors & Fragrances Inc (Monmouth, NJ)	0	110	0	0.5	240
Mane USA (Wayne, NJ)	0	10	0	0.04	240
Arylessence Inc. (Marietta, GA)	0	9	0	0.04	240
Symrise Inc (Somerset, NJ)	0	9	0	0.04	240
Flavorchem Corp (Dupage, IL)	0	3	0	0.01	240

POTW = publicly owned treatment works; WWT = wastewater treatment
Note: For brevity, only the sites with non-zero release or transfer quantities are provided in this table. For a full list of the sites, see Table_Apx B-6.
Numbers rounded to the nearest integer; for values <1, numbers were rounded to 1 significant figure.

Regarding final disposition of the waste at the receiving POTW, the three following sites indicated "experimental and estimated treatment": International Flavors & Fragrances Inc, Robertet Inc., and Flavorchem Corp. Mane USA all apportioned the expected disposition among air, sludge (to disposal), and sludge (to incineration). Arylessence Inc. reported sludge (to disposal) as the final disposition at its receiving POTW, while Symrise Inc reported other or unknown treatment.

For the basis behind their estimates, most sites relied on published emissions factors to quantify HHCB except one site used mass balance calculations, and another reported using other methods.

The optional pollution prevention information (Section 8.11 of the TRI Submission Form) for Andrea Aromatics Inc, which reported no releases to water, indicates the company is replacing HHCB with another chemical in new product formulations. Among sites that reported production or activity ratios, values ranged from 0.72 to 1.29, indicating HHCB use remains relatively steady at these locations (U.S. EPA, 2024).

3.3.4 Formulation of End-Use Products

3.3.4.1 Process Description

HHCB is used to add fragrance to a variety of products, including liquid cleaning products, detergents, gel air fresheners, scented candles, and aerosol-type air fresheners (see Table 3-1). The ESD Blending of Fragrance Oils into Commercial and Consumer Products provides generic process descriptions for formulating these products, as shown in Figure 3-1 (OECD, 2010). While process details—such as HHCB concentration, additives, and packaging—depend on the final product, the general process of blending, and packaging for shipment remains consistent for most products.

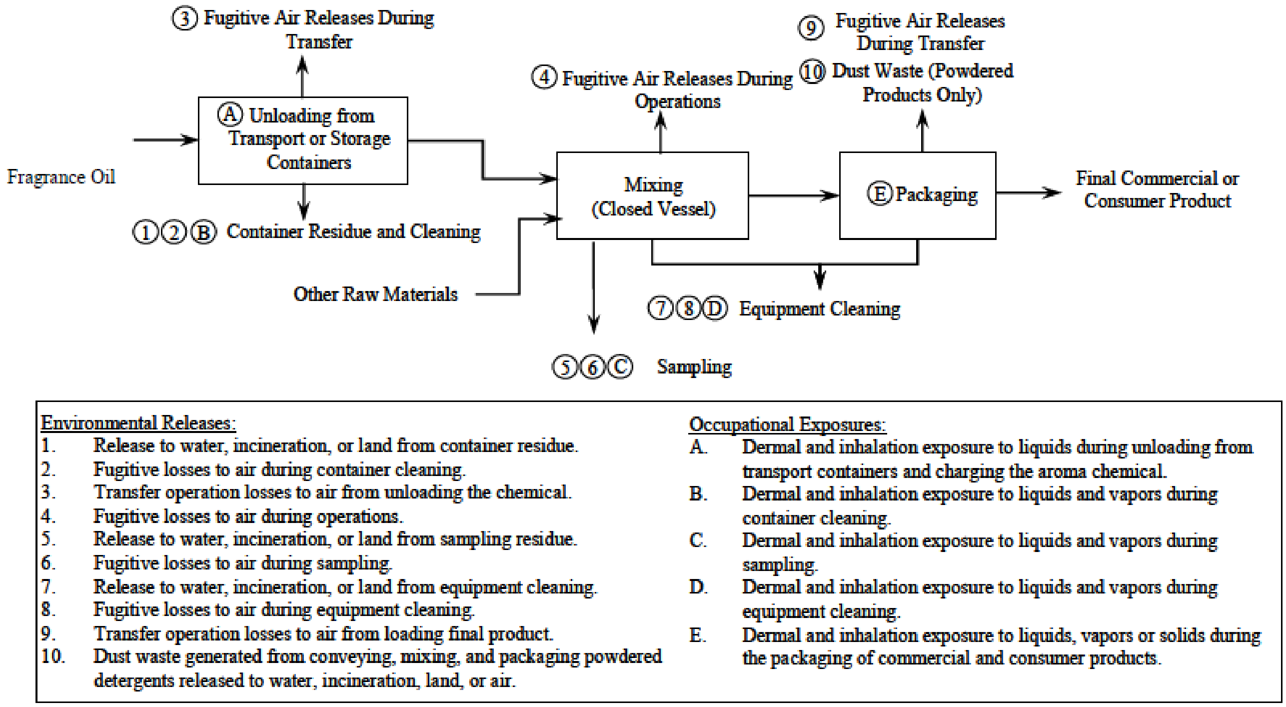

Figure 3-1. Process Diagram of Formulation of End-Use Products Containing HHCB

Formulation begins with the unloading of fragrance oil from transport containers (drums or smaller), after which the oil is pumped or poured into a mixing tank. If heating is required for the base product, fragrance oils are generally added after the product has cooled to room temperature because they tend to be heat-sensitive (OECD, 2010). In unheated processes, the fragrance oil can be blended with other materials early in the process (OECD, 2010). Once formulation is complete, the final product is packaged for shipment and sale (OECD, 2010). Automated packaging lines typically fill consumer products into small, product-specific containers (*e.g.*, aerosol cans), while workers may manually fill large-volume commercial products, such as industrial and institutional laundry detergents, into drums or totes (OCSPP, 2014). Gel air fresheners and candles are made by blending fragrance oils with gelling agents like silica or wax, whereas aerosol products are produced by filling cans with liquid formulations and injecting propellant (OECD, 2010).

A RIFM survey reported high-end (95th percentile) HHCB concentrations of 14.52% in air fresh plug-ins, 1.575% in scented candles, and 0.525% in air fresh aerosols (FCA, 2020). EPA conducted product-specific searches and identified SDSs and ingredient disclosures for HHCB, documented in the HHCB Product Concentration Data (U.S. EPA, 2025b). For air fresheners, EPA found a range of concentration for air fresheners to be less than 0.01 to 12.5%.

HHCB is also used as an odorant in plastics and resin manufacturing. International Flavors & Fragrances (IFF) estimated that about 1% of its HHCB volume is used in polymer production for consumer items (IFF, 2019). HHCB is incorporated into plastic resin used in manufacturing of air fresheners (such as fragrance sachets with scented beads in a mesh bag), scented toiletries, and scented garbage bags (IFF, 2019).

The Draft Generic Scenario (GS) for Use of Additives in Plastics Compounding (U.S. EPA, 2014) provides generic process descriptions for plastic compounding. According to the GS, polymer resin is blended with additives and other raw materials to form a masterbatch using either an open or closed blending processes (U.S. EPA, 2014).

After compounding, HHCB-containing pellets are either converted into final plastic articles on-site or packaged and shipped to plastic converting sites (U.S. EPA, 2014). Converting thermoplastics typically involves melting plastic, forming it into a new shape, and then cooling it. Often, melting is performed using an extrusion process, which delivers a hot melt into a mold in either batch or continuous process (OECD, 2009b).

3.3.4.2 Facility Estimates

Seven submitters to the 2020 CDR reported incorporation into a formulation, mixture, or reaction product (U.S. EPA, 2020a). Of these, 4 submitters reported fewer than 10 sites, 1 reported at least 10 but fewer than 25 sites, 1 reported at least 250 but fewer than 1,000 sites, and 1 reported the number of sites is not known or reasonably ascertainable (U.S. EPA, 2016). It is unclear whether these sites incorporate HHCB into fragrance oil formulation, specific end-use products, or both.

A 2020 CDR submitter reported HHCB incorporating into articles at fewer than 10 sites (U.S. EPA, 2020a), specifically for use in scented plastics.

Using 2023 TRI data (U.S. EPA, 2024), 34 sites were identified that potentially formulate HHCB into end-use products, including manufacturers of cleaning and laundry products. Additionally, 12 sites were identified that sell products not identified as TSCA COUs, such as hair and skincare items, which are not included in this scenario; see Appendix B.2 for those sites.

A 2021 survey of formulators reported operating days ranging from 250 to 365 days per year (average: 328; mode: 365) (FCA, 2021b). To reflect that HHCB may not be used daily, the lower bound of 250 days per year was used.

The 2021 survey of formulators also indicated that some sites have throughput below 100 kg/yr-site (FCA, 2021b). Such facilities may fall below TRI reporting thresholds if their throughput is below 100 lb/yr (45 kg/yr).

TRI-reported production/activity ratios indicate that many sites are likely to increase HHCB use relative to 2022. However, stakeholder comments suggest some companies are substituting HHCB with an alternative chemical or have HHCB-free fragrance oils in their products.

3.3.4.3 Water Release Assessment

Table 3-12 summarizes releases to surface water and transfers to POTW or WWT facilities from sites that formulate HHCB into TSCA-relevant product types (U.S. EPA, 2024). Of 34 sites, 33 sites had no waste streams containing (or previously containing) HHCB discharged to on-site receiving waters. Reynolds Consumer Products reported direct discharges to a nearby water body, but HHCB quantity in those waste streams was 0.

Twenty-three sites reported no transfers to either POTWs or WWT facilities, indicating no water releases from these sites. Eleven sites did transfer wastewater containing HHCB to a POTW and/or WWT site. Most transferred less than 25 kg 2023, but one site (Colgate-Palmolive Co Cambridge Plant) reported nearly 1,200 kg transferred to a WWT facility. None indicated pretreating HHCB-containing waste streams prior to transfer.

Table 3-12. Water Release and Transfer Estimates for Formulation of End-Use Products

Site Identity and Location	Annual Release to Surface Water (kg/yr-site)	Annual Transfer to POTW (kg/yr-site)	Annual Transfer to WWT (kg/yr-site)	Daily Release or Transfer (kg/day-site)	Number of Release Days
Colgate-Palmolive Co Cambridge Plant (Cambridge, OH)	0	0	1,196	5	250
ABC Compounding Co. Inc. (Conyers, GA)	0	0	1	0.005	250
Spartan Chemical Co Inc (Maumee, OH) [a]	0	0.09	0	0.0004	250
Church & Dwight Co. Inc. (Harrisonville, MO)	0	23	0	0.09	250
Henkel Us Operation Corp (Salt Lake City, UT)	0	0.5	15	0.06[b]	250
Procter & Gamble Tabler Station Manufacturing Plant (Inwood, WV)	0	6	0	0.03	250
Amano Pioneer Eclipse Corp (Sparta, NC)	0	0	0.09	0.0004	250
Apex International Mfg (Eden Prairie, MN)	0	2	0	0.009	250
Apex International (Chaska MN)	0	2	0	0.007	250
Hillyard Industries Inc (Saint Joseph, MO)	0	1	0	0.004	250
Misco Products Corp (Reading, PA)	0	0.4	0	0.002	250

For brevity, only sites with non-zero release or transfer quantities are provided in this table. For a full list of the sites, see Table_Apx B-6.
Number provided is rounded to the nearest integer. For values <1, numbers were rounded to 1 significant figure.
[a] The Section 9.1 (Miscellaneous and Optional Information) for Spartan Chemical Co Inc indicated that waste was from a production spill of fragrance containing HHCB.
[b] Daily release or transfer amounts were calculated by combining the amounts sent to POTW and the amount sent to WWT site by the number of release days. This daily release amount is not being sent to the same facility.

For transfers at the POTWs, the four sites—Apex International Mfg, Apex International, and Misco Products Corp, Henkel US Operation Corp—reported the ultimate disposition of the waste as “experimental and estimated treatment.” Procter & Gamble Tabler Station Manufacturing Plant, Church & Dwight Co. Inc. (Harrisonville, MO) and Hillyard Industries Inc did not know the treatment method or the ultimate disposition at their receiving POTWs. Spartan Chemical Co Inc reported HHCB was ultimately discharged to water from its POTW.

Most sites reported “other approaches” as the basis for their estimated transfers. Three sites used published emission factors to estimate HHCB transfers (Apex International Mfg, Apex International, and Misco Products Corp). Procter & Gamble Tabler Station Manufacturing Plant and Hillyard Industries Inc relied on mass balance calculations.

3.3.5 Waste Handling, Treatment and Disposal

3.3.5.1 Process Description

HHCB COUs may generate waste streams that are transported to third-party facilities for disposal or treatment. Industrial sites that discharge, treat or dispose of on-site waste are evaluated within each COU assessment. This scenario covers the information available for releases from the third-party facilities that receive HHCB waste.

Wastes generated during HHCB COUs and sent to third-party facilities for treatment may include the following:

- wastewater discharged to POTW, or other, non-public treatment works;
- waste managed via municipal or hazardous waste incineration; and
- disposal in municipal or hazardous landfills.

Although HHCB is not a Resource Conservation and Recovery Act (RCRA) hazardous waste, it could be present in RCRA hazardous waste. Off-site waste may be first processed at transfer stations for temporary storage before transport to landfills or other treatment or disposal facilities.

Municipal solid waste landfills accept household waste and other non-hazardous wastes, including industrial/commercial wastes. Hazardous waste landfills are engineered for final disposal of non-liquid hazardous wastes and must meet design stringent standards—double liner, dual leachate collection/removal, leak detection, run on/runoff and wind-dispersal controls, and a construction quality assurance program—with closure/post-closure requirements (final cover, ongoing monitoring/maintenance) to prevent groundwater and surface water contamination (U.S. EPA, 2018). Hazardous waste landfills are regulated under RCRA Part 264/265, Subpart N.

Municipal incineration typically involves dumping of solid waste into a pit, then transferring it to the combustion unit. A sorting step may remove unsuitable materials. The tipping process can generate dust; ventilation air is captured and routed to the combustion unit. Commercial hazardous waste incinerators generally comprise a rotary kiln followed by an afterburner and accept both solid and liquid waste. Liquid wastes are pumped and fed through atomizing nozzles to optimize combustion, while solids are introduced as loose material via gravity hoppers or in drums/containers via conveyor (ETC, 2018; Heritage, 2018).

3.3.5.2 Facility Estimates

The 2023 TRI identified a total of 77 third-party waste management sites. Note that these counts would not capture the number of sites receiving HHCB-containing waste from commercial and consumer users. Some of these sites may also be waste transfer stations that consolidate waste and ship it to other, unknown facilities.

In the 2023 TRI HHCB data, two third-party waste management sites reported directly to TRI. The other sites were identified as receiving waste transfers from TRI reporters:

- 22 POTWs (not required to report to TRI);
- 6 WWT sites (non-POTWs); and
- 46 other third-party waste management sites identified by TRI reporters that may treat the waste or transfer to other unknown sites (including sites that receive waste from excluded sites; see Appendix B.2).

3.3.5.3 Water Release Assessment

No additional HHCB discharge information is available from POTW/WWT sites, as these sectors are not required to report to TRI. Two third-party waste management sites reported their release information on HHCB to TRI. None of the third-party waste management sites reported on-site discharges to receiving waters from HHCB-containing waste streams, nor indirect discharges to POTWs or non-POTW WWT facilities.

TRI also identifies 46 off-site waste management facilities receiving HHCB waste; most transfers were designated for incineration, energy recovery, or unknown disposal. However, releases from those facilities are unknown. This uncertainty was incorporated in the weight of scientific conclusions in Section 3.6.1. Some of these facilities may function solely as waste transfer stations, with treatment occurring at one of the two waste management sites that report directly to TRI.

None of the two third-party waste management sites reported on-site discharges to receiving waters from HHCB-containing waste streams, nor indirect discharges to POTWs or non-POTW WWT facilities. For a full list of the sites see Table_Apx B-6.

Both third-party waste management sites reported treating HHCB-containing aqueous and non-aqueous wastes primarily by incineration: Veolia ES Technical Solutions LLC (Port Arthur) achieved greater than 99.9999% efficiency, and Clean Harbors Deer Park LLC reported 99.99 to 99.9999% efficiency. Clean Harbors also treated additional liquid and solid HHCB waste streams via neutralization, chemical precipitation, settling/clarification, other treatment, and stabilization/chemical fixation prior to disposal and incineration.

3.3.6 Distribution in Commerce

For purposes of assessment, distribution in commerce includes transporting HHCB or HHCB-containing products or articles between manufacturing, processing, and use sites as well as transporting HHCB-containing wastes to recycling or final disposal. These materials are expected to be moved in a closed system or in forms (*e.g.*, articles) with negligible release potential except in the event of an accident. Accordingly, no separate assessment was conducted for the Distribution in commerce COU.

3.4 Commercial Releases

For this draft assessment and HHCB risk evaluation, releases associated with COUs under the life cycle stages of commercial use are categorized as "commercial" releases. As discussed in Section 3.1, only Release Scenarios expected to contribute to frequent water releases were evaluated. This section provides an overview of the key release assessment components for each commercial RS. Each subsection describes the (1) primary activity associated with the RS; (2) key data elements used to estimate the number of facilities; (3) quantity of the chemical released to the environment or transferred off-site for treatment or disposal from the facilities considered in the RS; and (4) source(s) (*e.g.*, programmatic data, modeling, literature) of data.

3.4.1 Use of Laundry Products

3.4.1.1 Process Description

HHCB is included in industrial/institutional liquid fabric softener and in laundry detergents (liquid, liquid-packs, and powder). It is commonly used as a fragrance ingredient to leave a residual scent on textiles and mask detergent and soil odors in the wash solution (OCSPP, 2014).

Releases/transfers for this scenario were modeled using the OECD ESD for Water-Based Washing Operations at Industrial and Institutional Laundries. The ESD categorizes facilities as follows:

- Industrial laundries: off-site operations handling table and bed linens, work uniforms, and shop or wiping towels; and
- Institutional laundries: on-premises operations (primarily hospitals, nursing homes, and hotels) with laundered items varying by facility (OECD, 2011).

For industrial laundries, liquid products are typically dosed via automated liquid-injection systems, while solids are added manually. In most facilities, liquids are pumped directly from transport containers to the machine; where injection systems are absent workers manually scoop or pour solid or liquids into washers. Fabric softeners are added late in the washing cycle, before final rinse (OECD, 2011).

HHCB concentrations in laundry products were sourced from SDSs and public comments. For industrial/institutional products, one fabric softener SDS indicated a maximum of 0.1% HHCB; no commercial (industrial/institutional) laundry detergents were identified. Consumer laundry detergents with HHCB concentrations ranging from 0.01 to 0.9% were identified, and these values were used. This may overestimate concentration in consumer products as FCA's public comment reported 90th-percentile HHCB concentrations of 0.05% (weight by weight [w/w]) in consumer hand-wash detergents and 0.03% in consumer laundry pre-treatment sprays (FCA, 2021a). Consistent with a screening assessment, the higher SDS values were used to estimate commercial releases. Implications for the weight of scientific evidence are discussed in Section 3.6.1.

In addition, a commercial dryer sheet (<1%) and a European professional pre-spotter (0.1–1%) were identified but excluded from the assessment as dryer sheets are not expected to contribute to water releases, and pre-spotter use rates were not available.

Potential release sources and rationales are listed in Table 3-13; key sources assessed include the following:

- **Laundry Release Source #1** (container residue): Leftover product may be rinsed to a POTW (down-the-drain) or disposed via landfill or incineration.
- **Laundry Release Source #4** (solid-product dust): Solid products may generate dust during transfer operations; airborne dust is expected to settle and be managed via floor cleaning (down-the-drain), incineration or landfill. Many facilities use local capture and air controls to minimize airborne dust prior to environment release.
- **Laundry Release Source #6** (down-the-drain discharge): Remaining product is discharged with wash water after operations, leading to releases to POTWs.

Table 3-13. Use of Laundry Products Potential Release Sources

Release Source Number	Release Source	Assessed/ Not Assessed	Rationale
1	Container Residue to Water, Incineration, or Landfill	Assessed	Industrial laundries are expected to receive products in drums, which are likely returned to the supplier or drum recycler/ reconditioner. These drums could be rinsed (water, incineration, or landfill). Institutional laundries typically receive smaller containers, which are typically discarded without rinsing into municipal solid waste (incineration or landfill).
2	Open Surface Losses to Air During Container Cleaning	Not Assessed	HHCB has a low vapor pressure and weight concentration in these products, air releases are expected to be negligible.
3	Transfer Operation Losses to Air from Loading Laundry Cleaning Product into Washers	Not Assessed	
4	Dust Generation from Transfer Operations Released to Air, Water, Incineration, or Landfill	Assessed	For solid products, airborne dust may be generated during transfer operations, which may settle on surfaces. Settled dust is likely disposed of during facility cleanings either to water or landfill dependent on the method of cleaning.
5	Releases to Air into the Worker's Breathing Zone from Water-Washing Process	Not Assessed	HHCB has a low vapor pressure and weight concentration in these products, air releases are expected to be negligible.
6	Release from the Water-Washing Process to Water	Assessed	During the rinse cycle at the end of the water-washing process, the laundry products are assumed to go to POTW.

3.4.1.2 Facility Estimates

The number of commercial facilities using HHCB-containing laundry products is difficult to estimate. Based on 2011 census data, the OECD ESD (OECD, 2011) estimated 4,338 industrial laundries and up to 108,197 institutional facilities in the United States.

To estimate the number of commercial facilities, the total volume of HHCB in the United States for each product type is divided by the annual per-site HHCB use rate for that product type. Bounds are calculated as follows:

- Upper bound value for number of sites equals the upper-bound production volume divided by the 50th percentile annual use rate; and
- Lower bound value for number of sites equals the lower-bound production volume divided by the 95th percentile annual use rate.

Product-type production volumes are discussed in Section 3.2.4.1 (based on 2020 CDR).

CDR reports HHCB production volume for only two commercial laundry categories: liquid laundry detergents and liquid fabric enhancers. Due to the lack of product-specific data, these volumes were also applied to solid products. Facility counts were then calculated by dividing these production volumes by per-site annual HHCB use rates. For industrial laundries, estimates ranged from 37 to 26,372 sites, with the upper bound exceeding the ESD maximum—suggesting either an overestimate of the upper-bound production volume or an underestimate of per-site HHCB use. For institutional laundries, estimates ranged from 80 to 65,737 sites, remaining below the ESD maximum of 108,197. Given this uncertainty, per capita prevalence by NAICS code was used to support environmental release modeling (Section 4.3.1.2.2). The results are provided in Table 3-14.

Table 3-14. Number of Commercial Sites Using HHCB-Containing Laundry Products Based on 2020 CDR

Product Type	Type of Facilities	Product Type Production Volume		Annual Use Rate		Number of Sites
		Lower Bound	Upper Bound	50th Percentile	95th Percentile	Range
Liquid Laundry Detergent	Industrial	4,536	45,359	2.59	54.51	83–17,513
Liquid Fabric Softener[a]	Industrial	1,134	11,340	0.43	2.69	422–26,372
Liquid Laundry Detergent	Institutional	4,536	45,359	1.44	57.05	80–31,499
Liquid Fabric Softener[a]	Institutional	1,134	11,340	0.34	3.50	324–33,353
Solid Laundry Detergent[b]	Industrial	4,536	45,359	9.47	121.90	37–4,790
Solid Fabric Softener[c]	Industrial	1,134	11,340	1.63	15.23	75–6,957
Solid Laundry Detergent[b]	Institutional	4,536	45,359	0.69	5.83	778–65,737
Solid Fabric Softener[c]	Institutional	1,134	11,340	1.5	7.80	145–7,560

[a] No production volume specified for liquid fabric softeners, the volume for liquid fabric enhancers is used.
[b] No production volume specified for solid laundry detergents, the volume for liquid laundry detergents is used.
[c] No production volume specified for solid fabric softeners, the volume for liquid fabric enhancers is used.

3.4.1.3 Water Release Assessment

This approach combines data from the OECD ESD on the Chemicals Used in Water Based Washing Operations at Industrial and Institutional Laundries (OECD, 2011) with Monte Carlo simulation. The ESD distinguishes process parameters for industrial versus institutional laundry facilities, enabling facility-specific input and output. The TSCA COU includes liquid and powder products, with differing throughputs for detergent and fabric softeners. Accordingly, 12 model runs were conducted varying facility type (industrial/institutional), product form (liquid/powder), and product class (detergent/softener). Within each form, Monte Carlo "what-if" scenarios evaluated concurrent HHCB use in both the detergents and fabric softeners at the same facility.

Results for potential HHCB water releases from industrial laundries are shown in Table 3-15; results for institutional laundries are provided in Table 3-16. A full description of the modeling approach, parameters, and equations is provided in Appendix C.3.

1513 **Table 3-15. Water Release Estimates for Commercial Use of Laundry Products at Industrial Laundries**

Model Runs	Release Source	Environmental Media [a]	Annual Release (kg/site-yr)		Number of Release Days		Daily Release (kg/site-day)	
			CT	HE	CT	HE	CT	HE
Liquid Detergent at Industrial Laundries	Container Residue to water (POTW), incineration, or landfill	Water (POTW), incineration, or landfill	7.21E−03	1.68E−01	197	216	3.66E−05	7.80E−04
	Release from the Water-Washing Process to water (POTW)	Water (POTW)	2.58E00	5.43E01	202	213	1.28E−02	2.55E−01
Liquid Softeners at Industrial Laundries	Container Residue to water (POTW), incineration, or landfill	Water (POTW), incineration, or landfill	3.50E−03	4.57E−02	202	209	1.74E−05	2.18E−04
	Release from the Water-Washing Process to water (POTW)	Water (POTW)	4.27E−01	2.66E00	205	236	2.08E−03	1.13E−02
Liquid Detergent and Softeners at Industrial Laundries	Container Residue to water (POTW), incineration, or landfill	Water (POTW), incineration, or landfill	1.68E−02	1.86E−01	198	216	8.47E−05	8.61E−04
	Release from the Water-Washing Process to water (POTW)	Water (POTW)	3.39E00	5.58E01	203	214	1.67E−02	2.61E−01
Solid Detergent at Industrial Laundries	Container Residue to water (POTW), incineration, or landfill	Water (POTW), incineration, or landfill	9.47E−02	1.22E00	199	222	4.75E−04	5.48E−03
	Dust Generation from Transfer Operations Released to water (POTW)	Water (POTW)	9.61E−02	1.45E00	200	217	4.81E−04	6.68E−03
	Release from the Water-Washing Process to water (POTW)	Water (POTW)	9.27E00	1.19E02	200	223	4.64E−02	5.35E−01
Solid Softeners at Industrial Laundries	Container Residue to water (POTW), incineration, or landfill	Water (POTW), incineration, or landfill	1.63E−02	1.52E−01	200	261	8.14E−05	5.83E−04
	Dust Generation from Transfer Operations Released to water (POTW)	Water (POTW)	1.50E−02	1.97E−01	195	219	7.68E−05	9.02E−04
	Release from the Water-Washing Process to water (POTW)	Water (POTW)	1.60E00	1.49E01	200	262	7.96E−03	5.69E−02

Model Runs	Release Source	Environmental Media [a]	Annual Release (kg/site-yr)		Number of Release Days		Daily Release (kg/site-day)	
			CT	HE	CT	HE	CT	HE
Solid Detergent and Softeners at Industrial Laundries	Container Residue to water (POTW), incineration, or landfill	Water (POTW), incineration, or landfill	1.32E−01	1.28E00	205	217	6.46E−04	5.89E−03
	Dust Generation from Transfer Operations Released to water (POTW)	Water (POTW)	1.35E−01	1.55E00	200	215	6.78E−04	7.21E−03
	Release from the Water-Washing Process to water (POTW)	Water (POTW)	1.30E01	1.25E02	205	217	6.32E−02	5.76E−01

CT = central tendency; HE = high-end; POTW = publicly owned treatment works
[a] When multiple environmental media are addressed together, releases may go all to 1 media or be split between media depending on site-specific practices. Insufficient data provided to estimate the partitioning between media.

Table 3-16. Water Releases Estimates for Commercial Use of Laundry Products at Institutional Laundries

Model Runs	Release Source[a]	Environmental Media[a]	Annual Release (kg/site-yr)		Number of Release Days		Daily Release (kg/site-day)	
			CT	HE	CT	HE	CT	HE
Liquid Detergent at Institutional Laundries	Container Residue to water (POTW), incineration, or landfill	Water (POTW), incineration, or landfill	4.09E−03	1.75E−01	199	215	2.06E−05	8.13E−04
	Release from the Water-Washing Process to water (POTW)	Water (POTW)	1.44E00	5.69E01	200	220	7.20E−03	2.59E−01
Liquid Softeners at Institutional Laundries	Container Residue to water (POTW), incineration, or landfill	Water (POTW), incineration, or landfill	1.01E−03	1.06E−02	207	217	4.90E−06	4.90E−05
	Release from the Water-Washing Process to water (POTW)	Water (POTW)	3.42E−01	3.49E00	221	227	1.54E−03	1.54E−02

Model Runs	Release Source[a]	Environmental Media[a]	Annual Release (kg/site-yr)		Number of Release Days		Daily Release (kg/site-day)	
			CT	HE	CT	HE	CT	HE
Liquid Detergent and Softeners at Institutional Laundries	Container Residue to water (POTW), incineration, or landfill	Water (POTW), incineration, or landfill	7.02E−03	1.81E−01	202	215	3.48E−05	8.41E−04
	Release from the Water-Washing Process to water (POTW)	Water (POTW)	2.43E00	5.79E01	206	220	1.18E−02	2.63E−01
Solid Detergent at Institutional Laundries	Container Residue to water (POTW), incineration, or landfill	Water (POTW), incineration, or landfill	6.93E−03	5.83E−02	207	212	3.35E−05	2.75E−04
	Dust Generation from Transfer Operations Released to water (POTW)	Water (POTW)	7.31E−03	6.83E−02	203	215	3.59E−05	3.17E−04
	Release from the Water-Washing Process to water (POTW)	Water (POTW)	6.78E−01	5.71E00	207	212	3.28E−03	2.69E−02
Solid Softeners at Institutional Laundries	Container Residue to water (POTW), incineration, or landfill	Water (POTW), incineration, or landfill	1.50E−02	7.80E−02	189	238	7.94E−05	3.28E−04
	Dust Generation from Transfer Operations Released to water (POTW)	Water (POTW)	1.52E−02	1.06E−01	199	223	7.63E−05	4.75E−04
	Release from the Water-Washing Process to water (POTW)	Water (POTW)	1.47E00	7.63E00	192	237	7.67E−03	3.22E−02
Solid Detergent and Softeners at Institutional Laundries	Container Residue to water (POTW), incineration, or landfill	Water (POTW), incineration, or landfill	2.55E−02	1.21E−01	203	204	1.26E−04	5.91E−04
	Dust Generation from Transfer Operations Released to water (POTW)	Water (POTW)	2.63E−02	1.62E−01	201	226	1.31E−04	7.19E−04
	Release from the Water-Washing Process to water (POTW)	Water (POTW)	2.49E00	1.18E01	203	204	1.23E−02	5.78E−02

CT = central tendency; HE = high-end; POTW = publicly owned treatment works
[a] When multiple environmental media are addressed together, releases may go all to 1 media or be split between media depending on site-specific practices. Insufficient data were provided to estimate the partitioning between media.

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3.4.2 Use of Dishwashing Products

3.4.2.1 Process Description

In the food service industry, hand dish washing with soap is used as part of a three-basin cleaning system, diluted in hot water via manual or automated dispensing system. Dishwashing detergent is typically auto-dispensed into commercial machines. Potential release sources include open-surface volatilization during unloading and washing (Release Source #1 and #4), which are expected to be minimal given the low vapor pressure of HHCB and substantial dilution. If it is powder dishwashing detergent, then some of the product may be lost when transferring (Release Source #3). The use of the dishwashing detergent or soap ultimately results in down-the-drain releases (Release Source #5). Small container residues are likely disposed of to landfills due to small container sizes (Release Source #2). Release sources are summarized in Table 3-17.

Table 3-17. Use of Dishwashing Products Release Sources

Release Source Number	Release Source	Assessed/ Not Assessed	Rationale
1	Open Surface Losses to Air During Unloading of Dish Soap/Detergent	Not Assessed	HHCB has a low vapor pressure and weight concentration in these products, air releases are expected to be negligible.
2	Releases from Container Disposal to Landfill	Assessed	After final use of the dishwashing product, there may be some residue remaining in the container. Based on the small package size (1 gallon), it is not expected to be rinsed and re-used but will be disposed of as trash.
3	Transfer Operation Losses to POTW (Solids Only)	Assessed	For solid products, airborne dust may be generated during transfer operations, which may settle on surfaces. It is assumed that much of this dust for dishwasher detergents will likely be rinsed down-the-drain.
4	Releases to Air into Worker Breathing Zone from Washing	Not Assessed	HHCB has a low vapor pressure and weight concentration in these products, air releases are expected to be negligible.
5	Release of Dirty Water to POTW	Assessed	During use of dishwashing products, HHCB will be released down-the-drain

In the absence of commercial dishwashing product concentration data, the consumer SDS listing of 0.1% HHCB was used to estimate releases. This likely overestimates typical consumer concentrations; FCA reports a 90th percentile of 0.04% HHCB in "washing-up liquid" (FCA, 2021a). Consistent with a screening assessment, the higher SDS value was used to estimate commercial releases. Implications for the weight of scientific evidence are discussed in Section 3.6.1.

3.4.2.2 Facility Estimates

Due to the lack of data on the distribution of HHCB-containing dishwashing products to commercial sites, facility counts were estimated using product-type production volumes from 3.2.4.1. For each product type, the total U.S. HHCB production volume was divided by the corresponding annual per-site HHCB use rate to derive the number of facilities. The results are provided in Table 3-18.

Table 3-18. Number of Commercial Sites Using HHCB-Containing Dishwashing Products Using 2020 CDR

Product Type	Product Type Production Volume		Annual Use Rate		Number of Sites
	Lower Bound	Upper Bound	50th Percentile	95th Percentile	Range
Liquid Dishwasher Detergent	4,536	45,359	1.68	2.18	2,081–26,999
Solid Dishwasher Detergent	4,536	45,359	0.09	0.13	34,892–503,989
Liquid Dish Soap (Hand)	4,536	45,359	1.78	2.45	1,851–25,483

Counts by relevant NAICS code are shown in Table 3-19. Commercial dishwashing product use extends beyond food service to sports arena/stadiums, hospitals, and schools, which are expected to have high daily usage. For the environmental concentration modeling, a per capita prevalence rate by NAICS code was applied to support the analysis (see Section 4.3.1.2.2).

Table 3-19. NAICS Codes for Commercial Use of Dishwashing Products

NAICS Code	NAICS Code Description	Number of Sites	Primary Product
722310	Food Service Contractors	29,474	Dishwashing Products
722320	Caterers	12,800	Dishwashing Products
722330	Mobile Food Services	10,134	Dishwashing Products
722410	Drinking Places (Alcoholic Beverages)	38,398	Dishwashing Products
722511	Full-Service Restaurants	250,186	Dishwashing Products
722513	Limited-Service Restaurants	256,375	Dishwashing Products
722514	Cafeterias, Grill Buffets, and Buffets	4,783	Dishwashing Products
722515	Snack and Nonalcoholic Beverage Bars	72,985	Dishwashing Products
	Total	**675,135**	

3.4.2.3 Water Release Assessment

Three scenarios were modeled for the commercial use of dishwashing products:

- liquid dishwasher detergent;
- solid dishwasher detergent; and
- liquid hand dish soap.

For all three product types, small container sizes are assumed to be rinsed and are disposed of in the trash without rinsing (landfill). Daily use rates were primarily derived from the Consumer Exposure Model (CEM) v3.2 default values (U.S. EPA, 2023a), scaled to commercial conditions (*e.g.*, 8-hour operation), or taken directly from information from public comments. Modeled results are provided in Table 3-20. A full description of the modeling approach, parameters, and equations is provided in Appendix C.

Table 3-20. Water Release Estimates for Commercial Use of Dishwasher Products

Model Run	Release Source	Environmental Media[a]	Annual Release (kg/site-yr)		Number of Release Days		Daily Release (kg/site-day)	
			CT	HE	CT	HE	CT	HE
Liquid Dishwasher Detergent	Container Disposal to Landfill	Landfill	5.01E−03	9.25E−03	350	350	1.43E−05	2.64E−05
	Dirty Water to POTW	Water (POTW)	1.67E00	2.18E00	350	350	4.79E−03	6.22E−03
Solid Dishwasher Detergent	Container Disposal to Landfill	Landfill	8.82E−04	1.30E−03	350	350	2.52E−06	3.71E−06
	Transfer Operation Losses to POTW (Solids Only)	Water (POTW)	9.03E−04	2.42E−03	350	350	2.58E−06	6.90E−06
	Dirty Water to POTW	Water (POTW)	8.63E−02	1.27E−01	350	350	2.46E−04	3.63E−04
Liquid Hand Soap	Container Disposal to Landfill	Landfill	5.24E−03	1.02E−02	350	350	1.50E−05	2.92E−05
	Dirty Water to POTW	Water (POTW)	1.78E00	2.44E00	350	350	5.08E−03	6.97E−03

CT = central tendency; HE = high-end; POTW = publicly owned treatment works
[a] When multiple environmental media are addressed together, releases may go all to one media or be split between media depending on site-specific practices. Insufficient data were available to estimate media partitioning.

3.4.3 Use of Cleaning Products

3.4.3.1 Process Description

Based on product searches, HHCB is present in multi-surface, bath/washroom (including toilet/urinal), floor, floor conditioners, carpet, furniture, and glass cleaners. Limiting to products marketed for industrial/commercial use only, HHCB was identified in bath/washroom (including toilet/urinal cleaners), floor cleaners, floor conditioners, and carpet cleaners. Four scenarios were modeled: surface cleaners, toilet cleaners, liquid carpet cleaners and powder carpet cleaners.

Publicly available SDSs for commercial/industrial cleaning products reported HHCB concentrations of 0.1 to 0.3% (w/w), which were used to estimate releases.

Handling and application of cleaning products can lead to releases. During use, products may be transferred from containers to buckets or solution reservoirs (*e.g.*, auto scrubbers, carpet extractors) or applied directly to surface; some require dilution. Transfer operations can cause evaporative losses; but given HHCB's low vapor pressure, fugitive air emissions are expected to be minimal and not assessed (Cleaning Source #1).

Powder products containing HHCB may generate dust during transfer; the dust settles on surfaces and when these surfaces are cleaned (*e.g.*, vacuumed, mopped, etc.), is disposed of down-the-drain or to landfill (Cleaning Source #2). Near-empty containers may be rinsed to a drain or discarded to landfill (Cleaning Source #3).

The primary release source is product application; depending on the product, residues are disposed of down-the-drain, sent to landfill or remain on surfaces. For spray-applied products, a portion is initially airborne but is assumed to deposit and ultimately be managed via POTW or landfill (Cleaning Source #4).

The releases sources are shown below in Table 3-21.

Table 3-21. Use of Cleaning Products Release Sources

Release Source Number	Release Source	Assessed/ Not Assessed	Rationale
1	Transfer Operation Losses of Volatile Liquids to Fugitive Air	Not Assessed	Release of HHCB is considered negligible based on its low vapor pressure and weight fraction in cleaning products.
2	Transfer Operation Losses of Solids to Fugitive Air, POTW, or Landfill	Assessed	Powder products may generate airborne dust during transfer operations that eventually settle on surfaces. When the surfaces are cleaned, that dust may end up in a landfill or down-the-drain to a POTW.
3	Container Residuals to POTW or Landfill	Assessed	After final use of the cleaning product, there may be some residue remaining in the container. For small product package sizes, it is not expected to be rinsed and re-used but will be disposed of as trash.
4	Release from Application and Use to Fugitive Air and POTW or Landfill (media of release partitioning per discrete distribution)	Assessed	If the cleaning product is spray applied, some portions of the product will be released into the air during application. Non-spray applications are not expected to result in release to air. As floor cleaners are expected to be non-spray applications, no release to air is assumed. The bulk of the cleaning product after application is expected to either be released down-the-drain to a POTW or remain on the surface where potentially it may end up in landfill.

3.4.3.2 Facility Estimates

To estimate the number of commercial sites, total HHCB volume by product type was used to approximate the number of facilities using each product nationwide. Given limited information on allocation across products and between commercial and consumer markets, facility counts were calculated by dividing product-type HHCB volume by product-specific annual per-site use rates. Product-type volumes were derived from 2020 CDR data (Section 3.2.4.1). The results are provided in Table 3-22.

Table 3-22. Number of Commercial Sites Nationwide Using HHCB Containing Cleaning Products Based on 2020 CDR Approach

Release Scenario	Product Type Production Volume		Annual Use Rate		Number of Sites
	Lower Bound	Upper Bound	50th Percentile	95th Percentile	Range
Liquid Surface Cleaners	5,103	51,029	3.55	19.04	268–14,387
Liquid Toilet Cleaners	4,536	45,359	0.61	2.52	1,803–73,790
Liquid Carpet Cleaners	5,103	51,029	2.27E−03	6.13E−03	832,708–22,447,839
Solid Carpet Cleaners	4,536	45,359	2.2E−03	6.60E−03	687,261–20,617,835

This approach has key limitations and uncertainties:

- confidentiality claims restrict use of actual CDR production volumes;
- misalignment between modeled scenarios and CDR product categories necessitates surrogates (*e.g.*, using all-purpose foam spray cleaner volumes for powder carpet cleaners due to the lack of commercial powder data in the 2020 CDR; and
- reliance on manufacturers and importers reporting end uses, even if they do not produce the end-use products.

Consequently, the resulting facility count estimates are uncertain.

Given these uncertainties, EPA also complied counts of facilities by relevant NAICS codes from the U.S. Census (see Table 3-23). These counts serve as sector-specific upper bounds. Due to limited market data, EPA cannot refine these totals to the subset specifically using HHCB-containing products. The listed NAICS codes were selected because these sectors are expected to have frequent high usage of cleaning products; however, cleaning products are used across many NAICS codes. For environmental concentration modeling, per capita prevalence rate by NAICS code were applied to support the analysis (Section 4.3.1.2.2).

Table 3-23. NAICS Codes for Use of Cleaning Products

NAICS Code	NAICS Description	Number of Sites	Primary Product Types Used
561720	Janitorial Services	66,471	Surface and Toilet Cleaners
Hospitals and lodging accommodations			
622110	General Medical and Surgical Hospitals	5,849	Surface and Toilet Cleaners
622210	Psychiatric and Substance Abuse Hospitals	795	Surface and Toilet Cleaners
622310	Specialty (except Psychiatric and Substance Abuse) Hospitals	821	Surface and Toilet Cleaners
623110	Nursing Care Facilities (Skilled Nursing Facilities)	17,692	Surface and Toilet Cleaners
623210	Residential Intellectual and Developmental Disability Facilities	36,315	Surface and Toilet Cleaners
623220	Residential Mental Health and Substance Abuse Facilities	8,416	Surface and Toilet Cleaners

NAICS Code	NAICS Description	Number of Sites	Primary Product Types Used
623311	Continuing Care Retirement Communities	5,420	Surface and Toilet Cleaners
623312	Assisted Living Facilities for the Elderly	21,265	Surface and Toilet Cleaners
623990	Other Residential Care Facilities	6,067	Surface and Toilet Cleaners
721110	Hotels (except Casino Hotels) and Motels	56,478	Surface and Toilet Cleaners
721120	Casino Hotels	478	Surface and Toilet Cleaners
721191	Bed-and-Breakfast Inns	2,554	Surface and Toilet Cleaners
721199	All Other Traveler Accommodation	1,771	Surface and Toilet Cleaners
721310	Rooming and Boarding Houses, Dormitories, and Workers' Camps	1,666	Surface and Toilet Cleaners
	Total	**165,587**	
561740	Carpet and Upholstery Cleaning Services	7,023	Carpet Cleaning Products
N/A	Housing Units, July 1, 2024	146,770,711	Carpet Cleaning Products
Source: (U.S. Census Bureau, 2024, 2021)			

3.4.3.3 Water Release Assessment

Releases from various cleaning products were modeled using the potential release sources described in Section 3.4.3.1. A full description of the modeling approach, parameters, and equations are provided in Appendix C.2.

Surface Cleaners

For surface cleaners, the HHCB use rate was estimated from the surface area cleaned and the product application rate per unit area. Because data on professionally cleaned areas for multi-surface or bathroom cleaners were unavailable, but floor-area data were available, only the floor-cleaner scenario was estimated and is expected to be a larger contributor than multi-surface and bathroom cleaners due to their smaller surface areas.

Occupied floor area estimates were taken from an EPA study (U.S. EPA, 2023b). A default application rate of 40 mL/m^2 was assumed for floor cleaning, based on the National Institute for Public Health and the Environment [Netherlands] (RIVM) Consumer Cleaning Products Fact Sheet (RIVM, 2018); this represents the maximum identified rate. Other sources reported lower application rates (20 and 30 mL/m^2).

Floor cleaners are typically diluted before use (*e.g.*, in buckets or machine reservoirs). The dilution ratio was based on a commercial floor cleaner containing HHCB. Because the HHCB concentration was unavailable in the floor cleaners, HHCB concentration from only commercial cleaning products (bathroom cleaners) was used as a surrogate. While some product remains on the floors as residue, most is disposed of down-the-drain with spent wash water. The results are provided in Table 3-24.

Table 3-24. Water Release Estimates for Commercial Use of Surface Cleaners

Release Source	Environmental Media[a]	Annual Release (kg/site-yr)		Number of Release Days		Daily Release (kg/site-day)	
		CT	HE	CT	HE	CT	HE
Container Residuals to POTW or Landfill	Water (POTW) or Landfill	1.0E−02	6.2E−02	294	296	3.4E−05	2.1E−04
Release from Application and Use to POTW or Landfill	Water (POTW) or Landfill	3.5E00	1.9E01	294	296	1.2E−02	6.4E−02

CT = central tendency; HE = high-end; POTW = publicly owned treatment works
[a] When multiple environmental media are addressed together, releases may go all to one media or be split between media depending on site-specific practices. Insufficient data were available to estimate media partitioning.

Toilet Cleaners

For toilet cleaners, a daily HHCB use rate was estimated from cleaner applied used per toilet and the number of toilets in commercial buildings. The default RIVM (RIVM, 2018) was used for the amount per toilet used for consumers as it should be the same for commercial use. The number of toilets was estimated using the international plumbing code of one toilet per 50 people for each gender (ICC, 2020), combined with occupancy data from a sample of commercial buildings in the BASE study (U.S. EPA, 2023b). Results are provided in Table 3-25.

Table 3-25. Water Release Estimates for Commercial Use of Toilet Cleaners

Release Source	Environmental Media[a]	Annual Release (kg/site-yr)		Number of Release Days		Daily Release (kg/site-day)	
		CT	HE	CT	HE	CT	HE
Container Residuals to POTW or Landfill	Water (POTW) or Landfill	1.73E−03	8.51E−03	293	296	5.90E−06	2.88E−05
Release from Application and Use to POTW	Water (POTW)	6.13E−01	2.51E00	294	296	2.08E−03	8.46E−03

CT = central tendency; HE = high-end; POTW = publicly owned treatment works
[a] When multiple environmental media are addressed together, releases may go all to one media or be split between media depending on site-specific practices. Insufficient data were available to estimate media partitioning.

Carpet Cleaners

For liquid carpet cleaners, professional services cover both residential and commercial spaces; because only portions of floors are carpeted, the application area is smaller than for floor cleaners. The daily HHCB use rate was estimated assuming a typical job uses a full 12-gallon machine reservoir. Product usage was calculated from the reservoir volume and the labeled dilution for a HHCB-containing cleaner. While some residue remains in carpets, most is released with the spent extraction water. Results are provided in Table 3-26.

Solid (powder) carpet cleaners are expected to be used in limited areas. Thus, a default application rate equivalent to cleaning a residential living room was applied, based on the RIVM fact sheet (RIVM, 2018). Results are shown in Table 3-26.

Table 3-26. Water Release Estimates for Commercial Use of Carpet Cleaners

Product Type	Release Source	Environmental Media[a]	Annual Release (kg/site-yr)		Number of Release Days		Daily Release (kg/site-day)	
			CT	HE	CT	HE	CT	HE
Liquid Carpet Cleaners	Container Residuals to POTW or Landfill	Water (POTW) or Landfill	6.45E−06	2.14E−05	1	1	6.45E−06	2.14E−05
	Release from Application and Use to POTW or Landfill	Water (POTW) or Landfill	2.27E−03	6.11E−03	1	1	2.27E−03	6.11E−03
Solid (powder) Carpet Cleaners	Transfer Operation Losses of Solids to POTW or Landfill	Water (POTW) or Landfill	2.20E−06	1.98E−04	1	1	2.20E−06	1.98E−04
	Container Residuals to POTW or Landfill	Water (POTW) or Landfill	2.20E−05	6.60E−05	1	1	2.20E−05	6.60E−05
	Release from Application and Use to POTW or Landfill	Water (POTW) or Landfill	2.18E−03	6.34E−03	1	1	2.18E−03	6.34E−03

CT = central tendency; HE = high-end; POTW = publicly owned treatment works
[a] When multiple environmental media are addressed together, releases may go all to 1 media or be split between media depending on site-specific practices. Insufficient data were available to estimate media partitioning.

3.5 Consumer Releases

For this evaluation, COUs under the consumer use life-cycle stage are categorized as "consumer" releases. Consistent with Section 3.1, only scenarios expected to contribute to frequent water releases were evaluated. Residential uses of HHCB-containing products (*e.g.*, laundry detergents, dishwashing detergents, surface cleaners and mopping solutions) result in down-the-drain disposal. In this assessment, "surface cleaners" include mopping solutions disposed of down-the-drain. Per-capita loadings were estimated with Stochastic Human Exposure and Dose Simulation – High Throughput (SHEDS-HT v0.1.10) model (ICF, 2024). Although individual households contribute small amounts and do not discharge directly to the environment, community wastewater is aggregated at POTWs, and after treatment, discharged as a single continuous release to the receiving water. Accordingly, consumer release modeling focuses on community-scale, treated point source releases. Implementation details integrating SHEDS-HT, national POTW data, and the Point Source Calculator (PSC) are provided in Section 4.2.2.

3.6 Overall Release Assessment Conclusions and Weight of Scientific Evidence

For each RS, a weight-of-scientific-evidence rating is assigned based on the assessment approach; data and model quality; and the strengths, limitations, assumptions, and key uncertainties in the results. Factors evaluated that affect confidence in the release estimate (*e.g.*, data quality), the applicability of the data to the RS (*e.g.*, temporal and locational relevance), and representativeness for the broader industry. Evidence was categorized as robust, moderate, slight, or indeterminate per EPA's Application of Systematic Review in TSCA Risk Evaluations (U.S. EPA, 2021). For example, moderate may be assigned to measured release data from a limited number of sources that do not cover most sites within the RS; slight may reflect sparse information that does not sufficiently cover sites and for which key assumptions and uncertainties are not fully characterized. See (U.S. EPA, 2021) for additional details on conclusions.

3.6.1 Overall Confidence in Release Estimates by COU

Table 3-27. Weight of Scientific Evidence Conclusions by COU

Condition of Use	Release Scenario	Weight of Scientific Evidence Conclusions in Release Estimates
Manufacturing – Domestic manufacturing	Manufacturing	Water-release estimates are based on a single year of TRI (U.S. EPA, 2024) data (Reporting Year 2023), with only 2 facilities reporting under the manufacturing RS (based on TRI sub-use codes). The TRI data received a medium data-quality rating under EPA's systematic review process, which is a strength. The single year introduces uncertainty, as manufacturing and processing of HHCB may vary year to year due to shifts in demand of HHCB. However, a review of the preliminary 2024 data (see Appendix B.1.3) shows little change at 1 site while there was a decrease in releases at the other site. The low number of sites (n = 2) could be a limitation; however, the Agency expects manufacturing of HHCB to be limited. In recent CDR cycles (2012–2020) for HHCB, most sites report import-only activity. Additionally, the low reporting threshold for HHCB (>100 lb) increases confidence in capturing sites handling the large quantities of HHCB. However, because TRI reporting also applies only to facilities with 10 or more full-time employees, some small-size manufacturers may not be captured. TRI submissions indicate no direct on-site discharges of HHCB-containing (or previously containing) waste streams; most water releases occur via indirect transfers to POTWs. This pattern appears consistently across other HHCB-processing sites. Transfers estimates were generally based on mass-balance calculations, a strength of this approach. Although an HHCB manufacturing facility in the EU reported operating approximately 330 days per year, EPA used 250 days/yr to align with operating schedules of domestic processing sites for HHCB. There is some uncertainty in the assumption that the operating schedule is consistent with the number of days that HHCB-containing waste was released to POTWs. HHCB may not be manufactured every day of operation and/or the water release of HHCB may not occur every day. Therefore, the estimates may underestimate the daily release rate of HHCB to POTWs. Given limited release data and the lack of information on release frequency, EPA has concluded that the weight of scientific evidence for the manufacturing RS is moderate.

Condition of Use	Release Scenario	Weight of Scientific Evidence Conclusions in Release Estimates
Manufacturing – Importing	Repackaging	The water release estimates are based on a single year of TRI (U.S. EPA, 2024) data (RY 2023) with a single site reporting under the Repackaging RS. The mapping for this RS is based on company information, which includes Galaxolide (HHCB) as a product and a reported industry sector of wholesale and retail trade. TRI had a medium data quality rating through EPA's systematic review process, which is one of the strengths in this approach. The single year of release data introduces some uncertainties as manufacturing and processing of HHCB may vary year to year depending on the demand of HHCB. A single year of release information may fail to capture the variability in the releases of HHCB across different production years. Therefore, the preliminary data for reporting year 2024 was reviewed (see Appendix B.1.3), revealing a new reporter who did not release HHCB to water while the site that reported release to water in 2023 no longer reported any HHCB going to either a direct or indirect discharge to water. The low number of sites (n = 1) is a limitation, as the total number of sites repackaging HHCB in the U.S. is unknown. The low reporting threshold for HHCB (>100 lb) increases confidence in capturing sites likely handling the largest quantities of HHCB. However, because TRI reporting also applies only to facilities with 10 or more full-time employees, some repackaging sites with limited staff may not be captured. The site transfers its wastewater to a POTW and estimated the amount of HHCB using a published emission factor, which strengthens the approach. The operating schedule of 250 days/yr is based on the draft Chemical Repackaging Generic Scenario and is similar to the operating schedule for compounders and formulators. There is some uncertainty in the assumption that the operating schedule is consistent with the number of days that HHCB-containing waste was released to POTWs. HHCB may not be repackaged every day of operation and/or the water release of HHCB may not occur every day. Therefore, the estimates may underestimate the daily release rate of HHCB to POTWs. Based on the limited release information, uncertainty in the estimation method, and lack of offsite treatment information, the EPA has concluded that the weight of scientific evidence for the repackaging RS is slight-to-moderate.

Condition of Use	Release Scenario	Weight of Scientific Evidence Conclusions in Release Estimates
Processing – Processing – Incorporation into formulation, mixture or reaction product – Odor agent in: All other chemical product and preparation manufacturing; Miscellaneous manufacturing; Soap, cleaning compound, and toilet preparation manufacturing; Fragrance mixtures and fragrance raw materials	Formulation of Fragrance Oils	The water release estimates are based on a single year of TRI (U.S. EPA, 2024) data (RY 2023) with twelve sites reporting under the Formulation of Fragrance Oils RS. The mapping for this RS is based on TRI sub-use codes and company information. TRI had a medium data quality rating through EPA's systematic review process, which is one of the strengths in this approach. The single year of release data introduces some uncertainties as manufacturing and processing of HHCB may vary year to year depending on the demand of HHCB. A single year of release information may fail to capture the variability in the releases of HHCB across different production years. Preliminary data for 2024 (see Appendix B.1.3) suggests higher releases occurred in 2024. Facility estimates are based on the reported processing sites from TRI with a reporting threshold of 100 lb. Therefore, the data captures a more representative distribution of releasing facilities. The representativeness of this distribution conveys more confidence in the risk characterization. Six of the 12 reporting sites release wastewater containing HHCB only to POTWs. Most sites calculated their estimates based on published emission factors, which is a strength of the approach. The TRI production/activity ratio for facilities mapped to this RS indicates that from 2022–2023 production volume changes ranged from decreases of nearly 30% to increases of nearly 30%. The number of operating days is based on the low end of an FCA survey as the survey indicates that HHCB may not be used every operating day. There is some uncertainty in the assumption that the operating schedule is consistent with the number of days that HHCB-containing waste was released to POTWs. HHCB may not be formulated into fragrance oils every day of operation and/or the water release of HHCB may not occur every day. Therefore, the estimates may underestimate the daily release rate of HHCB to POTWs. Based on the strength of the release information provided in TRI, the limited number of reporting years and the uncertainty in the number of release days across reporting sites, the EPA has concluded that the weight of scientific evidence for the Formulation of Fragrance Oils RS is moderate.
3 COUs: Processing – Processing – Incorporation into formulation, mixture or reaction product – Odor agent in: All other chemical product and preparation manufacturing; Miscellaneous manufacturing; Soap,	Formulation of End-Use Products	The water release estimates are based on a single year of TRI (U.S. EPA, 2024) data (RY 2023) with thirty-three sites reporting under the Formulation of End-Use Products RS. The mapping for this RS is informed by TRI sub-use codes, company information and SDSs. TRI had a medium data quality rating through EPA's systematic review process, which is one of the strengths in this approach. However, relying on a single year of data introduces some uncertainties as manufacturing and processing of HHCB may vary year to year depending on the demand of HHCB. A single year of release information may fail to capture the variability in the releases of HHCB across different production years. The TRI production/activity ratio for facilities mapped to this RS ranged from a 35% decrease in production (2022–2023) to over a 200% increase in production (2022–2023). Preliminary data for 2024 (see Appendix B.1.4) suggests that releases remain consistent between 2023 and 2024.

Condition of Use	Release Scenario	Weight of Scientific Evidence Conclusions in Release Estimates
cleaning compound, and toilet preparation manufacturing; Fragrance mixtures and fragrance raw materials Processing – Processing – Incorporation into articles – Odor agent in Plastics material and resin manufacturing Processing – Recycling		Most of the release estimates were based on published emission factors and mass balance calculations; however, a few sites reported other unspecified approaches. These unspecified approaches are an uncertainty in the assessment as the validity of the estimation approach cannot be judged. Facility estimates are based on the reported processing sites from TRI with a reporting threshold of 100 lb. As indicated in a survey submitted by FCA, there may be formulators who handle very small quantities of HHCB each year and therefore may not be included in the releases estimated for the manufacturing or processing COUs. Based on the strength of the release information provided in TRI, the limited number of reporting years, the uncertainty in the number of release days across reporting sites, and the highly variable production volumes across facilities from 2022–2023, the EPA has concluded that the weight of scientific evidence for the Formulation of End-Use Products is moderate.
Disposal	Waste Handling, Treatment, and Disposal	The facility estimates are based on identification of 'disposal' sites from TRI information (U.S. EPA, 2024). TRI had a medium data quality rating through EPA's systematic review process, which is one of the strengths in this approach. There are no water releases estimated for the two identified sites. The mapping for facilities under this RS is based on TRI sub-use code and NAICS code information. For HHCB, the TRI reporting threshold is 100 lb with no *de minimis* limit. This production volume threshold is lower (because it is classified under TRI as persistent, bioaccumulative, and toxic) than the threshold for most chemicals (25,000 lb. for manufacturing and processing, 10,000 lb. for otherwise use) and therefore captures a more representative distribution of releasing facilities. The representativeness of this distribution should convey more confidence in the risk characterization. The single year of release data introduces some uncertainties as quantities sent off-site for disposal vary year to year depending on the demand of HHCB. A single year of release information may fail to capture the variability in the releases of HHCB across different production years. Preliminary data for 2024 suggests that disposal sites continue to report no releases of HHCB to water. Additionally, the 2024 data include four additional waste management sites. There are only 2 facilities mapped to this RS and both report 0 direct and indirect discharges to water. Based on the 2023 TRI data, many facilities reported transferring their waste to off-site facilities; however, these facilities did not appear as a reporting facility. There is uncertainty whether these additional waste management companies may release HHCB into water. However, the treatment and disposal methods reported do not indicate that these sites would have additional water releases. While the Agency has the amount transferred; EPA does not have the final amounts released into the

Condition of Use	Release Scenario	Weight of Scientific Evidence Conclusions in Release Estimates
(Continued)		environment. Based on the limited programmatic release information and the uncertainty that it is representative of disposal sites, the EPA has concluded that the weight of scientific evidence for the Waste Handling, Treatment, and Disposal RS is moderate.
Commercial use – Laundry and dishwashing products – Laundry detergent (liquid); Laundry detergent (unit dose/granule); Fabric enhancers; Stain removers; Dishwashing detergent (liquid/ gel); Dishwashing detergent (unit dose/granule); Dishwashing detergent liquid (hand-wash)	Use of Liquid Laundry Products (Industrial)	The EPA assessed water releases assuming that HHCB associated with the use and application of laundry products will primarily go down-the-drain. EPA used EPA models as well as assumptions on daily use rates from ESD on Water-based Washing Operations at Industrial and Institutional Laundries (OECD, 2011) with Monte Carlo modeling to estimate releases to the environment. The ESD received data quality ratings of medium. This assessment used HHCB concentration data from a commercial fabric softener product; for laundry detergents, consumer product concentrations were used because commercial data were not available. Typically, commercial products can be more concentrated than consumer products; however, it is unknown if fragrance content will be more concentrated in commercial than consumer products. For example, fragrances may be lower or non-existent in commercial products to avoid including allergens in laundered products for public use. For solid laundry detergents and fabric softeners, the concentrations used were for HHCB in liquid products, which is an uncertainty in the assessment. In addition, the consumer concentrations from SDSs were higher than suggested from industry submissions (FCA, 2021a). The use of Monte Carlo modeling is a strength of the assessment as variation in model input values and a range of potential release values are more likely to capture actual releases than discrete values. Monte Carlo modeling also considers a large number of data points (simulation runs) and the full distributions of input parameters. The primary limitation to be the uncertainty in the production volume attributed to laundry products, which is used to estimate releases when the estimated number of sites exceeds the maximum number of U.S. sites as documented in Census data. This may overestimate HHCB down-the-drain releases from industrial and institutional laundries. Additionally, EPA lacked chemical-specific information on the prevalence of HHCB-containing products at these laundries. Based on this information, EPA concluded that the weight of scientific evidence for the Use of Liquid Laundry Products is moderate.
	Use of Liquid Laundry Products (Institutional)	
	Use of Powder Laundry Products (Industrial)	
	Use of Powder Laundry Products (Institutional)	
	Use of Dishwashing Products – Use of Liquid	EPA assessed water releases assuming that HHCB associated with the use and application of dishwashing products will primarily go down-the-drain. The Agency used EPA models as well as assumptions on daily use rates combined with Monte Carlo modeling to estimate releases to the environment. The daily use rates were derived from defaults in the CEM model (U.S. EPA, 2023a)

Condition of Use	Release Scenario	Weight of Scientific Evidence Conclusions in Release Estimates
(Continued) Commercial use – Laundry and dishwashing products – Laundry detergent (liquid); Laundry detergent (unit dose/granule); Fabric enhancers; Stain removers; Dishwashing detergent (liquid/ gel); Dishwashing detergent (unit dose/granule); Dishwashing detergent liquid (hand-wash)	Dishwashing Detergent Use of Dishwashing Products – Use of Liquid Hand Dish Soap Use of Dishwashing Products – Use of Powder Dishwashing Detergent	and based on a public comment from industry (P&G, 2023) which had data quality rating of medium. EPA used the chemical-specific concentration information of HHCB in consumer hand washing products. Typically, commercial products can be more concentrated than consumer products, however, it is unknown if fragrance content will be more concentrated in commercial than consumer products. For example, fragrances may be lower or non-existent in commercial products to avoid including allergens for public use. In addition, the consumer concentrations from SDSs were higher than suggested from industry submissions (FCA, 2021a). For solid dishwashing products, the concentrations used were for HHCB in liquid products, which is an uncertainty in the assessment. The use of the Monte Carlo modeling is a strength of the assessment as variation in model input values and a range of potential release values are more likely to capture actual releases than discrete values. Monte Carlo modeling also considers a large number of data points (simulation runs) and the full distributions of input parameters. The primary limitation to be the uncertainty in the concentration of HHCB in dishwasher detergents and commercial hand-washing products. Additionally, since EPA scales up CEM defaults to derive a daily use rate, there is uncertainty of the representativeness of values toward the true distribution of daily use rates at commercial sites. Based on this information, EPA has concluded that the weight of scientific evidence for the Use of Dishwashing Products is moderate.
Commercial Use – Cleaning and furnishing care products – All-purpose foam spray cleaner; All-purpose liquid cleaner/polish; All-purpose liquid spray cleaner; All-purpose waxes and polishes; Appliance cleaners; drain and toilet cleaners (liquid); Powder cleaners (floors); Powder cleaners (porcelain)	Use of Cleaning Products – Use of Liquid Surface Cleaners Use of Cleaning Products – Use of Liquid Toilet Cleaners	Water releases were assessed for the use of cleaning products using EPA models as well as assumptions on daily use rates combined with Monte Carlo modeling to estimate releases to the environment. Based on the type of products and application, HHCB is expected to primarily go down-the-drain. The underlying sources employed to predict the amount of HHCB used per day of application were EPA BASE study (U.S. EPA, 2023b), RIVM Factsheet on Cleaning Products (RIVM, 2018), and product instruction information. These references received data quality ratings of medium to high and have clearly documented sources, approaches and assumptions. The Agency used the chemical-specific concentration and product instruction information of HHCB in commercial cleaning products. The use of the Monte Carlo modeling is a strength of the assessment as variation in model input values and a range of potential release values are more likely to capture actual releases than discrete values. Monte Carlo modeling also considers a large number of data points (simulation runs) and the full distributions of input parameters.

Condition of Use	Release Scenario	Weight of Scientific Evidence Conclusions in Release Estimates
	Use of Cleaning Products – Use of Liquid Carpet Cleaners	The primary limitation to be the uncertainty in the daily usage rates toward the true distribution of potential releases. Additionally, EPA lacked an approach to estimate daily use rates for multi-surface or bathroom cleaners for commercial buildings and therefore derived an estimate based on the daily use of floor cleaners. For solid carpet cleaners, the concentrations used were for HHCB in liquid products, which is an uncertainty in the assessment. Based on this information, EPA concluded that the weight of scientific evidence for the Use of Cleaning Products RS is moderate.
	Use of Cleaning Products – Use of Powder Carpet Cleaners	

4 ENVIRONMENTAL CONCENTRATIONS AND EXPOSURES

This section builds on the information presented in Section 2 and Section 3 and (1) presents the conceptual exposure models—organized by environmental media; (2) explains the rational for whether or not a given media is further assessment (Section 4.1), (3) describes the assessment approaches and methodologies (Section 4.2); and (4) provides a summary of available monitoring data and modeled estimated environmental concentrations by media (Section 4.3).

4.1 Conceptual Exposure Overview

HHCB is released from industrial, commercial and consumer COUs and across multiple environmental media. HHCB is emitted to air and surface waters and is present in wastewater-derived biosolids, with subsequent transport and partitioning to sediment and soil. Considering HHCB's chemistry, transport, fate, and COU release scenarios, the primary HHCB exposure pathways into aquatic and terrestrial ecosystems are through discharges into surface water and land application of biosolids to soil after municipal wastewater treatment (Sections 2 and 3). Subsequent bioaccumulation into aquatic and terrestrial organisms also lead to oral/dietary exposures in upper trophic levels of food webs (Section 2.4.7). While HHCB is released directly to air, its low volatility (Section 2.3.6) and rapid photolysis (Section 2.4.1) lead to low persistence in ambient air (Appendix D). HHCB has also been measured in but is not expected to persist in groundwater due to partitioning to sediment and soil (Section 2.4.5; Appendix E). Based on the available evidence, HHCB environmental exposures are assessed as follows:

- assessments of industrial, commercial, and consumer COU release scenarios with subsequent surface water and sediment exposures near wastewater treatment outflows using measured and modeled concentrations (Sections 4.1.2, 4.2.2, and 4.3.1);
- a screening assessment of biosolids to soil land-applications using a non-COU related scenario and an upper bound measured concentration (Sections 4.1.3, 4.2.3, and 4.3.2); and
- assessment of bioaccumulation and trophic transfer in aquatic and terrestrial food webs using measured and modeled concentrations (Sections 4.1.4, 4.2.4, and 4.3.3).

This environmental exposure assessment considered the potential HHCB hazards to populations of ecological receptors in surface water and sediment, and in soil and on land (Section 4.1.5) in support of the *Draft Risk Evaluation for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026j) that uses the environmental hazard thresholds in the *Draft Human Health and Environmental Hazard Assessment for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026i). Environmental releases into water were refined for human exposures in the *Draft Human Exposure Assessment for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026h).

4.1.1 Air

HHCB can enter ambient air via industrial emissions and incineration of biosolids or HHCB-containing products. Volatilization from surface water may also occur but is limited (Section 2.3.6). Atmospheric persistence is low due to limited volatility and rapid photolysis (Section 2.4.1). Short atmospheric half-lives and low potential for long range transport (Section 2.4.1) indicate that, while detectable in air at low concentrations locally including in the Great Lakes region (Appendix D), HHCB is unlikely to be widespread in ambient air. Therefore, air is not a major exposure route for environmental organisms and air exposure pathways to ecological receptors were not evaluated in this assessment.

4.1.2 Surface Water and Sediment

Most HHCB in the United States is expected to be disposed of down-the-drain, reaching surface waters downstream of wastewater treatment effluent releases, with potential exposure to populations of aquatic organisms. Wastewater treatment can achieve substantial removal (*e.g.,* >95%; Section 2.4.6; (Clara et al., 2011)), reducing effluent and downstream concentrations, with residual HHCB primarily partitioning to biosolids. However, based on hazard thresholds, concentrations of HHCB in effluent may expose aquatic organisms to adverse effects. Additionally, residual HHCB will partition to particulates and sediments, diminishing water-column exposure but increasing exposure for sediment-dwelling and sediment-ingesting organisms.

4.1.3 Biosolids and Soil

During wastewater treatment, HHCB sorbs to sludge. Processed sludge may be incinerated, landfilled, or applied to land as biosolids. Following land applications, HHCB is not expected to leach through the soil profile or runoff, based on its physical and chemical properties and environmental fate characteristics (Section 2). Residual HHCB in soil may persist with limited mobility, potentially exposing soil-dwelling organisms including earthworms and plants.

Based on HHCB's properties and fate behavior (Section 2), leaching to groundwater and runoff to surface water after land application or landfilling are unlikely. Thus, groundwater exposure is expected to be limited, which aligns with the low number of detections from monitoring datasets (Appendix E). Accordingly, this exposure assessment does not further evaluate groundwater or runoff.

4.1.4 Bioaccumulation and Trophic Transfer

Due to its lipophilic properties (*e.g.,* log octanol/water partition coefficient or log K_{OW} = 5.9; Section 2), HHCB is expected to bioaccumulate in animals. HHCB has also been widely reported in the tissues of both aquatic and terrestrial animals including predators in upper trophic levels (Section 2.4.7). HHCB can enter animal bodies through water exposures via direct chemical exchange across respiratory surfaces, and through ingestion exposures via the alimentary canal (Arnot and Gobas, 2006) with the net concentration of HHCB in an animal at any one time being the result of exposure pathway, duration, and within-animal metabolism.

In terrestrial ecosystems, HHCB may be present in soil due to land application of biosolids (Section 2.4). Soil-dwelling organisms, including earthworms, may be exposed to and bioaccumulate HHCB as a result. Higher-tropic-level terrestrial mammals may be exposed to HHCB via consumption of earthworms containing HHCB.

4.1.5 Receptors

Aquatic and terrestrial receptors may be exposed to HHCB at concentrations sufficient to cause adverse, population-level effects. Environmental hazard thresholds were derived in *the Draft Human Health and Environmental Hazard Assessment for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026i).

The hazards to the following receptor groups informed the environmental exposure assessment:

- acute exposure hazards to aquatic animals;
- chronic exposure hazards to aquatic vertebrates;
- chronic exposure hazards to sediment dwelling invertebrates;
- chronic soil exposure hazards to terrestrial invertebrates and plants; and
- chronic dietary exposure hazards to terrestrial mammals.

4.2 Approach and Methodology

Environmental exposure to HHCB is characterized by (1) compiling and summarizing available environmental monitoring data across environmental media and (2) estimating environmental concentrations via modeling for relevant release scenarios. This draft assessment focuses on a screening level approach assuming that the highest modeled concentrations in water and sediment and the highest measured concentrations in soil are protective across TSCA COUs as described in the subsections below by environmental media.

4.2.1 Environmental Monitoring Data

U.S. monitoring data was compiled focusing on samples collected post-1999. Data before this date was not considered relevant as it is less likely to represent modern practices and uses of HHCB. Concentrations for surface water, sediments, groundwater, and sewage sludge were obtained from the Water Quality Portal in March of 2025, the largest repository by scope and duration, with nationwide coverage across diverse water body types and site vulnerabilities. This dataset includes other monitoring data (*i.e.,* ocean water, street sweepings, etc.) that are not described in this document but are provided in the supplemental file. Although sampling programs generally were not designed to target specific chemical occurrences (timing, frequency, site selection) or TSCA COUs, many locations coincide with discharge areas. Sampling frequency is typically sporadic, ranging from annual events to several times per month depending on site and year. Data are summarized for the number of sampling events, the number and frequency of detections, non-detections, and the reported values. If samples are below the detection limit, the value is not included in the summary.

Monitoring data for ambient air and groundwater are not the focus of this assessment but are provided in Appendix D and Appendix E, respectively, because these media are not expected to be major exposure pathways.

4.2.2 Surface Water and Aquatic Sediment Modeling

4.2.2.1 Surface Water Release Scenarios

HHCB concentrations in surface water and sediment were estimated for four environmental release scenarios (described in the subsections below) for TSCA COUs that release HHCB to surface waters. This approach was used because the available monitoring data, while informative, cannot be attributed to specific TSCA COUs, and may not be representative of the national distribution of concentrations at the point of release. The four exposure scenarios are introduced here and detailed methods for each are presented in the sections that follow:

- **Industrial Releases:** Manufacturing and Processing COUs transfer HHCB-containing wastewater to offsite treatment facilities (POTWs or commercial), which are assumed to treat it and discharge HHCB-containing effluent to surface water (Figure 4-1).

Figure 4-1. Graphical Summary of Modeled Industrial Surface Water Release Scenario

- **Commercial Down the Drain:** Commercial use COUs (Cleaning and furnishing care products, Laundry and dishwashing products) generate down-the-drain HHCB releases from product usage in commercial settings (at hotels, laundromats, hospitals, restaurant kitchens, and other business types) across a municipality, which combine to a single POTW that treats and discharges HHCB-containing effluent (Figure 4-2).

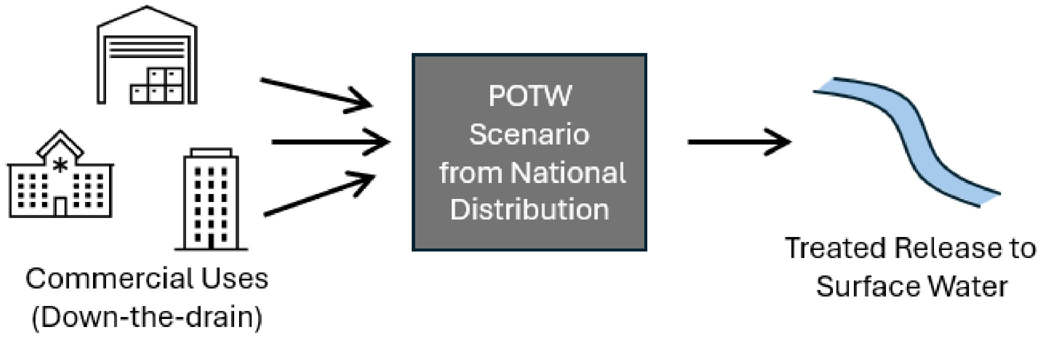

Figure 4-2. Graphical Summary of Modeled Commercial Down-the-Drain Surface Water Release Scenario

- **Consumer Down-the-Drain:** Consumer use COUs (Cleaning and furnishing care products, Laundry and dishwashing products) generate down-the-drain HHCB releases from residential use of cleaning, dishwashing, and laundry products across a municipality, which combine to a single POTW that treats and discharges HHCB-containing effluent (Figure 4-3).

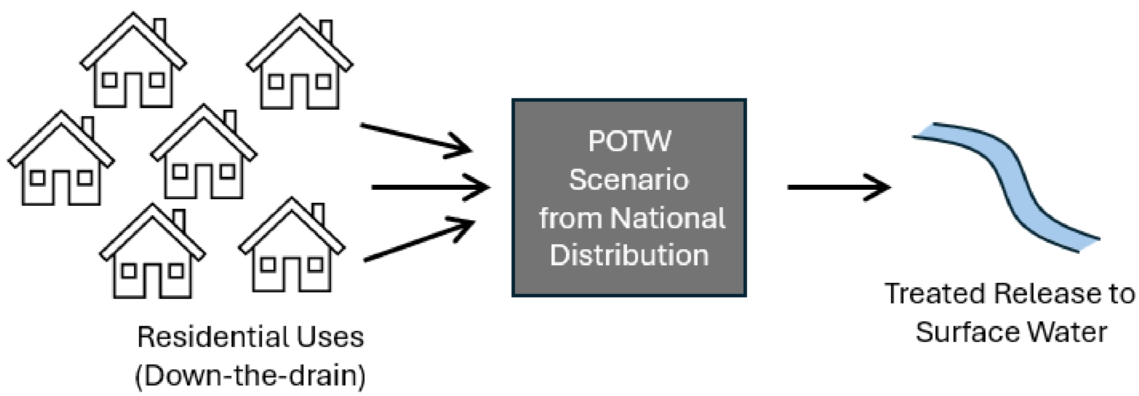

Figure 4-3. Graphical Summary of Modeled Consumer Down-the-Drain Surface Water Release Scenario

- **Combined Commercial Plus Consumer Down-the-Drain:** The two previous down-the-drain scenarios assume combination of commercial-only or consumer-only down-the-drain release to a single POTW, which then discharges to a receiving water body. In practice, commercial and consumer release co-occur at the same POTW producing combined downstream HHCB releases from both sources (Figure 4-4). Industrial releases are excluded from this analysis. The POTW distribution applied for down-the-drain modeling represents thousands of known release sites (Section 4.2.2.2.2); however, only a small number of industrial discharges are reported to occur to community POTWs and (the contribution to HHCB loading at those POTWs are minimal in comparison (Section 4.3.1.2).

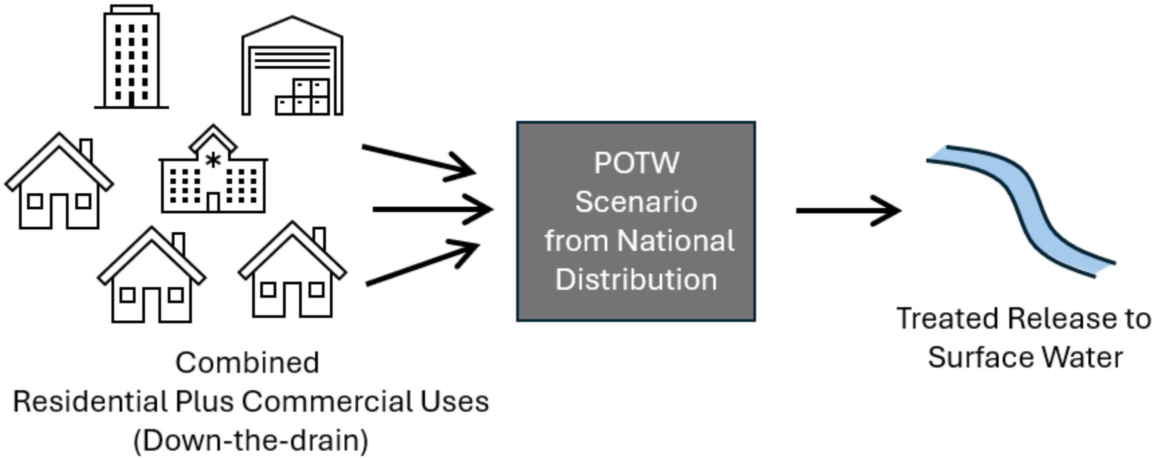

Figure 4-4. Graphical Summary of Modeled Combined Commercial Plus Consumer Down-the-Drain Surface Water Release Scenario

4.2.2.2 Point Source Calculator (PSC)

The Variable Volume Water Model (VVWM) in EPA's PSC v1.05 (U.S. EPA, 2019b) was used to estimate HHCB concentrations in surface water and benthic sediment from TSCA COU releases. PSC uses chemical-specific inputs (*e.g.,* K_{OC}; water column, photolysis, hydrolysis, and benthic half-lives) as well as release schedules and receiving water body parameters to model water column and benthic sediment concentrations. Modeled releases were evaluated at the discharge point (*i.e.,* the immediate receiving water body receiving the effluent) for resulting environmental media concentrations.

4.2.2.2.1 Static Inputs

HHCB physical and chemical properties (Table 4-1) were input into PSC (based on the selected values described in Section 1.2). Because HHCB is persistent in benthic sediment and stable to hydrolysis, benthic and hydrolysis half-life were set to an arbitrary large value to render these processes negligible in the model. A common environmental/media setup was applied across all COUs (PSC simulations), combining standard exposure assessment parameters with user-defined inputs from release modeling and site-specific data. Default water body characteristics for water column chemistry and sediment parameters (Table 4-2) were applied that promotes sediment retention due to the elevated organic carbon and when combined with other parameters results in a conservative screening scenario (U.S. EPA, 2019b). A single receiving-water body geometry, which represents a short segment of a flowing stream, was used across all simulations, (width of 5 m, length of 40 m, and depth of 1 m, which is consistent with EPA's standard farm pond scenario).

Table 4-1. PSC Model Chemical Inputs

Parameter	Value[a]
K_{OC}	7,762.5 mL/g
Water column half-life	556 days at 25 °C
Photolysis half-life	0.154 days
Hydrolysis half-life	9,999 days at 25 °C
Benthic half-life	9,999 days at 25 °C
Molecular weight	258.41 g/mol
Vapor pressure	0.000545 torr
Solubility	1.75 mg/L at 25 °C

Henry's Law constant	1.06E-04[4] atm m^3/mol at 25 °C
Heat of Henry[b]	45,727 J/mol
Reference temperature	25 °C
[a] Selected values for these parameters are described in Section 1.2 [b] Estimated using HENRYWIN™ in EPI Suite™ (U.S. EPA, 2015b)	

Table 4-2. Water Body Characteristics for PSC Model Inputs

Parameter	Value[a]
DFAC (represents the ratio of vertical path lengths to depth as defined in EPA's exposure analysis modeling system [EXAMS] (U.S. EPA, 2019b))	1.19
Water column suspended sediment	30 mg/L
Chlorophyll	0.005 mg/L
Water column f_{oc} (fraction of organic carbon associated with suspended sediment)	0.04
Water column dissolved organic carbon (DOC)	5.0 mg/L
Water column biomass	0.4 mg/L
Benthic depth	0.05 m
Benthic porosity	0.50
Benthic bulk density	1.35 g/cm^3
Benthic f_{oc}	0.04
Benthic DOC	5.0 mg/L
Benthic biomass	0.006 g/m^2
Mass transfer coefficient	0.00000001 m/s
[a] Water body characteristic parameters align with those of the standard EPA farm pond (U.S. EPA, 2019b).	

4.2.2.2.2 Variable Inputs

Hydrologic flow rate and release parameters (daily release amount and days of release) were parameterized to reflect site-specific conditions for each facility for each COU scenario.

Hydrologic Flow

The PSC model requires a hydrologic flow rate as an input. In TSCA risk evaluations, EPA typically applies three flow statistics: the 7Q10 (lowest 7-day average flow with a 10-year recurrence interval), the 30Q5 (lowest 30-day average flow with a 5-year recurrence interval), and the harmonic mean flow. The 7Q10 represents a worst-case low-flow condition for assessment of short-term exposure; 30Q5 provides a moderate low-flow condition for assessment of short-term exposure, and the harmonic mean represents an average flow for assessing longer-term exposure.

Receiving water body flow metrics for the modeled releasing facilities were developed using National Pollutant Discharge Elimination System (NPDES) permit data and NHDPlus-modeled flow statistics. For industrial releases, the NPDES permit for the offsite wastewater processing facility was identified; for the representative POTW scenarios, the NPDES permits for specific POTWs listed in the 2022 Clean Watersheds Needs Survey (CWNS) database were identified (U.S. EPA, 2025a). EPA's Enforcement and Compliance History Online (ECHO) API (DMR REST service) was queried to obtain NHDPlus reach codes for each facility's receiving water body. Modeled flow metrics were then extracted for those reaches from the NHDPlus V2.1 Flowline Network EROM Flow database, which provides monthly average flows, and mean annual flow. Because EROM values represent 30-year averages, the minimum monthly average flow was used as a proxy for the 30Q5. This substitute 30Q5 flow was then input to the EFAST regression to convert between flow metrics and estimate the 7Q10 (Equation 4-1).

Equation 4-1. Calculating the 7Q10 Flow

$$7Q10 = \frac{\left(0.409\frac{cfs}{MLD} \times \frac{30Q5}{1.782}\right)^{1.0352}}{0.409\frac{cfs}{MLD}}$$

Where:

$7Q10$	=	Modeled 7Q10 flow, in million liters per day (MLD)
cfs	=	Cubic feet per second
$30Q5$	=	Lowest monthly average flow from NHD (MLD)

Furthermore, the harmonic mean (HM) flow was calculated using Equation 4-2, derived from the relevant EFAST regression, applying the estimated 7Q10, and the arithmetic mean annual flow from the NHD.

Equation 4-2. Calculating the Harmonic Mean Flow

$$HM = 1.194 \times \frac{\left(0.409\frac{cfs}{MLD} \times AM\right)^{0.473} \times \left(0.409\frac{cfs}{MLD} \times 7Q10\right)^{0.552}}{0.409\frac{cfs}{MLD}}$$

Where:

HM	=	Modeled harmonic mean flow (MLD)
AM	=	Annual average flow from NHD (MLD)
$7Q10$	=	Modeled 7Q10 flow from the previous equation (MLD)

In addition to the hydrologic flow data from NHDPlus, facility effluent discharge rates were obtained, when available, from the ECHO API. The receiving water body flow was set to the greater of the hydrologic flow estimated by regression or the facility effluent flow. This accounts for intermittent or small streams where low-flow conditions are dominated by effluent contributions unlikely to be captured in EROM estimates. This avoids overestimating concentrations when reports of facility effluent are available.

Release Parameters

This subsection summarizes the methods used to estimate environmental loadings of HHCB used in PSC for each environmental release scenario described above.

Industrial Releases: Release information for industrial is taken directly from release assessment Section 3.3. Per Section 3.2.3.1, TRI 2023—the only year with available reported HHCB releases—was used to quantify HHCB industrial loads to wastewater. Annual TRI facility releases were converted to average daily loads by dividing by the expected operating days (Section 3). Daily loads and release schedules were used as inputs to PSC. For COUs with multiple exposure scenarios or multiple releasing facilities, the maximum modeled concentration was reported for screening.

Commercial Down the Drain: Release information for commercial is taken directly from the release assessment presented in Section 3.4. Per Section 3.4, Monte Carlo distributions of annual HHCB down-the-drain disposal from commercial uses were calculated for the following product use categories: laundry detergent and softener, dishwashing detergent, and other cleaning solutions such as toilet cleaner, surface cleaner, and carpet cleaner. These release distributions were applied to the surface water pathway as population-scaled scenarios combining all commercial sources to a POTW. For the commercial down-the-drain release scenario, NAICS-based site counts were normalized by population to derive national per capita prevalence for facility types in the commercial down-the-drain analysis (Table 4-3). To capture variability across business types, individual-business loadings were parameterized using Monte Carlo-derived CT (central tendency) and HE (high-end) releases, results are reported CT and HE scenarios.

Table 4-3. Prevalence of Business-Category Sites Associated with Commercial Down the Drain Releases (10K)

Business Category	U.S. Average Number of Sites per Capita (10K) [a]
Cleaning Services	2.2
Janitorial Services	2.0
Carpet and Upholstery Cleaning Services	0.21
Hospitals and Nursing Facilities	3.1
Lodgings	1.9
Food Service	20.3
Laundries	0.58

[a] Derived from Census data (see Section 3.4 for details).

Like industrial releases, annual commercial releases were converted to average daily loads and used as inputs to PSC. Because the commercial combined down-the-drain scenarios encompasses multiple product uses, numerous use sites (*e.g.*, hospitals, hotels, restaurants, etc.), and thousands of POTWs nationwide, specific facilities from a national distribution of potential release scenarios were selected to streamline PSC modeling. This was done using nationwide POTW data from the Clean Watershed Needs Survey (CWNS) (U.S. EPA, 2025a) along with the Census data to develop representative HHCB loading and effluent-release scenarios. P50 and P95 scenarios are summarized in Table 4-5. Because receiving-water flows vary widely, greater population or influent loading does not necessarily yield higher concentration; larger flows provide more dilution and faster washout. Percentile scenarios jointly consider influent loads and receiving-water flows, ranking facilities by the ratio of contributing population to receiving-water flow to derive concentration percentiles. Relationships are developed by facility, linking each POTW's contributing population and estimated influent loading to its permitted receiving water body. Scenario-development details are provided in Appendix E.

Modeling results characterize the range of estimated environmental concentrations for each scenario. The full distribution of modeling results is provided in the *Draft Commercial Down-the-Drain POTW Release Calculations for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026a).

Consumer Down the Drain[4]*:* Due to the lack of direct POTW discharge data for HHCB for consumer COUs, consumer down-the-drain releases were estimated using EPA's Stochastic Human Exposure and Dose Simulation – High Throughput (SHEDS-HT v0.1.10) Model (ICF, 2024). SHEDS-HT is a probabilistic (Monte Carlo) platform that simulates individual-day activity patterns and product-use events, using inputs such as product concentrations, use frequency and amount, physical and chemical properties, and life-stage/sex-specific behavior patterns. Outputs characterize population variability and can incorporate parameter uncertainty. Product data from the *Product Concentration Data for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2025b) were used as inputs. HHCB weight fractions varied by product types and individual products and were typically near 0.1% (1 g/kg).

Input files were separated by product type, enabling individual SHEDS-HT runs to quantify product-specific contribution and combined loading. The model parameterized 15 TSCA COU products with HHCB plus eight other non-TSCA products (generally personal care products; Table 4-4). To estimate the apportionment of TSCA and non-TSCA consumer down-the-drain sources of HHCB, all 23 product types were modeled. The complete inputs and code used to prepare and execute the SHEDS-HT runs are provided in *Draft SHEDS-HT Consumer Product Modeling Files for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)*(U.S. EPA, 2026b).

Table 4-4. Consumer Product Types Included in SHEDS-HT for Estimating Consumer Down-the-Drain Loading

SHEDS-HT Product Code (source.id)	SHEDS-HT Product Name (source.description)
Products included in TSCA COUs	
P.IH.010.007	air freshener-gel
P.IH.010.029	air freshener-spray
P.IH.010.999	air freshener-NOC
P.IH.040.999	bathroom cleaner-NOC
P.IH.070.029	carpet cleaner-spray
P.IH.070.999	carpet cleaner-NOC
P.IH.080.000	carpet deodorizer
P.IH.260.013	laundry detergent-liquid
P.IH.260.023	laundry detergent-powder
P.IH.260.999	laundry detergent-NOC
P.IH.270.000	laundry fragrance
P.IH.280.999	laundry stain remover-NOC
P.IH.340.999	surface cleaner-NOC
P.PT.060.999	pet stain cleaner-NOC

[4] The basis of the down-the-drain modeling approach was previously reviewed by the Scientific Advisory Committee on Chemicals (SACC) as applied for the 2024 Supplement to the Risk Evaluation for 1,4-Dioxane (https://www.epa.gov/chemicals-under-tsca/epa-releases-meeting-minutes-and-final-report-science-advisory-committee; accessed March 23, 2026). Further refinement of the method with newer data are included in the methodology for this assessment.

SHEDS-HT Product Code (source.id)	SHEDS-HT Product Name (source.description)
Products not included in TSCA COUs	
P.PC.160.000	body care set
P.PC.170.999	body oil-NOC
P.PC.200.000	body wash
P.PC.480.999	fragrance-NOC
P.PC.550.999	hair conditioner-NOC
P.PC.630.999	hand or body lotion-NOC
P.PC.820.999	shampoo-NOC
P.IH.100.029	disinfectant-spray
P.IH.100.999	disinfectant-NOC
NOC = not otherwise classified	

SHEDS-HT produces per capita daily down-the-drain load distributions. For POTW scenarios, product-specific mean per capita loads were summed and scaled by the contributing population to estimate daily HHCB influent loads, reflecting variability in product characteristics and use patterns.

Like for commercial uses there are multiple variables that drive exposure – multiple product uses, numerous use sites (*e.g.*, residential homes, apartments), and greater than 13,000 POTWs nationwide, a probabilistic approach was applied to develop a distribution of potential release scenarios to streamline PSC modeling and the P50 and P95 scenarios summarized.

Combined Commercial Plus Consumer Down the Drain: Combined exposures were estimated by summing commercial and consumer down-the-drain loadings to the same POTW to produce an overall POTW release estimate. The CT results from Monte Carlo down-the-drain modeling are used in this combined analysis to be representative of typical loading conditions, when applied across many facilities sending waste to a community-based POTW.

Wastewater Treatment

All releases are expected to undergo wastewater treatment at commercial treatment facilities for industrial releases and at POTWs for other industrial and all down-the-drain releases. To reflect the variability in HHCB removal, results reflect three assumptions: 50% (primary), 92% (secondary), and 99% (advanced) (Section 2.4.6). Details of the POTWs selected for representative down-the-drain scenarios are presented in Table 4-5. The POTW release scenario percentiles were estimated by analyzing facility-specific input sets (information about the contributing population, level of treatment, and receiving water body flow) to predict the relative ranking of the model results, focusing on the 50th (P50) and 95th (P95) percentiles within a large set of potential inputs. Further details of the development of these scenarios are presented in Appendix F.

Table 4-5. Characteristics of Representative POTW Release Scenarios for Down-the-Drain Surface Water Releases

POTW Release Scenario	Contributing Population	Receiving Water Body 7Q10 Flow (MLD)	Receiving Water Body 30Q5 Flow (MLD)	Receiving Water Body HM Flow (MLD)	Removal Efficiency Applied (%)
P95	38,000	17.3	17.3	20.7	92
P50	950,000	1,260	1,260	1,260	99

Note: Flow rates are identical across some metrics due to substituting the facility effluent flow rate for the receiving waterbody flow, where the facility effluent flow rate exceeds the hydrologic flow in the receiving water body.

4.2.3 Biosolid Land Application and Soil Modeling

HHCB soil concentrations were estimated for industrial and commercial and consumer down-the-drain sources applied in large volumes to agricultural sites. Biosolids marketed for residential use were not separately assessed as agricultural application involves higher application rates than would be expected in home gardens.

To estimate soil concentrations from biosolid applications, Equation 4-3 was used. This equation is based on Equation 60 of the European Commission Technical Guidance Document (ECB, 2003). The equation is as follows:

Equation 4-3. Estimation of Soil Concentration from Biosolid Application

$$PEC_{soil} = \frac{C_{sludge} \times AR_{sludge}}{D_{soil} \times BD_{soil}}$$

Where:

PEC_{soil}	=	Predicted environmental concentration (PEC) for soil (mg/kg)
C_{sludge}	=	Concentration in sludge (mg/kg)
AR_{sludge}	=	Application rate to sludge amended soils (kg/m^2/yr); default = 0.5
D_{soil}	=	Depth of soil tillage (m); default = 0.2 m in agricultural soil and 0.1 m in pastureland
BD_{soil}	=	Bulk density (kg/m^3); default =1,700 kg/m^3

Given up to 90 percent HHCB is dissipated in soil over 1 year (see Section 2.4.4), this assessment assumes a single biosolids application, with most HHCB degrading before any subsequent application. Sludge HHCB concentrations from available monitoring data ranged from less than 0.33 ng/kg to 554,000 μg/kg (see Section 4.3.2.1), reflecting variability in wastewater treatment facility size, served population, product-use behaviors, treatment technologies, and sludge organic content. Soil concentrations were estimated iteratively at logarithmic steps ranging from 0.01 to 1.0×10^6 μg/kg to encompass all monitored biosolid concentration values.

4.2.4 Bioaccumulation, Biomagnification, and Trophic Transfer

HHCB can enter animals through direct uptake from water across respiratory surfaces (*e.g.,* gills in aquatic organisms), or through oral ingestion of food, water, or sediment containing HHCB through the alimentary canal (Arnot and Gobas, 2006). Given high lipophilicity (*e.g.,* log octanol/water partition coefficient or log K_{OW} = 5.9, Section 1.2), HHCB is expected to bioaccumulate. Although animals metabolize HHCB (Schneider et al., 2021; Van Dijk, 1996), uptake rate may exceed elimination rates, leading to measurable concentrations in exposed organisms and animals that consume aquatic organisms (Section 2.4.7).

Bioaccumulation is the net buildup of a chemical in an organism from all environmental exposure routes (*e.g.*, dietary and respiratory) typically expressed as a bioaccumulation factor (BAF) (Arnot and Gobas, 2006). Bioconcentration refers specifically to uptake from water via respiratory and dermal surfaces and is described by the BCF. EPA considers chemicals with BAF or BCF greater than 1,000 to be of bioaccumulation concern (Zeeman, 1995).

Bioaccumulation indices for HHCB are widely reported but vary by study type, species, and ecosystem (Wang et al., 2023). BCF and BAF values can also be estimated using modeling approaches, including regression-based QSAR models (Arnot and Gobas, 2006), kinetic mass-balance models (Gobas et al., 2019), fugacity-based multimedia models (Mackay, 2004), and food web bioaccumulation models (U.S. EPA, 2009). HHCB bioaccumulation indices derived from empirical data including BAF and BCF values were reviewed (Section 2.4.7 and Section 4.3.3.1).

For bioaccumulation in aquatic ecosystems, a screening-level approach was initially used to estimate HHCB in fish tissues by using an upper-bound bioaccumulation index (*e.g.,* BCF = 1,584 L/kg derived from respiratory surface uptake only) and a series of upper bound measured and modeled surface water concentrations (Sections 4.2.4.1 and 4.3.3.4.2). Due to uncertainties in the relative importance of respiratory versus dietary uptake and the significant variability in empirical BAF and BCF values, this analysis was supplemented with a two-compartment kinetic mass-balance model (ADME-B; (Gobas et al., 2019)) and a food web bioaccumulation model (KABAM) (U.S. EPA, 2009)). This screening approach was augmented by modeling HHCB absorption, distribution, metabolism and excretion in fish using ADME-B (Section 4.2.4.2 and Section 4.3.3.2.1; (Gobas et al., 2019)) and KABAM (Section 4.3.3.2.2; (U.S. EPA, 2009), resulting in additional lines of evidence and increased confidence in the screening results.

Evidence indicates that animals obtain HHCB through their diet, indicating measurable trophic transfer from prey to predators (Kinney et al., 2006; Kannan et al., 2005) (Section 2.4.7). The potential biomagnification (*e.g.,* higher relative HHCB body burdens at higher trophic levels) was considered by reviewing the reasonably available evidence from food web studies (Section 4.3.3.3.1) and by modeling food web bioaccumulation with KABAM (Section 4.3.3.2.2 and Section 4.3.3.4.3; (U.S. EPA, 2009)).

As part of the *Draft Risk Evaluation for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026j) EPA evaluated the potential risks to aquatic and terrestrial organisms, recognizing that risk depends on both environmental exposures and hazards. Accordingly, the scope of this assessment is limited to pathways with reasonable evidence of environmental hazard (U.S. EPA, 2026j). No evidence of diet- or trophic-based hazard was identified for aquatic organisms (U.S. EPA, 2026i). Similarly, no diet-based hazard from HHCB was found for terrestrial organisms (*e.g.,* mammals, birds, invertebrates). In lieu of wild mammal hazard data, a dietary hazard threshold was derived using laboratory rodent experiments and extrapolated to representative wild mammals. Accordingly, this assessment evaluates two exposure pathways:

- **Water to Fish-Eating Mammals** (water → fish tissues → fish-eating mammals): Industrial and commercial and consumer down-the-drain releases lead to HHCB concentrations in surface waters that accumulate in fish tissues, resulting in dietary exposure for fish-eating mammals.
- **Biosolids to Earthworm-Eating Mammals** (biosolids → soils → earthworms → earthworm-eating mammals): Industrial and down-the-drain releases result in HHCB concentrations in biosolids following wastewater treatment that when applied to land can lead to accumulation in

earthworms resulting in dietary exposure to earthworm-consuming mammals.

4.2.4.1 Modeling Concentrations in Fish Using Screening Level BCF

A BCF value of 1,584 L/kg (Section 2.4.7) was used in a first-tier screen to conservatively estimate HHCB in representative fish tissues, using measured or modeled water concentrations for industrial and down-the-drain releases.

In this assessment, EPA used the following steady-state BCF equation:

Equation 4-4. Calculation of Bioconcentration Factor (BCF)

$$BCF = C_{Fish}/C_{Water}$$

Where BCF is reported for whole-fish or wet weight basis (1,584 L/kg) and C_{Water} was the modeled or measured surface water concentration (µg/L) for each scenario, the equation was rearranged to solve for C_{Fish}. C_{Fish} is the predicted HHCB concentration (µg/kg ww) in representative fish for each scenario.

4.2.4.2 ADME-B Modeling

ADME-B is a two-compartment toxicokinetic model that describes bioaccumulation of neutral hydrophobic organic chemicals in fish (Gobas et al., 2019). ADME-B was used to parameterize HHCB ADME (absorption, distribution, metabolism, and excretion) for an OECD Guideline 305 dietary bioaccumulation test (Schneider et al., 2021), deriving bioconcentration and biomagnification factors, and somatic and intestinal biotransformation rates. Unlike one-compartment models, ADME-B accounts for exposure pathway (*i.e.,* aqueous vs. dietary) effects on bioaccumulation. ADME-B allowed information integration from aqueous and dietary endpoints to assess the relative contributions of respiratory and dietary uptake.

EPA entered HHCB log K_{OW} (5.9), water solubility (1.75 mg/L), and test conditions and output from Schneider (2021) (Table 4-6) into the ADME spreadsheet (Gobas et al., 2019).

Table 4-6. HHCB-Specific Parameters Used as Inputs to ADME-B Model

Input	Value
Logarithm of octanol-water partition coefficient (K_{OW})	5.90
Solubility in water	1.75E−03 g/L
Fish body weight	0.00187 kg
Concentration of chemical in diet	0.5480 g HHCB/kg food
Proportional feeding rate	0.02 kg food/kg fish ww-day
Duration of the exposure (uptake) period	14 days
Lipid content of fish body	0.045 kg lipid/kg fish ww
Lipid content of diet	0.165 kg lipid/kg diet
Water content of diet	0.12 kg water/kg diet
Water temperature	22.1 °C
Dissolved oxygen concentration	8.4 mg O_2/L
Dietary assimilation efficiency	0.1648
Rate constant for growth dilution	0.0194 1/day

4.2.4.3 KABAM Modeling

KABAM v1.0 (U.S. EPA, 2009) was used to refine screening-level estimates of HHCB bioaccumulation in a generalized freshwater food web that includes terrestrial mammals. KABAM uses the octanol-water partition coefficient (K_{OW}) to estimate the uptake and elimination of a chemical through the respiration and diet of aquatic organisms at multiple trophic levels. The model was used to calculate HHCB tissue concentrations and then estimate dose- and dietary-based exposures to mammal consumers. The results provide additional lines of evidence for the potential dietary HHCB risk estimates to wild mammal populations and for risk estimates to humans via fish ingestion.

EPA used the default settings outlined in the KABAM version 1.0 User's Manual (U.S. EPA, 2009) for all inputs except for the chemical-specific user inputs (*i.e.,* HHCB log K_{OW} = 5.9 and K_{OC} = 70,800), typical particulate organic carbon (POC = 4.5 mg/L) and dissolved organic carbon (DOC = 10 mg/L) concentrations near wastewater treatment outflows (Yang et al., 2016; Krasner et al., 2009), and the calculated metabolic rate constants (k_M) that were derived from an OECD study of bluegill (Van Dijk, 1996) (Appendix G).

4.2.4.4 Modeling Concentrations in Earthworms

HHCB concentrations in earthworms range from below detection limit to 3,340 µg/kg (Kinney et al., 2008). Estimates of HHCB bioaccumulation in terrestrial organisms are limited to a few field studies of earthworms in biosolids-amended soils in the United States. (Kinney et al., 2012; Kinney et al., 2008) and in Norway (Havranek et al., 2017). In U.S. studies, earthworm BAF values (whole-body, dry-weight tissue:soil) ranged from 0.05 to 36, varying with biosolid percentage and time since application (Kinney et al., 2012; Kinney et al., 2008). The maximum BAF (36) occurred 2 weeks after 3% biosolids application (Kinney et al., 2012). These BAFs are field-derived and reflect empirical uptake under *in situ* field conditions rather than equilibrium partitioning.

Using the maximum field-derived earthworm BAF of 36 and conservative assumptions (fresh, peak biosolid applications, high-end bioavailability, and non-steady-state post-application), an upper-bound earthworm concentration was calculated by multiplying the upper-bound soil concentration (1,629 µg/kg; Section 4.2.3 by the maximum BAF of 36 for screening to get a resulting earthworm concentration of 58,644 µg/kg ug/kg.

4.3 Results

Environmental exposure concentrations for HHCB are presented in this section considering both available environmental monitoring data and model estimated concentrations. Results are presented by environmental media in the following subsections.

4.3.1 Surface Water and Sediment

4.3.1.1 Surface Water Monitoring Data

EPA compiled HHCB monitoring data for ambient surface water and freshwater sediments, primarily from the Water Quality Portal (WQP) database (NWQMC, 2025). Many samples were collected by the U.S. Geological Survey (USGS) and are presumed to follow USGS guidance, increasing confidence in data validity. Metadata indicates numerous sample locations downstream of WWTPs and POTWs, increasing relevance to this risk evaluation. Surface water monitoring data has spatial and temporal uncertainties and is often non-targeted, potentially underestimating true concentrations and not fully representing use areas or vulnerable waterbodies. Additionally, sampling data are often duplicated across databases and publications (*e.g.,* Gefell et al. (2025)) referencing the same source data. Accordingly, this national-scale assessment primarily relies on WQP data to minimize duplication and ensure consistency. A weight-of-evidence evaluation is presented below, considering monitoring frequency, timeframe relevance, alignment with toxicological endpoints, and site characteristics. Site-specific conditions evident in WQP metadata and studies cited in EPA's 2014 HHCB assessment (OCSPP, 2014) include sampling at treated-wastewater discharge locations and direct sampling of facility influent, effluent, and sludge.

4.3.1.1.1 Measured Surface Water Concentrations

The WQP portal was queried (accessed March 2025) for all available HHCB surface water concentrations from 1999 onward and visualized (detection frequency (Figure 4-5) and locations mapped (Figure 4-6) on a national level. Of 6,877 sampling events, HHCB was detected in 664 samples. Most detected water concentrations (n = 660) were below 3.0 µg/L. Reported detection limits ranged from 0.27 to 50 µg/L, with nearly all at or below 0.5 µg/L. The two highest reported values, 25 and 25.5 µg/L, from low-flow samples collected, in October 2021 in a creek downstream from a California POTW serving approximately 100,000 residents align with modeled release scenarios. However, because these were generated using non-standard methods with no reported detection limits, they are excluded from Figure 4-5 and Figure 4-6. Other high concentrations were measured in Texas. Also not shown in Figure 4-5 are sampling events where HHCB was not detected.

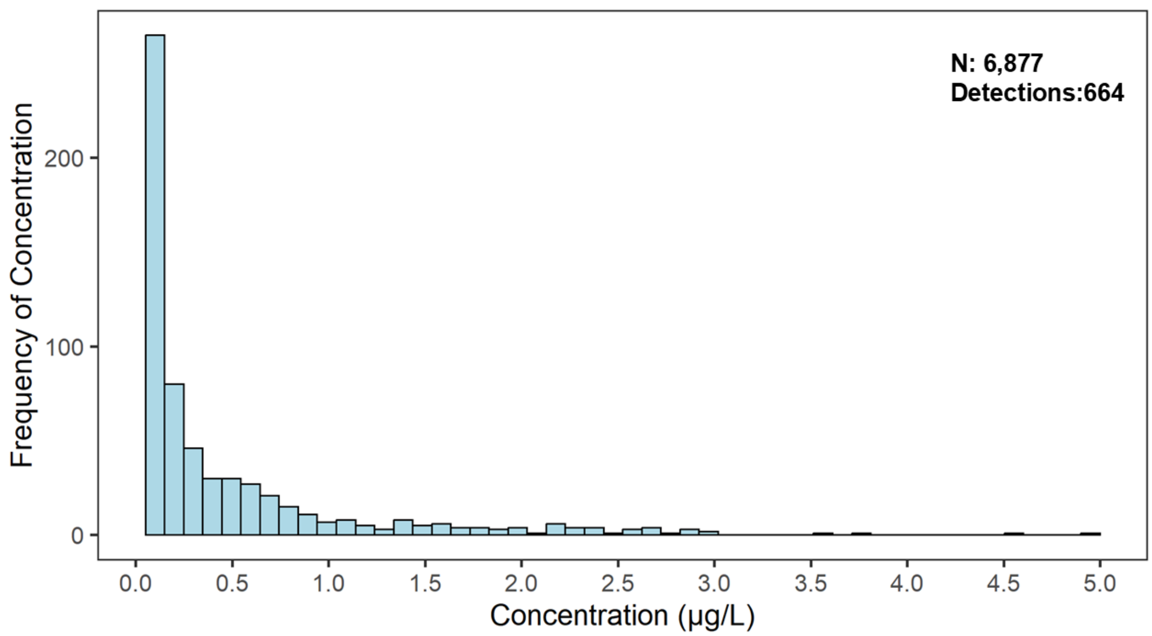

Figure 4-5. Monitored Surface Water HHCB Concentrations

Data based on all WQP entries post-1999; note: samples below the method detection limit (MDL) not shown

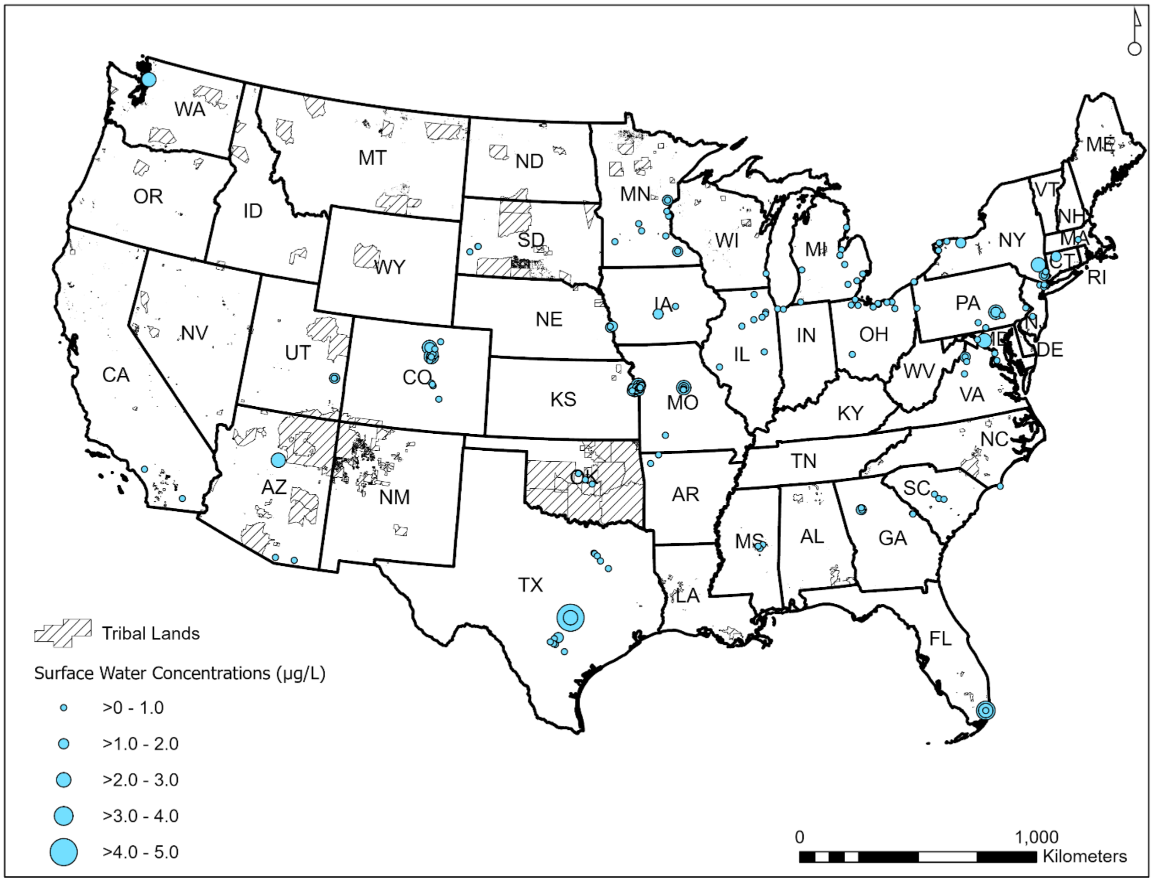

Figure 4-6. Location and Concentrations of HHCB Surface Water Monitoring Data

Data based on all WQP entries post-1999; note: samples below the MDL not shown

4.3.1.1.2 Aquatic Sediment Monitoring Data

The WQP was queried (downloaded March 2025) for aquatic sediment samples collected after January 1999 and visualized (detection frequency (Figure 4-7) and locations mapped (Figure 4-8) on a national basis. Of the 1,727 sampling events, HHCB was detected above method detection limits in 60 samples; most were below 1,000 µg/kg (sediment concentration method detection limits ranged from 0.5–1,145 µg/kg). The highest number of samples and the highest sediment concentrations of HHCB were observed in Idaho and Pennsylvania (Figure 4-5) with a high of 6,860 µg/kg for an October 2007 benthic sediment sample from Idaho. This monitoring location is in a creek downstream from a POTW serving a population of approximately 7,800 people and is noted as a low-stage flow condition, which aligns with the scenario modeled in this assessment. It is notable that these locations differ from the highest concentrations detected or measured in surface water. Generally, HHCB concentrations in sediment are higher than those in water. This observation is consistent with fugacity modeling (see Section 2.4.5.1) and other fate characteristics (water solubility and log K_{OW}) summarized in this TSD.

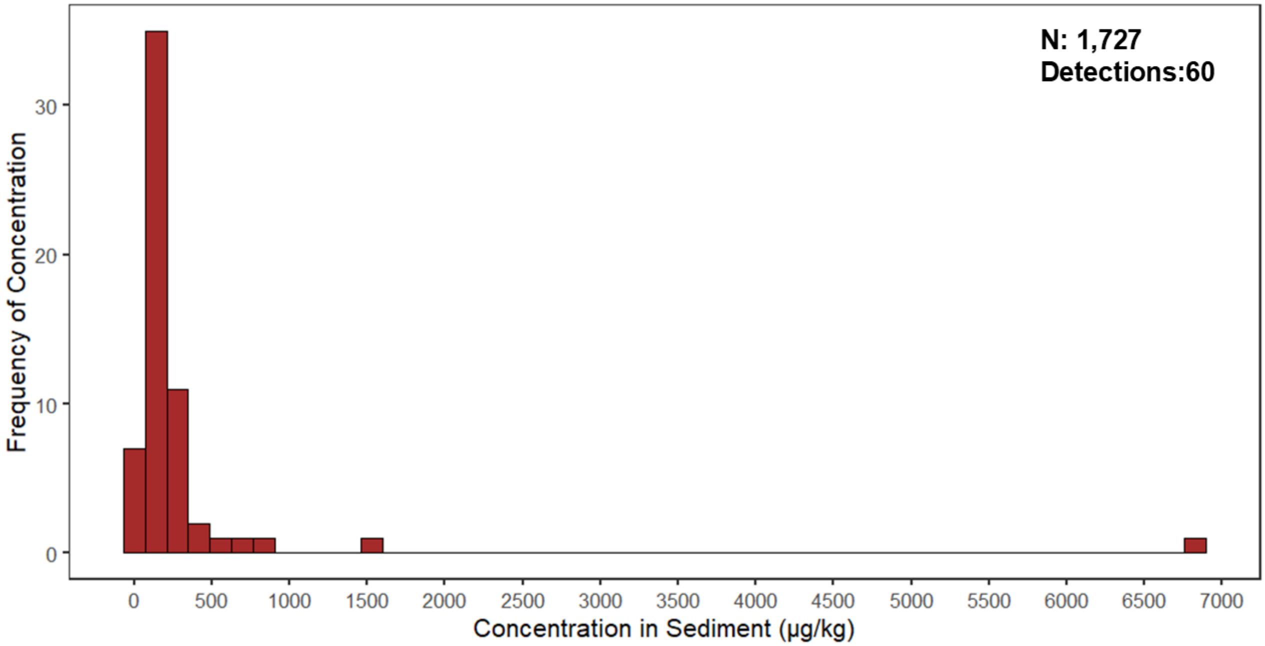

Figure 4-7. Measured Sediment HHCB Concentrations

Data based on all WQP entries post 1999; note: samples below the MDL not shown

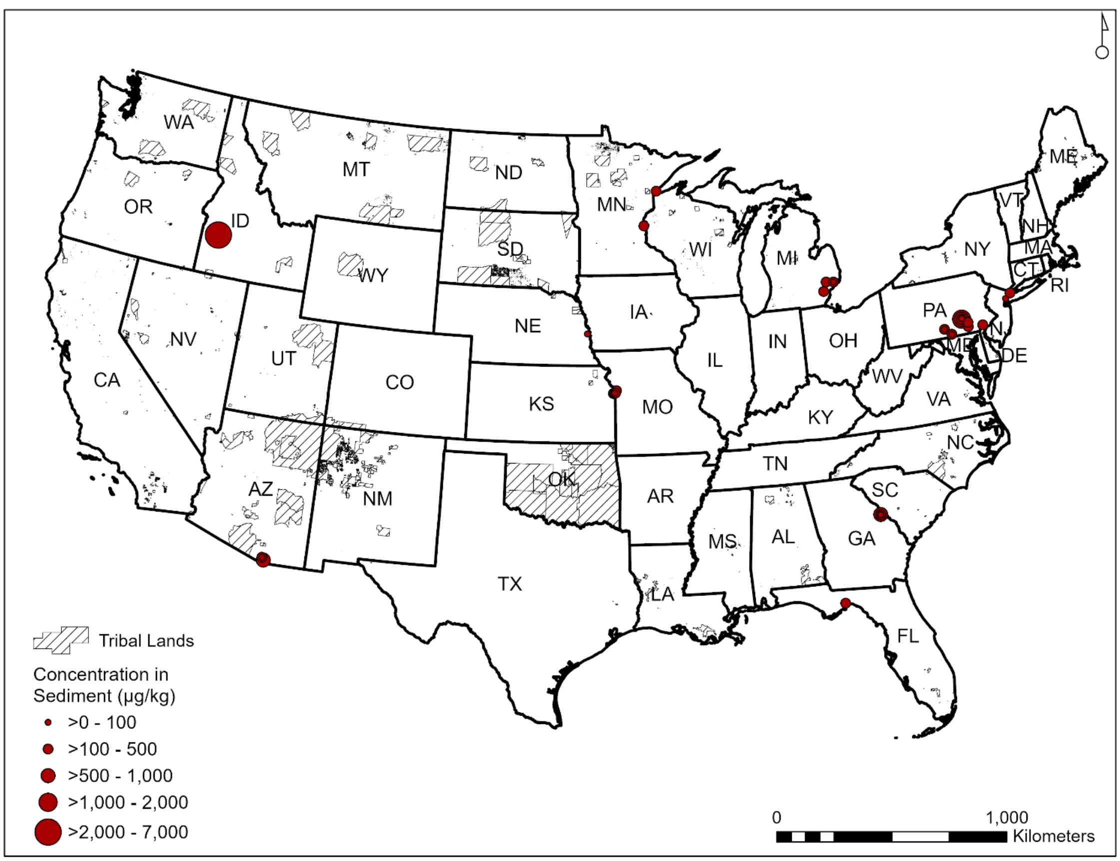

Figure 4-8. WQP Location and Concentrations of HHCB Sediment Monitoring Data Post-1999

Note: Samples below the MDL not shown

4.3.1.2 Modeled Results

4.3.1.2.1 Industrial Releases

For each release scenario, the representative screening scenario uses the facility with the maximum modeled surface water concentration or, where applicable, the sole facility with traceable releases to a flowing receiving water body. These high-end results serve as a screening analysis of the industrial COUs for the surface water pathway. Daily release estimates assume 92% WWTP removal prior to discharge and are reported in Table 4-7 (Section 2.4.6 provides description of wastewater removal). Modeled HHCB concentrations for industrial COUs under low-flow conditions (7Q10 flow rates) are reported in Table 4-7; surface water concentrations ranged from 0.035 to 0.57 µg/L, and sediment concentrations ranged from 11 to 171 µg/kg. Maximum estimated concentrations occurred for the Manufacturing release scenario with an estuarine discharge; estuarine flow was conservatively approximated as the sum of the contributing stream flows, with additional tidal dilution excluded. These estimates are expected to be an overestimate but can be used for screening.

Table 4-7. Industrial Releases 7Q10 HHCB Concentrations

Release Scenario[a]	Daily Release[b] (kg/day)	SWC (µg/L) [c]	Sediment (µg/kg) [c]
Processing/ Formulation of Fragrance Oils	0.038[d]	0.258	78
Processing/ Formulation of End-Use Products	0.025[d]	0.131	39.4
Processing/ Repackaging	0.082	0.035	11
Manufacturing/ Domestic manufacturing	8.9	0.57	171

[a] Releases represent the facilities with the maximum release to be used for screening for each Release Scenario/COU.
[b] Release days out of the year differ by Life Cycle Stage/Category/Subcategory and are reported in Section 3.2.5.
[c] Estimated maximum 1-day average surface water concentration of HHCB
[d] Assumes 92% treatment removal

7Q10 results for the high-end facility in each scenario indicate that industrial release concentrations are substantially lower than down-the-drain (see sections that follow). Therefore, additional refinement with 30Q5 flow scenarios and central tendency facility releases are not presented, as it would result in even lower concentrations. Down-the-drain scenarios are prioritized for exposure assessment because they represent the higher end of environmental concentrations.

4.3.1.2.2 Commercial Down-the-Drain

Down-the-drain releases from commercial product use contribute to overall POTW loading by combining from commercial locations (*e.g.*, restaurant kitchens, hospitals, offices, and laundry facilities) using similar products across a community (locations served by the same sewer system). Model results for commercial down-the-drain releases under P95 and P50 POTW release scenarios (Section 4.2.2.2.2 and Appendix D) under low-flow conditions (7Q10 flow rates) are reported in Table 4-8, and the concentrations under 30Q5 and HM flow conditions carried forward for human health exposure are presented in Table 4-9. The P95 and P50 POTW scenarios refer to a combination of contributing population, treatment, and receiving water body flow that result in the 95th and 50th percentile surface water concentrations at the point of discharge, respectively.

Table 4-8. Commercial Down-the-Drain 7Q10 HHCB Concentrations

Commercial Down-the-Drain Scenario	Release Rate Applied from Modeled Scenario	Total Daily Loading[a] for P95 POTW (kg/day)	P95 POTW Release		P50 POTW Release	
			Water Column Conc. (µg/L)	Sediment (µg/kg)	Water Column Conc. (µg/L)	Sediment (µg/kg)
Industrial Liquid Laundry and Softener	HE	0.4739	2.2	667	0.8	229
	CT	0.0290	0.13	41	0.05	14
Institutional Liquid Laundry and Softener	HE	4.7220	21.8	6,649	7.5	2,285
	CT	0.1982	0.92	279	0.31	96
Liquid Dishwasher Detergents	HE	0.4828	2.2	680	0.8	234
	CT	0.3699	1.71	521	0.59	179
Liquid Dish Soap	HE	0.5404	2.5	761	0.9	262
	CT	0.3942	1.82	555	0.63	191
Surface Cleaner	HE	1.4470	6.7	2,037	2.3	700
	CT	0.2698	1.25	380	0.43	131
Toilet Cleaner	HE	0.1908	0.9	269	0.3	92
	CT	0.0466	0.22	66	0.07	23
Carpet Cleaner	HE	0.1200	0.6	169	0.2	58
	CT	0.0775	0.36	109	0.12	37
Total	**HE**	**8.2**	**37.8**	**11,500**	**1.6**	**494**
	CT	**1.4**	**6.62**	**2,016**	**0.28**	**87**

7Q10 = lowest 7-day average flow in a 10-year period; P50 = 50th percentile; P90 = 90th percentile; CT = central tendency; HE = high-end; POTW = publicly owned treatment works
[a] The "loading" amount refers to the mass of HHCB disposed of down-the-drain and transferred to the POTW prior to treatment and release to the environment.
Monte Carlo modeling details for commercial down-the-drain release scenarios are presented in Section 3.4.
Details of how these release totals are applied to POTW scenarios to produce environmental concentrations are presented in Section 4.2.2.2.2.

The loading estimated for the P95 scenario was HE institutional laundry uses (liquid laundry detergent and fabric softener), consistent with the highest annual per-facility release in the Monte Carlo (Section 3.4.1). Receiving-water concentrations reflect population-scaled POTW loading (4.2.2.2.2) and include removal from applicable wastewater treatment. For the P95 POTW scenario, the 7Q10 water-column concentration is 21.8 µg/L, and the 7Q10 benthic sediment concentration is 6,694 µg/kg. Across COU subcategories, P95 7Q10 water-column concentrations ranged from 6.62 (CT) to 37.8 µg/L (HE), while P50 7Q10 concentrations ranged from 0.28 (CT) to 1.6 µg/L (HE). In the commercial down-the-drain scenarios, CT and HE assignments are based on the Monte Carlo-derived central tendency or high-end release scenario across business types, accounting for variability in individual business loading to the POTW. The HE scenarios reported here assume the high-end loading amount for each of the multiple commercial operations releasing HHCB to the POTW. As discussed in Section 3.4, a community typically includes a range of business sizes, from small to large. For this reason, the CT results are carried forward into the combined analysis as being more representative of typical, or average, loading across many facilities, expected to account for the potential mixture of businesses releasing both more and less HHCB per establishment.

Further detail on facility types and prevalence is provided in the Supplemental File (U.S. EPA, 2026a), along with analysis details and intermediate values. Combined commercial plus consumer down-the-drain 7Q10 receiving-water concentrations are reported; 7Q10 represents rare low-flow conditions and provides conservative exposure estimates. Table 4-9 presents 30Q5 and HM flow-based concentrations. These flows are generally higher than 7Q10 and yield lower concentrations, aligning with longer-term exposure patterns (*e.g.*, drinking water consumption and fish consumption[5]) and chronic toxicity effects. Some concentrations are identical across flow statistics because, where facility effluent flow exceeds receiving-water hydrologic flow, the effluent flow was substituted; in low-flow waters with high facility effluent rates, modeled concentrations may therefore be based on the same effluent flow. This occurs when facility effluent dominates receiving-water flow and is not uncommon in small streams.

Table 4-9. Commercial Release 30Q5 and HM Receiving Water Body HHCB Concentrations for Population-Scaled, Treated POTW

POTW Release Scenario	30Q5 Water Column Conc. (µg/L)	HM Water Column Conc. (µg/L)
P95, with HE Commercial Release Total	37.8	31.6
P95, with CT Commercial Release Total	6.62	5.53
P50, with HE Commercial Release Total	1.6	1.6
P50, with CT Commercial Release Total	0.3	0.3
30Q5 = lowest 30-day average flow in a 5-year period; CT = central tendency; HE = high-end; HM = harmonic mean; POTW = publicly owned treatment works		

Figure 4-9 summarizes the relative contributions of commercial product type to population-scaled POTW load estimates. Dishwashing predominates (approximately 65% of total), likely due to the high per capita density of restaurant-type businesses. High-end releases from individual laundry facilities exceed those of other types of businesses; however, the lower prevalence, especially for large industrial and institutional laundries, reduces the contribution at the community/POTW-scale.

[5] The *Draft Human Exposure Assessment for 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta[γ]-2-benzopyran (HHCB)* (U.S. EPA, 2026h) uses 30Q5 flow-based concentrations to estimate potential human exposures via drinking water and fish ingestion.

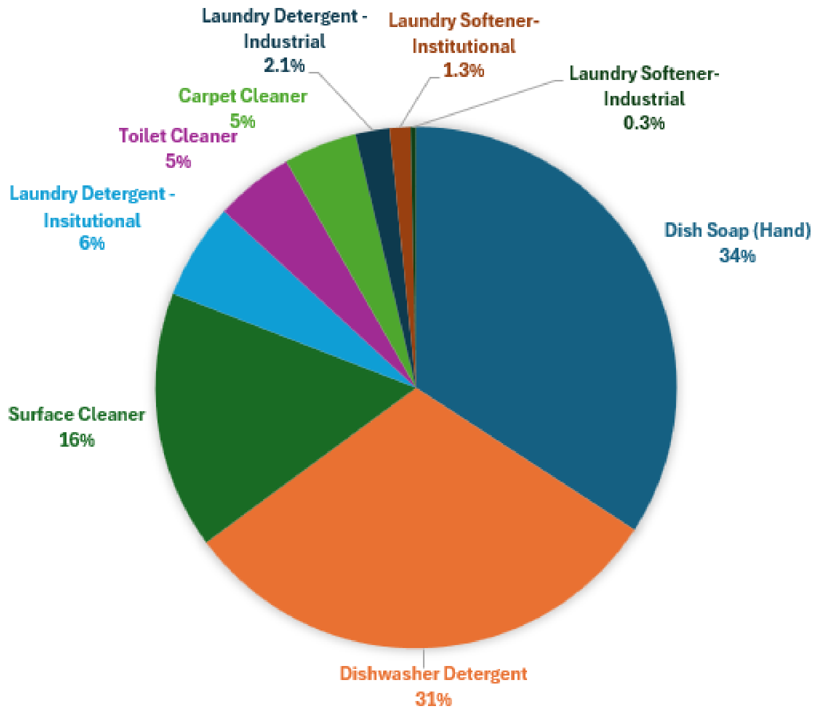

Figure 4-9. Relative Contribution of Commercial Product Categories to HHCB Surface Water Loading for Population-Scaled POTW Scenarios

4.3.1.2.3 Consumer Down-the-Drain

Down-the-drain releases from consumer product use contribute to overall POTW loading by combining many small residential uses of similar products across a community (*e.g.*, multiple households served by the same sewer system. Table 4-10 summarizes average per capita down-the-drain HHCB releases by product type modeled in SHEDS-HT, ranging from 0.05 mg/person/day (carpet cleaners) to 42 mg/person/day (surface cleaners including floor/mopping products). These release totals include conservative assumptions of product usage, prevalence of HHCB-containing products, and product HHCB weight fractions that bias the results toward higher estimates when scaled in this screening analysis.

Table 4-10. Consumer Product Mean Per Capita Down-the-Drain Releases Modeled in SHEDS-HT

Product Classification	Mean Down-the-Drain Loading (mg/day per capita)
Surface Cleaner (including floor cleaner)	42.0
Dish Soap	23.0
Laundry Detergent	15.6
Bathroom Cleaner	10.6
Carpet Cleaner Other	7.49
Fragrance	2.93
Pet Stain Cleaner	2.57

Product Classification	Mean Down-the-Drain Loading (mg/day per capita)
Carpet Deodorizer	1.65
Laundry Stain Remover	1.03
Laundry Fragrance	0.09
Carpet Cleaner Spray	0.05
Total	**107**

POTW release scenarios estimate receiving-water concentration from treated POTW discharges, assuming influent HHCB from the contributing population at mean per capita down-the-drain rates (Table 4-10). Under 7Q10 conditions, water-column concentrations ranged from 0.81 µg/L (P50) to 18.8 µg/L (P95) and sediment concentrations from 246 µg/kg (P50) to 5725 µg/kg (P95) (Table 4-11). The high-end P95 POTW yields 30Q5 and HM water-column concentrations of 18.8 and 15.7 µg/L (with 92% treatment removal), respectively (Table 4-12). As noted previously, some concentrations are identical across flow statistics because the facility effluent dominates receiving-water flow. Modeled concentrations from the consumer down-the-drain assessment exceeded those modeled from industrial releases (Section 4.3.1.2.1).

Table 4-11. Consumer Down-the-Drain Estimated 7Q10 Water Column and HHCB Sediment Concentrations in Receiving Waters

Product Classification	P95 POTW		P50 POTW	
	7Q10 Water Column Conc. (µg/L)	7Q10 Sediment (µg/kg)	7Q10 Water Column Conc. (µg/L)	7Q10 Sediment (µg/kg)
Surface Cleaner (including floor cleaner)	7.38	2,248	0.32	96.6
Dish Soap	4.04	1,231	0.17	52.9
Laundry Detergent	2.74	834	0.12	35.8
Bathroom Cleaner	1.86	566	0.08	24.3
Carpet Cleaner Other	1.32	401	0.06	17.2
Fragrance	0.51	157	0.02	6.73
Pet Stain Cleaner	0.45	138	0.02	5.92
Carpet Deodorizer	0.29	88	0.01	3.78
Laundry Stain Remover	0.18	55	0.01	2.38
Laundry Fragrance	0.02	5	0.00	0.22
Carpet Cleaner Spray	0.01	3	0.00	0.12
Total	**18.80**	**5,725**	**0.81**	**246**

Table 4-12. Consumer Down-the-Drain Estimated 30Q5 and HM Water-Column Concentrations

Product Classification	P95 POTW		P50 POTW	
	30Q5 Water Column Conc. (µg/L)	HM Water Column Conc. (µg/L)	30Q5 Water Column Conc. (µg/L)	HM Water Column Conc. (µg/L)
Surface Cleaner (including floor cleaner)	7.38	6.17	2.53	0.32
Dish Soap	4.04	3.38	1.39	0.17
Laundry Detergent	2.74	2.29	0.94	0.12
Bathroom Cleaner	1.86	1.55	0.64	0.08
Carpet Cleaner Other	1.32	1.10	0.45	0.06
Fragrance	0.51	0.43	0.18	0.02
Pet Stain Cleaner	0.45	0.38	0.16	0.02
Carpet Deodorizer	0.29	0.24	0.10	0.01
Laundry Stain Remover	0.18	0.15	0.06	0.01
Laundry Fragrance	0.02	0.01	0.01	0.00
Carpet Cleaner Spray	0.01	0.01	0.00	0.00
Total	**18.80**	**15.71**	**6.46**	**0.81**

SHEDS-HT results indicate consumer down-the-drain HHCB releases are dominated by surface cleaner products including floor/mopping products, contributing approximately 39% of the mean per capita loading (Figure 4-10).

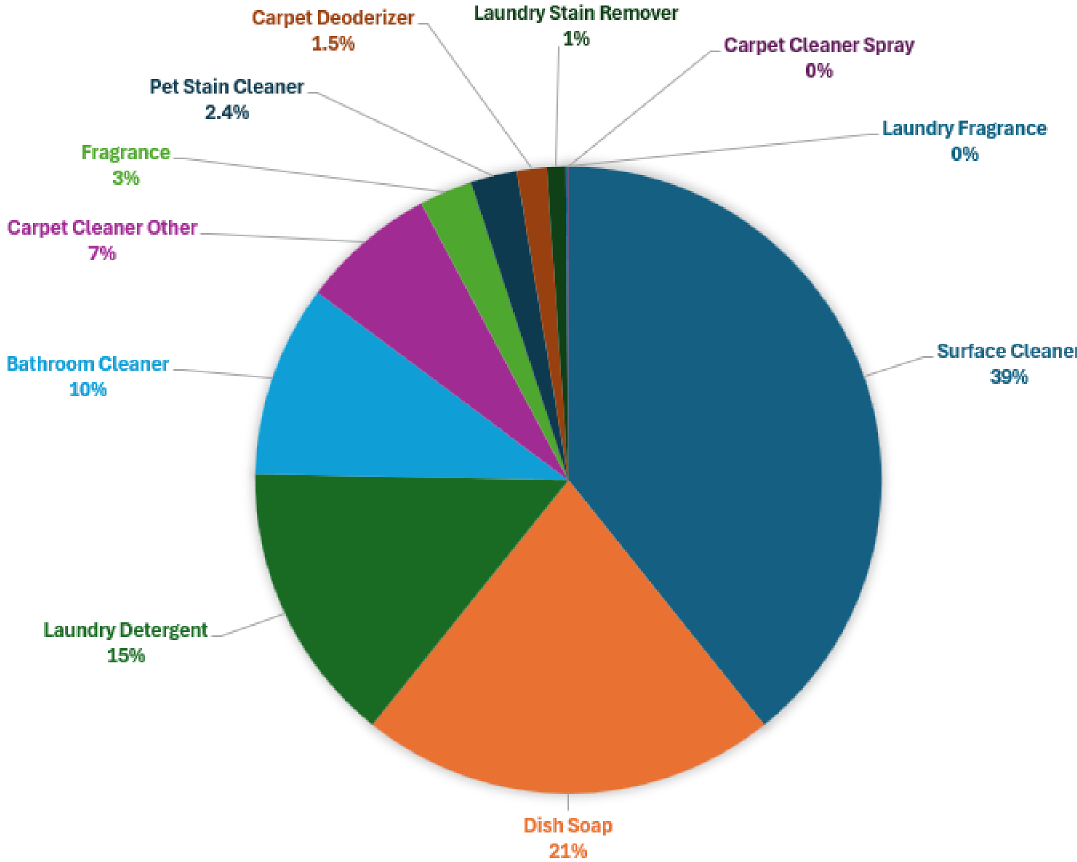

Figure 4-10. Relative Contributions of Consumer Product Categories to Down-the-Drain HHCB Loading

To contextualize the SHEDS-HT consumer down-the-drain model results, the average product usage suggested by these results was back-calculated from the loading estimates. Review of product data indicates a typical HHCB weight fraction of 0.1% (1 mg/kg) was observed. For this exercise, 0.1% was assumed and applied to sum loading totals by product groups to estimate the mass of product required to produce the modeled HHCB loads. Usage totals were expressed as fluid ounces of liquid product and loads of laundry (Table 4-13) to reflect mean per capita usage consistent with the model. Population-level variability is expected (some individuals use more, others less). The estimates are provided for context only and are not used directly in subsequent exposure analyses. The modeled loadings and resulting receiving water concentrations are carried forward.

Table 4-13. Back-Calculated Mean Per Capita Daily Product Usage from Consumer Down-the-Drain Modeling

Product Group	Average Daily Product Per Capita Usage (kg/day)	Average Daily Product Per Capita Usage
Bathroom Cleaner	0.011	0.34 fl oz of cleaner
Carpet Cleaning	0.009	0.3 fl oz of cleaner
Dish Soap	0.023	0.8 fl oz of soap (≈1 load of dishes per day)
Laundry	0.017	0.6 fl oz of soap (≤ ≈1 load of laundry per day)
Surface Cleaner (including floor cleaner)	0.043	1.4 fl oz of cleaner
Pet Stain Cleaner	0.002	0.07 fl oz of cleaner

For reference, 0.3 fl oz is approximately 2 teaspoons, and 1.4 fl oz is approximately 3 tablespoons of cleaner. A typical trigger spray bottle for cleaning solutions releases approximately 0.03 fl oz (1 mL) per spray (supported by modeling from (RIVM, 2018)). The surface-cleaner category includes floor-mopping solutions (assumed fully disposed DTD) and spray cleaners where residues enter wastewater via laundered cloths. Modern high-efficiency washers use 1 to 2 tablespoons (0.5–1 fl oz) of detergent per load, whereas traditional laundry machines use 2 or more tablespoons. These usage rates are plausible per capita averages across a POTW's contributing population, acknowledging wide variability, and support the reasonableness and representativeness of the SHEDS-HT modeling.

On a per capita basis, mean HHCB loadings to POTWs from TSCA COU consumer products is 0.107 g/day. Combined across a POTW's contributing population substantial HHCB mass is expected to be discharged to surface water via POTW effluent, even with high treatment removals (92% for P95 and 99% for the P50).

4.3.1.2.4 Combined Down-the-Drain

Because communities include both residents and commercial businesses disposing of HHCB-containing products, combined loads were estimated by summing the totals from preceding scenarios (2 + 3), to represent the overall loading to POTWs from COUs assessed, and the resultant environmental concentrations driven by the treated effluent. Both commercial and consumer down-the-drain receiving-water concentrations are modeled as combined releases to a single POTW, using population-scaled average product-us rates. POTW scenarios characteristics are derived from CWNS data (U.S. EPA, 2025a), and reflect collection from multiple contributing locations, treatment, and discharge from a single point source. Industrial releases were not included due to the limited number of industrial discharges and the relatively low contribution to POTW influent at known release locations (see Section 4.3.1.2.1).

Table 4-14 reports model surface water and sediment concentrations from down-the-drain scenarios under 7Q10 low-flow conditions. Surface water concentrations range from less than 1 to 25.42 µg/L HHCB. Estimates incorporate POTW treatment removal efficiencies of 92% (P95) and 99% (P50). Maximum concentrations occur under the combined consumer plus commercial down-the-drain scenario, reflecting population-level combination at a community POTW. The P95 scenario represents a high loading-to-receiving-flow ratio and is expected to be exceeded at only 5% of POTWs nationwide for the down-the-drain loads in this assessment.

Table 4-14. Combined Commercial Plus Consumer Down-the-Drain Estimated 7Q10 Water Column and Sediment Concentrations

POTW Release Scenario	Down-the-Drain Scenario	Water Column Concentration (µg/L)	Sediment Concentration (µg/kg)
P95	Commercial	6.62	2,016
	Consumer	18.8	5,725
	Combined	25.42	7,741
P50	Commercial	0.3	87
	Consumer	0.8	246
	Combined	1.11	333

POTW = publicly owned treatment works
Note: 92% and 99% wastewater treatment removal efficiency applied to P95 and P50 POTW scenarios respectively, based on site-specific information.

4.3.1.3 Strengths, Limitations, and Sources of Uncertainty for Modeled and Monitored Surface Water Concentration

HHCB concentrations in surface water and sediment from industrial and down-the-drain disposals were estimated using PSC. Modeled concentrations vary with inputs such as the loading rates, receiving-water characteristics, and physical, chemical, and fate properties. The high-end combined down-the-drain scenario yields a modeled surface water concentration of 25.4 µg/L, closely aligning with the highest WQP detection of 25.5 µg/L. This highest monitored value in surface water (25.5 µg/L) reflects low flow sampling downstream of a POTW serving a large community, consistent with the modeled POTW scenarios. As presented in Section 4.3.1.1.1, the metadata available in WQP for this high-end monitored concentration in surface water reports that a modification of a standard method was used to analyze the sample. While this non-standard method differs from other samples included in the database, this result is included as reference for the potential for environmental concentrations to reach this magnitude, as predicted by the modeled exposure scenarios.

4.3.1.3.1 The Loading Amount

EPA used both programmatic data (TRI-reported HHCB releases) and probabilistic, modeled release estimates. In TRI 2023, all facilities reporting water-based HHCB releases indicated off-site wastewater transfers. As discussed in Section 3.6.1, EPA has moderate confidence in the transferred volumes. The releases provide a snapshot of the waste transferred off-site in 2023 for water-based treatment, but these volumes may vary year to year as the demand of HHCB shifts each year. Although not incorporated, a review of the 2024 TRI data indicates that there have been some changes in amounts and new reporters identified. Because effluent quantities from off-site treatment facilities reported via TRI are less certain, downstream concentrations were estimated using a range of assumed wastewater-treatment removal efficiencies (50–92%).

EPA has moderate confidence in HHCB loading estimates from probabilistic modeling. For commercial down-the-drain releases, Monte Carlo methods consistent with peer-reviewed TSCA risk evaluations were applied using literature-derived parameters (Section 3.4) and product weight fractions from current SDSs. The laundry scenarios include a market prevalence term (fraction of products containing HHCB, excluding fragrance-free), which increases confidence; the dishwashing-detergent scenario lacks a prevalence term due to data limitations. Key uncertainties include the number and mix of business types (Section 3.6). A strength of the analysis is the population-scaling approach, which produces plausible counts of contributing businesses for a generic population and links them to a distribution of empirical POTW release scenarios.

For consumer down-the-drain releases, EPA applied SHEDS-HT with Monte Carlo methods to simulate individual and combined product use resulting in down-the-drain. Strengths include integration of HHCB specific physical and chemical properties into release modeling, alignment of product-use parameters within peer-reviewed TSCA approaches, and use of population mean per capita loading scalable across scenarios. The resulting average release values are plausible (see Table 4-13). A key limitation is the absence of market-prevalence term (fraction of products containing HHCB), assumptions/inputs used may overestimate release by assuming all products in a category contain HHCB.

Population inputs for POTW loadings were based on current figures reported by POTWs in EPA's 2022 CWNS, providing high confidence; projected populations were excluded. Monitoring of POTW influent, effluent, and sludge indicates substantial HHCB enters POTWs, while WQP data (see Section 4.3.1) show treatment can effectively remove HHCB prior to discharge. Treatment processes vary by facility, yielding a range of removal efficiencies; this assessment incorporates each POTW's CWNS-reported treatment level and applies corresponding removal efficiencies in the distribution analysis.

4.3.1.3.2 Chemical and Receiving Water Body Parameters

PSC uses HHCB specific physical and chemical properties (K_{OC}, water column half-life, photolysis half-life, hydrolysis half-life, and benthic half-life) to model both water-column and sediment concentrations. Property values refined via the systematic review and EPA models increase confidence in PSC applications. Because K_{OC} strongly influences sediment estimates, and varies with environmental conditions, the K_{OC} selected was based on an organic carbon content representative of the modeled scenario 1.2% (Litz et al., 2007). A standard receiving water geometry established by EPA for risk assessment, and standard chemistry were applied to provide consistent, conservative scenario. Flow data were derived from NHDPlus V2.1 for the receiving waters of the modeled industrial facilities and POTWs, based on information collected from NPDES permits. Collectively, these inputs support moderate to high confidence in the modeling results.

4.3.1.4 Weight of Scientific Evidence Conclusions

EPA modeled HHCB releases using Monte Carlo methods that incorporate variability and uncertainty for commercial and consumer down-the-drain sources, estimating impacts to surface water and benthic sediments nationwide. The weight of scientific shows substantial HHCB enters wastewater via combined down-the-drain disposals, with resulting media concentrations strongly driven by POTW characteristics (contributing population, treatment level, and receiving water body). While each individual consumer down-the-drain input (product usage, HHCB weight fractions, and assumed prevalence) is plausible, the compounding conservative assumptions yield national release estimates that are biased high. For example, extrapolating an average disposal rate of approximately 0.1 g/person/day to a full year for the entire U.S. population results HHCB down-the drain HHCB releases exceeding the total U.S. production volume. Although an individual could readily reach 0.1 g/day, this rate is not representative of national average for the entire population. EPA has moderate confidence that this analysis identifies potential high-end (P95 POTW) receiving water and sediment concentrations that can be used in human health and environmental risk assessment. The bias toward overestimation of releases increases confidence in the application of these modeled results in a screening analysis. Uncertainties such as prevalence of HHCB within product groups may bias the modeled concentrations high, while limiting business types may bias them low. The distribution of available monitoring data generally aligns with the combined down-the-drain POTW scenarios assumptions and results. P50 results indicate that concentrations at most POTW discharge sites are low. While the WQP surface water monitoring data (Section 4.3.1.1.1) comes from diverse studies and locations not necessarily targeting POTWs receiving waters, and may not be statistically representative nationally, most samples indicate low or non-detect HHCB. However, elevated monitored concentrations (25 µg/L), in water near POTW outfalls are consistent with modeling, indicating that under certain conditions, higher HHCB concentrations can occur in immediate receiving water.

4.3.2 Biosolid Land Application and Soil

4.3.2.1 Biosolid and Soil Monitoring Data

According to the WQP (NWQMC, 2025), monitoring data are more common for wastewater effluents (n = 169) than for sludge (n = 9) and sludge concentrations are about 100-fold higher than the effluent concentrations (Figure 4-11, Figure 4-12, Figure 4-13, and Figure 4-14). Effluent concentrations are all nearly below 4.0 µg/L (median 1.6 µg/L, 48 detections) whereas sludge concentrations are nearly all below 3,000 µg/kg (median 1364.5 µg/kg, 8 detections out of 9 sampling events). The sole non-detect in sludge used a method with a 263 µg/kg detection limit—an order of magnitude higher than methods for samples with detections.

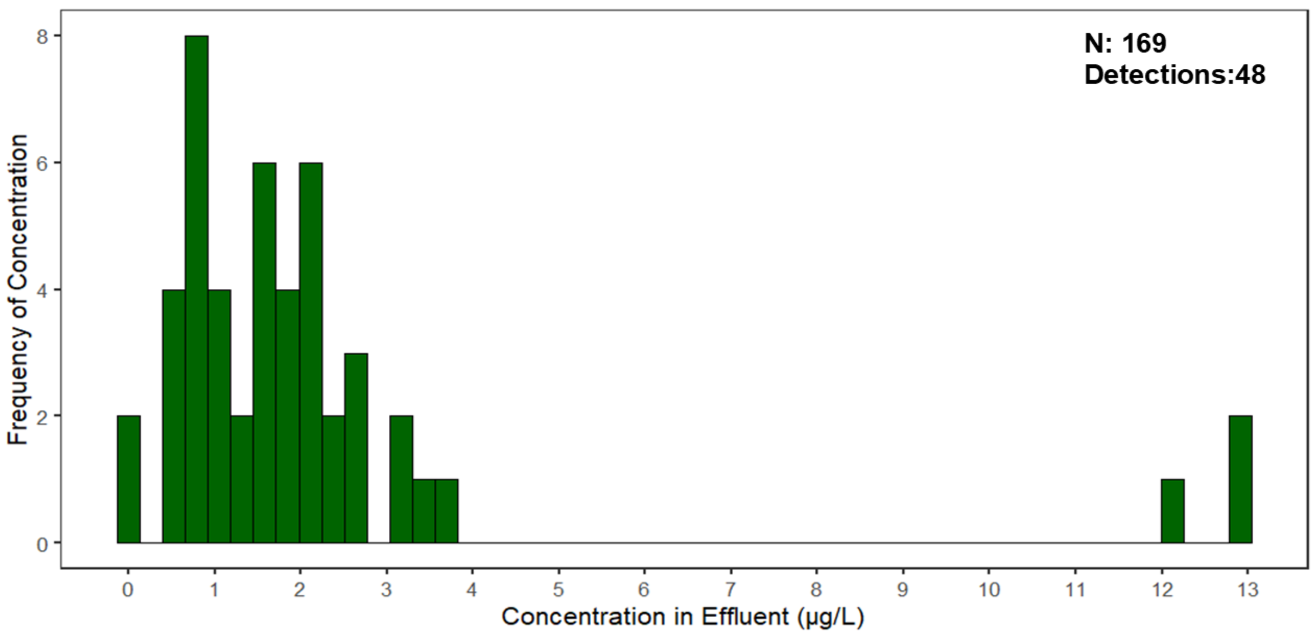

Figure 4-11. Monitoring Wastewater Effluent Concentrations for HHCB Post-1999
Note: Samples below the MDL not shown

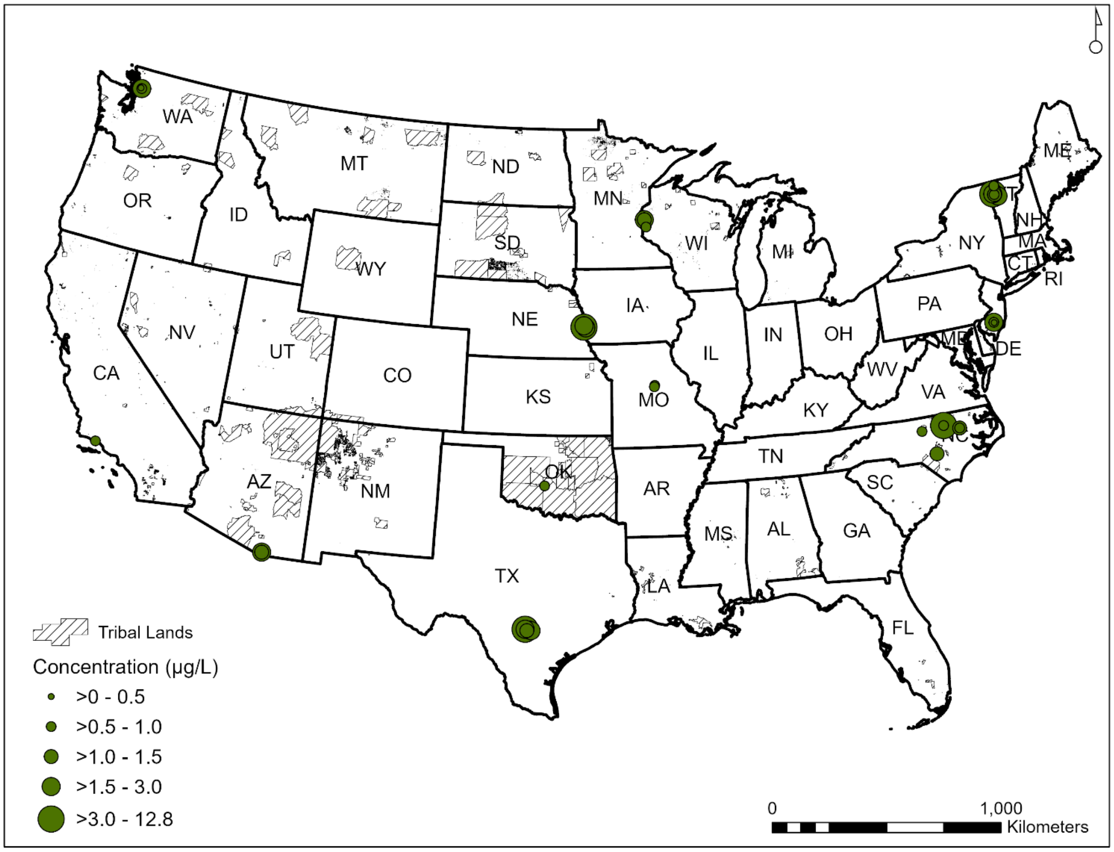

Figure 4-12. Locations and Concentrations of HHCB in Effluent Monitoring Samples

Data based on all WQP entries post-1999; note: samples below the MDL not shown

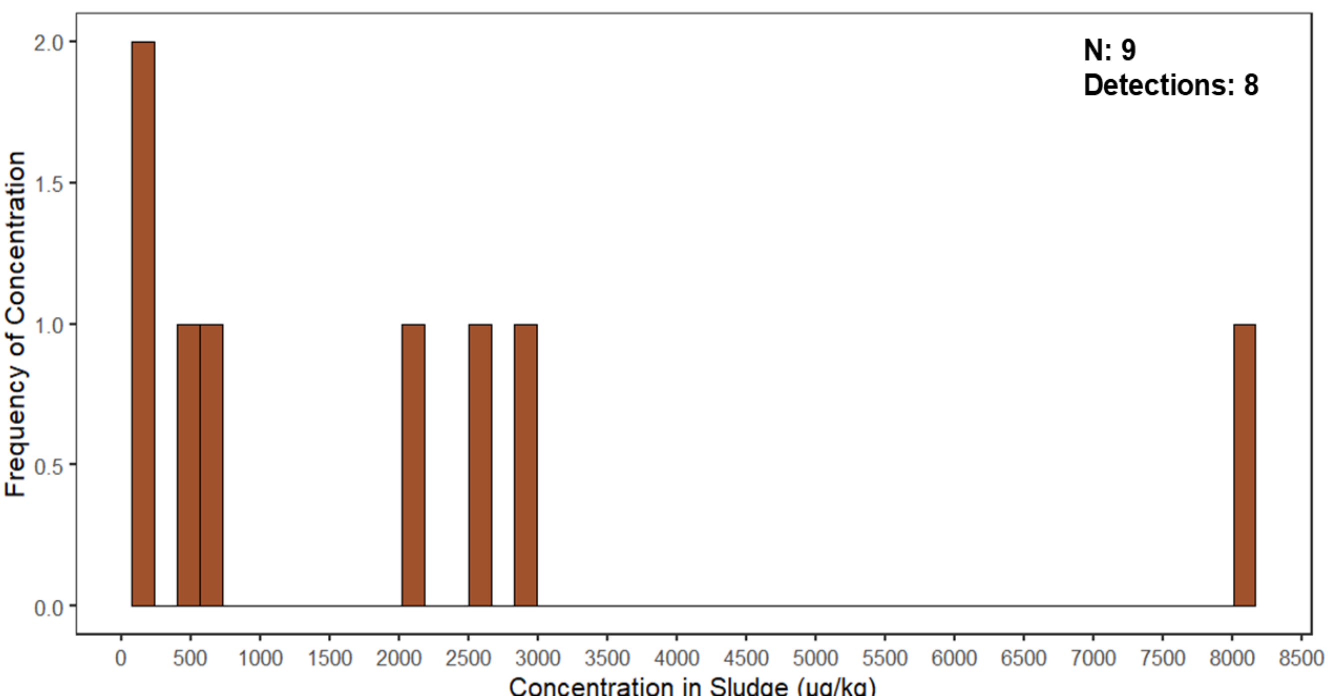

Figure 4-13. Monitored Sludge Concentrations for HHCB (WQP Post-1999)

Note: Samples below the MDL are not shown

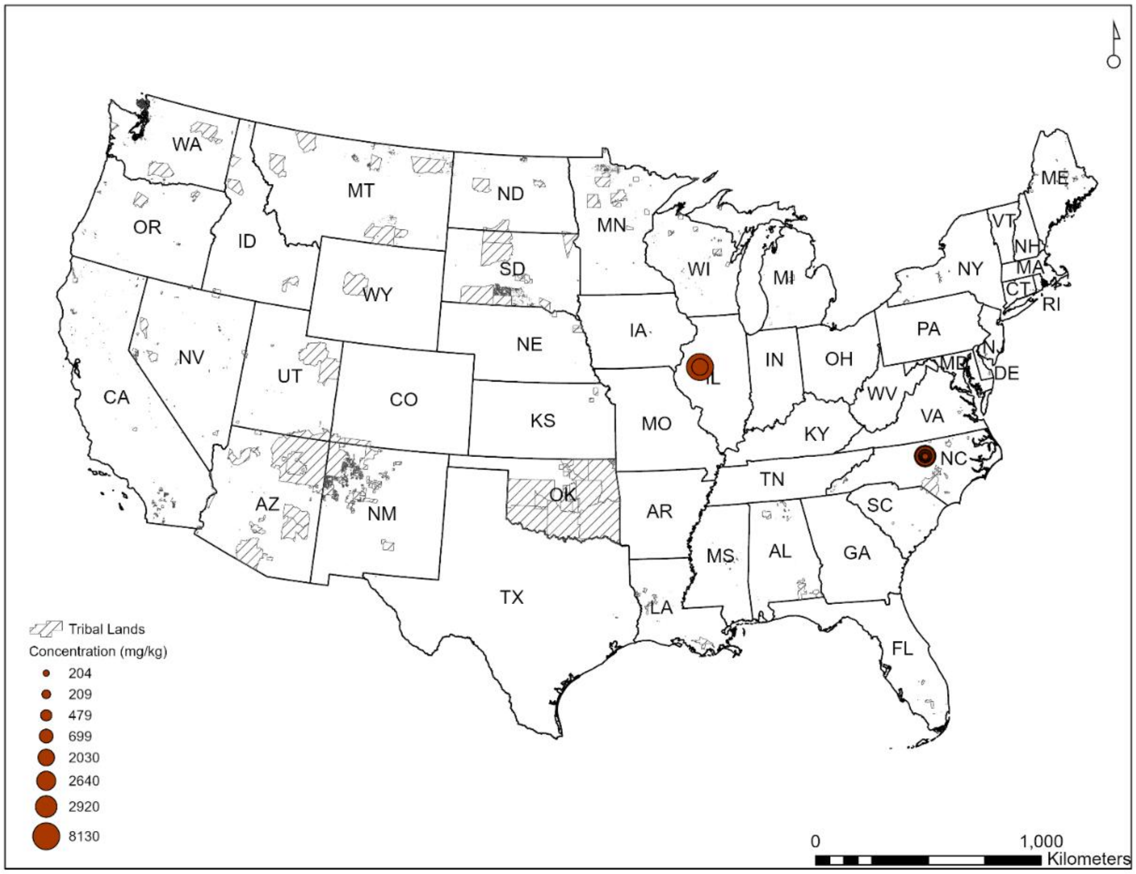

Figure 4-14. Locations and Concentrations of HHCB in Sludge Monitoring Samples (WQP Post-1999)

Note: Samples below the MDL not shown

Beyond WQP, HHCB in sewage sludge is documented in the 2005, 2007, 2009, and 2017 Biennial Reviews of Sewage Sludge. U.S.G.S. (2012) analyzed effluent from 9 wastewater facilities in Oregon and Washington, reporting 0.38 to 2.5 µg/L (median: 1.2 µg/L); sludge was not measured at these facilities.

WQP includes an Oregon effluent study with 98 samples from 49 different POTWs. Most were below the 10 µg/L detection limit, with two detections at 12 and 13 µg/L. Additionally, 61 samples tagged as POTW effluent elsewhere ranged from 0.038 to 12.8 µg/L, and 50 samples tagged as raw wastewater range from 0.093 to 9.2 µg/L.

In addition, Sun et al. (2014) analyzed effluent and sewage sludge grab samples from 40 municipal wastewater treatment plants nationwide. Effluent concentrations ranged from 0.45 µg/L to 4.79 µg/L (mean ± 1 SD: 1.86 ± 1.01 µg/L). Sludge concentrations ranged from 4,100 and 91,000 µg/kg (mean ± 1SD: 34,000 ± 23,100 µg/kg). The median for these samples was 25,800 µg/kg and the 90th percentile concentration was 68,000 µg/kg (Sun et al., 2014). European sludge also contained HHCB at 7,400 to 36,000 µg/kg (Kupper et al., 2004). This information indicates wide variability in HHCB concentrations in sewage sludge and biosolids.

Kinney et al. (2006) analyzed nine different biosolid products from municipal WWTPs in seven different states – six marketed for commercial, homeowner, and municipal use and three used in agriculture – and detected HHCB in all. Concentrations ranged from 47 to 554,000 µg/kg (median: 3,900, n=9). Chase et al. (2012) reported HHCB in soils amended with wastewater effluent in Lubbock, TX, ranging from less than 3.3×10^{-4} to 5.69×10^{-3} µg/kg. These concentrations warrant consideration of exposure from biosolids amended soil. Note that HHCB in sewage sludge reflects all wastewater sources, including personal care products outside this evaluation and TSCA-regulated products (up to 17% as described in Section 4.3.1.2).

As noted in Section 2.4.4, HHCB exhibits limited biodegradation in soil and may persist for more than 60 days. DiFrancesco et al. (2004) conducted a 1-year die-away study of HHCB in biosolids-amended soils across four soil types (sandy agricultural soil; silty agricultural soil; clayey soil; and highly weathered oxide-rich soil), with and without spiking. Anaerobically digested, dewatered sludge from Georgetown, DE (100% domestic sewage; 10% solids) and Wilmington, DE (70% domestic sewage; 17% solids) contained 86 and 38 mg/kg dry weight (Georgetown) 43 and 22 mg/kg dry weight (Wilmington). Initial HHCB concentrations in spiked soil were 6 and 13 mg/kg soil; un-spiked soil concentrations were 0.1 to 0.27 mg/kg. HHCB declined rapidly. After one month, 30 to 90% of initial remained. After 90 days, 8 to 60%. Concentrations were stable during three frozen months. After one year, less than 10 to 14% of initial remained. Dissipation was faster in the soils with lower organic material, and while volatilization and leaching could have contributed (although not expected) biotransformation dominated.

Collectively, the data indicates that biosolids-amended soils can contain HHCB, with biosolids concentrations spanning a wide range and yielding variable soil concentrations. Section 4.3.2.2 presents modeled HHCB soil concentrations.

4.3.2.2 Biosolid Application and Soil Modeling

Table 4-15 presents estimated HHCB soil concentrations across application scenarios, spanning biosolids concentration ranges by land use (agricultural and pastureland). Calculation methods are described in Section 4.2.3.

Table 4-15. Estimated HHCB Concentrations in Soils Following Land Applied Biosolids

Concentration of HHCB in Biosolids (µg/kg)	Concentration in Soils for Agricultural Land (µg/kg)	Concentration in Soils for Pastureland (µg/kg)
0.01	1.47E−05	2.94E−05
0.1	1.47E−04	2.94E−04
1	1.47 E−03	2.94E−03
10	1.47 E−02	2.94 E−02
100	1.47 E−01	2.94 E−01
1000	1.47	2.94
10,000	14.7	29.4
100,000	147	294
1,000,000	1.47E03	2.94E03

Because PEC_{soil} scales linearly with biosolids concentration (C_{sludge}), Table 4-15 shows soil concentrations increasing by an order of magnitude with each 10-fold increase in C_{sludge}. The highest illustrative case (C_{sludge} = 1,000,000 µg/kg) yields 2.94×10^{3} µg/kg in pastureland soils. To understand how these potential concentrations of HHCB fit within the context of monitored data, the Agency reviewed all monitored data and identified 554,000 µg/kg (Kinney et al., 2006) as a potential upper bound in biosolids. Concentrations in soil may exceed this value but monitoring is not regularly completed on soils for many chemicals. By using this value as an upper bound of biosolid concentration, the Agency estimated pastureland soil concentration of 1,629 µg/kg using Equation 4-3 described in Section 4.2.3. The Agency used 1,629 µg/kg as an upper bound soil concentration for screening purposes. These concentrations are highest immediately after land application and decline over time due to biodegradation (Section 2.4). Estimated concentrations are slightly lower with deeper tilled agricultural land vs. pastureland because the mass is mixed through a larger soil volume; greater mixing depths would further reduce concentrations. However, the Agency limited its soil tillage depths to the most common practices of sub-soiling and discing.

4.3.2.3 Biosolid Land Application and Soil Weight of Scientific Evidence Conclusions

The strength of this biosolids assessment is in its consideration of a wide range of possible concentrations of biosolids rather than a single estimation. This consideration allows the Agency to consider the sensitivity of soil concentrations relative to the concentration of HHCB in biosolids. As noted, biosolid HHCB concentrations vary with wastewater treatment plants size, the population served, product use behaviors, and treatment technologies. This current assessment relies on measured biosolids concentrations from monitoring studies to bound soil concentrations, increasing confidence in predicted exposures. However, this approach leaves uncertainty apportioning potential concentrations specifically to TSCA COUs.

There is currently no direct evidence that biosolids containing HHCB are being consistently applied to agricultural fields in any part of the United States. However, this may be due to lack of testing and monitoring data, as HHCB has been identified in various wastewater sludges as previously stated. Furthermore, biosolid application is not often monitored for semi-volatile compounds. Despite limited information on how often HHCB is being applied, direct evidence that HHCB has been found in soils post land application in addition to transport and fate characteristics (Section 2.4) provides plausible evidence that HHCB will be present at locations that utilize this practice and that soil concentrations will vary based on frequency of application. Because of these uncertainties, there is moderate confidence in the absolute value of the modeled soil concentration derived from the highest measured biosolid concentration, but robust confidence that the value represents an upper bound for this screening assessment.

4.3.3 Bioaccumulation, Biomagnification, and Trophic Transfer

4.3.3.1 Bioaccumulation Values and Uptake Routes

4.3.3.1.1 Laboratory-Based Bioaccumulation Values

EPA reviewed three laboratory-based studies on HHCB bioaccumulation. Van Dijk (1996) conducted an OECD Guideline 305 study of aqueous exposure of bluegill (*Lepomis macrochirus*) to HHCB in a flow through system. The reported whole-fish, wet-weight BCF was 1,584 L/kg after 14 days of uptake followed by 14 days of depuration. Tissue-specific BCFs were noted for the muscle and skin (BCF = 522 L/kg), and viscera, skeleton, and fins (BCF = 2,221 L/kg). Schneider (2021) conducted an OECD Guideline 305 study of dietary HHCB exposure to bluegill, deriving the depuration rate constant (−0.1468), assimilation efficiency (0.1648), and lipid corrected biomagnification factor (0.082). Although this study did not directly provide a BCF or BAF, the resulting data can be used to parameterize mechanistic or kinetic models to derive bioaccumulation indices. Both studies indicate significant metabolic transformation and depuration of HHCB after aqueous (Van Dijk, 1996) and dietary (Schneider et al., 2021) exposure. Uptake appears faster through aqueous exposure than dietary exposure, though direct comparisons are limited by differing experimental objectives and designs. Another laboratory study yielding a bioaccumulation index was conducted by Schreur (2004), which used transgenic zebrafish to investigate endocrine effects and reported a BCF of 600 L/kg.

4.3.3.1.2 Field-Derived Bioaccumulation Values

Field-derived HHCB BAFs reviewed by Wang et al. (2023), range from 261 to 66,030, based on a snapshot fish-and-water measurements the United States (Goodbred et al., 2020; Reiner and Kannan, 2011), Europe, and Asia (Hu et al., 2011a). These values are lipid-normalized and reflect unknown exposure concentration and durations. Because lipid-normalization removes dilution by non-lipid tissues, lipid-normalized BAFs exceed whole-body, wet-weight values by approximately the inverse of the fish lipid content. Consequently, reported BAFs can vary by an order of magnitude depending on the lipid content and sampling context. For example, Reiner (2011) reported lipid-normalized BAFs for largemouth bass in the Hudson River ranging from 434 to 2,080. HHCB therefore lacks universal lipid-normalized BAF suitable for exposure and risk assessment. EPA instead used laboratory-derived BCF (1,584 L/kg) and modeled bioaccumulation indices expressed on a whole-body, wet-weight basis, enabling direct comparison of tissue concentrations to hazard thresholds in the same units.

4.3.3.2 Modeled Bioaccumulation Uptake Routes

Given variability and uncertainties in empirical BCF/BAF values, EPA modeled HHCB bioaccumulation using ADME-B (Gobas et al., 2019) and KABAM (U.S. EPA, 2009)). These models (1) quantified the relative contributions of respiratory vs. dietary uptake, and (2) provided refined fish-tissue concentrations.

4.3.3.2.1 ADME-B Modeling

Using ADME-B, EPA estimated BCF and BAF for potential field scenarios based on the TSCA COUs. For upper bounds, EPA used a high-end down-the-drain estimated surface water concentration (25.4 µg/L) and the highest HHCB fish tissue concentration reported in the United States as the diet concentration input (2,100 mg/kg). Model results were BCF=2649 L/kg, BAF = 2,653 L/kg, with uptake apportioned at 94% via gills and 6% via diet.

4.3.3.2.2 KABAM Modeling

Using KABAM, EPA estimated that gill exchange accounted for 78% of HHCB in large (1.0 kg) fish and 76% in medium (0.1 kg) fish, with the gill contribution decreasing proportionally to decreases in as animal mass (Table_Apx G-3).

4.3.3.3 Bioaccumulation and Uptake Weight of Scientific Evidence

Overall, EPA has robust confidence in using a BCF of 1,584 L/kg to derive upper-bound predicted fish tissue concentrations from measured and modeled HHCB water concentrations and to assess exposure to fish-eating predators. A key strength of using BCF of 1,584 L/kg is that it represents an upper-bound: most reported lipid-normalized BAF values U.S. field studies and food web modeling are less than 1,500 L/kg (Reiner and Kannan, 2011). Although some studies conducted in Asia report BAFs much greater than 1,500 L/kg (Yao et al., 2019; Hu et al., 2011b), the associated fish tissues HHCB concentrations (maximum 823.3 µg/kg lipid weight (Hu et al., 2011b)) are lower than those observed in the controlled OECD guideline test with bluegill (15,840 µg/kg ww or 316,800 µg/kg lipid weight) (Van Dijk, 1996). No fish collected from U.S. waterbodies have reported HHCB concentrations greater than 2,100 µg/kg lipid weight (Ramirez et al., 2009).

The laboratory-derived BCF of 1,584 L/kg encompasses the net results of intake, metabolism, and elimination in a common fish species, *L. macrochirus*, that occupies a middle trophic level in many U.S. water bodies (Van Dijk, 1996). Fish occupying higher trophic levels tend to have lower bioaccumulation indices and HHCB concentrations; for example, largemouth bass (*Micropterus salmoides)* exhibited a BAF of 146 L/kg and tissues concentrations of 10.9 µg/kg lipid weight or 0.545 µg/kg ww) (Reiner and Kannan, 2011). Thus, EPA has robust confidence in using BCF = 1,584 L/kg from a middle trophic level and common fish species like bluegill that is representative of a high-end and protective value for a first-tier assessment. The predominance of lipid-normalized BAF values less than 1,500 L/kg in U.S. field studies and food-web modeling further indicates that the selected BCF is protective.

EPA has robust confidence that the ADME-B and KABAM models provide upper bounds of the dietary contribution to overall HHCB uptake and indicate that the major chemical flux occurs through the respiratory surfaces (*e.g.,* gills) in fish. In ADME-B, modeled BCF and BAF estimates depend on the relative HHCB concentration in the water versus the fish diet: higher dietary concentrations increase the proportion of uptake via diet and reduce the proportion via gills. EPA used upper-bound water and diet concentrations as screens in both models, resulting in upper-bound BCF and BAF values. In ADME-B, scenarios with lower dietary HHCB relative to water produced higher proportional uptake via gills and lower via diet; thus, 94% via gills and 6% diet, represent, respectively, a lower bound on gill-mediated flux and an upper bound on diet-mediated flux. KABAM results suggest a somewhat smaller gill contribution (≈78%) than ADME-B but still indicate that respiratory-surfaces uptake dominates HHCB exchange in aquatic animals. EPA has confidence in this conclusion.

Overall, evidence from ADME-B and KABAM supports using the laboratory-derived BCF of 1,584 L/kg to screen fish-tissue concentrations across water concentration scenarios. Differences between model outputs further justify EPA's use of KABAM to refine modeled fish concentration estimates in a second-tier assessment.

4.3.3.3.1 Biomagnification in Aquatic Food Webs

HHCB bioaccumulates in aquatic organisms, but the reasonably available evidence indicates that it does not biomagnify and, in some cases, biodilutes (*i.e.,* lower concentrations in higher trophic levels) (Kim et al., 2022; Goodbred et al., 2020; Zhang and Kelly, 2018; Zhang et al., 2013). Metabolic transformation of HHCB to more polar HHCB-lactone and subsequent depuration likely explain the absence of biomagnification (Schneider et al., 2021). In bluegill, Schneider (2021) reported a depuration rate constant k2 of −0.15 and BMF of 0.082, indicating only about 8% of dietary HHCB was retained (BMF >1 = no biomagnification). Van Dijk (1996) estimated a depuration half-life of 2 to 3 days in *L. macrochirus*. Overall, metabolism and depuration limit trophic transfer of HHCB, resulting in no biomagnification.

4.3.3.4 Trophic Transfer

Evidence indicates dietary uptake and trophic transfer of HHCB from prey to predator (Kannan et al., 2005) (Kinney et al., 2006) (Section 2.4.7) but it does not biomagnify into upper trophic levels (Section 4.3.3.3.1). Measured tissue concentrations in biota were reviewed (Section 2.4.7 and Section 4.3.3.4.1). For the water-to-fish-eating mammal pathway, modeled tissue concentrations in fish were estimated for industrial, combined commercial and consumer down-the-drain COU scenarios using the initial BCF (1,584 L/kg) approach and further refinement with KABAM. For the biosolid to earthworm-eating mammal pathway, earthworm concentrations were estimated using maximum measured soil concentrations.

4.3.3.4.1 Measured Concentrations in Biota

Aquatic Organisms

In U.S. water bodies, HHCB has been detected in fish tissues ranging from less than 1 µg/kg in several different fish species to 2,100 µg/kg ww in common carp (*Cyprinus carpio*) (Reiner and Kannan, 2011; Ramirez et al., 2009) (Section 2.4.7 and Table 2-4). Ramirez et al. (2009) reported concentrations in fish from effluent-dominated rivers receiving direct discharge from wastewater treatment facilities in U.S. cities. These represent the highest monitored concentrations in U.S. freshwaters, with the highest concentrations in benthic and sediment-dwelling species (*e.g.*, common carp with 2,100 µg/kg ww). Additionally in U.S. freshwaters, zebra mussels contain up to 19.3 µg/kg (Reiner and Kannan, 2011). HHCB has also been measured in marine and coastal mammals up to 25 µg/kg (Kannan et al., 2005). Globally, reported HHCB concentrations in fish range from less than 1 µg/kg to 18,400 µg/kg lipid-weight (lw), with high-end concentrations observed in *C. carpio* collected near sewage discharge points in Germany (Wang et al., 2023). Overall, the available data indicate that animals at higher trophic levels (*i.e.,* top predators) have lower HHCB concentrations than those at lower trophic levels (*i.e.*, primary consumers and omnivores) (Wang et al., 2023).

Terrestrial Organisms

HHCB has been measured in the tissues of terrestrial organisms, including mink livers (3.7 µg/kg), ducks (up to 2.7 µg/kg in multiple species), and earthworms (up to 3,340 µg/kg) (Kinney et al., 2006; Kannan et al., 2005) (Section 2.4.7). Mink and ducks are closely associated with aquatic environments and include aquatic prey in their diets. No evidence was available for the presence of HHCB in predators that consume earthworms.

4.3.3.4.2 Modeled Fish Concentrations Based on Screening Level BCF

Modeled Fish Concentrations Based on Industrial Releases

Predicted fish concentrations associated with industrial COUs ranged from less than 1 to 902 µg/kg ww (Table 4-16). The highest estimated concentration (902 µg/kg ww) arose under the Manufacturing COU involving a single reporting facility discharging to a POTW with subsequent release to an estuary. The next highest predicted concentration (409 µg/kg ww) was associated with the maximum daily release in the Processing/Formulation of Fragrance Oils COU assuming 50% wastewater treatment removal.

Table 4-16. Estimated HHCB Concentration in Fish Tissues from Industrial Releases

COU	Daily Release (kg/day)	WWT (%) [a]	SWC (µg/L) [b]	HHCB in Fish (µg/kg ww)
Processing/Formulation of Fragrance Oils	Maximum	92	0.258	409
	Median	92	0.021	33
Processing/Formulation of End-Use Products	Maximum	92	0.1312	208
	Median	92	0.000278	0.44
Processing/Repackaging	Maximum (1 facility)	92	0.035	55
Manufacturing/Domestic manufacturing	Maximum (1 facility)	92	0.57	902
Highest monitored fish tissue (common carp, whole fish) [c]		N/A	N/A	2,100

SWC = surface water concentration; WWT = wastewater treatment
[a] Percentage of WWT removal of HHCB.
[b] Estimated surface water concentration of HHCB.
[c] From (Ramirez et al., 2009)

Modeled Fish Concentrations for Combined Down-the-Drain

HHCB concentrations in surface water from all exposure scenarios are reported in this assessment (Section 4.3.1.2.4). Calculated fish tissue concentrations from combined commercial and consumer down-the-drain scenarios were 1,758 µg/kg ww under the P50 POTW scenario and 40,265 µg/kg wet weight under the P95 POTW scenario (Table 4-17).

Table 4-17. Combined Commercial Plus Consumer Down-the-Drain HHCB Concentrations in Receiving Waters and Calculated Fish Tissues Concentration

POTW Release Scenario	Down-the-Drain Scenario	Water Column Concentration (µg/L)	Fish Tissue Concentration (µg/kg ww)
P95	Commercial	6.62	10,486
	Consumer	18.8	29,779
	Combined	25,42	40,265
P50	Commercial	0.3	475
	Consumer	0.8	1,267
	Combined	1.11	1,758
Highest monitored fish tissue (Common Carp, Whole Fish) [a]		NA	2,100
[a] From (Ramirez et al., 2009)			

4.3.3.4.3 Modeled Concentrations in Fish Using KABAM

EPA used KABAM version 1.0 (U.S. EPA, 2009)) to estimate potential HHCB bioaccumulation in a freshwater ecosystem and to evaluate potential exposure to fish-eating mammals (Appendix G). KABAM was applied as a refinement to the screening assessment in Section 4.3.3.4.2 which used a laboratory-based BCF of 1,584 L/kg to estimate HHCB concentrations in fish tissues from estimated water concentrations.

EPA modeled HHCB concentrations in animals across trophic levels using the highest estimated water concentration from industrial releases and from combined commercial and consumer down-the-drain releases (Table 4-18). The highest modeled concentrations in all trophic levels, including small, medium, and large fish occurred under the combined consumer plus commercial down-the-drain P95 POTW scenario (P95 POTW). The highest modeled concentration in large fish (6,112 µg/kg ww) was 2.9 times the highest monitored concentration measured from U.S. water bodies (2,100 µg/kg ww; (Ramirez et al., 2009)).

Table 4-18 Estimated HHCB Concentrations in Ecosystem Components Using KABAM

Scenario	SWC (µg/L) [a]	HHCB Concentration (µg/kg ww)					
		Zooplankton	Benthic Invertebrates	Filter Feeders	Small Fish	Medium Fish	Large Fish
Consumer Plus Commercial Combined DTD[b] (P95 POTW)	25.4 [c]	30,339	20,426	13,364	10,828	8,530	6,112
Consumer Plus Commercial Combined DTD[b] (P50 POTW)	1.1	1,314	886	580	470	370	265
Highest Estimated Water Concentration From Industrial Releases (Manufacturing) [d]	0.57	681	457	299	243	191	137
Highest Monitored Fish Tissue (Common Carp, Whole Fish) [e]	NA	NA	NA	NA	NA	NA	2,100

[a] Surface water concentration (SWC) of HHCB.
[b] DTD = down-the-drain
[c] Highest SWC from monitored surface water = 25.5, effectively equal to the Consumer Plus Commercial Combined DTD (P95 POTW)
[d] modeled release values estimated using 2023 TRI data.
[e] from (Ramirez et al., 2009)

4.3.3.4.4 Weight of Scientific Evidence of Trophic Transfer to Fish

The weight of scientific evidence is robust and indicates that estimated fish tissue concentrations are conservative and protective, providing upper bounds on possible HHCB tissue burdens. Specifically, the screening BCF is derived from a standardized OECD 305 laboratory study conducted under controlled, constant aqueous exposure (Van Dijk, 1996). While metabolic transformation and depuration were observed, the controlled conditions minimize environmental variability (*e.g.*, sorption to organic matter, fluctuating exposure, and dietary dilution). As a result, laboratory-based BCFs are expected to yield higher bioaccumulation than typically occurs in heterogenous natural systems. This provides confidence in the reported screening level values.

Actual HHCB concentrations in wild fish are often lower than those predicted by simple steady-state equations using a BCF of 1,584 L/kg, largely because natural aquatic environments rarely meet the assumptions underlying the laboratory-derived steady-state BCF. The steady-state BCF concept assumes continuous exposure to a constant HHCB concentrations, no within-fish metabolism, and equilibrium between water and fish tissue (Arnot and Gobas, 2006). In natural systems, HHCB rapidly sorbs to organic matter (suspended and in sediment) (Section 2), and it is not clear whether the bound fraction remains bioavailable via direct uptake or dietary exposure. HHCB is metabolized within fish to the more polar HHCB-lactone and subsequently excreted (Schneider et al., 2021; Van Dijk, 1996).

Additionally, fluctuating water concentrations driven by variable flow rates, growth dilution in fish (Burkhard et al., 2012), limited residence time withing effluent plumes due to movement ranges that extend beyond the high-concentration zones (including upstream habits), and behavior avoidance of contaminant-containing wastewater plumes (Ehiguese et al., 2019) can further reduce HHCB uptake in the environment. Collectively across these lines of evidence, EPA has robust confidence that the estimated fish tissue concentrations in this assessment are conservative and protective, providing upper bounds of potential dietary HHCB exposures.

Because the laboratory BCF of 1,584 L/kg exceeds the EPA bioaccumulation concern criteria (BCF >1,000) (Zeeman, 1995), EPA modeled bioaccumulation and derived mammal exposure estimate within a complex food web using KABAM (U.S. EPA, 2009). HHCB bioaccumulation using KABAM was simulated with metabolic transformation in animals at the P95 POTW, P50 POTW, and the highest industrial release COU (Manufacturing). Modeled HHCB concentrations in fish tissue from KABAM were lower than first-tier screening estimates based on BCF value of 1,584 L/kg (Appendix G). The KABAM results provide an additional line of evidence and increase confidence that the fish HHCB concentrations reported in this assessment are conservative and protective upper bounds on potential dietary exposures.

4.3.3.4.5 Modeled Concentrations in Earthworms

Using the maximum field-derived earthworm HHCB BAF of 36, EPA estimated the upper bound of earthworm HHCB concentrations using the conservative assumptions of peak and fresh biosolid additions, high-end HHCB bioavailability fraction in soil, and non-steady state conditions shortly after biosolid application. Accordingly, the screening-level upper bound was calculated by multiplying the upper bound soil concentration (1,629 µg/kg; Section 4.2.3) by a BAF of 36, yielding 58,644 µg/kg dry weight of HHCB in earthworms from recently amended soils. This modeled upper bound is more than one order of magnitude greater than the highest measured HHCB in earthworms (3,340 µg/kg (Kannan et al., 2005)).

This estimate represents a short-term earthworm concentration scenario shortly immediately following biosolid application to soils. HHCB concentrations are expected to decline thereafter, depending on environmental conditions and biosolid reapplication intervals. The reported HHCB soil half-life is approximately 140 days (DiFrancesco et al., 2004), while Kinney et al. (2006) observed more than a 90% decrease in HHCB in earthworms over 120 days. Accordingly, this scenario reflects upper-bound soil and earthworm concentrations immediately post-application for this screening assessment.

4.3.3.4.6 Weight of Scientific Evidence of Concentrations in Earthworms

A strength of this assessment is that it estimates an upper-bound, protective concentration of HHCB in earthworms by combining the maximum modeled soil concentration with the highest measured earthworm BAF. Accordingly, EPA has robust confidence that the estimated upper bound is protective across scenarios with lower soil HHCB and lower earthworm BAF values.

EPA did not estimate soil HHCB from COU-related releases because of uncertainties in linking COUs releases through wastewater treatment to biosolids applied to land. HHCB concentrations in biosolids vary with wastewater treatment plant size, the population served, product-use behaviors, and treatment technologies. Further uncertainty arises from reliance on TRI releases data and wastewater treatment modeling software to estimate concentrations in biosolids. As a result, this assessment relied on maximum reported values to develop protective, upper-bound earthworm concentrations for a screening-level assessment of potential dietary exposure to earthworm-eating mammals.

4.4 Overall Environmental Exposure Assessment Conclusions and Weight of Scientific Evidence

EPA evaluated physical, chemical, fate and transport data alongside environmental HHCB releases and estimated concentrations in surface water, sediment and soil from industrial and down-the-drain (commercial and consumer) sources. Bioaccumulation and fish tissue concentrations were also estimated. Exposure via air was considered, however, not quantified because evidence indicates limited atmospheric persistence with limited volatility and rapid photolysis with HHCB unlikely to be widespread in ambient air. Exposure via groundwater was considered but was not assessed due to

HHCB's physical chemical properties and fate behavior limiting leaching to groundwater and supported by limited detections within monitoring datasets.

EPA expects exposure in surface water and sediment downstream of wastewater treatment facility discharges and in soil following land application of biosolids. EPA's Variable Volume Water Model in Point Source Calculator tool (VVWM-PSC) was used to estimate HHCB concentrations in surface water, sediment, and fish tissue from industrial releases and combined down-the-drain releases (commercial plus consumer).

Modeled surface-water concentrations from industrial releases to streams under 7Q10 flow conditions ranged from less than 0.01 to 0.57 µg/L HHCB. Corresponding modeled sediment concentrations ranged from less than 11 to 171 µg/kg HHCB. The weight of evidence indicates that substantial HHCB also enters wastewater via combined down-the-drain disposals, with resulting media concentrations strongly driven by POTW characteristics. The combined P95 POTW release scenario produced the highest modeled surface-water concentration (25.4 µg/L) and the highest modeled sediment concentration (7,741 µg/kg). These modeled concentrations are at least one order of magnitude greater than the highest surface water HHCB measured in U.S. water bodies. EPA has moderate confidence that this analysis identifies potential high-end (P95 POTW) receiving water and sediment concentrations that can be used in the human health and environmental risk assessment (Section 4.3.1.4).

EPA modeled soil concentrations resulting from biosolid applications using a range of biosolid concentrations not linked to specific HHCB COUs, facilities, or locations. The maximum reported biosolids concentration (554,000 µg/kg) yielded a high-end modeled soil concentration of 2,940 µg/kg. EPA has moderate confidence in the absolute value of this soil concentration because of uncertainties due to our inability to apportion soil exposures to TSCA COUs and non-TSCA COUs and biosolid application rate, frequency, depth and timing. However, the Agency has robust confidence that it represents an upper bound for this screening assessment (Section 4.3.2.3).

EPA used modeled surface water concentrations from industrial and down-the-drain (commercial and consumer) releases to evaluate HHCB concentrations in fish tissues in a first-tier screen using a screening-level BCF, and in a refined assessment of modeled fish concentrations using KABAM. Using a BCF of 1,584 L/kg, calculated fish tissue concentrations from industrial releases ranged from less than 1 to 5,639 µg/kg ww. Calculated fish concentrations from combined down-the-drain (commercial plus consumer) scenarios ranged from 475 to 40,265 µg/kg ww, depending on the POTW release percentile, with high-end estimates exceeding the highest measured HHCB in U.S. fish (2,100 µg/kg ww) by over two orders of magnitude (Section 4.3.3.4.1 and Section 4.3.3.4.2).

Using KABAM, EPA estimated HHCB concentrations in large fish ranged from 263 to 6,071 µg/kg ww HHCB—which is comparable to the highest measured fish concentrations (Section 4.3.3.4.3). The KABAM results provide an additional line of evidence and increased confidence that the fish HHCB concentrations reported in this assessment are conservative and protective upper bounds on potential dietary exposures. Overall, the weight of evidence from measured fish concentrations, screening-level fish concentrations estimates, and KABAM fish concentration estimates result in robust confidence that the exposure concentrations provide upper bounds on possible HHCB tissue burdens that can be used in human health and environmental risk assessment (Section 4.3.3.4.4).

For earthworms, EPA estimated upper-bound concentrations for screening assessment by multiplying the upper-bound soil concentration (1,629 µg/kg; Section 4.3.3.4.5) by the maximum field derived BAF (36), resulting in 58,644 µg/kg dry weight HHCB in earthworms from recently amended soils. Despite uncertainties in biosolid applications to soil, EPA has confidence that this soil concentration is an upper-bound and protective concentration of HHCB in earthworms because it combined the maximum modeled soil concentration with the highest measured earthworm BAF. Accordingly, EPA has robust confidence that the estimated upper bound is protective across scenarios with lower soil HHCB and lower earthworm BAF values (Section 4.3.3.4.6).

EPA seeks public comment on all aspects of this draft risk evaluation. In particular, the Agency seeks comment on the following:

- product-specific HHCB concentration ranges and use patterns (*e.g.,* air care, cleaning, laundry/dishwashing, plastics/rubber, water treatment chemicals); and
- down-the-drain release estimates; wastewater treatment removal efficiencies; WWTP influent/effluent, biosolids, and receiving-water/sediment monitoring; and fish tissue data; and
- selection and characterization of the bioaccumulation value, implementation of additional modeling refinements, and resulting conclusions.

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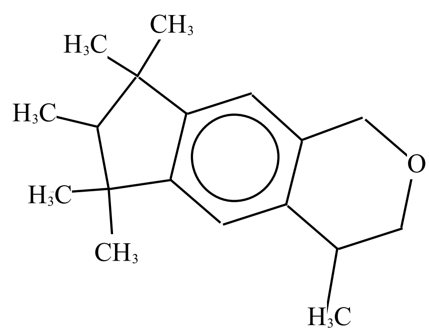
APPENDICES

Appendix A EPI SUITE™ RESULTS USING SELECTED PHYSICAL AND CHEMICAL PROPERTIES

EPI Suite Results for CAS 1222-05-5




```
SMILES : O(CC(c(c1cc(c2C(C3C)(C)C)C3(C)C)c2)C)C1
CHEM   : Cyclopenta g -2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamet
hyl-
MOL FOR: C18 H26 O1
MOL WT : 258.41
------------------------------ EPI SUMMARY (v4.11) --------------------------
Henry LC (atm-m3/mole) :   0.000106
Log Kow (octanol-water):   5.90
Boiling Point (deg C)  :   325.00
Water Solubility (mg/L):   1.75
Physical Property Inputs:
Vapor Pressure (mm Hg) :   0.000545
Melting Point (deg C)  :   -5.00

KOWWIN Program (v1.68) Results:
===============================

Log Kow(version 1.68 estimate): 6.26

Experimental Database Structure Match:
Name      :  Galaxolide
CAS Num   :  001222-05-5
Exp Log P:  5.90
Exp Ref   :  US EPA (2004)

SMILES : O(CC(c(c1cc(c2C(C3C)(C)C)C3(C)C)c2)C)C1
CHEM   : Cyclopenta g -2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamet
hyl-
MOL FOR: C18 H26 O1
MOL WT : 258.41
-------+-----+--------------------------------------------+---------+--------
```

TYPE	NUM	LOGKOW FRAGMENT DESCRIPTION	COEFF	VALUE
Frag	6	-CH3 [aliphatic carbon]	0.5473	3.2838
Frag	2	-CH2- [aliphatic carbon]	0.4911	0.9822
Frag	2	-CH [aliphatic carbon]	0.3614	0.7228
Frag	1	-O- [oxygen, aliphatic attach]	-1.2566	-1.2566
Frag	6	Aromatic Carbon	0.2940	1.7640
Frag	2	-tert Carbon [3 or more carbon attach]	0.2676	0.5352
Const		Equation Constant		0.2290

```
Log Kow   =   6.2604



MPBPVP (v1.43) Program Results:
================================
Experimental Database Structure Match:
Name      :  Galaxolide
CAS Num   :  001222-05-5
Exp MP (deg C):  -5
Exp BP (deg C):  325
Exp VP (mm Hg):  5.45E-04
(Pa   ):  7.27E-002
Exp VP (deg C):  25
Exp VP ref     :  US EPA (2004)

SMILES : O(CC(c(c1cc(c2C(C3C)(C)C)C3(C)C)c2)C)C1
CHEM   : Cyclopenta g -2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamet
hyl-
MOL FOR: C18 H26 O1
MOL WT : 258.41
------------------------ SUMMARY MPBVP v1.43 --------------------


Boiling Point:  325.30 deg C (Adapted Stein and Brown Method)

Melting Point:  181.69 deg C (Adapted Joback Method)
Melting Point:   76.28 deg C (Gold and Ogle Method)
Mean Melt Pt :  128.99 deg C (Joback; Gold,Ogle Methods)
Selected MP:  102.64 deg C (Weighted Value)

Vapor Pressure Estimations (25 deg C):
(Using BP: 325.00 deg C (user entered))
(MP not used for liquids)
VP:  0.000319 mm Hg (Antoine Method)
:  0.0425 Pa  (Antoine Method)
VP:  0.000512 mm Hg (Modified Grain Method)
:  0.0683 Pa  (Modified Grain Method)
VP:  0.000994 mm Hg (Mackay Method)
:  0.133 Pa  (Mackay Method)
Selected VP:  0.000512 mm Hg (Modified Grain Method)
:  0.0683 Pa (Modified Grain Method)
```

TYPE	NUM	BOIL DESCRIPTION	COEFF	VALUE
Group	6	-CH3	21.98	131.88
Group	2	-CH2- (ring)	26.44	52.88

```
Group |  2  |  >CH-   (ring)       |   21.66  |   43.32
Group |  2  |  >C<    (ring)       |   11.12  |   22.24
Group |  1  |  -O-    (ring)       |   32.98  |   32.98
Group |  2  |  CH (aromatic)       |   28.53  |   57.06
Group |  4  |  -C (aromatic)       |   30.76  |  123.04
*   |     |  Equation Constant |          |  198.18
============+====================+=========+=========
RESULT-uncorr|  BOILING POINT in deg Kelvin  |  661.58
RESULT- corr |  BOILING POINT in deg Kelvin  |  598.46
|  BOILING POINT in deg C       |  325.30
-------------------------------------------------------

-------+-----+--------------------+----------+---------
TYPE   | NUM |  MELT DESCRIPTION  |  COEFF   |  VALUE
-------+-----+--------------------+----------+---------
Group |  6  |  -CH3              |   -5.10  |  -30.60
Group |  2  |  -CH2- (ring)      |    7.75  |   15.50
Group |  2  |  >CH-   (ring)     |   19.88  |   39.76
Group |  2  |  >C<    (ring)     |   60.15  |  120.30
Group |  1  |  -O-    (ring)     |   23.05  |   23.05
Group |  2  |  CH (aromatic)     |    8.13  |   16.26
Group |  4  |  -C (aromatic)     |   37.02  |  148.08
*   |     |  Equation Constant |          |  122.50
============+====================+=========+=========
RESULT    |  MELTING POINT in deg Kelvin  |  454.85
|  MELTING POINT in deg C       |  181.69
-------------------------------------------------------



Water Sol from Kow (WSKOW v1.42) Results:
========================================

Water Sol: 0.4265 mg/L

Experimental Water Solubility Database Match:
Name     :  Galaxolide
CAS Num  :  001222-05-5
Exp WSol :  1.75 mg/L (25 deg C)
Exp Ref  :  US EPA (2004)

SMILES : O(CC(c(c1cc(c2C(C3C)(C)C)C3(C)C)c2)C)C1
CHEM   : Cyclopenta g -2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamet
hyl-
MOL FOR: C18 H26 O1
MOL WT : 258.41
---------------------------------- WSKOW v1.42 Results ------------------------
Log Kow  (estimated)  :  6.26
Log Kow (experimental):  5.90
Cas No: 001222-05-5
Name  : Galaxolide
Refer : US EPA (2004)
Log Kow used by Water solubility estimates:  5.90 (user entered)

Equation Used to Make Water Sol estimate:
Log S (mol/L) = 0.693-0.96 log Kow-0.0092(Tm-25)-0.00314 MW + Correction

Melting Pt (Tm) = -5.00 deg C (Use Tm = 25 for all liquids)

Correction(s):         Value
```

```
--------------------   -----
No Applicable Correction Factors

Log Water Solubility  (in moles/L) :  -5.782
Water Solubility at 25 deg C (mg/L):  0.4265



WATERNT Program (v1.01) Results:
===============================

Water Sol (v1.01 est): 0.20116 mg/L

Experimental Water Solubility Database Match:
Name      :  Galaxolide
CAS Num   :  001222-05-5
Exp WSol  :  1.75 mg/L (25 deg C)
Exp Ref   :  US EPA (2004)

SMILES : O(CC(c(c1cc(c2C(C3C)(C)C)C3(C)C)c2)C)C1
CHEM   : Cyclopenta g -2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamet
hyl-
MOL FOR: C18 H26 O1
MOL WT : 258.41
-------+-----+--------------------------------------------+----------+---------
TYPE   | NUM |    WATER SOLUBILITY FRAGMENT DESCRIPTION    |  COEFF   |  VALUE
-------+-----+--------------------------------------------+----------+---------
Frag   |  6  |  -CH3    [aliphatic carbon]                |-0.3213   | -1.9276
Frag   |  2  |  -CH     [aliphatic carbon]                |-0.5285   | -1.0570
Frag   |  1  |  -O-     [oxygen, aliphatic attach]        | 1.2746   |  1.2746
Frag   |  2  |  Aromatic Carbon  (C-H type)               |-0.3359   | -0.6717
Frag   |  4  |  Aromatic Carbon  (C-substituent type)     |-0.5400   | -2.1598
Frag   |  2  |  -tert Carbon  [3 or more carbon attach]   |-0.5774   | -1.1547
Frag   |  2  |  -CH2-  [aliphatic carbon, cyclic]         |-0.3308   | -0.6617
Const  |     |  Equation Constant                         |          |  0.2492
-------+-----+--------------------------------------------+----------+---------
Log Water Sol (moles/L) at 25 dec C  =   -6.1088
Water Solubility (mg/L) at 25 dec C  =  0.20116



ECOSAR Program (v1.11) Results:
===============================
ECOSAR Version 1.11 Results Page

SMILES : O(CC(c(c1cc(c2C(C3C)(C)C)C3(C)C)c2)C)C1
CHEM   : Cyclopenta g -2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamet
hyl-
CAS Num:
ChemID1:
MOL FOR: C18 H26 O1
MOL WT : 258.41
Log Kow: 6.260       (EPISuite Kowwin v1.68 Estimate)
Log Kow:             (User Entered)
Log Kow: 5.90        (PhysProp DB exp value - for comparison only)
Melt Pt: -5.00       (deg C, User Entered for Wat Sol estimate)
Melt Pt: -5.00       (deg C, PhysProp DB exp value for Wat Sol est)
Wat Sol: 0.4265      (mg/L, EPISuite WSKowwin v1.43 Estimate)
Wat Sol: 1.75        (mg/L, User Entered)
Wat Sol: 1.75        (mg/L, PhysProp DB exp value)
```

```
---------------------------------------
Values used to Generate ECOSAR Profile
---------------------------------------
Log Kow: 6.260      (EPISuite Kowwin v1.68 Estimate)
Wat Sol: 1.75       (mg/L, User Entered)



---------------------------------------
ECOSAR v1.11 Class-specific Estimations
---------------------------------------
Neutral Organics
Predicted
ECOSAR Class                 Organism           Duration  End Pt   mg/L (ppm)
===========================  ================== ========  ======   ==========
Neutral Organics           : Fish               96-hr     LC50        0.032
Neutral Organics           : Daphnid            48-hr     LC50        0.027
Neutral Organics           : Green Algae        96-hr     EC50        0.101
Neutral Organics           : Fish                         ChV         0.005
Neutral Organics           : Daphnid                      ChV         0.008
Neutral Organics           : Green Algae                  ChV         0.063
Neutral Organics           : Fish (SW)          96-hr     LC50        0.041
Neutral Organics           : Mysid              96-hr     LC50       0.0017
Neutral Organics           : Fish (SW)                    ChV         0.060
Neutral Organics           : Mysid (SW)                   ChV     4.15e-005
Neutral Organics           : Earthworm          14-day    LC50      162.443 *

Note:  * = asterisk designates: Chemical may not be soluble enough to
measure this predicted effect. If the effect level exceeds the
water solubility by 10X, typically no effects at saturation (NES)
are reported.


------------------------------
Class Specific LogKow Cut-Offs
------------------------------
If the log Kow of the chemical is greater than the endpoint specific cut-offs
presented below, then no effects at saturation are expected for those endpoints.

Neutral Organics:
----------------
Maximum LogKow: 5.0 (Fish 96-hr LC50; Daphnid LC50, Mysid LC50)
Maximum LogKow: 6.0 (Earthworm LC50)
Maximum LogKow: 6.4 (Green Algae EC50)
Maximum LogKow: 8.0 (ChV)



HENRYWIN (v3.20) Program Results:
=============================

Bond Est :  1.32E-004 atm-m3/mole  (1.34E+001 Pa-m3/mole)
Group Est:  7.56E-007 atm-m3/mole  (7.66E-002 Pa-m3/mole)

SMILES : O(CC(c(c1cc(c2C(C3C)(C)C)C3(C)C)c2)C)C1
CHEM   : Cyclopenta g -2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamet
hyl-
MOL FOR: C18 H26 O1
```

```
MOL WT : 258.41
--------------------------- HENRYWIN v3.20 Results --------------------------
----------+---------------------------------------------+---------+----------
CLASS  |     BOND CONTRIBUTION DESCRIPTION          | COMMENT |  VALUE
----------+---------------------------------------------+---------+----------
HYDROGEN |  24  Hydrogen to Carbon (aliphatic) Bonds   |         | -2.8722
HYDROGEN |   2  Hydrogen to Carbon (aromatic) Bonds    |         | -0.3086
FRAGMENT |   9  C-C                                    |         |  1.0467
FRAGMENT |   4  C-Car                                  |         |  0.6477
FRAGMENT |   2  C-O                                    |         |  2.1709
FRAGMENT |   6  Car-Car                                |         |  1.5828
----------+---------------------------------------------+---------+----------
RESULT   |    BOND ESTIMATION METHOD for LWAPC VALUE   |  TOTAL  |  2.267
----------+---------------------------------------------+---------+----------
HENRYs LAW CONSTANT at 25 deg C = 1.32E-004 atm-m3/mole
= 5.40E-003 unitless
= 1.34E+001 Pa-m3/mole

---------+---------------------------------------------+------------+--------
|         GROUP CONTRIBUTION DESCRIPTION          |   COMMENT   |  VALUE
---------+---------------------------------------------+------------+--------
|            1  CH2 (Car)(O)                      |  ESTIMATE  |  0.02
|            6  CH3 (X)                           |            | -3.72
|            1  CH2 (C)(O)                        |            | -0.13
|            1  CH (C)(C)(C)                      |            |  0.24
|            1  CH (C)(C)(Car)                    |            |  0.29
|            2  C (C)(C)(C)(Car)                  |            |  1.86
|            2  Car-H (Car)(Car)                  |            |  0.22
|            4  Car (C)(Car)(Car)                 |            |  2.80
|            1  O (C)(C)                          |            |  2.93
---------+---------------------------------------------+------------+--------
RESULT |  GROUP ESTIMATION METHOD for LOG GAMMA VALUE  |    TOTAL    |  4.51
---------+---------------------------------------------+------------+--------
HENRYs LAW CONSTANT at 25 deg C = 7.56E-007 atm-m3/mole
= 3.09E-005 unitless
= 7.66E-002 Pa-m3/mole


For Henry LC Comparison Purposes:
Exper Database:  none available
User-Entered Henry LC:  1.060E-004 atm-m3/mole  (1.074E+001 Pa-m3/mole)
Henrys LC [via VP/WSol estimate using User-Entered or Estimated values]:
HLC:  1.059E-004 atm-m3/mole  (1.073E+001 Pa-m3/mole)
VP:   0.000545 mm Hg (source: User-Entered)
WS:   1.75 mg/L (source: User-Entered)



Log Octanol-Air (KOAWIN v1.10) Results:
======================================

Log Koa: 8.263

SMILES : O(CC(c(c1cc(c2C(C3C)(C)C)C3(C)C)c2)C)C1
CHEM   : Cyclopenta g -2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamet
hyl-
MOL FOR: C18 H26 O1
MOL WT : 258.41
--------------------------- KOAWIN v1.10 Results --------------------------
```

```
Log Koa (octanol/air) estimate:  8.263
Koa (octanol/air) estimate:  1.833e+008
Using:
Log Kow:  5.90  (user entered)
HenryLC:  0.000106  atm-m3/mole (user entered)
Log Kaw:  -2.363  (air/water part.coef.)

LogKow  : 5.90 (exp database)
LogKow  : 6.26 (KowWin estimate)
Henry LC: --- atm-m3/mole(exp database)
Henry LC: 0.000132 atm-m3/mole (HenryWin bond estimate)

Log Koa (octanol/air) estimate:  8.528 (from KowWin/HenryWin)



BIOWIN (v4.10) Program Results:
==============================
SMILES : O(CC(c(c1cc(c2C(C3C)(C)C)c3(C)C)c2)C)C1
CHEM   : Cyclopenta g -2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamet
hyl-
MOL FOR: C18 H26 O1
MOL WT : 258.41
--------------------------- BIOWIN v4.10 Results ----------------------------

Biowin1 (Linear Model Prediction)    :  Does Not Biodegrade Fast
Biowin2 (Non-Linear Model Prediction):  Does Not Biodegrade Fast
Biowin3 (Ultimate Biodegradation Timeframe):  Months
Biowin4 (Primary  Biodegradation Timeframe):  Weeks
Biowin5 (MITI Linear Model Prediction)    :  Does Not Biodegrade Fast
Biowin6 (MITI Non-Linear Model Prediction):  Does Not Biodegrade Fast
Biowin7 (Anaerobic Model Prediction):  Does Not Biodegrade Fast
Ready Biodegradability Prediction:  NO

------+-----+--------------------------------------------+---------+---------
TYPE | NUM |       Biowin1 FRAGMENT DESCRIPTION         |  COEFF  |  VALUE
------+-----+--------------------------------------------+---------+---------
Frag |  2  |  Carbon with 4 single bonds & no hydrogens | -0.1839 | -0.3679
Frag |  1  |  Aliphatic ether  [C-O-C]                  | -0.3474 | -0.3474
Frag |  1  |  Alkyl substituent on aromatic ring        |  0.0547 |  0.0547
MolWt|  *  |  Molecular Weight Parameter                |         | -0.1230
Const|  *  |  Equation Constant                         |         |  0.7475
============+============================================+=========+=========
RESULT   |    Biowin1 (Linear Biodeg Probability)     |         | -0.0360
============+============================================+=========+=========

------+-----+--------------------------------------------+---------+---------
TYPE | NUM |       Biowin2 FRAGMENT DESCRIPTION         |  COEFF  |  VALUE
------+-----+--------------------------------------------+---------+---------
Frag |  2  |  Carbon with 4 single bonds & no hydrogens | -1.7232 | -3.4464
Frag |  1  |  Aliphatic ether  [C-O-C]                  | -3.4294 | -3.4294
Frag |  1  |  Alkyl substituent on aromatic ring        |  0.5771 |  0.5771
MolWt|  *  |  Molecular Weight Parameter                |         | -3.6694
============+============================================+=========+=========
RESULT   |  Biowin2 (Non-Linear Biodeg Probability)   |         |  0.0009
============+============================================+=========+=========

A Probability Greater Than or Equal to 0.5 indicates --> Biodegrades Fast
A Probability Less Than 0.5 indicates --> Does NOT Biodegrade Fast
```

TYPE	NUM	Biowin3 FRAGMENT DESCRIPTION	COEFF	VALUE
Frag	2	Carbon with 4 single bonds & no hydrogens	-0.2121	-0.4242
Frag	1	Aliphatic ether [C-O-C]	-0.0087	-0.0087
Frag	1	Alkyl substituent on aromatic ring	-0.0749	-0.0749
MolWt	*	Molecular Weight Parameter		-0.5710
Const	*	Equation Constant		3.1992
RESULT		Biowin3 (Survey Model - Ultimate Biodeg)		2.1204

TYPE	NUM	Biowin4 FRAGMENT DESCRIPTION	COEFF	VALUE
Frag	2	Carbon with 4 single bonds & no hydrogens	-0.1534	-0.3069
Frag	1	Aliphatic ether [C-O-C]	-0.0097	-0.0097
Frag	1	Alkyl substituent on aromatic ring	-0.0685	-0.0685
MolWt	*	Molecular Weight Parameter		-0.3728
Const	*	Equation Constant		3.8477
RESULT		Biowin4 (Survey Model - Primary Biodeg)		3.0898

Result Classification: 5.00 -> hours 4.00 -> days 3.00 -> weeks
(Primary & Ultimate) 2.00 -> months 1.00 -> longer

TYPE	NUM	Biowin5 FRAGMENT DESCRIPTION	COEFF	VALUE
Frag	2	Carbon with 4 single bonds & no hydrogens	0.0676	0.1352
Frag	1	Aliphatic ether [C-O-C]	0.0015	0.0015
Frag	1	Aromatic-CH2	-0.0557	-0.0557
Frag	1	Aromatic-CH	-0.0098	-0.0098
Frag	2	Aromatic-H	0.0082	0.0164
Frag	6	Methyl [-CH3]	0.0004	0.0025
Frag	1	-CH2- [cyclic]	0.0197	0.0197
Frag	1	-CH - [cyclic]	0.0124	0.0124
MolWt	*	Molecular Weight Parameter		-0.7688
Const	*	Equation Constant		0.7121
RESULT		Biowin5 (MITI Linear Biodeg Probability)		0.0657

TYPE	NUM	Biowin6 FRAGMENT DESCRIPTION	COEFF	VALUE
Frag	2	Carbon with 4 single bonds & no hydrogens	0.3990	0.7980
Frag	1	Aliphatic ether [C-O-C]	-0.1071	-0.1071
Frag	1	Aromatic-CH2	-0.1246	-0.1246
Frag	1	Aromatic-CH	0.2624	0.2624
Frag	2	Aromatic-H	0.1201	0.2403
Frag	6	Methyl [-CH3]	0.0194	0.1166
Frag	1	-CH2- [cyclic]	0.2365	0.2365
Frag	1	-CH - [cyclic]	-0.1295	-0.1295
MolWt	*	Molecular Weight Parameter		-7.4599
RESULT		Biowin6 (MITI Non-Linear Biodeg Probability)		0.0255

```
A Probability Greater Than or Equal to 0.5 indicates --> Readily Degradable
A Probability Less Than 0.5 indicates --> NOT Readily Degradable


------+-----+--------------------------------------------+---------+---------
TYPE | NUM |       Biowin7 FRAGMENT DESCRIPTION         |  COEFF  |  VALUE
------+-----+--------------------------------------------+---------+---------
Frag |  2  |  Carbon with 4 single bonds & no hydrogens | -0.3342 | -0.6685
Frag |  1  |  Aliphatic ether  [C-O-C]                  | -0.2573 | -0.2573
Frag |  1  |  Alkyl substituent on aromatic ring        | -0.1145 | -0.1145
Frag |  1  |  Aromatic-CH2                              | -0.0073 | -0.0073
Frag |  1  |  Aromatic-CH                               |  0.0331 |  0.0331
Frag |  2  |  Aromatic-H                                | -0.0954 | -0.1909
Frag |  6  |  Methyl  [-CH3]                            | -0.0796 | -0.4774
Frag |  1  |  -CH2-  [cyclic]                           | -0.1200 | -0.1200
Frag |  1  |  -CH -  [cyclic]                           |  0.0395 |  0.0395
Const|  *  |  Equation Constant                         |         |  0.8361
============+============================================+=========+=========
RESULT   |   Biowin7 (Anaerobic Linear Biodeg Prob)   |         | -0.9272
============+============================================+=========+=========

A Probability Greater Than or Equal to 0.5 indicates --> Biodegrades Fast
A Probability Less Than 0.5 indicates --> Does NOT Biodegrade Fast

Ready Biodegradability Prediction: (YES or NO)
----------------------------------------------
Criteria for the YES or NO prediction:  If the Biowin3 (ultimate survey
model) result is "weeks" or faster (i.e. "days", "days to weeks", or
"weeks" AND the Biowin5 (MITI linear model) probability is >= 0.5, then
the prediction is YES (readily biodegradable). If this condition is not
satisfied, the prediction is NO (not readily biodegradable). This method
is based on application of Bayesian analysis to ready biodegradation data
(see Help). Biowin5 and 6 also predict ready biodegradability, but for
degradation in the OECD301C test only; using data from the Chemicals
Evaluation and Research Institute Japan (CERIJ) database.



BioHCwin (v1.01) Program Results:
==============================
SMILES : O(CC(c(c1cc(c2C(C3C)(C)C)C3(C)C)c2)C)C1
CHEM   : Cyclopenta g -2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamet
hyl-
MOL FOR: C18 H26 O1
MOL WT : 258.41
-------------------------- BioHCwin v1.01 Results ---------------------------

NO Estimate Possible ... Structure NOT a Hydrocarbon
(Contains atoms other than C, H or S (-S-))



AEROWIN Program (v1.00) Results:
===============================
Sorption to aerosols (25 Dec C)[AEROWIN v1.00]:
Vapor pressure (liquid/subcooled):  0.0727 Pa (0.000545 mm Hg)
Log Koa (Koawin est  ): 8.263
Kp (particle/gas partition coef. (m3/ug)):
Mackay model           :  4.13E-005
Octanol/air (Koa) model:  4.5E-005
```

```
Fraction sorbed to airborne particulates (phi):
Junge-Pankow model      :  0.00149
Mackay model            :  0.00329
Octanol/air (Koa) model:  0.00359


AOP Program (v1.92) Results:
===========================
SMILES : O(CC(c(c1cc(c2C(C3C)(C)C)C3(C)C)c2)C)C1
CHEM   : Cyclopenta g -2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamet
hyl-
MOL FOR: C18 H26 O1
MOL WT : 258.41
------------------- SUMMARY (AOP v1.92): HYDROXYL RADICALS (25 deg C) --------
Hydrogen Abstraction       =  22.3773 E-12 cm3/molecule-sec
Reaction with N, S and -OH =   0.0000 E-12 cm3/molecule-sec
Addition to Triple Bonds   =   0.0000 E-12 cm3/molecule-sec
Addition to Olefinic Bonds =   0.0000 E-12 cm3/molecule-sec
**Addition to Aromatic Rings =  15.4099 E-12 cm3/molecule-sec
Addition to Fused Rings    =   0.0000 E-12 cm3/molecule-sec

OVERALL OH Rate Constant =  37.7872 E-12 cm3/molecule-sec
HALF-LIFE =     0.283 Days (12-hr day; 1.5E6 OH/cm3)
HALF-LIFE =     3.397 Hrs
........................ ** Designates Estimation(s) Using ASSUMED Value(s)
------------------- SUMMARY (AOP v1.91): OZONE REACTION (25 deg C) -----------

******  NO OZONE REACTION ESTIMATION ******
(ONLY Olefins and Acetylenes are Estimated)

Experimental Database:  NO Structure Matches
Fraction sorbed to airborne particulates (phi):
0.00239 (Junge-Pankow, Mackay avg)
0.00359 (Koa method)
Note: the sorbed fraction may be resistant to atmospheric oxidation



KOCWIN Program (v2.00) Results:
==============================
SMILES : O(CC(c(c1cc(c2C(C3C)(C)C)C3(C)C)c2)C)C1
CHEM   : Cyclopenta g -2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamet
hyl-
MOL FOR: C18 H26 O1
MOL WT : 258.41
---------------------------  KOCWIN v2.00 Results  ---------------------------

Koc Estimate from MCI:
---------------------
First Order Molecular Connectivity Index  ........... :  8.759
Non-Corrected Log Koc (0.5213 MCI + 0.60)  .......... :  5.1658
Fragment Correction(s):
1   Ether, aliphatic  (-C-O-C-)  .......... : -0.8716
Corrected Log Koc  .................................. :  4.2942

Estimated Koc:  1.969e+004  L/kg   <===========

Koc Estimate from Log Kow:
-------------------------
Log Kow  (User entered   )  ......................... :  5.90
```

```
Non-Corrected Log Koc (0.55313 logKow + 0.9251)  .... :  4.1886
Fragment Correction(s):
1   Ether, aliphatic  (-C-O-C-)  .......... : -0.0906
Corrected Log Koc  .................................. :  4.0980

Estimated Koc:  1.253e+004  L/kg   <===========



HYDROWIN Program (v2.00) Results:
=================================
SMILES : O(CC(c(c1cc(c2C(C3C)(C)C)C3(C)C)c2)C)C1
CHEM   : Cyclopenta g -2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamet
hyl-
MOL FOR: C18 H26 O1
MOL WT : 258.41
--------------------------- HYDROWIN v2.00 Results ---------------------------


Currently, this program can NOT estimate a hydrolysis rate constant for
the type of chemical structure entered!!

ONLY Esters, Carbamates, Epoxides, Halomethanes (containing 1-3 halogens),
Specific Alkyl Halides & Phosphorus Esters can be estimated!!

When present, various hydrolyzable compound-types will be identified.
For more information, (Click OVERVIEW in Help  or  see the User's Guide)

*****   CALCULATION NOT PERFORMED   *****



BCFBAF Program (v3.01) Results:
==============================
SMILES : O(CC(c(c1cc(c2C(C3C)(C)C)C3(C)C)c2)C)C1
CHEM   : Cyclopenta g -2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamet
hyl-
MOL FOR: C18 H26 O1
MOL WT : 258.41
---------------------------------- BCFBAF v3.01 --------------------------------
Summary Results:
Log BCF (regression-based estimate):  3.56  (BCF = 3.63e+003 L/kg wet-wt)
Biotransformation Half-Life (days) :  3.58  (normalized to 10 g fish)
Log BAF (Arnot-Gobas upper trophic):  3.26  (BAF = 1.83e+003 L/kg wet-wt)

Log Kow (experimental):  5.90
Log Kow used by BCF estimates:  5.90 (user entered)

Equation Used to Make BCF estimate:
Log BCF = 0.6598 log Kow - 0.333 + Correction

Correction(s):                     Value
No Applicable Correction Factors

Estimated Log BCF =  3.560  (BCF = 3629 L/kg wet-wt)

===========================================================
Whole Body Primary Biotransformation Rate Estimate for Fish:
===========================================================
------+-----+--------------------------------------------+---------+---------
```

```
TYPE | NUM | LOG BIOTRANSFORMATION FRAGMENT DESCRIPTION |  COEFF  |  VALUE
------+-----+--------------------------------------------+---------+---------
Frag |  2  |  Carbon with 4 single bonds & no hydrogens | -0.2984 | -0.5969
Frag |  1  |  Aliphatic ether  [C-O-C]                  | -0.0232 | -0.0232
Frag |  1  |  Alkyl substituent on aromatic ring        |  0.1781 |  0.1781
Frag |  1  |  Aromatic-CH2                              | -0.3365 | -0.3365
Frag |  1  |  Aromatic-CH                               | -0.4629 | -0.4629
Frag |  2  |  Aromatic-H                                |  0.2664 |  0.5328
Frag |  6  |  Methyl  [-CH3]                            |  0.2451 |  1.4706
Frag |  1  |  -CH2-  [cyclic]                           |  0.0963 |  0.0963
Frag |  1  |  -CH -  [cyclic]                           |  0.0126 |  0.0126
Frag |  1  |  Number of fused acyclic rings             |  0.6477 |  0.6477
Frag |  1  |  Number of fused 6-carbon aromatic rings   | -0.5779 | -0.5779
Frag |  6  |  Polycyclic -CH3 (3 fused rings or less)   |  0.0000 |  0.0000
L Kow|  *  |  Log Kow =   5.90 (user-entered   )       |  0.3073 |  1.8133
MolWt|  *  |  Molecular Weight Parameter                |         | -0.6626
Const|  *  |  Equation Constant                         |         | -1.5371
============+============================================+=========+=========
RESULT   |       LOG Bio Half-Life (days)            |         |  0.5542
RESULT   |           Bio Half-Life (days)            |         |   3.582
NOTE     |  Bio Half-Life Normalized to 10 g fish at 15 deg C   |
============+============================================+=========+=========

Biotransformation Rate Constant:
kM (Rate Constant):  0.1935 /day (10 gram fish)
kM (Rate Constant):  0.1088 /day (100 gram fish)
kM (Rate Constant):  0.06118 /day (1 kg fish)
kM (Rate Constant):  0.03441 /day (10 kg fish)

Arnot-Gobas BCF & BAF Methods (including biotransformation rate estimates):
Estimated Log BCF (upper trophic) =  3.090  (BCF = 1231 L/kg wet-wt)
Estimated Log BAF (upper trophic) =  3.261  (BAF = 1826 L/kg wet-wt)
Estimated Log BCF (mid trophic)   =  3.223  (BCF = 1671 L/kg wet-wt)
Estimated Log BAF (mid trophic)   =  3.667  (BAF = 4648 L/kg wet-wt)
Estimated Log BCF (lower trophic) =  3.262  (BCF = 1829 L/kg wet-wt)
Estimated Log BAF (lower trophic) =  3.970  (BAF = 9334 L/kg wet-wt)

Arnot-Gobas BCF & BAF Methods (assuming a biotransformation rate of zero):
Estimated Log BCF (upper trophic) =  4.308  (BCF = 2.03e+004 L/kg wet-wt)
Estimated Log BAF (upper trophic) =  6.307  (BAF = 2.03e+006 L/kg wet-wt)



Volatilization From Water
=========================

Chemical Name: Cyclopenta g -2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-
hexamethyl-

Molecular Weight    :  258.41 g/mole
Water Solubility    :  1.75 ppm
Vapor Pressure      :  0.000545 mm Hg
Henry's Law Constant:  0.000106 atm-m3/mole  (entered by user)

RIVER              LAKE
---------          ---------
Water Depth     (meters):   1                  1
Wind Velocity    (m/sec):   5                  0.5
Current Velocity (m/sec):   1                  0.05
```

```
HALF-LIFE (hours) :   10.52               249.5
HALF-LIFE (days ) :   0.4383              10.4


STP Fugacity Model:  Predicted Fate in a Wastewater Treatment Facility
======================================================================
(using 10000 hr Bio P,A,S)
PROPERTIES OF: Cyclopenta g -2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-
hexamethyl-
-------------
Molecular weight (g/mol)                                  258.41
Aqueous solubility (mg/l)                                 1.75
Vapour pressure (Pa)                                      0.0726607
(atm)                                  7.17105E-007
(mm Hg)                                0.000545
Henry 's law constant (Atm-m3/mol)                        0.000106
Air-water partition coefficient                           0.00433508
Octanol-water partition coefficient (Kow)                 794328
Log Kow                                                   5.9
Biomass to water partition coefficient                    158866
Temperature [deg C]                                       25
Biodeg rate constants (h^-1),half life in biomass (h) and in 2000 mg/L MLSS (h):
-Primary tank         0.00       9968.63       10000.00
-Aeration tank        0.00       9968.63       10000.00
-Settling tank        0.00       9968.63       10000.00

STP Overall Chemical Mass Balance:
---------------------------------
g/h                  mol/h         percent

Influent                     1.00E+001         3.9E-002        100.00

Primary sludge               5.81E+000         2.2E-002        58.07
Waste sludge                 3.27E+000         1.3E-002        32.73
Primary volatilization       1.23E-003         4.8E-006         0.01
Settling volatilization      2.75E-003         1.1E-005         0.03
Aeration off gas             9.70E-003         3.8E-005         0.10

Primary biodegradation       1.70E-002         6.6E-005         0.17
Settling biodegradation      4.19E-003         1.6E-005         0.04
Aeration biodegradation      5.51E-002         2.1E-004         0.55

Final water effluent         8.30E-001         3.2E-003         8.30

Total removal                9.17E+000         3.5E-002        91.70
Total biodegradation         7.64E-002         3.0E-004         0.76


Level III Fugacity Model (Full-Output):
=======================================
Chem Name    : Cyclopenta g -2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-
hexamethyl-
Molecular Wt: 258.41
Henry's LC   : 0.000106 atm-m3/mole (user-entered)
Vapor Press  : 0.000545 mm Hg  (user-entered)
Log Kow      : 5.9  (user-entered)
Soil Koc     : 1.97e+004  (KOCWIN MCI method)

Mass Amount     Half-Life    Emissions
(percent)         (hr)       (kg/hr)
```

```
Air       0.224           6.79          1000
Water     8.41            1.44e+003     1000
Soil      79.2            2.88e+003     1000
Sediment  12.2            1.3e+004      0

Fugacity    Reaction    Advection   Reaction    Advection
(atm)      (kg/hr)      (kg/hr)    (percent)   (percent)
Air       1.1e-011     1.19e+003   117         39.7         3.9
Water     8.41e-010    211         439         7.04         14.6
Soil      1.99e-010    994         0           33.1         0
Sediment  1.37e-009    33.9        12.7        1.13         0.423

Persistence Time: 1.74e+003 hr
Reaction Time:    2.15e+003 hr
Advection Time:   9.18e+003 hr
Percent Reacted:  81.1
Percent Advected: 18.9

Half-Lives (hr), (based upon Biowin (Ultimate) and Aopwin):
Air:      6.794
Water:    1440
Soil:     2880
Sediment: 1.296e+004
Biowin estimate: 2.120  (months      )

Advection Times (hr):
Air:      100
Water:    1000
Sediment: 5e+004
```

Appendix B ADDITIONAL TRI INFORMATION

B.1 Changes Indicated by Preliminary 2024 TRI Submissions

TRI submissions are required six months (June) after the end of the reporting year, with a preliminary data set released to the public around July. This preliminary dataset has not undergone the TRI data quality process; therefore, some submissions may change or be submitted during this preliminary period. However, it does provide the current complete submissions. The EPA usually releases the National Analysis dataset in October after completing the quality checks.

This preliminary data from 2024 TRI submissions was reviewed because HHCB has only one year of TRI data. For this assessment, EPA used the 2024 dataset that was last updated on August 13, 2025. This appendix section discusses the differences between the preliminary 2024 data and the 2023 data[6] that was used. For 2024, 31 new facilities reported to TRI while 9 previous submitters from 2023 did not submit TRI forms. The RS-by-RS analysis details the differences year to year in the variability of releases of HHCB. These releases were not used to derive media concentrations, as these numbers were not finalized by the EPA during the time that the TSD was being developed. Overall, there were only small changes in the amounts released to POTW and WWT except for a new site that reported 7,451 kg transferred to a POTW in 2024, which is larger than was reported by any site in 2023 (2023 maximum: 2,226 kg/yr-site). In addition, the 2023 dataset had no direct discharges of HHCB, but the 2024 dataset reports an on-site direct discharge in 2024 of 99 kg from one site. The site previously reported no direct discharges in 2023 but reported waste both directly discharge to waterbodies on site and waste sent to a POTW in 2024.

B.1.1 Manufacturing

For manufacturing, there were no changes in the number of facilities that reported. The most significant difference being a decrease of 316 kilograms in the amount of HHCB transferred off-site to POTW last year by Takasago International. Their reported production ratio of 1.15, indicates that use of HHCB was mostly consistent with the previous year but still resulted in lower releases.

Table_Apx B-1. Preliminary 2024 Changes in Water Releases for Manufacturing

Site Identity and Location	Change to Annual Release to Surface Water (kg/yr-site)	Change to Annual Release to POTW (kg/yr-site)	Change to Annual Release to WWT (kg/yr-site)
Takasago International Corp. (Harriman, NY)	0	−316	0
Chemia (Maryland Heights, MO)	0	+2	0

B.1.2 Repackaging

For repackaging, there is one new facility reported to 2024 TRI, Aerofil Technology Inc. This new facility did not report any waste to surface water, POTW or a WWT. The other repackaging site had a small decrease in the amount going to POTW from 2023.

[6] TRI release data was extracted in March 2025. Facilities can make corrections to their TRI submission if needed, therefore they may differ from the currently available version.

Table_Apx B-2. Preliminary 2024 Changes in Water Releases for Repackaging

Site Identity and Location	Change to Annual Release to Surface Water (kg/yr-site)	Change to Annual Release to POTW (kg/yr-site)	Change to Annual Release to WWT (kg/yr-site)	Notes
Tilley Distribution Inc. (Norwood, NJ)	0	−21	0	
Aerofil Technology Inc. (Sullivan, MO)	0	0	0	New TRI Reporter

B.1.3 Formulation of Fragrance Oils

For Formulation of Fragrance Oils, all sites that reported in 2023 also reported in 2024 with the addition of four new sites. Two of these new sites reported 1,029 and 7,451 kg sent to POTW over 2024, which is larger than the quantities reported for this RS in 2023. Notably a facility that reported no direct discharges in 2023 reported a direct discharge of 99 kg of HHCB.

Table_Apx B-3. Preliminary 2024 Changes in Water Releases for Formulation of Fragrance Oils

Site Identity and Location	Change to Annual Release to Surface Water (kg/yr-site)	Change to Annual Release to POTW (kg/yr-site)	Change to Annual Release to WWT (kg/yr-site)	Notes
Robertet Inc. (Budd Lake, NJ)	0	+23	0	
International Flavors & Fragrances Inc (Monmouth, NJ)	0	≈0	0	<kg decrease from 2023–2024 in amount transferred to POTW
Mane USA (Wayne, NJ)	0	≈0	0	<kg decrease from 2023–2024 in amount transferred to POTW
Arylessence Inc. (Marietta, GA)	0	−6	0	
Symrise Inc (Somerset, NJ)	0	+3	0	
Flavorchem Corp (Dupage, IL)	0	0	0	
Belle Aire Creations (Round Lake, IL)	0	0	0	
Andrea Aromatics Inc (Trenton, NJ)	0	0	0	
Cosmo International Corp (Deerfield Beach, FL)	0	0	0	
Intarome Fragrance Corp (Bergen, NJ)	0	0	0	
Flavor & Fragrance Specialties (Essex, MD)	0	0	0	
Firmenich Inc (Plainsboro, NJ)	+99	+17	0	In 2023, no water releases reported. In 2024, both a release to surface water at the facility occurred and waste was also transferred to a POTW.

Site Identity and Location	Change to Annual Release to Surface Water (kg/yr-site)	Change to Annual Release to POTW (kg/yr-site)	Change to Annual Release to WWT (kg/yr-site)	Notes
Givaudan Fragrances Corp (Towaco, NJ)	0	1,029	0	New site first reported for 2024
Givaudan Fragrances Corp - Mount Olive Site (Budd Lake, NJ)	0	7,451	0	New site first reported for 2024
International Aromatics Inc (Moonachie, NJ)	0	0	0	New site first reported for 2024
Marcy Laboratories Inc (Glendale Heights, IL)	0	0	0	New site first reported for 2024
Number provided rounded to the nearest integer. For values <1, numbers rounded to 1 significant figure.				

B.1.4 Formulation of End-Use Products

For formulation of end-use products, the biggest change was a decrease from Colgate-Palmolive Co Cambridge Plant of 425 kg transferred in 2024. The other repeat reporters had small (±5 kg) changes from 2023 to 2024. There were seven sites that reported in 2023 but were not in the preliminary dataset for 2024. These sites may not have met the reporting requirements for 2024. There were 20 new reporters with no direct releases to surface water and only seven reporters that had releases to POTW or WWT site (range: 0.08–56 kg/yr-site).

Table_Apx B-4. Preliminary 2024 Changes in Water Releases for Formulation of End-Use Products

Site Identity and Location	Change to Annual Release to Surface Water (kg/yr-site)	Change to Annual Release to POTW (kg/yr-site)	Change to Annual Release to WWT (kg/yr-site)	Notes
Colgate-Palmolive Co Cambridge Plant (Cambridge, OH)	0	0	-425	
ABC Compounding Co. Inc. (Conyers, GA)	0	0	−1	
Spartan Chemical Co Inc (Maumee, OH) [a]	0	−0.09	0	
Church & Dwight Co. Inc. (Harrisonville, MO)	0	+2	0	
Henkel US Operation Corp (Salt Lake City, UT)	0	−0.3	−13	
Procter & Gamble Tabler Station Manufacturing Plant (Inwood, WV)	0	−3	0	
Amano Pioneer Eclipse	0	0	+0.1	

Site Identity and Location	Change to Annual Release to Surface Water (kg/yr-site)	Change to Annual Release to POTW (kg/yr-site)	Change to Annual Release to WWT (kg/yr-site)	Notes
Corp (Sparta, NC)				
Apex International Mfg (Eden Prairie, MN)	–	–	–	Did not report for reporting year (RY)2024
Apex International (Chaska MN)	–	–	–	Did not report for RY2024
Hillyard Industries Inc (Saint Joseph, MO)	0	+0.5	0	
Misco Products Corp (Reading, PA)	–	–	–	Did not report for RY2024
Beaumont Products Inc (Kennesaw, GA)	0	0	0	
People Against Dirty Property Management (Chicago, IL)	–	–	–	Did not report for RY2024
Kringle Candle (Bernardston, MA)	0	0	0	
Yankee Candle Co (Whately, MA)	0	0	0	
ABC Compounding Co of Texas Inc (Grand Prairie, TX)	0	0	0	
Questspecialty Corp (Brenham, TX)	0	0	0	
Crawford Plant (Crawford, GA)	0	0	0	
Crown Chemical Inc (Crestwood, IL)	–	–	–	Did not report for RY2024
Reynolds Consumer Products (Temple, TX)	0	0	0	
Clean Control Corp[b] (Warner Robins, GA)	0	0	+0.05	
Chase Products Co (Broadview, IL)	0	0	0	
Colortech Inc (Morristown, TN)	0	0	0	
BMC Manufacturing LLC (Spartanburg, SC)	0	0	0	
Empire Candle Co. LLC (Kansas City, KS)	0	0	0	
Candle-Lite Co LLC (Leesburg, OH)	0	0	0	

Site Identity and Location	Change to Annual Release to Surface Water (kg/yr-site)	Change to Annual Release to POTW (kg/yr-site)	Change to Annual Release to WWT (kg/yr-site)	Notes
Globaltech Industries Inc. (Cornelia, GA)	0	0	0	
Church & Dwight Co Inc (Green River, WY)	0	+3	0	
Rimports (Provo, UT)	–	–	–	Did not report for RY2024
Plaze Inc (Saint Clair, MO)	0	0	0	
Midlab Inc. (Athens, TN)	0	0	0	
The A.I. Root Co (Medina, OH)	0	0	0	
Church & Dwight Co. Inc. (Victorville, CA)	0	0	0	
Alene Candles LLC (Milford, NH)	–	–	–	Did not report for RY2024
IFS Industries INC (Reading, PA)	0	0	0	
ACCRA-PAC INC. DBA Voyant Beauty (Elkhart, IN)	0	0	0	New site first reported for 2024
ACCRA-PAC INC. DBA Voyant Beauty (Elkhart, IN)	0	0	0	New site first reported for 2024
Buckeye International Inc. (Maryland Heights, MO)	0	2	0	New site first reported for 2024
Century Products Inc. (Carrollton, TX)	0	0.2	0	New site first reported for 2024
Church & Dwight Co Inc (York, PA)	0	0	0	New site first reported for 2024
Church & Dwight Co Inc (Colonial Heights, VA)	0	3	0	New site first reported for 2024
Ecolab Inc (McDonough, GA)	0	0	0	New site first reported for 2024
Ecolab Inc (City of Industry, CA)	0	0	0	New site first reported for 2024
Ecolab Inc (Martinsburg, WV)	0	0.08	0	New site first reported for 2024
Ecolab Inc Kay Chemical Co (Greensboro, NC)	0	0	0	New site first reported for 2024
Ecolab Inc. (Joliet, IL)	0	0	0	New site first reported for 2024
Ecolab Inc. (Garland, TX)	0	0.08	0	New site first reported for 2024

Site Identity and Location	Change to Annual Release to Surface Water (kg/yr-site)	Change to Annual Release to POTW (kg/yr-site)	Change to Annual Release to WWT (kg/yr-site)	Notes
Henkel Us Operations Corp (Bowling Green, KY)	0	0.5	56	New site first reported for 2024
Hill Manufacturing Co. Inc. (Atlanta, GA)	0	0	0	New site first reported for 2024
Kik (Houston) Inc (Houston, TX)	0	0	0	New site first reported for 2024
National Carwash Solutions (De Pere, WI)	0	5	0	New site first reported for 2024
Plaze Inc (Pacific, MO)	0	0	0	New site first reported for 2024
Questspecialty Corp (Benham, TX)	0	0	0	New site first reported for 2024
Reynolds Consumer Products LLC (Jacksonville, IL)	0	0	0	New site first reported for 2024
Sewell Products of Florida LLC (Maumee, OH)	0	0	0	New site first reported for 2024
Note: Number provided rounded to the nearest integer. For values <1, numbers rounded to 1 significant figure.				

B.1.5 Disposal

For disposal, there were little to no differences in the 2024 TRI dataset with still no releases to surface water, POTW, or WWT reported by a disposal site. However, four new facilities were reported in 2024.

Table_Apx B-5. Preliminary 2024 Changes in Water Releases for Disposal

Site Identity and Location	Change to Annual Release to Surface Water (kg/yr-site)	Change to Annual Release to POTW (kg/yr-site)	Change to Annual Release to WWT (kg/yr-site)	Notes
Veolia ES Technical Solutions LLC Port Arthur Facility (Beaumont, TX)	0	0	0	
Clean Harbors Deer Park LLC (La Porte, TX)	0	0	0	
Clean Harbors Aragonite LLC	0	0	0	New site first reported for 2024
Clean Harbors El Dorado LLC	0	0	0	New site first reported for 2024
EQ Detroit Inc	0	0	0	New site first reported for 2024
Tradebe Treatment & Recycling LLC	0	0	0	New site first reported for 2024

B.2 2023 Full TRI Data

The below sections covered the full set of TRI data for the reporting year 2023. The data provided is the annual release amounts to surface water, to POTWs or to WWT.

B.2.1 2023 TRI Data by Release Scenario

Table_Apx B-6 provides the site information and reported releases for discharges to surface water and transfers to POTW or other WWT.

Table_Apx B-6. Annual and Daily Releases of HHCB by Release Scenario

Site Identity and Location	Annual Release to Surface Water (kg/yr-site)	Annual Release to POTW (kg/yr-site)	Annual Release to WWT (kg/yr-site)	Daily Release (kg/day-site)	Number of Release Days
Manufacturing RS					
Takasago International Corp. (Harriman, NY)	0	2,226	0	9	250
Chemia[a] (Maryland Heights, MO)	0	0	0	0	250
Repackaging RS					
Tilley Distribution Inc. (Norwood, NJ)	0	21	0	0.1	250
Formulation of Fragrance Oils RS					
Robertet Inc. (Budd Lake, NJ)	0	340	0	1	240
International Flavors & Fragrances Inc (Monmouth, NJ)	0	110	0	0.5	240
Mane USA (Wayne, NJ)	0	10	0	0.04	240
Arylessence Inc. (Marietta, GA)	0	9	0	0.04	240
Symrise Inc (Somerset, NJ)	0	9	0	0.04	240
Flavorchem Corp (Dupage, IL)	0	3	0	0.01	240
Belle Aire Creations (Round Lake, IL)	0	0	0	0	240
Andrea Aromatics Inc (Trenton, NJ)	0	0	0	0	240
Cosmo International Corp (Deerfield Beach, FL)	0	0	0	0	240
Intarome Fragrance Corp (Bergen, NJ)	0	0	0	0	240
Flavor & Fragrance Specialties (Essex, MD)	0	0	0	0	240
Firmenich Inc (Plainsboro, NJ)	0	0	0	0	240

Site Identity and Location	Annual Release to Surface Water (kg/yr-site)	Annual Release to POTW (kg/yr-site)	Annual Release to WWT (kg/yr-site)	Daily Release (kg/day-site)	Number of Release Days
Formulation of End-Use Products RS					
Colgate-Palmolive Co Cambridge Plant (Cambridge, OH)	0	0	1196	5	250
ABC Compounding Co. Inc. (Conyers, GA)	0	0	1	0.005	250
Spartan Chemical Co Inc (Maumee, OH) [b]	0	0.09	0	0.0004	250
Church & Dwight Co. Inc. (Harrisonville, MO)	0	23	0	0.09	250
Henkel Us Operation Corp (Salt Lake City, UT)	0	0.5	15	0.06[c]	250
Procter & Gamble Tabler Station Manufacturing Plant (Inwood, WV)	0	6	0	0.03	250
Amano Pioneer Eclipse Corp (Sparta, NC)	0	0	0.09	0.0004	250
Apex International Mfg (Eden Prairie, MN)	0	2	0	0.009	250
Apex International (Chaska MN)	0	2	0	0.007	250
Hillyard Industries Inc (Saint Joseph, MO)	0	1	0	0.004	250
Misco Products Corp (Reading, PA)	0	0.4	0	0.002	250
Beaumont Products Inc (Kennesaw, GA)	0	0	0	0	250
People Against Dirty Property Management (Chicago, IL)	0	0	0	0	250
Kringle Candle (Bernardston, MA)	0	0	0	0	250
Yankee Candle Co (Whately, MA)	0	0	0	0	250
ABC Compounding Co of Texas Inc (Grand Prairie, TX)	0	0	0	0	250
Questspecialty Corp (Brenham, TX)	0	0	0	0	250
Crawford Plant (Crawford, GA)	0	0	0	0	250
Crown Chemical Inc (Crestwood, IL)	0	0	0	0	250

Site Identity and Location	Annual Release to Surface Water (kg/yr-site)	Annual Release to POTW (kg/yr-site)	Annual Release to WWT (kg/yr-site)	Daily Release (kg/day-site)	Number of Release Days
Reynolds Consumer Products (Temple, TX)	0	0	0	0	250
Clean Control Corp[d] (Warner Robins, GA)	0	0	0	0	250
Chase Products Co (Broadview, IL)	0	0	0	0	250
Colortech Inc (Morristown, TN)	0	0	0	0	250
BMC Manufacturing LLC (Spartanburg, SC)	0	0	0	0	250
Empire Candle Co. LLC (Kansas City, KS)	0	0	0	0	250
Candle-Lite Co LLC (Leesburg, OH)	0	0	0	0	250
Globaltech Industries Inc. (Cornelia, GA)	0	0	0	0	250
Church & Dwight Co Inc (Green River, WY)	0	0	0	0	250
Rimports (Provo, UT)	0	0	0	0	250
Plaze Inc (Saint Clair, MO)	0	0	0	0	250
Midlab Inc. (Athens, TN)	0	0	0	0	250
The A.I. Root Co (Medina, OH)	0	0	0	0	250
Church & Dwight Co. Inc. (Victorville, CA)	0	0	0	0	250
Alene Candles LLC (Milford, NH)	0	0	0	0	250
IFS Industries INC (Reading, PA)	0	0	0	0	250
Waste Handling, Treatment, and Disposal RS					
Veolia ES Technical Solutions LLC Port Arthur Facility (Beaumont, TX)	0	0	0	0	250
Clean Harbors Deer Park LLC (La Porte, TX)	0	0	0	0	250

POTW = publicly owned treatment works; RS = Release Scenario; WWT = wastewater treatment
Note: Number provided rounded to the nearest integer. For values <1, numbers rounded to 1 significant figure.
[a] This site reported no releases or transfers of HHCB either on-site or off-site. The 2023 Form R (Miscellaneous and

Site Identity and Location	Annual Release to Surface Water (kg/yr-site)	Annual Release to POTW (kg/yr-site)	Annual Release to WWT (kg/yr-site)	Daily Release (kg/day-site)	Number of Release Days
Optional Information) for the Chemia site indicated a 2022 production volume of 11,698 lb and a 2023 production volume of 16,964 lb. No basis of estimate is required for comments provided in the Miscellaneous and Optional Information section of Form R. [b] The Section 9.1 (Miscellaneous and Optional Information) for Spartan Chemical Co Inc indicated that waste was from a production spill of fragrance containing HHCB. [c] Daily release amounts were calculated by combining the amounts sent to POTW and the amount sent to WWT site by the number of release days. This daily release amount is not being sent to the same facility. [d] Section 8.11 (optional pollution prevention information) for Clean Control Corp indicated that waste is recycled or reused within the process to reduce amounts for disposal and that HHCB may be associated with FIFRA regulated disinfectants.					

B.2.2 Excluded: Other Sources

The EPA has determined that some of uses of HHCB falls outside TSCA's definition of "chemical substance" such as soaps, cosmetics, and other personal care products. During the mapping of TRI sites, the companies listed in Table_Apx B-7 were excluded because they are suspected to use HHCB in the production of hair care, cosmetics, or other personal care products.

The information available on the company websites do not directly describe the use of HHCB at their facilities. Therefore, these sites are classified as other sources. For large companies, they may produce both TSCA products as well as other (non-TSCA) products, as much as possible, determinations were made specific to the activities occurring at the site location from publicly available information.

Table_Apx B-7. Additional TRI Facilities with Potentially Non-TSCA Activities

Year	TRIFD	Facility Name	Total Surface Water (kg/yr)	Total POTW Transfer (kg/yr)	Off-Site – Wastewater Treatment (kg/yr)
2023	29653SRLKN5421H	COLGATE PALMOLIVE CO (Hodges, SC)	0	342.5	0
2023	7501WBTYMN125FR	BEAUTY MANUFACTURING SOLUTIONS CORP. (Coppell, TX)	0	0	0
2023	0885WLRLSP81NEW	LOREAL USA PRODUCTS INC (Piscataway, NJ)	0	18.8	0
2023	4615WNCPKPNENIC	NICE-PAK PRODUCTS INC. (Mooresville, IN)	0	0	0
2023	0773WCSMTC2182R	COSMETIC ESSENCE DBA VOYANT BEAUTY (Holmdel, NJ)	0	2.3	0

Year	TRIFD	Facility Name	Total Surface Water (kg/yr)	Total POTW Transfer (kg/yr)	Off-Site – Wastewater Treatment (kg/yr)
2023	0887WLRLXX1CMME	L'OREAL USA PRODUCTS INC (Somerset, NJ)	0	0.9	0
2023	37408DBLCL3350S	CHATTEM INC PLANT 2 (Chattanooga, TN)	0	10.7	0
2023	4104WLRLSX78NEW	LOREAL USA (Florence, KY)	0	60.3	0
2023	6813WCHRBT11222	COHERE BEAUTY (Omaha, NE)	0	1.4	0
2023	18201DLCRP125JA	HENKEL US OPERATION CORP (Hazelton, PA)	0	0.5	12.2
2023	08701CHRCH800AI	CHURCH & DWIGHT CO. INC. (Lakewood, NJ)	0	131.4	0
2023	91311CSMTC20245	KDC ONE / COSMETIC LABORATORIES OF AMERICA INC (Chatsworth, CA)	0	9.1E-04	0
2023	9131WTHBNT232PR	KDC / ONE - THIBIANT INTERNATIONAL (Chatsworth, CA)	0	4.5E-03	0
2024 [a]	7501WBTYMN125FR	BEAUTY MANUFACTURING SOLUTIONS CORP. (Coppell, TX)	0	21.3	0
2024 [a]	37408DBLCL3350S	CHATTEM INC PLANT 2 (Chattanooga, TN)	0	9.6	0
2024 [a]	08701CHRCH800AI	CHURCH & DWIGHT CO. INC. (Lakewood, NJ)	0	143.3	0
2024 [a]	29653SRLKN5421H	COLGATE PALMOLIVE CO (Hodges, SC)	0	130.2	0
2024 [a]	0773WCSMTC2182R	COSMETIC ESSENCE DBA VOYANT BEAUTY (Holmdel, NJ)	0	0.1	0
2024 [a]	18201DLCRP125JA	HENKEL US OPERATION CORP (Hazleton, PA)	0	1.4	8.2

Year	TRIFD	Facility Name	Total Surface Water (kg/yr)	Total POTW Transfer (kg/yr)	Off-Site – Wastewater Treatment (kg/yr)
2024[a]	14456ZTSNTPOBOX	HENKEL US OPERATIONS CORP (Geneva, NY)	0	41.2	17.9
2024[a]	3865WJSTRC142DE	J. STRICKLAND & CO. (Olive Branch, MS)	0	0	0
2024[a]	9131WTHBNT232PR	KDC / ONE - THIBIANT INTERNATIONAL (Chatsworth, CA)	0	9.1E-03	0
2024[a]	91311CSMTC20245	KDC ONE / COSMETIC LABORATORIES OF AMERICA INC (Chatsworth, CA)	0	0.5	0
2024[a]	4104WLRLSX78NEW	LOREAL USA (Florence, KY)	0	22.2	0
2024[a]	0885WLRLSP81NEW	LOREAL USA PRODUCTS INC (Piscataway, NJ)	0	8.5	0
2024[a]	0887WLRLXX1CMME	L'OREAL USA PRODUCTS INC (Somerset, NJ)	0	2.7	0
2024[a]	4615WNCPKPNENIC	NICE-PAK PRODUCTS INC. (Mooresville, SC)	0	6.4	0

POTW = publicly owned treatment works
[a] This data are preliminary data from 2024 TRI submissions (see Appendix B.1)

Appendix C MODEL APPROACH AND PARAMETERS FOR COMMERCIAL RELEASES

C.1 EPA/OPPT Models

For this risk evaluation, the Agency evaluated products that are expected to be fully released after the final application or use of the product; therefore, it can be considered that 100% of the product is released to the environment. EPA/OPPT standard loss fraction models were used to estimate the amounts loss due to residue left in containers or loss during transferring. For the amount released during application or use, the Agency used a mass balance to calculate the remaining amount available to be released to respective environmental media expected for the product type. For example, laundry, dishwashing, and certain cleaning products are released down-the-drain during application as part of using the product.

The standard loss fraction model follows the following format:

$$DR_{RS} = Q_{HHCB\_site\_day} \times LF$$

Where:

DR_{RS} = Daily release amount for specific release source (kg/site-day)

$Q_{HHCB\_site\_day}$ = Daily HHCB throughput for scenario and product type (kg/site-day)

LF = Loss fraction based on the standard EPA/OPPT model for the release source (kg remaining/kg shipped)
EPA/OPPT Small Container Residual Model
EPA/OPPT Drum Residual Model
EPA/OPPT Dust Emissions from Transferring Solids Model
EPA/OPPT Solid Residue Container Model

The loss fractions for potential upstream losses prior to application or use were taken from standard EPA/OPPT models, as described in Table_Apx C-1.

Table_Apx C-1. EPA/OPPT Models Used

Model	Description
EPA/OPPT Small Container Residual Model (liquid)	The EPA/OPPT Small Container Residual Model uses a loss fraction with a lower bound of 0.0003 kg residual/kg product, an upper bound of 0.006 kg residual/kg product, and a mode of 0.003 kg residual/kg product. The mode and upper bound of the distribution are based on the central tendency and high-end values listed in the EPA/OPPT Small Container Residual Model from the ChemSTEER User Guide (U.S. EPA, 2015a). Note that the underlying data for this model comes from a 1988 study by PEI Associates Inc. that looked at literature sources and conducted a pilot-scale experiment to determine the amount of residual material left in containers (PEI Associates, 1988). EPA reviewed the data from this study and the underlying distribution of the container residual loss fraction is unknown; therefore, EPA assigned a triangular distribution as discussed above.
EPA/OPPT Solid Residue Container Model	The EPA/OPPT Solid Residuals in Transport Containers Model provides a loss fraction 0.01 kg of solid chemicals remaining in a container per kg transported. Therefore, EPA could not develop a distribution of values for this parameter and used the single value 0.01 kg/kg from the model (U.S. EPA, 2015a). Note that the underlying data for this model comes from a 1988 study that reviewed literature sources and conducted a pilot scale experiment to determine the amount of

Model	Description
	residual material left in containers (PEI Associates, 1988).
EPA/OPPT Drum Residual Model	Specifically, EPA modeled container residual fraction for drums using a triangular distribution with a lower bound of 0.017 kg residual/kg product, an upper bound of 0.03 kg residual/kg product, and a mode of 0.025 kg residual/kg product. The lower bound is based on the minimum value for pumping and the upper bound is based on the default high-end value in the EPA/OPPT Drum Residual Model from the ChemSTEER User Guide (U.S. EPA, 2015a). EPA used the central tendency value for pumping as the mode of the triangular distribution. Note that the underlying data for this model comes from a 1988 study by PEI Associates Inc. that looked at literature sources and conducted a pilot-scale experiment to determine the amount of residual material left in containers (PEI Associates, 1988). EPA reviewed the data from this study and the underlying distribution of the container residual loss fraction is unknown; therefore, the Agency assigned a triangular distribution.
EPA/OPPT Dust Emissions from Transferring Solids Model	EPA modeled the fraction of chemical lost during transfer of solid powders using a triangular distribution with a lower bound of 0.001 kg dust lost/kg transferred, an upper bound of 0.03 kg, and a mode of 0.005 kg. These values were taken from the EPA/OPPT Dust Emissions from Transferring Solids Model from the ChemSTEER User Guide (U.S. EPA, 2015a)

C.2 Use of Cleaning Products Modeling Approach and Parameters for Estimating Environmental Releases

Environmental releases of HHCB from the use of cleaning products are a function of the HHCB concentration in the cleaning products, amount of cleaning products used per application, number of applications occurring at a commercial site. There are multiple cleaning product types with varying amounts used per application. An approach was developed that uses information on floor area of commercial buildings to estimate the environmental releases for all surface cleaning products

C.2.1 Model Equations

Daily Use Rate for Surface Cleaning

Equation_Apx C-1.

$$Qproduct_{site_{day_1}} = AREA_{floor} \times AMOUNT_{Cleaning_{solution}} \times 0.001\frac{m^3}{L} \times AMOUNT_{Cleaning_{product}} \times 264.17\frac{gal}{m^3} \times p_{product} \times 0.000029574\frac{m^3}{oz}$$

Where:

$Q_{product\_site\_day\_1}$	=	Daily amount of surface cleaning used
$AREA_{floor}$	=	Occupied floor area (surface cleaning) (m[2)]
$AMOUNT_{cleaning\ solution}$	=	Amount of cleaning solution used (L/m[2)]
$AMOUNT_{cleaning\ product}$	=	Amount of cleaning product per gallon of water used (oz/gallon)
$\rho_{product}$	=	Cleaning product density (kg/m[3)]

Daily Use Rate for Toilet Cleaner

Equation_Apx C-2.

$$\text{Qproduct}_{\text{site}_{\text{day}_2}} = NUM_{toilets} \times AMOUNT_{toilet_{cleaner}} \div 1000\,\frac{g}{kg}$$

Equation_Apx C-3.

$$NUM_{toilets} = NUM_{toilets\_occupant} \times NUM_{occupant}$$

Where:

$Q_{product\_site\_day\_2}$	=	Throughput for toilet cleaner (kg/site-day)
$NUM_{Toilets\_occupant}$	=	Number of toilets per site (toilets/site)
$AMOUNT_{Toilet\ Cleaner}$	=	Amount of toilet cleaner used per toilet (g/toilet)
$NUM_{Toilets\_occupant}$	=	Number of toilets per occupant (toilets/occupant)
$Num_{occupants}$	=	Building occupants (occupants)

Daily Use Rate for Liquid Carpet Cleaner

Equation_Apx C-4.

$$Qproduct_{site_{day_{3_{liquid}}}}$$

$$= Volume\ of\ reservoir\ \times AMOUNT_{cleaning\ product} \times 1{,}000\,\frac{kg}{m^3} \times 0.000029574\,\frac{m^3}{oz}$$

Where:

$Q_{product\_site\_day\_3}$	=	Throughput for liquid carpet cleaner (kg/site-day)
$Volume\ of\ reservoir$	=	Volume of reservoir for carpet cleaning machine (gallon/day)
$AMOUNT_{Cleaning\ product}$	=	Amount of floor cleaner used per water (oz/gallon)

Daily Use Rate for Solid Carpet Cleaner

$$Qproduct_{site_{day_{4_{solid}}}} = 2.2\ kg/day$$

Daily HHCB Throughput

Equation_Apx C-5.

$$Q_{hhcb\_site\_day} = Qproduct_{site_{day_X}} \times F_{HHCB\_prod}$$

Where:

$Q_{hhcb\_site\_day}$	=	Daily throughput of HHCB for Specific Product Type (kg/site-day)
$Q_{product\_site\_day\_X}$	=	Different throughput of product types (1, 2, 3, and 4) (kg/site-day)
F_{HHCB_prod}	=	Fraction of HHCB in the product (kg HHCB/kg product)

Facility HHCB Annual Throughput

Equation_Apx C-6.

$$Q_{hhcb\_site\_yr} = Q_{hhcb\_site\_day=} \times OP_{days}$$

Where:

$Q_{hhcb\_site\_yr}$	=	Annual throughput of HHCB for specific product types
$Q_{hhcb\_site\_day}$	=	Daily throughput of HHCB for specific product type (kg/site-day)
OP_{days}	=	Operating days (days/yr)

Number of Containers Unloaded Per Site-Day

Equation_Apx C-7.

$$N_{cont\_unload\_site\_day} = \frac{Q_{hhcb\_site\_day}}{F_{HHCB\_prod} \times V_{cont} \times p_{product} \times 0.0037854\ m^3/gal}$$

Where:

$N_{cont\_unload\_site\_day}$	=	Number of containers unloaded per day for each site (containers/day-site)
$Q_{hhcb\_site\_day}$	=	Daily throughput of HHCB for specific product type (kg/site-day)
F_{hhcb_prod}	=	Fraction of HHCB in the product (kg HHCB/kg product)
V_{cont}	=	Container Volume (gallons)
$\rho_{product}$	=	Density of Product (kg/m^3)

Number of Containers Unloaded Per Site-Year

Equation_Apx C-8.

$$N_{cont\_unload\_site\_yr} = N_{cont\_unload\_site\_day} \times OP_{days}$$

Where:

$N_{cont\_unload\_site\_yr}$	=	Number of containers unloaded per year for each site (containers/day-site)
$N_{cont\_unload\_site\_day}$	=	Number of containers unloaded per day for each site (containers/day-site)
OP_{days}	=	Operating Days (days/yr)

C.2.2 Model Input Parameters

Table_Apx C-2 summarizes the model parameters and their values for the Monte Carlo simulation. Additional explanations of EPA's selection of the distributions for each parameter are provided after this table. Central tendency and high-end releases are estimated by selecting the 50th and 95th percentile values from the output distribution.

Table_Apx C-2. Model Input Parameters for Use of Cleaning Products

Input Parameter	Symbol	Unit	Deterministic Values		Uncertainty Analysis Distribution Parameters			Distribution Type	Rationale/ Basis
			Value	Basis	Lower Bound	Upper Bound	Mode		
Production Volume of HHCB	PV	kg HHCB/yr	19,656	Default	19,656	196,557	–	Uniform	**Note**: Model runs include this PV, but PV estimates were updated.
Operating Days for Surface Cleaning and Toilet Cleaning	$OP_{days\_1\&2}$	days/yr	260	Mode	259	366	260	Discrete	See Appendix C.2.3
Amount of Cleaning Product Per Gallon of Water Used	$AMOUNT_{cleaning\ product}$	oz/gallon	2	Mode	1	8	2	Triangular	See Appendix C.2.4
Amount of Cleaning Product Used per square meter	$AMOUNT_{cleaning\ solution}$	L/m^2	0.04	Default	–	–	–	Discrete	See Appendix C.2.5
Amount of Toilet Cleaner Used Per Toilet	$AMOUNT_{Toilet\ Cleaner}$	g	55	Default	55	80	–	Uniform	See Appendix C.2.6
Cleaning Product Density	$\rho_{product}$	kg/m^3	1,000	Mode	1,000	1,060	1000	Triangular	See Appendix C.2.5
Container Volume	V_{cont}	gallon	0.25	Default	0.25	5	–	Uniform	See Appendix C.2.5
Throughput for Carpet Cleaning (liquid)	$Q_{product\_site\_day\_3\_liquid}$	kg/site-day	0.71	Mode	0.35	5.68	0.71	Triangular	See Appendix C.2.7
Throughput for Carpet Cleaning (solid)	$Q_{product\_site\_day\_3\_solid}$	kg/site-day	2.2	Default	–	–	–	Discrete	See Appendix C.2.7

Input Parameter	Symbol	Unit	Deterministic Values		Uncertainty Analysis Distribution Parameters			Distribution Type	Rationale/ Basis
			Value	Basis	Lower Bound	Upper Bound	Mode		
Loss Fraction from Transfer Operation Losses	LF_{RS2}	kg remaining/ kg shipped	0.005	Mode	0.001	0.03	0.005	Triangular	See Appendix C.2.1
Loss Fraction from Container Residue (liquid)	LF_{RS3_liquid}	kg remaining/ kg shipped	0.003	Mode	0.0003	0.006	0.003	Triangular	See Appendix C.2.1
Loss Fraction from Container Residue (solid)	LF_{RS3_solid}	kg remaining/ kg shipped	0.01	Default	–	–	–	Discrete	See Appendix C.2.1
Mass Fraction of HHCB in liquid Cleaning Products	F_{HHCB_liquid}	kg HHCB / kg product	0.001	Mode	0.001	0.003	0.001	Discrete	See Appendix C.2.4
Mass Fraction of HHCB in Solid Cleaning Products	$F_{HHCB\_Scenario\_3\_solids}$	kg HHCB / kg product	0.001	Mode	0.001	0.003	0.001	Discrete	See Appendix C.2.4
Occupied Floor Area (Surface Cleaning)	$AREA_{floor}$	m^2	98,474	Default	629	98,474	–	Beta	See Appendix C.2.8
Building Occupants (Toilet Cleaning)	$Num_{occupants}$	occupants	6,500	Default	87	6,500	–	Beta	See Appendix C.2.9

C.2.3 Operating Days for Surface Cleaning and Toilet Cleaning

The operating days for surface and toilet cleaning assume that most buildings will be cleaned each day of operations with businesses typically operating 5 days a week for 52 weeks per year (260 days per year). Some specific businesses such as hospitals or lodging places may clean every day of the year. The mode was set at 260 days with a decreasing probability until it reaches a maximum of 365 days per year.

C.2.4 Cleaning Products Specifications

Product searches identified 14 commercial cleaning products: 1 all-purpose foam spray cleaner, 12 all-purpose liquid cleaner/polishes, and 1 all-purpose liquid spray cleaner. Some of the all-purpose liquid cleaner/polishes act as drain and toilet cleaners (liquid). No commercial products were identified for appliance cleaners; waxes and polishes; powder cleaners (floors); and powder cleaners (porcelain). However, EPA did modeled releases from powder cleaning products for carpets (floor) using the concentration information from the identified liquid products.

EPA was able to identify products through SDSs as well as ingredient disclosure forms as provided from manufacturers to comply with the California Cleaning Product Right to Know Act of 2017. This act requires disclosure of cleaning product ingredients, and specifically fragrance allergens if concentrations are above 0.01%. Of the 14 commercial cleaning products, specific concentration information for HHCB was only available from the 5 products listed in Table_Apx C-3.

For selecting parameters for the modeling, EPA used the container volume, density and dilution information only from the products used to inform the mass fraction of HHCB in the cleaning product. For container volume, the parameter ranged from 0.25 to 5 gallons assuming a uniform distribution. For density, the parameter ranged from 1,000 to 1,060 kg/m^3 assuming a triangular distribution with a mode of 1,000 kg/m^3.

Amount of cleaning product per gallon of water (cleaning solution) was selected to be 1 to 8 oz per gallon of water using a triangular distribution with a mode of 2 oz per gallon. This was also generally supported by the other commercial products with unknown HHCB concentrations.

Table_Apx C-3. HHCB-Containing Cleaning Products Specifications

Identified Products	F_{HHCB} [a], Mass Fraction of HHCB	V_{cont}, Container Volume (gal)	*p*, Density (kg/m^3)[b]	$AMOUNT_{cleaning\ product}$, Dilution Information
Washroom/bathroom/toilet cleaners				
Triton Non-Acid Washroom Cleaner	0.001–0.003	1	1,060	8 oz per gallon
Clean on the Go NABC Concentrate	0.001	0.53	1,000	2 oz per gallon
BNC-15	0.001	0.53, 1	1,000	1 oz per gallon
Peroxy II FBC Antibacterial Foaming Bath & Surface Cleaner	0.001	0.25	1,020	Ready to use
NABC Non-Acid Disinfectant Bathroom Cleaner	0.001	0.25–5	1,000	Ready to use
Fresh & Clean Hi-Con 64 Neutral Disinfectant and Detergent	Unknown	1, 2.5, 5, 55	–	2 oz per gallon
Fresh Breeze Non-acid Disinfectant Bathroom Cleaner	Unknown	0.25	–	Ready to Use
5 Fresh Breeze Non-acid Disinfectant Restroom Cleaner	Unknown	0.63	–	2 oz per gallon
Fresh Breeze RTU Tuberculocidal Disinfectant	Unknown	0.25	–	Ready to Use
Floor cleaners				
4 Emerald Optically Enhanced Neutral Floor Cleaner[c]	Unknown	0.63, 0.79	–	0.5 oz per gallon

Identified Products	F_{HHCB} [a], Mass Fraction of HHCB	V_{cont}, Container Volume (gal)	p, Density (kg/m^3)[b]	$AMOUNT_{cleaning\ product}$, Dilution Information
Back Down Rinse and Neutralizer	Unknown	2.5, 5, 55	–	2 oz. per gallon
Emerald Optically Enhanced Neutral Floor Cleaner	Unknown	1, 2.5, 5, 55 gallon	–	General: 1–2 oz. per gal Heavy Duty: 2–4 oz. per gal
Flashback Spray Buff	Unknown	0.25, 1, 2.5, 5	–	Ready to Use
Carpet cleaners				
Deep Kleen Carpet Extraction Cleaner	Unknown	1, 2.5, 5, 55	–	General Cleaning: Use 1–3 oz per each gal Heavy Soil: Use 16 oz. per each gal

[a] Fraction of HHCB in cleaning products were not always specified in some products, with some products including HHCB on an ingredient disclosure form but no concentration information listed.
[b] Only products with HHCB weight concentration information were searched for density information.
[c] This product is a concentrated form of "Emerald Optically Enhanced Neutral."

C.2.5 Amount of Cleaning Solution Used Per Surface Area

A default of 0.04 L per m^2 was used based on the amount of liquid required to make a surface 'wet' as indicated in the RIVM factsheet (RIVM, 2018). For comparison, the product information for a ready to use (*i.e.*, no dilution) cleaning product[7] advertised a coverage of 1,500 to 2,000 ft^2 per gallon (≈0.02 L/m^2). A method protocol for measuring emissions from cleaning products indicated a default could be assumed of 1 gallon of wet product per 1,262 ft^2 (≈0.03 L/m^2) (GREENGUARD, 2008).

C.2.6 Amount Of Toilet Cleaner Used

The amount of toilet cleaner used per toilet is based on the RIVM fact sheet, which states 55g of acid-based cleaner or 80g of bleach cleaner is used per toilet. The HHCB-containing toilet cleaners are not known to fall into either of these categories but are assumed to be used at a similar rate (RIVM, 2018).

C.2.7 Throughput For Carpet Cleaner

Carpet cleaners were not expected to have same use pattern as general floor cleaners as not all areas within a commercial building are typically carpeted and it is not typically a daily activity.

Liquid Product

For the amount a commercial carpet cleaner used, it was assumed that a typical job will use the full reservoir of a commercial carpet cleaning machine. RIVM indicates that small carpet cleaning machines have a reservoir of 0.35 to 10 L and large carpet cleaners have a reservoir of 30 to 45 L. A search of commercial cleaning machines at U.S. supplier websites indicated the most common size machines had a reservoir of 45 L (12 gallons). If 12 gallons is assumed to be used during the carpet cleaning at one site, then the amount of cleaning product would be based on the product dilution specifications noted for carpet cleaners in Table_Apx C-3. This results in 0.35, 0.71, 1.06, and 5.68 kg/site-day used, depending

[7] ZEP Hard Surface Cleaner

on if it is general cleaning or a heavy soil. The model was run using a triangular distribution with a minimum of 0.35 kg/site-day to a maximum of 5.68 kg/site-day with a mode at 0.71 kg/site-day.

Solid (Powder) Product

For the use of powder carpet cleaner, it was generally assumed that this product would be used for smaller areas such as in residential homes that are cleaned by professional carpet and upholstery cleaners. The RIVM default for solid carpet cleaner (RIVM, 2018) was used which is based on a floor area that is approximately the size of a living room and product instructions from a sample solid carpet cleaner. This default value is 2.2 kg/site-day.

C.2.8 Occupied Floor Area (Surface Cleaning)

The EPA BASE Study (U.S. EPA, 2023b) provided statistics on the occupied floor area for commercial buildings (Table_Apx C-4). The study defined occupied floor area as spaces expected to be occupied such as office space and retail areas but not low traffic areas such as utility closets or stairwells. EPA selected to use the occupied floor area over the gross floor area provided in the study as the occupied floor area may also be the floor area most likely to be cleaned daily. EPA fit a beta distribution to this distribution with parameters ($\alpha1 = 0.84251$, $\alpha2 = 5.22750$, min = 629 m^2, and max = 98,474 m^2). The root-mean squared (RMS) error is 0.0330. The underlying data from the EPA BASE Study as well as the data curve fit graphs are presented in the EPA BASE Study Data Curve Fits sheet within Supplemental Information on Environmental Release Modeling for HHCB.

Table_Apx C-4. Floor Area in Commercial Buildings

Parameter	Occupied Floor Area (m^2)
Mean	16,380
Standard deviation	18,461
Minimum	629
10th percentile	2,256
25th percentile	5,061
50th percentile	8,477
75th percentile	21,271
90th percentile	35,912
Maximum	98,474

The U.S. Department of Energy (DOE) also has a commercial building energy reference building floor area of various types of commercial businesses (see Table_Apx C-5). For this dataset, the survey is categorized by the type of building activity. For the EPA BASE study 50th percentile floor area, the corresponding building activity is an in-patient health care facility. The U.S. DOE commercial reference buildings are referenced below which is a floor area defaults for DOE (DOE, 2026).

Table_Apx C-5. Floor Area of U.S. DOE Commercial Reference Buildings

Building Type Name	Floor Area (ft^2)	Floor Area (m^2)
Small Office	5,500	511
Quick Service Restaurant	2,500	232
Full-Service Restaurant	5,500	511
Supermarket	45,000	4,181
Outpatient Health Care	40,946	3,804
Medium Office	53,628	4,982
Strip Mall	22,500	2,090
Stand-Alone Retail	24,962	2,319
Small Hotel	43,200	4,013
Warehouse	52,045	4,835
Primary School	73,960	6,871
Large Hotel	122,120	11,345
Secondary School	210,887	19,592
Hospital	241,351	22,422
Large Office	498,588	46,320

For additional comparison, EPA examined reported floor areas from the City of Sherwood, Oregon, 2020 public buildings cleaning services procurement bid invitation (City of Sherwood, 2019). The contract covers several building types (see Table_Apx C-6). The breakdown of flooring between hard surface and carpet varies across these, as follows:

Table_Apx C-6. Floor Distribution in Public Building in Sherwood, Oregon

City of Sherwood, Oregon, Public Buildings			
Building	**Total Square Footage**	**Hard Surface (m^2)**	**Carpet (m^2)**
Library	2,635	673 (26%)	1,847 (74%)
Center for the Arts	1,234	914 (74%)	40 (3%)
Public Works	589	235 (40%)	357 (60%)
Senior Center	679	521 (77%)	193 (23%)

These examples demonstrate that proportion of the floor area varies by building type, and that the proportion of hard surface can vary based on the type and purpose of building. EPA modeling results generally assume that the distribution from the EPA BASE study can be 100% hard floors. With this assumption, the daily release rates for cleaning products are most applicable to large commercial buildings such as schools, hotels, and hospitals.

C.2.9 Building Occupants (Toilet Cleaner)

The EPA BASE Study (U.S. EPA, 2023b) provided statistics on the number of occupants for commercial buildings (Table_Apx C-7). EPA fit a beta distribution to this data with parameters: α1 = 0.86903, α2 = 5.8901, min = 87 m^2, and max = 6,500 m^2. The root-mean squared (RMS) error is 0.0176. The underlying data from the EPA BASE Study as well as the data curve fit graphs are presented in the Supplemental Information on Environmental Release Modeling for HHCB.

Table_Apx C-7. Number of Occupants in Commercial Buildings

Statistical Descriptor	Number of Building Occupants
Mean	1,020
Standard deviation	1,110
Minimum	87
10th percentile	178
25th percentile	304
50th percentile	705
75th percentile	1,200
90th percentile	2,257
Maximum	6,500

C.3 Use of Laundry Products Modeling Approach and Parameters for Estimating Environmental Releases

Environmental releases of HHCB from the use of laundry products are a function of the HHCB concentration in the laundry products and the amount of laundry products used per site at industrial or institutional laundry site. EPA evaluated releases if HHCB was in the laundry detergent, fabric softener, or in both set of products. EPA used daily use rate and other industry-specific information from the OECD ESD on the Chemicals Used in Water Based Washing Operations at Industrial and Institutional Laundries (OECD, 2011) combined with Monte Carlo simulation (a type of stochastic simulation).

C.3.1 Model Equations

Daily use rate selection based on physical form of detergent is based on the following equations, the first being for liquid detergent and the second being for powder detergent:

$$Q_{facility\_day} = Q_{liquid\_ind\_detergent\_site\_day}$$
or
$$Q_{facility\_day} = Q_{liquid\_ind\_softener\_site\_day}$$
or
$$Q_{facility\_day} = Q_{solid\_ind\_detergent\_site\_day}$$
or
$$Q_{facility\_day} = Q_{solid\_ind\_softener\_site\_day}$$
or
$$Q_{facility\_day} = Q_{liquid\_inst\_detergent\_site\_day}$$

or

$$Q_{facility\_day} = Q_{liquid\_inst\_softener\_site\_day}$$

or

$$Q_{facility\_day} = Q_{solid\_inst\_detergent\_site\_day}$$

or

$$Q_{facility\_day} = Q_{solid\_inst\_softener\_site\_day}$$

Where:

$Q_{facility\_day}$	=	Daily use rate (kg/site-day)
$Q_{phys\ form\_site\ type\_product\ type\_site\_day}$	=	Daily use for the specific physical form, type of laundry site, and product type (kg/site-day)

Daily use rate of laundry products containing HHCB is calculated using the equation below:

Equation_Apx C-9.

$$Q_{facility\_day\_adjusted} = Q_{facility\_day} \times F_{formulations\_hhcb} \times F_{HHCB\_prod\_det\ or\ soft\_liquid\_or\_solid}$$

Where:

$Q_{facility\_day\_adjusted}$	=	Daily use rate of product containing HHCB selected based on the physical form of the detergent (kg/site-day)
$Q_{facility\_day}$	=	Daily use rate based on physical form, laundry type and product type (kg/site-day)
$F_{formulations\_hhcb}$	=	Fraction of laundry products containing HHCB (kg/kg)
$F_{HHCB\_prod\_det\_liquid\_or\_solid}$	=	Fraction of HHCB in the product

Annual use rate of HHCB is calculated using the equation below:

Equation_Apx C-10.

$$Q_{HHCB\_site\_yr} = Q_{HHCB\_site-day} * OP_{days}$$

Where:

$Q_{HHCB\_site\_yr}$	=	Annual usage rate of HHCB (kg/site-yr)
$Q_{HHCB\_site-day}$	=	Daily use rate of HHCB (kg/site-day)
OP_{days}	=	Operating days (days/yr)

Number of containers used per year is calculated using the equation below:

Equation_Apx C-11.

$$N_{cont\_site\_yr} = \frac{Q_{facility\_day\_adjusted} * OP_{days}}{V_{container} * 0.00378541\frac{m^3}{gal} * RHO_{product}}$$

Where:

$N_{cont\_site\_yr}$	=	Number of containers used per site per year (containers/site-year)
$Q_{facility\_day\_adjusted}$	=	Daily use rate of product with HHCB (kg/site-day)

OD = Operating days (days/year)
$V_{container}$ = Container volume (gal/container)
$RHO_{detergent}$ = Product density (kg/L)

C.3.2 Model Input Parameters

Table_Apx C-8 summarizes the model parameters and their values for the Monte Carlo simulation. Additional explanations of EPA's selection of the distributions for each parameter are provided after this table. Central tendency and high-end releases are estimated by selecting the 50th and 95th percentile values from the output distribution.

Table_Apx C-8. Model Input Parameters for Use of Laundry Products

Input Parameter	Symbol	Unit	Deterministic Values		Uncertainty Analysis Distribution Parameters			Distribution Type	Rationale/ Basis
			Value	Basis	Lower Bound	Upper Bound	Mode		
Production Volume of HHCB	PV	kg HHCB/yr	168,283	Default	168,283	1,682,828	–	Uniform	Note: Model runs include this PV, but PV estimates updated.
Operating Days	OP_{days}	days/yr	260	Mode	19	366	260	Discrete	See Appendix C.3.3
Daily Use Rate of Liquid Industrial Detergents	$Q_{\text{liquid\_ind\_detergent\_site\_day}}$	kg product / site-day	35.706	Median	0.116	813.721	–	Discrete	See Appendix C.3.5
Daily Use Rate of Liquid Industrial Softeners	$Q_{\text{liquid\_ind\_softener\_site\_day}}$	kg product / site-day	4.004	Median	0.239	23.055	–	Discrete	See Appendix C.3.5
Daily Use Rate of Solid Industrial Detergents	$Q_{\text{solid\_ind\_detergent\_site\_day}}$	kg product / site-day	110.454	Median	1.329	1917.444	–	Discrete	See Appendix C.3.5
Daily Use Rate of Solid Industrial Softeners	$Q_{\text{solid\_ind\_softener\_site\_day}}$	kg product / site-day	2.293	Median	0.181	11.655	–	Discrete	See Appendix C.3.5
Daily Use Rate of Liquid Institutional Detergents	$Q_{\text{liquid\_inst\_detergent\_site\_day}}$	kg product / site-day	16.036	Median	0.124	512.624	–	Discrete	See Appendix C.3.5
Daily Use Rate of Liquid Institutional Softeners	$Q_{\text{liquid\_inst\_softener\_site\_day}}$	kg product / site-day	3.079	Median	0.742	28.711	–	Discrete	See Appendix C.3.5
Daily Use Rate of Solid Institutional Detergents	$Q_{\text{solid\_inst\_detergent\_site\_day}}$	kg product / site-day	8.631	Median	3.707	15.162	–	Discrete	See Appendix C.3.5

Input Parameter	Symbol	Unit	Deterministic Values		Uncertainty Analysis Distribution Parameters			Distribution Type	Rationale/ Basis
			Value	Basis	Lower Bound	Upper Bound	Mode		
Daily Use Rate of Solid Institutional Softeners	$Q_{solid\_inst\_softener\_site\_day}$	kg product / site-day	1.918	Median	0.099	6.601	–	Discrete	See Appendix C.3.5
Fraction of Laundry Products Containing HHCB	$F_{formulation\_HHCB}$	unitless	1.000	Maximum	0.111	1.000	–	Discrete	See Appendix C.3.7
Loss Fraction from Small Container Residue (liquid)	$LF_{RS1\_small\_container\_liquid}$	kg remaining/kg shipped	0.003	Mode	0.0003	0.006	0.003	Triangular	See Appendix C.1
Loss Fraction from Drum Residue (liquid)	$LF_{RS1\_drum\_liquid}$	kg remaining/kg shipped	0.025	Mode	0.0170	0.030	0.025	Triangular	See Appendix C.1
Loss Fraction from Transfer Operations (solid)	LF_{RS4}	kg remaining/kg shipped	0.005	Mode	0.001	0.030	0.005	Triangular	See Appendix C.1
Industrial Product Liquid and Solid Container Volume	$V_{ind\_prod\_liquid\_solid}$	gal / container	10	Median	1	55	10	Triangular	See Appendix C.3.6
Institutional Product Liquid and Solid Container Volume	$V_{inst\_prod\_liquid\_solid}$	gal / container	5	Median	1	5	5	Triangular	See Appendix C.3.6
Laundry Product Density (default)	$p_{product}$ (default)	kg product/m3	1,000	Default	–	–	–	Discrete	See Appendix C.3.4
Mass Fraction of HHCB in Solid Softeners	$F_{HHCB\_prod\_soft\_solid}$	kg HHCB / kg product	0.01	Discrete	–	–	–	Discrete	See Appendix C.3.4
Industrial Maximum Number of Sites	$N_{sites\_max\_ind}$	sites	4,338	Maximum	–	–	–	Discrete	See Appendix C.3.8
Institutional Maximum Number of Sites	$N_{sites\_max\_inst}$	sites	108,197	Maximum	–	–	–	Discrete	See Appendix C.3.8

C.3.3 Operating Days

EPA modeled the operating days per year using a triangular distribution with a lower bound of 20 days per year, an upper bound of 365 days per year, and a mode of 260 days per year for industrial laundries. The Agency used a triangular distribution with a lower bound of 250 days per, an upper bound of 365 days per year, and a mode of 260 days per year for institutional laundries. This is based on the ESD on the Chemicals Used in Water Based Washing Operations at Industrial and Institutional Laundries (OECD, 2011). The ESD provides the range and average of operating days for six separate years, which EPA took the minimum, maximum, and average of the 6 years to form the distributions.

C.3.4 Mass Fraction of HHCB in Laundry Detergent and Softener

EPA used the mass fraction of HHCB in the laundry products which had available weight concentration information. There were no commercial products with weight concentration information for laundry detergent and one industrial/institutional product for fabric softeners. EPA used the concentration information from consumer laundry detergents to inform both liquid and solid detergents. EPA assumed a concentration of 0.01 for solid softeners as no solid softener data was available, but this is the concentration in a fabric softener dryer sheet. Equal probability was given to each discrete value.

Table_Apx C-9. HHCB-Containing Laundry Products

Consumer or Industrial/ Institutional	Product Name	Physical Form	Product Concentration (kg/kg)		Product Density (kg/m^3)	Container Size (gal)
			Low-End	High-End		
Consumer	OxiClean Preserve Liquid Laundry Detergent	Liquid	0.001	0.001	1,000.0	0.785
Consumer	Arm & Hammer™ Deep Clean Stain Power Paks	Liquid	0.0001	0.009	999.974	0.232
Consumer	Arm & Hammer™ Deep Clean Odor Unit Dose Laundry Detergent Paks	Liquid	0.0006	0.001	999.974	0.797
Consumer	Arm & Hammer™ Deep Clean Odor Power Paks	Liquid	0.0006	0.001	1000.0	0.232
Consumer	Arm & Hammer™ Plus OxiClean™ Stain Fighters 3 in 1 Power Paks - Odor Blasters	Liquid and solid compartment	0.0004	0.0007	999.974	0.254, 1.3
Industrial/ Institutional	Clothesline Fresh Fabric Softener	Liquid	0.001	0.001	990	1, 5, 15, and 55
Commercial	Arm & Hammer™ Powder Laundry Detergent – Crisp Clean	Powder	Unknown	Unknown	590-700	≈3.08–3.65

C.3.5 Daily Use Rate of Detergent and Softeners

EPA modeled the daily use rate of detergent and softeners using a discrete distribution. For industrial laundries, the distribution ranged from 0.116 kg/day to 814 kg/day for liquid detergents and 1.33 kg/day to 1917.44 kg/day for powder detergents. For softener use in industrial laundries, the distribution ranged from 0.239 kg/day to 23.055 kg/day for liquid softeners and 0.181 kg/day to 11.655 kg/day for solid softeners. For institutional laundries, the distribution ranged from 0.124 kg/day to 513 kg/day for liquid detergents and 3.71 kg/day to 15 kg/day for powder detergents. For softener use in institutional laundries, the distribution ranged from 0.742 kg/day to 28.711 kg/day for liquid softeners and 0.099 kg/day to 6.601 kg/day for solid softeners. This discrete data was pulled from survey data from laundries sites used in the ESD on the Chemicals Used in Water Based Washing Operations at Industrial and Institutional Laundries (OECD, 2011). Equal probability was given to each discrete survey value.

C.3.6 Container Size

For industrial products, EPA modeled container size using a triangular distribution with a lower bound of 1 gallon, an upper bound of 55 gallons, and a mode of 10 gallons for industrial laundries. This matches with the container volume identified for the industrial/ institutional products.

For institutional laundries, EPA modeled container size using a triangular distribution with a lower bound of 1 gallon, an upper bound of 5 gallons, and a mode of 5 gallons for institutional laundries. This is based on the ESD on the default value for institutional laundries from the Chemicals Used in Water Based Washing Operations at Industrial and Institutional Laundries ESD (OECD, 2011).

C.3.7 Fraction of Laundry Detergents Containing HHCB

EPA applied a factor using the fraction of laundry detergent containing a chemical of interest, as not all laundry products at a facility may not all contain HHCB. EPA used the distribution from data on the use of products containing 1,4-dioxane as a surrogate for the fraction of laundry products containing HHCB using a discrete distribution. For industrial and institutional laundries, the distribution ranged from 0.111 to 1 kg detergents containing HHCB/kg all detergents. This discrete data was pulled from survey data from laundries sites used in the ESD on the Chemicals Used in Water Based Washing Operations at Industrial and Institutional Laundries (OECD, 2011). Equal probability was given to each discrete survey value.

C.3.8 Number of Sites

EPA did not find data on the number of laundry sites that specifically use detergents and softeners containing HHCB. During the modeling, a bounding estimate for the number of industrial laundries was used for U.S. Census and BLS data for the NAICS code 812330, Linen and Uniform Supply, to estimate a total of 2,453 industrial laundry sites within the industry (U.S. BLS, 2016). As a bounding estimate for the number of institutional sites, EPA used industry information as described in the ESD to estimate a total of 95,533 institutional laundries (OECD, 2011).

C.4 Dish Soap and Dishwasher Detergent Modeling Approach and Parameters for Estimating Environmental Releases

This approach utilizes data from a public comment (P&G, 2023) and standard EPA models combined with Monte Carlo simulation (a type of stochastic simulation).

Environmental releases of dish soap and dishwasher detergent are a function of the chemical's physical properties, daily throughput of soap/detergent, container size, mass fractions, and other model parameters.

C.4.1 Model Equations

Facility annual throughput is calculated using the equations below, the first being for dish soap and the second being for dishwasher detergent:

Equation_Apx C-12.

$$Q_{soap\_yr} = Q_{soap\_day} * OD$$

or

$$Q_{detergent\_yr} = Q_{detergent\_day} * OD$$

Where:

Q_{soap_yr}	=	Annual use rate of dish soap (kg/site-yr)
$Q_{detergent\_yr}$	=	Annual use rate of dishwasher detergent (kg/site-yr)
Q_{soap_day}	=	Daily use rate of dish soap (kg/site-day)
$Q_{detergent\_day}$	=	Daily use rate of dishwasher detergent (kg/site-day)
OD	=	Operating days (days/yr)

Daily use rate of 1,4-dioxane is calculated using the equations below, the first being for dish soap and the second being for dishwasher detergent:

Equation_Apx C-13.

$$Q_{HHCB\_day} = Q_{soap\_day} * F_{HHCB\_soap}$$

or

$$Q_{HHCB\_day} = Q_{detergent\_day} * F_{HHCB\_detergent}$$

Where:

$Q_{dioxane\_day}$	=	Daily use rate of HHCB (kg/site-day)
Q_{soap_day}	=	Daily use rate of dish soap (kg/site-day)
$Q_{detergent\_day}$	=	Daily use rate of dishwasher detergent (kg/site-day)
$F_{dioxane\_soap}$	=	Mass fraction of HHCB in dish soap (kg/kg)
$F_{dioxane\_detergent}$	=	Mass fraction of HHCB in dishwasher detergent (kg/kg)

Annual use rate of HHCB is calculated using the equation below:

Equation_Apx C-14.

$$Q_{HHCB\_yr} = Q_{HHCB\_day} * OD$$

Where:

$Q_{dioxane\_yr}$	=	Annual use rate of HHCB (kg/site-yr)
$Q_{dioxane\_day}$	=	Daily use rate of HHCB (kg/site-day)
OD	=	Operating days (days/yr)

Number of containers unloaded per year is calculated using the equation below:

Equation_Apx C-15.

$$N_{cont\_unload\_yr} = \frac{Q_{soap/detergent\_yr}}{V_{cont} * 0.00378541 \frac{m^3}{gal} * RHO}$$

Where:

$N_{cont\_unload\_yr}$	=	Number of containers unloaded per site per year (containers/site-year)
Q_{soap_yr}	=	Annual use rate of dish soap (kg/site-yr)
$Q_{detergent\_yr}$	=	Annual use rate of dishwasher detergent (kg/site-yr)
V_{cont}	=	Container volume (gal/container)
RHO	=	Dish soap/detergent density (kg/m^3)

Number of containers unloaded per day is calculated using the equation below:

Equation_Apx C-16.

$$N_{cont\_unload\_day} = \frac{N_{cont\_unload\_yr}}{OD}$$

Where:

$N_{cont\_unload\_day}$	=	Number of containers unloaded per site per day (containers/site-day)
$N_{cont\_unload\_yr}$	=	Number of containers unloaded per site per year (containers/site-year)
OD	=	Operating days (days/yr)

Daily operating hours for unloading containers is calculated using the equation below:

Equation_Apx C-17.

$$OH_{unload\_cont} = \frac{N_{cont\_unload\_yr}}{OD * RATE_{unload}}$$

Where:

OH_{unload_cont}	=	Daily operating hours for unloading containers (hours/day)
$N_{cont\_unload\_yr}$	=	Number of containers unloaded per site per year (containers/site-year)
OD	=	Operating days (days/yr)
$RATE_{unload}$	=	Container unloading rate (containers/hour)

Release Point 1 daily release per site (fugitive emissions during unloading) is calculated using the EPA/OAQPS AP-42 Loading Model equation below:

Equation_Apx C-18.

$$Release\_perDay_{RP1} =$$

If $N_{cont\_unload\_yr} < OD$:

$$Release\_perDay_{RP2} = V_{cont} * 0.00378541 \frac{L}{gal} * RHO * F_{HHCB\_soap/detergent} * LF_{cont}$$

If $N_{cont\_unload\_yr}$ >=OD:

$$Release\_perDay_{RP2} = Q_{dioxane\_day} * LF_{cont}$$

Where:

$Release\_perDay_{RP2}$	=	Daily HHCB release at release point 2(kg/site-day)
V_{cont}	=	Container volume (gal/container)
RHO	=	Dish soap/detergent density (kg/L)
$F_{dioxane\_soap}$	=	Mass fraction of HHCB in dish soap (kg/kg)
$F_{dioxane\_detergent}$	=	Mass fraction of HHCB in dishwasher detergent (kg/kg)
LF_{cont}	=	Container residual fraction (kg/kg)
$Q_{dioxane\_day}$	=	Daily use rate of HHCB (kg/site-day)

Release Point 3 daily release per site (fugitive emissions from washing) is calculated using the EPA/OPPT Penetration Model equations below (air speed ≤ 100 ft/min), the first being for dish soap and the second being for dishwasher detergent:

Equation_Apx C-19.

$$Release\_perDay_{RP4} = Q_{HHCB\_day} - \sum_{i=1}^{3} Release\_perDay_{RPi}$$

Where:

$Release\_perDay_{RP4}$	=	Daily HHCB release at release point 4 (kg/site-day)
$Q_{dioxane\_day}$	=	Daily use rate of HHCB (kg/site-day)
$\sum_{i=1}^{3} Release\_perDay_{RPi}$	=	The sum of release points 1–3 emissions (kg/site-day)

C.4.2 Model Input Parameters

Table_Apx C-10 summarizes the model parameters and their values for the Monte Carlo simulation. Additional explanations of EPA's selection of the distributions for each parameter are provided after this table. High-end and central tendency releases are estimated by selecting the 50th and 95th percentile values from the output distribution.

4607 **Table_Apx C-10. Summary of Parameter Values and Distributions Used in the Industrial and Commercial Use of Dish Soap and**
4608 **Dishwasher Detergent Release Model**

Input Parameter	Symbol	Unit	Deterministic Values		Uncertainty Analysis Distribution Parameters			Distribution Type	Notes/ Comments
			Value	Basis	Lower Bound	Upper Bound	Mode		
Production Volume of HHCB	PV	kg HHCB/yr	85,729	Default	85,729	857,290	–	Uniform	Note: Model runs include this PV, but PV estimates were updated.
Daily Use Rate of Dish Soaps	$Q_{soaps\_site\_day}$	kg product / site-day	3.0	Default	3.0	7.2	–	Uniform	See Appendix C.4.3
Daily Use Rate of Liquid Dishwasher Detergents	$Q_{liquid\_detergent\_site\_day}$	kg product / site-day	3.2	Default	3.2	6.4	–	Uniform	See Appendix C.4.4
Daily Use Rate of Solid Dishwasher Detergents	$Q_{solid\_detergent\_site\_day}$	kg product / site-day	0.120	Default	0.120	0.384	–	Uniform	See Appendix C.4.4
HHCB Mass Fraction in Dishwashing Product	F_{HHCB_prod}	kg HHCB/kg product	0.001	Discrete	–	–	–	Discrete	See Appendix C.4.5
Dishwashing Product Container Volume	V_{cont}	gal/container	1	Discrete	–	–	–	Discrete	See Appendix C.4.6
Operating Days	OP_{days}	days/yr	350	Discrete	–	–	–	Discrete	See Appendix C.4.7
Loss Fraction from Container Residue (liquid)	LF_{RS2_liquid}	kg remaining/kg shipped	0.003	Mode	0.0003	0.006	0.003	Triangular	See Appendix C.1
Loss Fraction from Solid Transfer Operations	LF_{RS3_solid}	kg remaining/kg shipped	0.005	Median	0.0010	0.030	0.005	Triangular	See Appendix C.1

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C.4.3 Facility Daily Throughput – Dish Soap

EPA did not identify chemical-specific or industry-specific information for this parameter from systematic review; therefore, EPA used generic data from the Consumer Exposure Model (CEM). For dish soap, the CEM cites a use rate of 75 to 125 g per use of dish soap, with a use duration of 5 to 20 minutes. EPA scaled up these consumer use rates from the CEM by assuming an 8-hour shift duration for occupational settings. Based on this, the facility daily throughput used a uniform distribution with a lower bound of 3 kg/site-day and an upper bound of 7.2 kg/site-day.

C.4.4 Facility Daily Throughput – Dishwasher Detergent

EPA did not identify chemical-specific or industry-specific information for this parameter from systematic review; therefore, the Agency used generic data from the CEM. For dishwasher detergent, the CEM cites a use rate of 20 to 40 g of detergent per cycle. A public comment for 1,4-Dioxane indicated that there are up to 160 cycles run per day at commercial dishwashing locations (P&G, 2023). Therefore, EPA scaled up the consumer values from the CEM for an occupational setting by multiplying 20 to 40 grams by 160 cycles/day. Based on this, EPA modeled facility daily throughput using a uniform distribution with a lower bound of 3.2 kg/site-day and an upper bound of 6.4 kg/site-day.

C.4.5 Concentration of HHCB in Dishwasher Detergent and Dish Soap

EPA did not identify concentration data for commercial dishwashing products and used concentration data for a consumer product for hand dish soap (INEOS Next Gen 2 in 1 Dish + Hand Pink Grapefruit + Tangelo) with an HHCB mass fraction of 0.001 kg HHCB/kg dishwashing soap.

C.4.6 Container Size

The HHCB-containing product container size was 0.132 gallons; however, EPA expects that this may underestimate the container sizes for commercial use. A public comment submitted for 1,4-Dioxane indicated that liquid dish soap and detergent are commonly packaged in 1- and 5-gallon containers, with 1-gallon containers the most common size (P&G, 2023). EPA used 1-gallon as the container size.

C.4.7 Operating Days

EPA did not identify chemical-specific information for this parameter from systematic review. The Agency could not develop a distribution of values for this parameter and assumed operation occurs 7 days/week, 50 weeks/year, for a total of 350 days/year.

Appendix D AMBIENT AIR MONITORING DATA

No monitoring data for HHCB in outdoor air was identified through database searching, however some peer-reviewed studies have evaluated the presence of HHCB in outdoor air. Peck and Hornbuckle (2004) and McDonough et al. (2016) collected air samples from around the Great Lakes and found outdoor air concentrations to be present in low concentrations. Specifically, airborne concentrations of HHCB were 4.6 ng/m^3 in Milwaukee, Wisconsin, and 1.1 ng/m^3 over Lake Michigan (Peck and Hornbuckle, 2004). These data are based on high-volume air samples collected during intervals ranging from every 4 hours to every 24 hours depending on location of sample collection. The source of HHCB in these areas is likely due to volatilization from surface water and will rapidly degrade once in the atmosphere. Furthermore, HHCB is more likely to partition to sediments from water than to air (see Figure 2-2). As such, HHCB is not expected to be readily found in ambient air across the landscape but in some locations may be present in low concentrations.

Volatilization of HHCB from surface waters is suspected but monitoring data are limited. In the Great Lakes, atmospheric concentrations of HHCB are highest in urban areas (McDonough et al., 2016; Peck and Hornbuckle, 2006). Volatilization fluxes ranged from 11 ± 6 to 346 ± 127 ng/m^2/day (McDonough et al., 2016) from water to air. Variation in these fluxes could be attributed to many environmental factors like humidity, wind speed, or temperature but were not noted in the study. In a series of die aways tests, Schaefer (2005) determined that up to 16% could be volatilized after 28 days and identified an overall half-life of 100 hours in a simulated system. Collectively, these studies show volatilization from surface water is a relevant mechanism for HHCB but may not lead to high concentrations of HHCB in the atmosphere due to rapid degradation. This conclusion is supported by the Henry's Law constant (1.06×10^{-4} atm-m^3/mol) suggesting low but possible volatilization and data on photolysis in air.

Appendix E GROUNDWATER MONITORING DATA

Monitoring data available through the water quality portal (WQP[8]) indicate HHCB has been detected in groundwater (see *Supplemental File – Water Quality Portal Results*). Several entries for groundwater concentrations of HHCB were detected above the method detection limit (or MDL) ranging from 0.056 to 4.0 µg/L (mean: 0.48 µg/L). These samples account for 1% (or 31 detections out of 3,080 sampling events) across the United States. These samples were collected in Colorado, Ohio, Oregon, Idaho, Florida, Iowa, Minnesota, New York, and North Carolina. It is unclear how HHCB contaminates groundwater as it preferentially binds to soils and has low water solubility, but its presence suggests that some leaching may occur post land application of biosolids. As previously noted, biosolids are not well monitored or regulated and this creates uncertainty. However, HHCB is unlikely to migrate from the site of its application sources.

[8] https://www.waterqualitydata.us/ (accessed March 17, 2026)

Appendix F DEVELOPING POTW DISTRIBUTIONS FOR DOWN THE DRAIN MODELING

EPA utilized data reported via the 2022 Clean Watersheds Needs Survey (CWNS) (U.S. EPA, 2025a) to develop a distribution of release conditions for down-the-drain loading to POTWs. The CWNS database includes current and projected population counts for the numbers of residents and non-residents contributing wastewater to the POTW, as well as NPDES permit details. For a given POTW, the concentration of HHCB in the receiving water body can be estimated as a function of the loading from the POTW effluent and the flow within the receiving water body, similar to other point-source releases.

POTW Effluent Loading

HHCB down-the-drain loading estimates presented in Section 4 are based a per capita loading rate to the POTW. Multiplying these per capita loading estimates by the contributing population counts produces an estimate of influent loading amount per day. Applying a wastewater treatment removal efficiency to this influent loading then produces an estimate of effluent loading per day. Total population contributing estimates were calculated by summing the residential and non-residential population counts reported for each POTW in the 2022 CWNS.

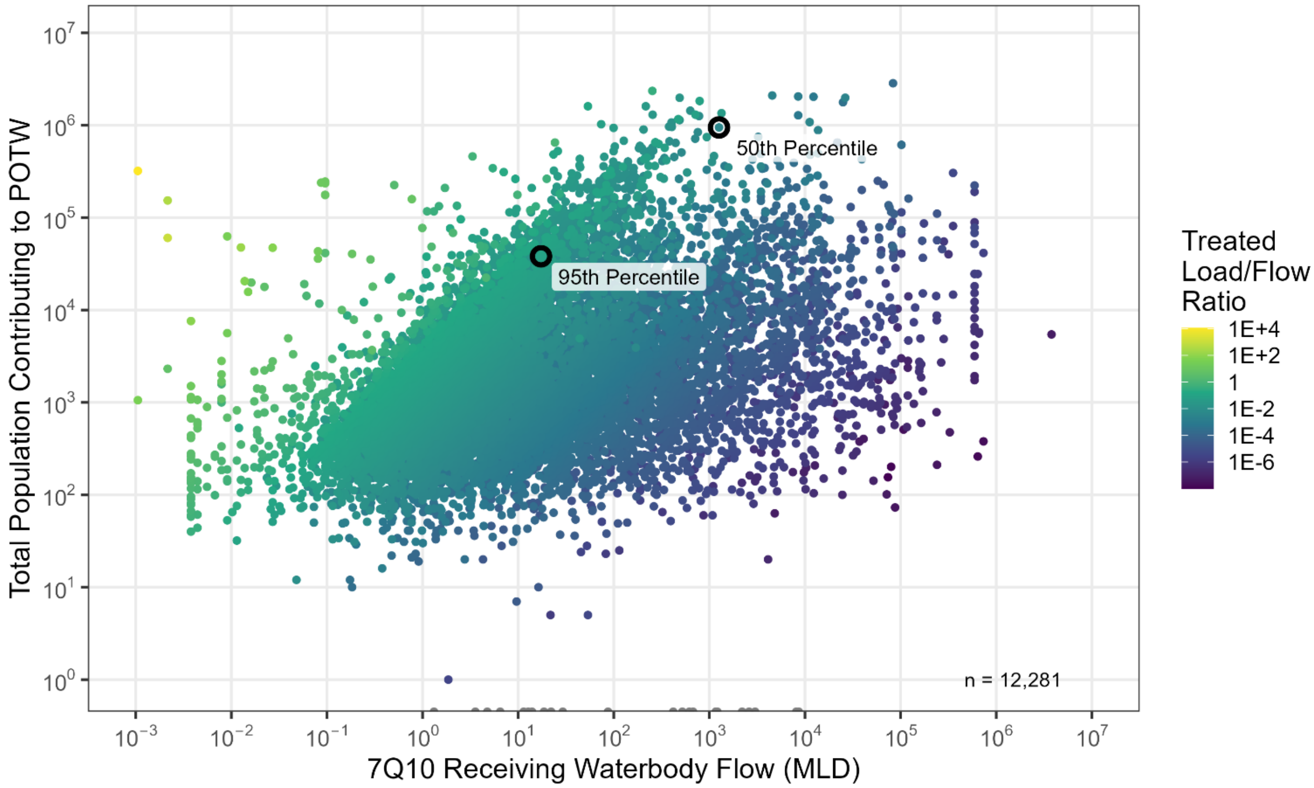
POTW Receiving Water Body Flow

As with the industrial releases, receiving water body flow data were collected using the method described in Section 4.2.2. NPDES permit information was used to identify the receiving water body reach code, and flow statistics were retrieved from the National Hydrography Dataset Plus (NHDPlus) V2.1.

Processing POTW Data

In processing the bulk 2022 CWNS data for this analysis, 12,796 of the reported 17,544 POTWs in the US were found to have total contributing populations reported as greater than zero, readily available receiving water body data from an automated permit lookup, and discharges to a freshwater water body within the NHDPlus V2.1 database. Facilities without successful reach code lookups may be due to the facilities discharging to lentic or coastal water bodies and were not included in this distribution.

As the total POTW loading estimates in the down-the-drain analysis are based on a linear relationship with the size of the population served by the POTW, the total contributing population can be viewed as a proxy for down-the-drain loading. For a given target flow statistic, the expected relative receiving water body concentration for each POTW analyzed (*i.e.*, the order of which release concentration will be higher or lower) can be calculated by sorting the dataset by the value of population divided by the receiving water body flow rate. An additional adjustment to reflect the reported level of treatment was included. For POTWs reporting only "primary" treatment, a 50% HHCB removal was assumed; for "secondary," a 92% HHCB removal was assumed; and for "advanced," a 99% removal was assumed. These removal rates are supported by data discussed in Sections 2.4.6 and 3.3.5. As this analysis focused on the environmental hazard endpoints, the 7Q10 flow statistic was used to normalize and sort the available POTW data to generate an ordered distribution of POTW-combined down-the-drain release conditions (Section 4.2.2). From this distribution, representative percentiles (based on the calculated population/flow ratio) were selected to contextualize the down-the-drain releases. These selected POTW characteristics representing the 95th percentile (P95) and 50th percentile (P50) were then applied to assess a realistic distribution of POTW scenarios for the down-the-drain analyses presented in Section 4.3.1.2. The distribution of the full POTW dataset used to produce these scenarios is visualized in Figure_Apx F-1.



Figure_Apx F-1. Scatterplot of POTW Population and 7Q10 Receiving Water Body Flow Derived from the CWNS, Used to Develop Representative Percentiles of POTW Release Conditions

Appendix G FOOD WEB MODELING ESTIMATES USING KABAM

EPA used the K_{OW} (based) Aquatic Bioaccumulation Model (KABAM version 1.0 (U.S. EPA, 2009)) to estimate potential HHCB bioaccumulation in a freshwater ecosystem and estimate risk to mammals. KABAM was used as a refinement of the screening assessment in Section 4 that used BCF=1,584 L/kg to estimate HHCB in fish tissues using estimated HHCB water concentrations. KABAM relies on the octanol-water partition coefficient (K_{OW}) of a chemical to estimate the uptake and elimination constants through respiration and diet of organisms in different trophic levels. The bioaccumulation portion of KABAM is based upon work by Arnot and Gobas (2004). HHCB tissue residues were calculated for different levels of an aquatic food web. The model then used HHCB tissue concentrations in aquatic animals to estimate dose- and dietary-based exposures and risk to mammals that consume aquatic organisms. Risk of HHCB to birds via dietary ingestion was not estimated because no evidence of HHCB dietary hazard to birds was reasonably available. The results provide additional lines of evidence for the potential dietary HHCB risk estimates to wild mammal populations and for risk estimates to humans via fish ingestion.

EPA used the default settings as outlined in the KABAM version 1.0 User's Manual (U.S. EPA, 2009) for all inputs except for the required chemical-specific user inputs (Table_Apx G-1), a typical dissolved organic carbon (DOC) concentration near wastewater treatment outflows (DOC = 30 mg/L; (Liu et al., 2022)), and the calculated metabolic rate constants that were derived from an OECD study of bluegill. EPA used the highest modeled surface water concentrations from the combined down-the-drain P95 POTW scenario with 92% wastewater treatment removal of 25.4 µg/L. Since no evidence of dietary hazard of HHCB to wild mammal populations was reasonably available, EPA extrapolated a wild mammal hazard threshold of 35 mg/kg-bw from a laboratory study of the dietary effects on laboratory rat reproduction (U.S. EPA, 2026i; IFF, 2021). BCF additional inputs reflect the supporting evidence of HHCB metabolic transformation in fish (Table_Apx G-2) Van Dijk (1996).

Table_Apx G-1. Properties of HHCB and Water Column and Pore Water HHCB Concentrations

Characteristic	Value
Log K_{OW}	5.9
K_{OW}	794,328
K_{OC} (L/kg OC)	70,800
Time to steady state (T_S; days)	219
Pore water EEC (µg/L)	24.9
Water column EEC (µg/L)	25.5

Van Dijk (1996) and Schneider et al. (2021) provide evidence of measurable metabolic transformation of HHCB in bluegill. HHCB elimination rate parameters k_T and k_2 in Equation 1 obtained from Van Dijk (1996), while k_E and k_G were derived using the KABAM model (U.S. EPA, 2009).

Equation_Apx G-1.

$$k_M = k_T - k_2 - k_E - k_G$$

Where:

k_M = Metabolic rate constant (d^{-1})
k_T = 0.748 (total bluegill elimination rate constant estimated from Van Dijk (1996))
k_2 = 0.261 (bluegill elimination rate of HHCB through respiration from

Van Dijk (1996))

k_E = 5.89×10^{-3} (bluegill elimination rate of HHCB through ingestion calculated by KABAM)

k_G = 6.08×10^{-3} (bluegill growth rate constant calculated by KABAM)

Thus, $k_M = 0.475\ d^{-1}$ represents the HHCB metabolic rate constant for bluegill.

The Agency used this k_M for the medium fish size group in KABAM because bluegill wet weights are most like the KABAM designation of 0.1 kg for medium-sized fish (*i.e.*, adult bluegill range from 50–200 g; OECD recommends 100 g fish).

EPA then scaled the bluegill k_M to the organisms in KABAM trophic levels using Kleiber's allometry scaling relationship (Foureman and Kenyon, 2006; Brown et al., 2004) and the equation below, to derive mass-specific metabolic rate constants for each trophic level (Table_Apx G-2).

Equation_Apx G-2.

$$k_M organism = k_M bluegill \times \left(\frac{M_{bluegill}}{M_{organism}}\right)^{0.25}$$

Where:

$k_M bluegill$ = 0.475/day

$M_{bluegill}$ = 0.1 kg (typical wet weight of bluegill)

$M_{organism}$ = Wet weight of typical organism at each trophic level (kg)

Table_Apx G-2 Typical Wet Weights of Animals at Each Trophic Level of the KABAM Model with Calculated Metabolic Rate Constants (kM) Using Allometric Scaling

Organisms at Each Trophic Level [a]	Typical Wet Weight (kg) [b]	k_M; Metabolic Rate Constant (d^{-1})
Zooplankton	1.0E−07	15
Benthic invertebrates	1.0E−05	2.67
Filter feeders	1.0E−03	1.5
Small fish	1.0E−02	0.844
Medium fish	0.1	0.475
Large fish	1.0	0.267

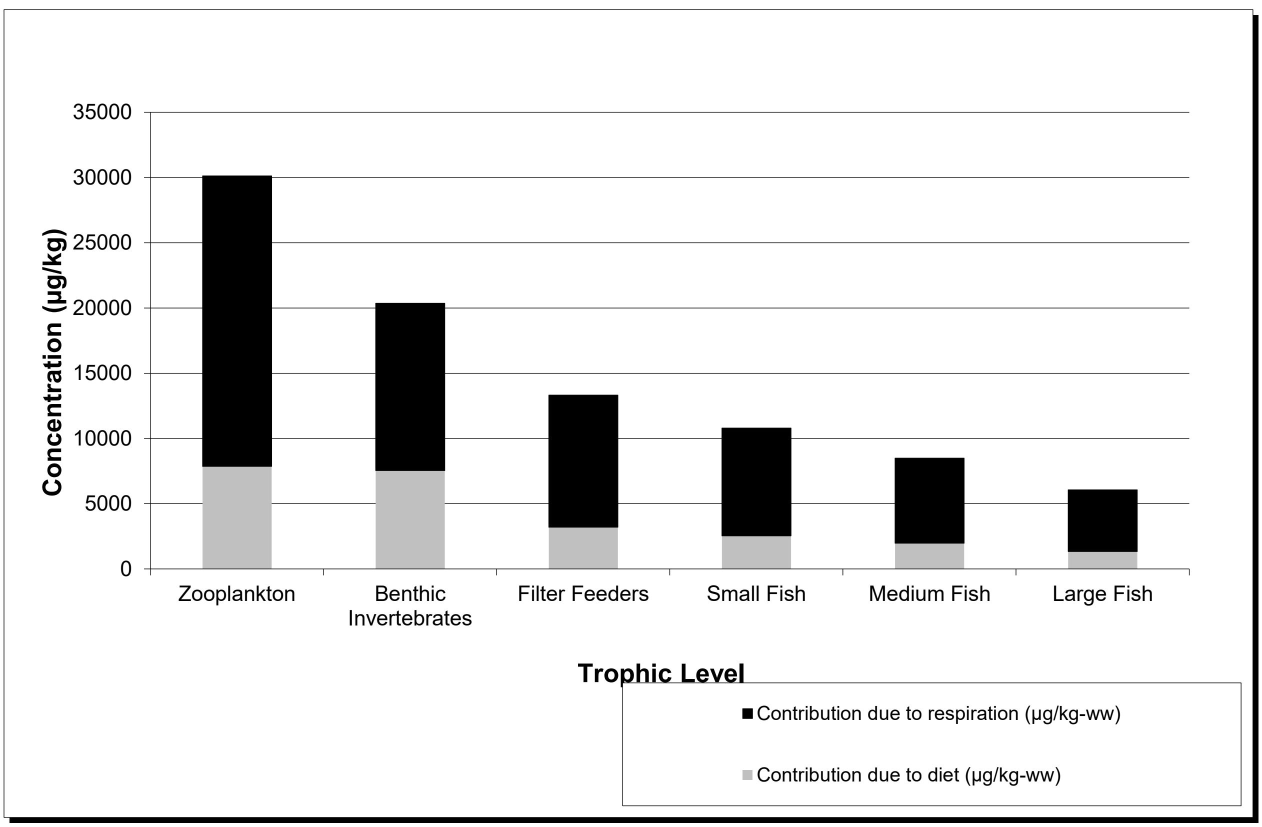
[a] Animals at trophic levels above phytoplankton
[b] Default wet weights used for each trophic level in KABAM

EPA estimated the HHCB in KABAM ecosystem components including the contributions due to respiration and diet (Table_Apx G-3), the estimated BCF and BAF values (Table_Apx G-4), expected environmental concentrations (EEC) (Table_Apx G-5), toxicity thresholds for different mammals (Table_Apx G-6), and risk quotient (RQ) estimates for different mammals using the upper bound water HHCB concentration from the P95 POTW scenario (Table_Apx G-7). Other water concentrations resulted in lower HHCB in fish concentrations as presented in Section 4 (Table 4-18).

Table_Apx G-3. Estimated Concentrations of HHCB in Ecosystem Components with 25.4 µg/L HHCB in Water

Ecosystem Component	Total Concentration (µg/kg-ww)	Contribution Due to Diet (µg/kg-ww)	Contribution Due to Respiration (µg/kg-ww)
Water (total) [a]	25	N/A	N/A
Water (freely dissolved) [a]	9	N/A	N/A
Sediment (pore water) [a]	25	N/A	N/A
Sediment (in solid) [b]	70,517	N/A	N/A
Phytoplankton	267,304	N/A	267,304
Zooplankton	30,339	7,899	22,440
Benthic Invertebrates	20,426	7,555	12,871
Filter Feeders	13,364	3,205	10,159
Small Fish	10,828	2,539	8,290
Medium Fish	8,530	1,962	6,567
Large Fish	6,112	1,345	4,767

[a] µg/L
[b] µg/kg-dw



Figure_Apx G-1. Total HHCB Concentration in Animals Using KABAM and 25.4 µg/L HHCB in Water

Table_Apx G-4. Total BCF and BAF Values of HHCB in Aquatic Trophic Levels with 25.4 µg/L HHCB in Water

Trophic Level	Total BCF (µg/kg-ww) / (µg/L)	Total BAF (µg/kg-ww) / (µg/L)
Phytoplankton	13,209	10,524
Zooplankton	9,412	1,194
Benthic Invertebrates	11,219	804
Filter Feeders	7,374	526
Small Fish	14,433	426
Medium Fish	14,433	336
Large Fish	13,223	241

Table_Apx G-5. Calculation of EECs for Mammals Consuming Fish Contaminated by HHCB with 25.4 µg/L HHCB in Water

Wildlife Species	Biological Parameters				EECs (HHCB Intake)	
	Body Weight (kg)	Dry Food Ingestion Rate (kg-dry food/ kg-bw/day)	Wet Food Ingestion Rate (kg-wet food/ kg-bw/day)	Drinking Water Intake (L/d)	Dose Based (mg/kg-bw/d)	Dietary Based (ppm)
Fog/water shrew	0.02	0.140	0.585	0.003	11.957	20.43
Rice rat/ star-nosed mole	0.1	0.107	0.484	0.011	7.226	14.93
Small mink	0.5	0.079	0.293	0.048	2.505	8.53
Large mink	1.8	0.062	0.229	0.168	1.957	8.53
Small river otter	5.0	0.052	0.191	0.421	1.632	8.53
Large river otter	15.0	0.042	0.157	1.133	0.962	6.11

Table_Apx G-6. Calculation of Toxicity Values for Mammals Consuming Fish Containing HHCB

Wildlife Species	Toxicity Values	
	Dose Based (mg/kg-bw)	Dietary Based (mg/kg-diet)
Fog/water shrew	73.50	700
Rice rat/star-nosed mole	49.86	700
Small mink	32.87	700
Large mink	23.24	700
Small river otter	18.00	700
Large river otter	13.68	700

Table_Apx G-7. Calculation of Risk Quotient (RQ) Values for Mammals Consuming Fish Containing HHCB with 25.4 µg/L HHCB in Water

Wildlife Species	Dose Based RQ	Dietary Based RQ
Fog/water shrew	0.163	0.029
Rice rat/star-nosed mole	0.145	0.021
Small mink	0.076	0.012
Large mink	0.084	0.012
Small river otter	0.091	0.012
Large river otter	0.070	0.009