Australian Government
Department of Health and Aged Care
Australian Industrial Chemicals Introduction Scheme

2-Ethylhexyl phosphates

Evaluation statement

26 June 2024

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AICIS evaluation statement

Subject of the evaluation

2-Ethylhexyl phosphates

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Phosphoric acid, 2-ethylhexyl diphenyl ester	1241-94-7
Phosphoric acid, octyl diphenyl ester	115-88-8

Reason for the evaluation

Evaluation Selection Analysis indicated a potential environmental risk.

Parameters of evaluation

This evaluation considers the environmental risks associated with the industrial uses of the organophosphate flame retardants and plasticisers tris(2-ethylhexyl) phosphate (TEHP, CAS RN 78-42-2), bis(2-ethylhexyl) phenyl phosphate (BEHPP, CAS RN 16368-97-1), 2-ethylhexyl diphenyl phosphate (EHDPP, CAS RN 1241-94-7), and octyl diphenyl phosphate (ODPP, CAS RN 115-88-8). These chemicals are listed on the Australian Inventory of Industrial Chemicals (the Inventory) and have been assessed for their risks to the environment according to the following parameters:

- default introduction volume of 100 t/year
- industrial uses listed in the ‘Summary of introduction, use and end use’ section
- expected emission to surface waters and soil due to consumer and commercial uses.

These chemicals have been assessed as a group as they are structurally similar and have similar use patterns.

The following acronyms have been used in this evaluation:

- TEHP (Phosphoric acid, tris(2-ethylhexyl) ester; CAS RN 78-42-2)
- BEHPP (Phosphoric acid, bis(2-ethylhexyl) phenyl ester; CAS RN 16368-97-1)
- EHDPP (Phosphoric acid, 2-ethylhexyl diphenyl ester; CAS RN 1241-94-7)
- ODPP (Phosphoric acid, octyl diphenyl ester; CAS RN 115-88-8).

Summary of evaluation

Summary of introduction, use and end use

Based on domestic and international use data, chemicals reported in this evaluation may be used as flame retardants, plasticisers, additives, or lubricating agents in the following products:

- plastics and polymers such as PVC, polyurethanes, rubber, cellulose-based materials and resins
- adhesives and sealant products
- paint and coating products
- lubricant and grease products
- fabric, textile and leather products
- construction products
- ink, toner, and colourant products
- paper products
- photographic products
- electronic devices
- agricultural products such as fertilisers (TEHP only).

No specific industrial use of the chemical BEHPP has been identified. Available data indicates that use of the chemical relates to introduction in commercial EHDPP.

There are no specific domestic introduction volume data available for TEHP, BEHPP, or ODPP. TEHP and EHDPP are used in high volumes (>1,000 tonnes/year) in Europe and/or the United States of America (USA). The total volume of EHDPP introduced into Australia, reported under previous mandatory and/or voluntary calls for information, was <100 tonnes per annum (NICNAS 2016). These chemicals are assumed to be used in Australia for similar applications to those reported internationally.

Environment

Summary of environmental hazard characteristics

Based on the information presented in this evaluation and according to the environmental hazard thresholds stated in the Australian Environmental Criteria for Persistent, Bioaccumulative and/or Toxic Chemicals (DCCEEW n.d.),

TEHP is:

- Persistent (P)
- Bioaccumulative (B)
- Not Toxic (Not T).

Chemicals EHDPP and ODPP are:

- Not Persistent (Not P)
- Bioaccumulative (B)
- Toxic (T).

The chemical BEHPP has been identified as a potentially PBT substance. This categorisation is based on conservative read across, as no hazard or degradation data are available for this chemical.

Environmental hazard classification

Chemicals TEHP, EHDPP, and ODPP satisfy the criteria for classification according to the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) for environmental hazards as follows (UNECE 2017). This does not consider classification of physical hazards and health hazards.

Chemicals EHDPP and ODPP are classified:

Environmental Hazard	Hazard Category	Hazard Statement
Hazardous to the aquatic environment (long-term)	Aquatic Chronic 1	H410: Very toxic to aquatic life with long lasting effects

The chemical TEHP is classified:

Environmental Hazard	Hazard Category	Hazard Statement
Hazardous to the aquatic environment (long-term)	Aquatic Chronic 4	H413: May cause long lasting harmful effects to aquatic life

Adequate information is not available for the chemical BEHPP, and so a classification has not been made.

Summary of environmental risk

Chemicals in this evaluation are used as flame retardants, plasticisers, and additives in a range of industrial and household products and articles. The main expected releases to the environment are release from articles due to their use as plasticisers and flame retardants or release from leakages due to their use in hydraulic fluids and lubricants. These releases are expected to affect surface waters, sediments, and soils, predominately in areas with high human or industrial activity.

The chemical TEHP is persistent in the environment. Chemicals, EHDPP and ODPP are not persistent in the environment. All chemicals are bioaccumulative and have the potential to biomagnify in some food webs. The chemical TEHP is not toxic. These chemicals EHDPP and ODPP are very toxic to aquatic life with long-lasting effects and may cause endocrine related effects in fish.

Based on concentrations measured in sewage treatment plant (STP) effluents, sediments, and soils internationally, TEHP is expected to be present in Australian surface waters, sediments, and soils at concentrations below levels of concern. As the calculated risk quotients (RQs) obtained for TEHP in these compartments are less than 1, the industrial use of TEHP in Australia is not expected to pose a significant risk to the environment.

Based on concentrations measured in STP effluents internationally and screening level calculations, EDHPP is expected to be present in Australian surface waters and sediments below levels of concern. As the calculated risk quotients (RQs) obtained for EHDPP in these

compartments are less than 1, the industrial use of EHDPP in Australia is not expected to pose a significant risk to the environment.

The environmental risk posed by EHDPP exposure in the soil compartment could not be determined due to a lack of ecotoxicity data for soil-dwelling organisms.

As ODPP is considered to be a synonym for EHDPP, the risk characterisation of EHDPP is considered to apply to ODPP.

The chemical BEHPP is conservatively characterised as persistent, bioaccumulative and toxic according to domestic PBT criteria, based on read across from the other chemicals in this group. PBT chemicals may become widely dispersed environmental contaminants, with potential for unpredictable adverse effects on environmental organisms. Therefore, PBT chemicals are considered to be highly hazardous to the environment. However, while BEHPP is expected to be present in some imported articles, based on available information it is unlikely that BEHPP is introduced into Australia for industrial use (except in commercial EHDPP). If information becomes available to indicate that environmental exposure is occurring in Australia from introduction and use of this chemical, a further evaluation of the risks would be required.

Proposed means for managing risk

Inventory listing

To manage the risks to the environment from the introduction and use of BEHPP, the Inventory listing for Phosphoric acid, bis(2-ethylhexyl) phenyl ester (CAS RN 16368-97-1) should be varied under *Section 86* of *the Industrial Chemicals (IC) Act 2019.*

Term of listing	Details
Specific requirements to provide information to the Executive Director under *Section 101* of the *IC Act*	Obligations to provide information apply. You must tell the Executive Director the volume of introduction, use and end use of the chemical within 20 working days if: • the chemical is being introduced for uses other than research and development.

Conclusions

The Executive Director is satisfied that the identified risks to the environment from the introduction and use of these chemicals can be managed.

However, the risk conclusions for BEHPP were driven by the limited expected introduction and use of BEHPP in Australia. Given that BEHPP is potentially persistent, bioaccumulative and toxic (PBT) it is important that the introduction and use of such a potentially highly hazardous chemical in Australia is known so that the risks can be appropriately managed. Therefore, a variation to the term of the listing for this chemical, to add a specific requirement to provide information, is necessary to manage the risks from introduction of the chemical (see **Proposed means of managing risk**).

Note:

1. Obligations to report additional information about hazards under *Section 100* of the *Industrial Chemicals Act 2019* apply.
2. You should be aware of your obligations under environmental, workplace health and safety and poisons legislation as adopted by the relevant state or territory

Supporting information

Grouping rationale

This evaluation considers the environmental risks associated with the industrial uses of organophosphate triesters of 2-ethylhexanol and phenol. The evaluation of these substances has been conducted as a group because they are structurally related, and are expected to have similar use patterns, primarily as flame retardants and plasticisers in plastic, rubber and resin products. Consequently, all chemicals are expected to have similar environmental exposure scenarios. Organophosphate flame retardants (OPFRs) were developed to replace other types of additive flame retardants, such as polybrominated diphenyl esters (PBDEs) (Cristale et al. 2013; Huang et al. 2020; Pakalin et al. 2007).

Tris(2-ethylhexyl) phosphate (TEHP) is a trialkyl phosphate, the triester of 2-ethylhexanol with phosphoric acid. Bis(2-ethylhexyl) phenyl phosphate (BEHPP) and 2-ethylhexyl diphenyl phosphate (EHDPP) are mixed alkyl aryl phosphates of 2-ethylhexanol and phenol. BEHPP and EHDPP are expected to have environmental hazards and physical and chemical properties that lie in between those of TEHP and triphenyl phosphate. The environmental risks of triphenyl phosphate have already been assessed (AICIS 2023).

The chemical EHDPP may have been referred to as octyl diphenyl phosphate (ODPP), with the CAS RN 115-88-8 (NICNAS 2016; UK EA 2009). The term "octyl" is often used to refer to the 2-ethylhexyl group. In the case of linear octyl groups, the prefix n- is normally used. While both CAS RNs are listed on the Australian Inventory of Industrial Chemicals (the Inventory), there is insufficient information to indicate that these represent two uniquely different chemicals. For this reason, any information available for EHDPP (CAS RN 1241-94-7) is assumed to apply to octyl diphenyl phosphate (CAS RN 115-88-8). Chemicals EHDPP and ODPP have been assessed for risks to human health under NICNAS (NICNAS 2016). However, their risks to the environment have not been assessed in Australia.

The evaluation selection analysis for chemicals in this group indicated a potential concern to the environment based on high international use volumes for TEHP and EHDPP, potential persistence characteristics for TEHP, and high ecotoxicity for EHDPP.

Chemical identity

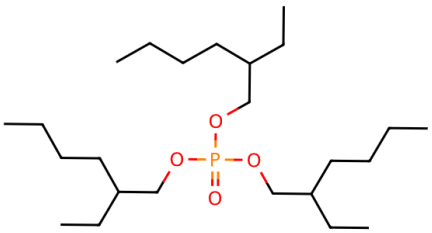
The chemical TEHP is an alkyl phosphate ester where the phosphorus atom is linked to three 2-ethylhexanol moieties. The chemical is produced from phosphorus oxychloride and 2-ethylhexanol (UNEP IPCS 2000). The chemical is composed of stereoisomers, as the 2-ethylhexyl chain is chiral, and the stereochemistry of the 2-ethylhexyl groups in the chemical is not specified.

Chemicals BEHPP and EHDPP are mixed alkyl aryl phosphates. In BEHPP, the phosphorus atom is linked to two 2-ethylhexanol and one phenol group, while in EHDPP, the phosphorus atom is linked to one 2-ethylhexanol and two phenol moieties. These chemicals BEHPP and EHDPP are also composed of stereoisomers.

The chemical EHDPP is manufactured by reaction of 2-ethylhexanol with phosphorus oxychloride to form 2-ethylhexyl phosphoryl dichloride, which is then reacted with sodium phenate (NCBI n.d.-b). Commercial samples of EHDPP are technical mixtures with reported

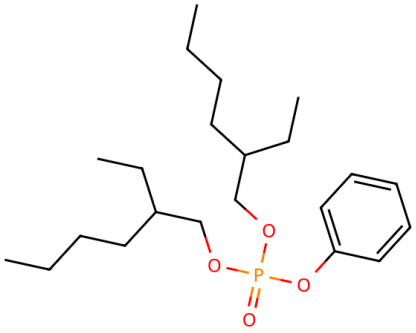
compositions of 90–94.5% EHDPP, 4.7% BEHPP, and 1.5–4% triphenyl phosphate (REACH n.d.-b; UK EA 2009).

The identity of chemicals reported in this evaluation is detailed below:

Chemical name	Phosphoric acid, tris(2-ethylhexyl) ester
CAS RN	78-42-2
Synonyms	Tris(2-ethylhexyl) phosphate (TEHP) Tri(2-ethylhexyl) phosphate Trioctyl phosphate
Molecular formula	C24H51O4P
Molecular weight (g/mol)	434.6
SMILES (canonical)	O=P(OCC(CC)CCCC)(OCC(CC)CCCC)OCC(CC)CCCC
Chemical description	-
Structural formula:	

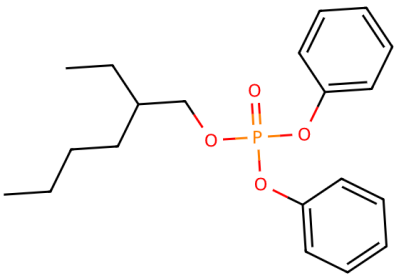
Chemical name	Phosphoric acid, bis(2-ethylhexyl) phenyl ester
CAS RN	16368-97-1
Synonyms	Bis(2-ethylhexyl) phenyl phosphate (BEHPP) Di(2-ethylhexyl)phenyl phosphate
Molecular formula	C22H39O4P
Molecular weight (g/mol)	398.5
SMILES (canonical)	O=P(OC=1C=CC=CC1)(OCC(CC)CCCC)OCC(CC)CCCC
Chemical description	-

Structural formula:



Chemical name	Phosphoric acid, 2-ethylhexyl diphenyl ester
CAS RN	1241-94-7
Synonyms	2-ethylhexyl diphenyl phosphate (EHDPP)
Molecular formula	C20H27O4P
Molecular weight (g/mol)	362.4
SMILES (canonical)	O=P(OC=1C=CC=CC1)(OC=2C=CC=CC2)OCC(CC)CCCC
Chemical description	-

Structural formula:



Chemical name	Phosphoric acid, octyl diphenyl ester
CAS RN	115-88-8
Synonyms	Octyl diphenyl phosphate (ODPP) Diphenyl octyl phosphate
Molecular formula	C20H27O4P
Molecular weight (g/mol)	362.4
SMILES (canonical)	-
Chemical description	Octyl diphenyl phosphate is assumed to refer to EHDPP. The term "octyl" is often used to refer to the 2-ethylhexyl group. In the case of linear octyl groups, the prefix, n-, is normally used.

Relevant physical and chemical properties

Measured physical and chemical properties for TEHP were obtained from the substance registration dossier for tris(2-ethylhexyl) phosphate submitted under the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) legislation in the European Union (REACH n.d.-a). Measured physical and chemical properties for EHDPP were obtained from the REACH dossier for 2-ethylhexyl diphenyl phosphate (REACH n.d.-b), from the relevant UK Environment Agency risk evaluation report (UK EA 2009), and from the relevant PubChem compound summary (NCBI n.d.-b). The Henry's law constants for TEHP and EHDPP were calculated from experimental vapour pressure and water solubility endpoints. Other calculated values were estimated using EPI Suite (US EPA 2017).

Chemical	TEHP	EHDPP
Physical form	liquid	liquid
Melting point	-74°C (exp.)	-60°C (exp.)
Boiling point	215°C (decomposition) (exp.)	375°C (decomposition) (exp.)
Vapour pressure	2.3×10^{-5} Pa (20°C, exp.)	3.4×10^{-4} Pa (20°C, exp., extrapolated from data at 150–250°C)
Water solubility	0.14 µg/L (20°C, exp.)	50.6 µg/L (23.5°C, exp.)
Henry's law constant	70 Pa·m^3/mol (calc.)	2.4 Pa·m^3/mol (calc.)
Ionisable in the environment?	No	No
log K_{ow}	9.06 (25°C, calc., adjusted from EHDPP)	5.87 (25°C, exp.)
log K_{oc}	2.5×10^6 L/kg (calc., MCI method)	3.2×10^4 L/kg (calc., MCI method)

Chemicals TEHP and EHDPP are very slightly to slightly volatile liquids. They are very slightly soluble in water. They are expected to be moderately volatile from water.

The physicochemical properties of BEHPP are expected to fall between the properties of TEHP and EHDPP listed in the table above.

A log K_{OW} value of 7.47 was estimated for BEHPP. The measured and calculated log K_{OW} values for chemicals reported in this evaluation indicate that these chemicals are very lipophilic. The calculation of the log K_{OW} values for TEHP and BEHPP were adjusted to the experimental log K_{OW} for EHDPP using the experimental value adjustment option in EPI Suite (US EPA 2017).

Introduction and use

Australia

No specific Australian introduction use and end use information has been identified for TEHP, BEHPP and ODPP.

For EHDPP, the following Australian industrial uses were reported under previous mandatory and/or voluntary calls for information. The chemical EHDPP has reported commercial use as a substance for softening materials to improve the feel, to facilitate finishing processes or to impart flexibility or workability. This includes use as a plasticiser and devulcanising agent. The total volume introduced into Australia, reported under previous mandatory and/or voluntary calls for information, was <100 tonnes per annum (NICNAS 2016).

Chemicals reported in this evaluation are expected to be introduced into Australia in imported articles. Release from articles is expected to contribute to environmental levels of these chemicals in Australia.

Chemicals TEHP and EHDPP have been detected in house dust and air in several Australian capital cities (He et al. 2018b; Huang et al. 2020), in car dust (Harrad et al. 2016), and in human urine (He et al. 2018a), confirming their presence in Australia.

International

Available information indicates that chemicals reported in this evaluation are used mainly as flame retardants, plasticisers, and lubricating agents in a range of products worldwide.

Chemicals TEHP and EHDPP are used as plasticisers and flame retardants in a wide range of polymers and rubbers (NCBI n.d.-a; n.d.-b; UK EA 2009; UNEP IPCS 2000; Valtris Specialty Chemicals n.d.). These polymers include:

- flexible polyvinyl chloride
- polyurethanes
- styrene butadiene rubber
- nitrile butadiene rubber
- cellulose nitrate
- cellulose acetate.

Chemicals TEHP and EHDPP have a variety of non-polymer end uses (NICNAS 2016; REACH n.d.-a; n.d.-b; UK EA 2009; US EPA n.d.). These end uses include:

- lubricants and greases, particularly hydraulic fluids and metal working fluids
- adhesives and sealants
- paint and coating products, including thinners and removers
- construction products
- ink, toner, and colourant products
- fabric, textile and leather products
- paper products
- photographic products.

In the USA and Europe, TEHP has a reported use as an adjuvant in agricultural products, both pesticidal (non-industrial use) and non-pesticidal (industrial use) (Nordic Council of Ministers n.d.; REACH n.d.-a; US EPA n.d.).

Chemicals TEHP, BEHPP and EHDPP may be present in articles made from plastic, rubber, fabric, and paper materials (Li et al. 2019b; REACH n.d.-a; UK EA 2009; US EPA n.d.; Valtris Specialty Chemicals n.d.; Zhang et al. 2019). These articles include:

- electronic devices
- wires and cables
- conveyor belts
- products made from hard or soft plastics
- furniture
- foam seating
- bedding products
- leather products
- photo films
- packaging, including food packaging.

Chemicals TEHP and EHDPP are each registered under REACH for use in the European Economic Area at 1,000–10,000 tonnes annually (ECHA 2020). The annual use volume for each of these chemicals was 453–9,072 tonnes in the USA in 2012–2019 (US EPA n.d.). Varying use volumes have been reported for TEHP and EHDPP in the Nordic European countries (Norway, Sweden, Finland, and Denmark). The use volumes range from < 0.1–8,489 tonnes per year per country from years 2000–2020 for TEHP (with typical volumes < 100 t), and < 0.1–282 tonnes per year per country from years 2000–2020 for EHDPP (Nordic Council of Ministers n.d.).

No specific industrial use of the chemical BEHPP has been identified. Reported introductions of BEHPP appear to be incidental to the introduction of other phosphate esters. The chemical is not registered under REACH for use in the European Economic Area. Additionally, each of the Nordic countries has reported comparatively low introduction volumes of < 0.5 tonnes per year (Nordic Council of Ministers n.d.). In the USA, reported information in the Chemical Data Reporting (CDR) data suggests that BEHPP introduction is related to the introduction of EHDPP (US EPA n.d.).

Existing Australian regulatory controls

Environment

The use of these chemicals in this group is not subject to any specific national environmental regulations.

International regulatory status

United Nations

Chemicals reported in this evaluation are not currently identified as persistent organic pollutants (POPs) (UNEP 2001), ozone depleting substances (UNEP 1987), or hazardous substances for the purpose of international trade (UNEP & FAO 1998).

OECD

Chemicals TEHP are EHDPP are listed as OECD High Production Volume (HPV) chemicals (OECD n.d.). The substances have not been sponsored for assessment yet.

Environmental exposure

Chemicals reported in this evaluation are expected to be released to the environment through diffuse emissions from imported articles and from point source emissions such as manufacturing plants, sewage treatment plants (STPs), e-waste recycling facilities and landfills.

Diffuse emissions from articles are expected to be a major source of releases to the environment for chemicals reported in this evaluation (OECD 2011). These chemicals occur in articles as additive flame retardants and plasticisers. They are not chemically bound to the polymer matrix in which they are blended. Emissions of these chemicals to the environment are expected from the migration of these chemicals onto the surface of rubber and plastic articles as well as from abrasion and wear of these articles during their normal use (Lassen 1999; Regnery and Püttmann 2010). These emissions may occur to air, water, and soil. Leaching of these chemicals may occur from plastic products and microplastics to the surrounding environment (Schmidt et al. 2021; van der Veen and de Boer 2012).

Emissions to air are expected to be in the form of dust particles, which are commonly detected in indoor settings such as houses and cars (Harrad et al. 2016; He et al. 2018b; Huang et al. 2020). Dust may reach the environment through ventilation, flushing of dust particles collected during wet cleaning and disposal of vacuum cleaner dust (Marklund et al. 2003), thus contributing to emissions of these chemicals to air, wastewaters, and soil. Diffuse emissions of these chemicals in this evaluation to the aquatic environment may also occur from laundering of treated fabrics.

Point emission sources of chemicals reported in this evaluation may include wastewater treatment plants, e-waste and paper recycling facilities, landfills, and contaminated biosolids. However, these chemicals may enter the environment from industrial activities such as the manufacture and recycling of plastic articles that contain these chemicals. These emissions may contribute to levels of the chemical in air, wastewaters, and soil nearby areas of manufacture, waste processing or recycling (Li et al. 2019b; Wang et al. 2018).

Depending on the degradation and partitioning processes in STPs, these chemicals in wastewater entering STPs may be emitted to the air compartment, to rivers or oceans in treated effluent, or to soil through application of biosolids to agricultural land (Struijs 1996).

Release of TEHP and EHDPP to air and soil may also occur through leakages and emissions of lubricants and hydraulic fluids from hydraulic machinery and aircraft (Li et al. 2019c).

Environmental fate

Partitioning

Chemicals in this group are expected to primarily partition to sediment and soil when released into the environment. They may also be present in air, where they will partially adsorb to particulate matter.

These chemicals are neutral organic chemicals with a very low water solubility. Estimated Henry's Law constants (9.3–70 Pa m^3/mol) indicate that these chemicals will be moderately volatile from water and moist soil. They are lipophilic chemicals (log K_{OW} = 5.87–9.06) with high estimated soil adsorption coefficients (log K_{OC} = 4.51–6.40) (US EPA 2017) that indicate they will be immobile in different types of soil and preferentially adsorb to phases in the environment with high organic carbon content (including sediment and soil).

In aquatic environments, chemicals in this group are expected to partition significantly to sediments. Releases to wastewater streams are treated at STPs, where these chemicals will preferentially partition to biosolids, releasing a minor proportion in effluent. Release to the soil compartment will likely occur through application of STP biosolids residues to land, through the use of agricultural products, or through the operation of hydraulic machinery. Releases to soil are expected to remain in soil.

If chemicals in this group undergo hydrolysis and lose an ethylhexyl or phenyl group, the corresponding phosphate diester degradants are expected to be chemicals with much higher water solubility and higher propensity to partition to or remain in the water compartment.

Degradation

Based on available evidence, chemicals EHDPP and ODPP are not expected to be persistent in the environment, but the chemical TEHP is expected to be persistent in water and soil. No data on the abiotic and biotic degradation of BEHPP in water, sediment, or soil are available. The chemical BEHPP is conservatively assumed to be persistent in these compartments based on the persistence of the related chemical TEHP.

Hydrolysis is not expected to be a significant degradation pathway for these chemicals in aqueous conditions. In a preliminary hydrolysis test the chemical TEHP was found to be hydrolytically stable in sterile aqueous solutions at 50°C at pH 4–9 (REACH n.d.-a). In another study, no degradation of TEHP was observed after 35 days at 20°C at pH 7 and pH 9 (Su et al. 2016). Based on these studies, TEHP is not expected to undergo abiotic hydrolysis in water under environmentally relevant conditions. The hydrolysis of EHDPP is slow in water at pH 4–7 (half-lives > 100 days). Half-lives > 41 days (25°C) and 130 days (20°C) were estimated at pH 9 (REACH n.d.-b; Su et al. 2016).

These chemicals may undergo photodegradation upon exposure to sunlight. Photolysis half-lives of 0.93–3.50 days were measured for TEHP at pH 4–9 (21°C) in an OECD TG 319 study (REACH n.d.-a). The degradation products 2-ethylhexanol and 2-ethylhexanoic acid were identified. Rapid photodegradation of EHDPP was observed in deionised or river water upon exposure to simulated or natural sunlight, with reported half-lives of approximately 2 hours. Photodegradation half-lives of 6–7 h were observed for TEHP in the same study, likely via indirect photolysis or photosensitisation. The simultaneous presence of nine

organophosphate esters in solution may have influenced the photodegradation processes observed in this study for TEHP and EHDPP (Cristale et al. 2017).

Biodegradation studies indicate that TEHP is not readily biodegradable in water. Ultimate degradation did not exceed 14% after 28 days in multiple OECD TG 301 ready biodegradability tests (REACH n.d.-a). Higher degradation rates have been observed for TEHP in inherent biodegradation and primary degradation tests. However, the reliability of these studies is uncertain. The degradation of TEHP at an initial concentration of 1 mg/L reached 32–73% in 14 to 15 days in river and seawater from the Osaka area, Japan, based on a colorimetric analysis of phosphate ion concentrations (Hattori et al. 1981; UNEP IPCS 2000). Approximately 45% primary degradation of TEHP was observed in an activated sludge test (Ishikawa et al. 1985). In another activated sludge test where TEHP was continuously added at a rate of 3 mg/L per 24-hour cycle, the equilibrium removal rate of TEHP was 20±8% after 34 weeks (Saeger et al. 1979).

The chemical EHDPP is readily biodegradable in water. The ultimate degradation of EHDPP reached 65–80% after 28 days in multiple OECD TG 301 ready biodegradability tests, as measured by CO_2 evolution or biological oxygen demand (REACH n.d.-b; UK EA 2009). The 10 day window was met in these tests.

The chemical EHDPP is not expected to be persistent in freshwater sediments. A primary degradation half-life of approximately 5 days was estimated for EHDPP in pond and river sediment from the Winnipeg area, USA. In aerobic conditions, the primary degradation reached 98% after 64 days at 20°C as measured using a ^{14}C-radiolabelled sample. The results suggested that the degradation of EHDPP was characterised by slow oxidation of the parent compound and rapid transformation of the resulting polar products (Muir et al. 1989; UK EA 2009). A study of the degradation of TEHP and EHDPP in coastal sediments suggests that these chemicals are not persistent in this compartment. Primary degradation half-lives of 47 and 34 days, respectively, were estimated for TEHP and EHDPP in biotic conditions in coastal sediment collected at the outlet of the Marseille STP, France (Castro-Jiménez et al. 2022). A significant decrease in TEHP concentrations was observed from raw STP biosolids to anaerobically digested biosolids, suggesting that anaerobic degradation of the chemical occurred during the digestion treatment (Castro et al. 2023).

The chemical TEHP is expected to be persistent in soils. A mean half-life of 769 days in soil at 12°C (436–1,620 days depending on the type of soil) was estimated by radiochemical measurement of a ^{14}C-labelled sample in an OECD TG 307 test (REACH n.d.-a).

The chemical EHDPP is not expected to be persistent in soils. A non-guideline soil degradation study with EHDPP using sandy loam and clay loam soils revealed primary degradation half-lives of 23–58 days (UK EA 2009).

These chemicals are expected to degrade in the atmosphere through reaction with photogenerated hydroxyl radicals in the gas phase. However, the rate of this degradation may be significantly reduced by the adsorption of these chemicals to particles in the air. Calculations performed assuming a typical hydroxyl radical concentration of 1.5×10^6 molecules/cm^3 and 12 hours of sunlight per day resulted in half-lives of 1.3 h for TEHP, 1.9 h for BEHPP and 3.2 h for EHDPP in the atmosphere in the gas phase (US EPA 2017). While EHDPP may be present in both the gas and particle phase in air, a major fraction of TEHP (87–100%) is expected to be sorbed to airborne particulates (Sühring et al. 2016b; US EPA 2017). When TEHP and EHDPP were deposited on $(NH_4)_2SO_4$ particles, their half-lives are estimated to increase to 1.9–4.6 days for TEHP and 4.5–11.0 days for EHDPP (Liu et al. 2019; Liu et al. 2014).

The primary degradants of TEHP, BEHPP, and EHDPP are expected to be the phosphate diesters bis(2-ethylhexyl) phosphate (CAS RN 298-07-7), diphenyl phosphate (CAS RN 838-85-7), and 2-ethylhexyl phenyl phosphate (CAS RN 20403-99-0). These phosphate diesters are not expected to be persistent in the environment. Bis(2-ethylhexyl) phosphate is readily biodegradable (REACH n.d.-c). Ready biodegradability data for triphenyl phosphate suggests that diphenyl phosphate is also readily biodegradable (AICIS 2023). The degradant 2-ethylhexyl phenyl phosphate is assumed to be readily biodegradable based on read across from bis(2-ethylhexyl) phosphate and diphenyl phosphate. 2-Ethylhexyl phenyl phosphate was detected in relatively high concentrations (0.168–2.12 µg/L) in influents at nine STPs in Europe (Been et al. 2017; Been et al. 2018). Chemicals TEHP, BEHPP, and EHDPP are also expected to be metabolised into other substances in some living organisms. For example, the hydroxylated product 2-ethyl-5-hydroxyhexyl diphenyl phosphate (5-OH-EHDPP) was identified as the major metabolite of EHDPP in zebrafish and medaka (Li et al. 2020; Yang et al. 2023a). Mono-hydroxylated metabolites of EHDPP were detected at 2.6–7.3 ng/L in European STP influents in the studies by Been et al. (Been et al. 2017; Been et al. 2018). The diester 2-ethylhexyl phenyl phosphate and the hydroxylated derivatives of EHDPP and BEHPP do not have reported industrial uses, so their presence in wastewaters is likely due to degradation or metabolism of EHDPP and BEHPP.

Bioaccumulation

Chemicals reported in this evaluation are bioaccumulative and have the potential to biomagnify in some food webs.

These chemicals are lipophilic compounds with high octanol-water partition coefficients. The log K_{OW} of 5.87–9.06 for these chemicals are above the domestic threshold for categorisation and indicate a potential to bioaccumulate in aquatic organisms.

Laboratory bioconcentration studies
Measured bioconcentration factors (BCFs) for the accumulation TEHP and EHDPP in fish through the respiring medium (water) are below the domestic threshold of 2,000 L/kg for categorisation. However, for very poorly soluble and highly hydrophobic chemicals such as TEHP and EHDPP, BCFs are not a reliable indicator of bioaccumulation due to the limited exposure and bioavailability throughout the water column. Dietary exposure is expected to be a more environmentally relevant exposure pathway.

The highest BCF values observed upon exposure of fish to TEHP were 149–528 L/kg ww for common carp (*Cyprinus carpio*) (OECD TG 305, kinetic BCF) (Bekele et al. 2018). For EHDPP, the highest bioconcentration from water was measured in bluegill fish (*Lepomis macrochirus*), with a BCF of 934±152 L/kg ww (ASTM test guideline, steady-state BCF) (REACH n.d.-b). A BCF of 854 L/kg ww for EHDPP was measured in the marine mussel *Mytilus galloprovincialis* (kinetic BCF) (Mata et al. 2022).

Field bioaccumulation studies
Field studies examined the bioaccumulation factors (BAFs) and biota-sediment accumulation factors (BSAFs) of TEHP and EHDPP in multiple aquatic organisms. In the field, aquatic organisms may be exposed to pollutants through diet as well as through the respiring medium. Both exposure pathways (aqueous and dietary) may contribute to the observed BAFs and BSAFs. A substance is considered bioaccumulative if it has a BAF > 2,000 (EPHC 2009). For BSAF endpoints, a domestic threshold is not available. The ECHA guidance on PBT and vPvB assessments advises that lipid- and organic carbon-normalised BSAF values of 0.5 and above are an indication of high bioaccumulation (ECHA 2023). Field studies have found a wide range of BAFs and BSAFs for TEHP and EHDPP, suggesting that the potential for these chemicals to bioaccumulate in aquatic organisms depends on the species and on

the environmental conditions. In some of the literature, field BAFs have been incorrectly reported as BCFs. These are correctly reported as BAFs below.

For TEHP, BAFs exceeding the 2,000 L/kg threshold have been reported in multiple studies. BAF values ranging from 2,138–155,000 L/kg based on wet weight (ww) concentrations in biota have been measured in marine and freshwater environments. The sampled organisms included phytoplankton, zooplankton, invertebrates (for example, crab, shrimp, oysters), coral, benthic fish, and pelagic fish. The sampling locations included the Bay of Marseille in the Mediterranean, the Pearl River estuary, coral reefs in the South China Sea, Laizhou Bay, Taihu Lake, and freshwaters around Beijing in China (Bekele et al. 2019; Ding et al. 2020; Hou et al. 2017; Kang et al. 2023; Schmidt et al. 2021; Wang et al. 2019; Xie et al. 2022). In other studies, some or all of the BAFs for TEHP were below 2,000 L/kg (Bekele et al. 2019; Huang et al. 2023; Kang et al. 2023; Liu et al. 2019a; Peng et al. 2021; Zhang et al. 2023). Regarding accumulation of TEHP from sediments to biota, most of the reported BSAFs are below 0.5 (Bekele et al. 2019; Huang et al. 2023; Liu et al. 2019a; Xie et al. 2022). However, BSAFs of 0.72–2.6 were measured for oriental river prawn, crucian carp, and snakehead fish from a pond containing e-wastes in South China (Liu et al. 2019a). A mean BSAF of 1.83 was also observed in three species of freshwater fish from the Beiyum river system in Beijing, China (Hou et al. 2017).

For EHDPP, a BAF of 52,857 L/kg was estimated from literature data for Atlantic cod in the Arctic Ocean (Fu et al. 2021). High BAFs of 6,100–24,300 have been measured in zooplankton from the Bay of Marseille in the Mediterranean (Schmidt et al. 2021). BAF values of 1,400–19,000 and 12.6–5,012, respectively, were observed in a range of freshwater organisms from Taihu Lake and marine animals from Laizhou Bay in China (Bekele et al. 2019; Wang X et al. 2019). In some other field studies, BAFs were below the 2,000 L/kg threshold (Grung et al. 2021; He et al. 2023; Hou et al. 2017; Huang et al. 2023; Liu et al. 2019a; Peng et al. 2021; Zhang et al. 2023). High BSAF values of 0.70–54 have been measured for the sediment to biota accumulation of EHDPP in benthic fish and invertebrates, including sea snails, shrimp and crabs, in the Pearl River estuary and the Bohai Sea in China (He et al. 2023; Huang et al. 2023; Xie et al. 2022). A few studies determined BSAF values below 0.5 for EHDPP (Bekele et al. 2019; Hou et al. 2017; Liu et al. 2019a).

Field biomagnification studies

Evidence of biomagnification of TEHP and EHDPP in some food webs and between predator–prey and insect–host plant pairs was obtained from field monitoring studies. For TEHP, a biomagnification factor (BMF) of 2.8 was observed from grass to the grasshopper larvae (Liu Y-E et al. 2021). Trophic magnification of TEHP was identified for 19 species of invertebrates and fish in a marine food chain in Laizhou Bay, China, with a trophic magnification factor (TMF) of 2.52 ($p < 0.05$, trophic levels ranging from 2 to 4) (Bekele et al. 2019). A TMF of 2.88 ($p = 0.039$) was reported for the food web of the East Asian finless porpoise. However, the species included in the determination of this TMF are not clearly reported, and the calculated trophic levels may not be representative of an actual food chain (Chen et al. 2024a). Other studies report trophic dilution of TEHP, with a TMF of 0.1 ($p = 0.006$) in a marine food web in Bohai Bay, China (He et al. 2023), and BMFs of 0.39 for snail–biofilm (Zhang et al. 2023), 0.17 for Chinese water snake–common carp (Liu Y-E et al. 2019b), and 0.31 for moth larvae–guava (Liu et al. 2021). In some field studies, the detection of TEHP was too infrequent to determine reliable BMF values (Hallanger et al. 2015; Strobel et al. 2018). In others, the TMF calculations were unreliable because the concentrations of TEHP in biota were not statistically significantly correlated to trophic level (Chen et al. 2024a; Ding et al. 2020; He et al. 2023; Huang et al. 2023; Kim et al. 2011; Wang et al. 2023b; Wang et al. 2022).

For EHDPP, evidence of biomagnification was found in the bald eagle–Great Lakes trout and snail–biofilm pairs, with BMFs of 4 and 2.5, respectively (Guo et al. 2018; Zhang et al. 2023). Trophic magnification of EHDPP was observed in a food web of freshwater fish in Taihu Lake, China, with a TMF of 3.6 ($p < 0.05$) (Wang et al. 2019). Trophic dilution was reported in marine food webs of the Bohai Sea (He et al. 2023). In other cases, no significant correlation between trophic levels and concentrations in biota were found (Bekele et al. 2019; Brandsma et al. 2015; Huang et al. 2023; Kim et al. 2011; Wang et al. 2023b; Xie et al. 2022; Zhao et al. 2018). In some trophic studies, only the muscle tissues of fish were analysed for contaminants (Ding et al. 2020; He et al. 2023; Zhao et al. 2018). In these cases, the body burden in fish is likely to be underestimated because TEHP and EHDPP are expected to accumulate predominantly in fatty tissues. The trophic magnification may not be accurately estimated in these studies.

Maternal transfer

Maternal transfer of TEHP and EHDPP was demonstrated between fish and water snakes and their offspring. After exposure of female Japanese medaka fish to EHDPP for four weeks and mating with unexposed males, higher concentrations of EHDPP were observed in the fish embryos (up to 4,825 ng/g lw) than in the exposed females (up to 4,166 ng/g lw) (Li et al. 2021). Eggs of the Chinese water snake *Enhydris chinensis* were collected from the belly of the snakes. Chemicals EHDPP and TEHP were present in the eggs at higher concentrations than in the muscle of the adult snakes. The concentrations of TEHP in snake eggs and muscle were 0.11 and 0.014 ng/g ww, respectively. EHDPP was present in the snake eggs at 0.61 ng/g ww and was below the limit of quantification of 0.45 ng/g ww in the snake muscle (Liu et al. 2019b).

Chemicals TEHP and EHDPP have been found in eggs of eagles, gulls, starlings, guillemots, European shags, eiders, and hens, at maximal concentrations ranging from 0.83–25 ng/g ww (Greaves and Letcher 2014; Guo et al. 2018; Hallanger et al. 2015; Huber et al. 2015; Lu et al. 2017; Zheng et al. 2016). Maternal transfer is the most likely pathway for the detection of these chemicals in bird eggs.

TEHP and EHDPP residues in animals and plants

The scientific literature reports measurable amounts of chemicals TEHP and EHDPP in a wide range of animal and plant species all over the world (Ding et al. 2020; Garcia-Garin et al. 2020; Giulivo et al. 2017; Greaves and Letcher 2014; He et al. 2023; Hou et al. 2017; Huang et al. 2023; Kang et al. 2023; Liu et al. 2019a; Liu et al. 2021; Papachlimitzou et al. 2015; Santín et al. 2016; Verreault et al. 2018).

The chemical TEHP has been found in fish, invertebrates, and mammals, with mean concentrations up to 2,838 ng/g lw in marine fish from Manila Bay (Philippines) and from Liaodong Bay (China), 5,961 ng/g lw in aquatic invertebrates from Liaodong Bay, and 629 ng/g lw in dolphins from the Southwestern Indian Ocean (Aznar-Alemany et al. 2019; Kim et al. 2011; Wang et al. 2023b). The chemical TEHP also occurs in plankton and plants, at maximum concentrations reaching 365 ng/g dw in zooplankton from the Bay of Marseille and 190 ng/g dw in pondweed from a reference lake in a rural area in Norway (Grung et al. 2021; Schmidt et al. 2021). The chemical TEHP has been detected in Arctic seabirds and in chickens and ducks from a Chinese farm at concentrations up to 13.9 ng/g lw (Hallanger et al. 2015; Ma et al. 2013).

The chemical EHDPP has been found in plants, plankton, fish, invertebrates, birds, and marine mammals. Mean concentrations up to 1,647 ng/g lw in Atlantic cod in the Arctic, 627 ng/g lw in Mantis shrimp from Liaodong Bay, 396 ng/g lw in kittiwake and eider from the Arctic, and 145 ng/g lw in dolphins from the Mediterranean have been measured (Evenset et al. 2009; Sala et al. 2019; Wang et al. 2023b). The highest reported concentration of EHDPP

is 14,000 ng/g lw in eelpout fish from the Swedish coast (Sundkvist et al. 2010). Significant residues of EHDPP have also been found in zooplankton from the Bay of Marseille and in mangrove trees from the Qi'ao Island Mangrove Nature Reserve in China, with maximum concentrations of 697 and 92 ng/g dw, respectively (Schmidt et al. 2021; Xie et al. 2022).

Most monitoring studies in biota do not screen for the chemical BEHPP. However, Li and co-workers analysed BEHPP in fish from Zhushan Bay, Taihu Lake in China. The chemical was found in 4 out of 5 species of fish, at a mean concentration of 0.023 ng/g ww (not detected – 0.22 ng/g ww). The mean concentration of BEHPP was higher than the TEHP concentration and in the same order as the EHDPP concentration in this study (Li et al. 2022d). BEHPP was found in samples of fish and mussels from the Swedish and German environmental specimen banks (Haglund 2022). The concentrations of BEHPP in these samples were lower than the concentrations of EDHPP.

Other considerations

No bioaccumulation data were identified for BEHPP. The chemical is assumed to be bioaccumulative based on estimated log K_{OW} = 7.47 and read across from TEHP and EHDPP.

The phosphate diester degradants of chemicals reported in this evaluation are not expected to be bioaccumulative. The measured or calculated log K_{OW} of these degradants are below 4.2 (AICIS 2023; REACH n.d.-c; US EPA 2017). Other degradants and metabolites of chemicals reported in this evaluation may be bioaccumulative. Hydroxylation is a common metabolic pathway for organophosphate esters in various organisms. For example, the chemical 2-ethyl-5-hydroxyhexyl diphenyl phosphate (5-OH-EHDPP) has been identified as a metabolite of EHDPP in snakes, fish and plants (Liu et al. 2019b; Yang et al. 2023a; Yu et al. 2023). The metabolite 5-OH-EHDPP has a calculated log K_{OW} of 4.73 (US EPA 2017), and it has been detected in eggs collected from the belly of water snakes (Liu et al. 2019b). Similarly, mono-hydroxylated metabolites of BEHPP and TEHP are expected to have log K_{OW} exceeding the threshold for categorisation as Bioaccumulative.

Environmental transport

Chemicals reported in this evaluation may undergo long range transport. Chemicals TEHP and EHDPP have been identified in remote environmental areas in air, surface water, sediment, soil, and biota samples. However, some monitoring studies in remote regions have been complicated by potential local contamination sources.

In the air compartment, lipophilic organophosphorus flame retardants such as TEHP and EHDPP are likely adsorbed to airborne particles (Sühring et al. 2016b; Wolschke et al. 2016). They have been found in the particulate phase of both urban and marine air (Castro-Jiménez et al. 2016; Chen et al. 2020; Möller et al. 2012; Shoeib et al. 2014). Substances that are adsorbed to particles may be more resistant to degradation, which results in an increased atmospheric half-life and increased potential for long range transport. The half-lives of TEHP and EHDPP in air are estimated to increase from 1.3 h and 3.2 h in the gas phase to 1.9–4.6 days and 4.5–11 days when deposited onto ammonium sulfate particles (Liu et al. 2019; Liu et al. 2014; US EPA 2017).

Chemicals TEHP and EHDPP have been detected in polar regions and other remote areas. For TEHP, maximal concentrations of 17.6 pg/m^3 in Antarctica, 194 pg/m^3 in the Arctic, and 350–890 pg/m^3 in the Atlantic, Indian, and Pacific Oceans have been measured in air (Castro-Jiménez et al. 2016; Han et al. 2020; Li et al. 2022e; Möller et al. 2012; Na et al. 2020; Wang et al. 2020). For EHDPP, the concentrations in air reach up to 80 pg/m^3 in Antarctica, 298 pg/m^3 in the Arctic, 630–1,730 pg/m^3 in the Atlantic, Indian, and Pacific

Oceans (Castro-Jiménez et al. 2016; Han et al. 2020; Li et al. 2022e; Salamova et al. 2014; Sühring et al. 2016a; Wang et al. 2020).

In the water compartment, TEHP has been detected in concentrations ranging from 1.4 to 81.6 ng/L in lake and seawater samples from the Fildes Peninsula in Antarctica (Gao et al. 2018; Li et al. 2023), <0.013–13 ng/L in the Canadian Arctic (Sühring et al. 2021), and <0.05–106 ng/L in the South Pacific (Li et al. 2023). Notably, the concentrations of TEHP in Antarctic and Pacific waters exceed the typical TEHP concentrations measured in rivers and coastal areas close to human settlements. Low concentrations of the chemical EHDPP (<0.001–7 ng/L) have been measured in Antarctic and Arctic waters (Gao et al. 2018; Gao et al. 2020; McDonough et al. 2018; Sühring et al. 2021).

Chemicals TEHP and EHDPP were found in sediments of the Eastern Indian Ocean, at depths exceeding 4,000 m, at concentrations 0.14–5.8 and 0.17–0.74 µg/kg dw, respectively (Cong et al. 2022). Similar levels (<0.002–0.87 µg/kg dw) were measured for EHDPP in sediments from Arctic locations (Evenset et al. 2018; Gao et al. 2020; Sühring et al. 2021). The chemical EHDPP was also detected in soil samples from the Svalbard area in the Arctic, with a mean concentration of 0.87 µg/kg dw (Han et al. 2020).

Chemicals TEHP and EHDPP have been found in fish, birds, ringed seals, and Arctic foxes in the Arctic and in background lakes in Sweden (Evenset et al. 2009; Hallanger et al. 2015; Sundkvist et al. 2010; Verreault et al. 2018). The chemical TEHP has also been detected in polar bears (Letcher et al. 2018; Strobel et al. 2018). While TEHP has only been measured at low concentrations in Arctic animals, high concentrations of EHDPP have been observed, reaching 651 ng/g lw in bird livers and 3,200 ng/g lw in fish (Evenset et al. 2009). In Antarctic and Arctic locations, a correlation was observed between the detection of TEHP in water samples and biological activities (seabird colonies and areas affected by bird droppings and penguin and seal faeces), suggesting that TEHP may be transported by biota (Gao et al. 2018; Sühring et al. 2021).

The use of TEHP and EHDPP in plastics can interfere with their measurements in environmental samples due to their presence in laboratory and sampling equipment (Fu et al. 2020). These chemicals have been excluded from some studies because they were detected in procedural or field blanks (Fu et al. 2020; Li R et al. 2023; Na et al. 2020). The detection of TEHP and EHDPP in some remote areas may also be due to local human activities rather than long-range transport. Some studies reported higher concentrations at or near settlements, harbours, or airports, suggesting that these chemicals originate primarily from local sources (Evenset et al. 2018; Gao et al. 2018; Gao et al. 2020; Han et al. 2020; Sühring et al. 2016a). However, the detection of these chemicals in marine air and sediments, far from significant human activities, supports their ability to undergo long-range transport (Castro-Jiménez et al. 2016; Cong et al. 2022).

Predicted environmental concentration (PEC)

The PECs for TEHP and EHDPP have been selected based on environmental monitoring of these chemicals in STP and surface waters, soil, and sediments in Australia and internationally. The PECs for TEHP are 10 ng/L in surface water, 530 µg/kg dw in sediment, and 93 µg/kg dw in soil. The PECs for EHDPP are 22 ng/L in surface water, 64 µg/kg dw in sediment, and 51 µg/kg dw in soil.

Monitoring data for BEHPP in the Australian environment are not available. The chemical is rarely analysed in monitoring studies internationally, although it was detected in sediments, soils and air in China when it was analysed (Gong et al. 2021; Ye et al. 2021; Ye and Su 2022; Zhao et al. 2023).

Surface water PECs of 10 ng/L and 22 ng/L were selected for TEHP and EHDPP, respectively, based on measured effluent concentrations in STPs internationally. These values are supported by Australian studies showing no TEHP or EHDPP in Australian STP effluent up to limits of detection. Additionally, surface water concentrations measured internationally are typically below these levels.

Chemicals TEHP and EHDPP were analysed in STP influents and effluents in 22 locations across all Australian states and territories except Western Australia (DAWE 2022). In STP influents sampled in 2019, TEHP was below the limit of detection (LOD) in most samples and was detected in 4 out of 44 pooled samples at concentrations 54.3–305 ng/L. In the same samples, EHDPP was only detected once at a concentration of 123 ng/L. The concentrations of TEHP and EHDPP were below the respective limits of detection of 40 ng/L and 50 ng/L in all STP effluent samples from the same locations, suggesting that these chemicals are efficiently removed from water in Australian STPs (DAWE 2022). In an earlier monitoring study, the chemical EHDPP was analysed in 11 STP influents across four eastern states (7 sites in Queensland, two in South Australia, one in the ACT and one in Tasmania) in August 2011. The chemical EHDPP was below the LOD of 0.1 µg/L in all but one samples. The concentrations in STP effluents were not measured in this study (O'Brien et al. 2015). In a recent monitoring study in three locations in the Sydney area, chemicals TEHP and EHDPP were only detected in 3 and 1 water samples, respectively, out of a total of 54 samples. The concentrations and LODs of these chemicals are not reported (Allinson et al. 2023).

Internationally, chemicals TEHP and EHDPP have been analysed in STP influents and effluents in various locations, including the USA, Canada, China, and multiple European countries. The concentrations of TEHP in STP wastewater vary and are typically in the range of 0–153 ng/L in influent and 0–10 ng/L in effluent, with removal rates from the water compartment generally ranging from 87–100% (Cristale et al. 2016; Loos et al. 2013; Lorenzo et al. 2019; Ofrydopoulou et al. 2022; Wang et al. 2023a; Woudneh et al. 2015). Higher concentrations of up to 1,850 ng/L in STP influent and 169 ng/L in STP effluent have been observed in a few locations, which may be due to heavily urbanised areas and industrial activities (Kim et al. 2017; Ng et al. 2023; Pantelaki and Voutsa 2022). The mean concentrations of EHDPP in STP influents typically range from not detected to 404 ng/L, with typical mean effluent concentrations of 0–22 ng/L (Cristale et al. 2016; Kim et al. 2017; Ofrydopoulou et al. 2022; Sutton et al. 2019; Wang et al. 2023a; Woudneh et al. 2015). High effluent concentrations of EHDPP, up to 710 ng/L, were measured at two STPs in Norway. Landfill leachates may have contributed to the high loads of the chemical in these locations (Green et al. 2008). In a monitoring study of 90 STPs throughout Europe, the maximum concentration of EHDPP in effluents was 5,400 ng/L. However, the median concentration of the chemical was 6.5 ng/L, suggesting that effluent concentrations are low in most locations (Loos et al. 2013).

In rivers, lakes, and coastal areas in the USA, Canada, and Europe, the environmental levels of TEHP and EHDPP in the dissolved phase are generally low, with mean concentrations ranging from 0–5.3 ng/L for TEHP and 0–10.8 ng/L for EHDPP (Awonaike et al. 2021; Cristale et al. 2013; Gadelha et al. 2019; Ginebreda et al. 2018; Grung et al. 2021; Guo et al. 2017a; Gustavsson et al. 2018; Gustavsson et al. 2019; Kim and Kannan 2018; Li et al. 2019c; Lorenzo et al. 2019; Pintado-Herrera et al. 2020; Shimabuku et al. 2022). High concentrations of TEHP and EHDPP (up to 4,300 and 730 ng/L, respectively) were recorded in Lake Victoria along the shore of Uganda. This waterbody potentially receives untreated domestic and industrial wastewaters (Nantaba et al. 2021). Similarly, TEHP was detected at concentrations of up to 1,568 ng/L in streams and drains receiving road run-off and treated and untreated wastewaters in an urbanised location in Greece. Samples taken from the nearby gulf also had slightly elevated concentrations of TEHP, with a mean concentration of 54.4 ng/L, presumably due to outlets of the above-mentioned streams and drains into the gulf (Pantelaki and Voutsa 2021). These international sites receiving untreated wastewater are

not expected to be representative of typical sites in the Australian environment. The levels of TEHP and EHDPP in rivers, lakes, and coastal areas internationally are typically lower than in STP effluents.

Australian monitoring data were not identified for TEHP and EHDPP in sediments, soils, and STP biosolids.

In the sediment compartment, conservative PECs of 3.9 mg/kg dw for TEHP and 0.064 mg/kg dw (64 µg/kg dw) for EHDPP were derived based on the LODs of these chemicals in Australian STP effluents, using the equilibrium partitioning (EqP) method. Sediment-water partition coefficients of 98.7 x 10^3 and 1,286 L/kg based on dw were estimated for TEHP and EHDPP, respectively, using the calculated K_{OC} (K_{OC} = 2.47 x 10^6 L/kg for TEHP and K_{OC} = 3.22 x 10^4 L/kg for EHDPP) (US EPA 2017), and assuming the fraction of organic content in the sediment is 4% (EPHC 2009).

In international monitoring studies from the USA, Canada and Europe, the concentration of TEHP in deposited sediments from rivers, lakes and coastal areas typically ranges from not detected to 530 µg/kg dw. For EHDPP, concentrations ranging 0–288 µg/kg dw are typically measured (Alkan et al. 2021; Blum et al. 2018; Brandsma et al. 2015; Cao et al. 2017; Cristale et al. 2013; Gadelha et al. 2019; Giulivo et al. 2017; Li et al. 2019a; Lorenzo et al. 2019; Onoja et al. 2023; Pintado-Herrera et al. 2017; Sutton et al. 2019). Higher concentrations of both chemicals have been measured in highly disturbed areas, such as landfills, urban sedimentation ponds, a car demolishing site, and the heavily polluted Bagmati River in Nepal, with the highest concentrations reaching 7,521 µg/kg dw for TEHP and 690 µg/kg dw for EHDPP (Green et al. 2008; Grung et al. 2021; Lee et al. 2020; Peverly et al. 2015; Yadav et al. 2018b). The heavily polluted sites are not expected to be representative of typical levels of TEHP and EHDPP in sediments in the Australian environment.

In Australia, the levels of EHDPP in sediments are expected to be lower than in some overseas locations, based on the EqP estimate. The PEC of 64 µg/kg dw in sediments based on the EqP method is selected for this chemical. For TEHP, however, the PEC based on the EqP method appears to be an overestimate of levels typically found in sediments internationally. The highest of the TEHP concentrations typically measured overseas, 530 µg/kg dw, is selected as the PEC for TEHP in sediments.

The chemical BEHPP was detected with a 96–100% frequency in sediments of Taihu Lake and rivers near industrial and e-waste areas in China. The mean concentrations of BEHPP in these studies were 9.5–34 µg/kg dw, with a maximal concentration of 335 µg/kg dw. The levels of BEHPP in these locations were generally lower than TEHP but higher than EHDPP (Ye et al. 2021; Ye and Su 2022).

In soils, most of the monitoring studies have focused on areas disturbed by human activity, such as industrial sites, urban locations, and waste processing sites. In less disturbed areas, including a forest in Spain, mountain valleys in the Himalayas, rural areas in Tibet, and farmlands throughout mainland China, the concentrations range from not detected to 93 µg/kg dw for TEHP and not detected to 51 µg/kg dw for EHDPP (Campo et al. 2017; Chen et al. 2024b; Han et al. 2022; You et al. 2022; Zhang et al. 2022). The highest concentrations measured in these studies are used as conservative PECs for TEHP and EHDPP in soils, specifically 93 µg/kg dw for TEHP and 51 µg/kg dw for EHDPP. Elevated concentrations in highly disturbed areas (up to 2,490 µg/kg dw for TEHP and 114 µg/kg dw for EHDPP) (Matsukami et al. 2015; Sánchez-Piñero et al. 2020; Yadav et al. 2018a; Yadav et al. 2018b) are not considered representative of expected soil levels in the Australian environment. In a study of soils from agricultural, scenic, commercial, industrial, and

residential areas in South China, the chemical BEHPP was detected with a frequency of 67%. The median concentration of the chemical in the soil samples was 0.455 µg/kg dw, ranging from <0.19–7.05 µg/kg dw. The levels of BEHPP in the soil samples were lower than TEHP but higher than EHDPP (Gong et al. 2021).

In STP biosolids, the chemical TEHP has been found in samples from Europe, the USA, and Canada at concentrations ranging from not detected to 2,750 µg/kg dw, with the highest mean concentration reaching 1,450 µg/kg dw. Similarly, levels of EHDPP in STP biosolids range from not detected to 4,600 µg/kg dw, and the highest mean concentration reported in the literature is 1,364 µg/kg dw (Castro et al. 2023; Celano et al. 2014; Cristale et al. 2016; Green et al. 2008; Kim et al. 2017; Marklund et al. 2005; Pantelaki and Voutsa 2022; Rede et al. 2024; Wang et al. 2019; Woudneh et al. 2015). Based on the maximal concentrations reported above, and assuming a soil mass of 1,300 t/ha dw, the application of STP biosolids to soils at 10 t/ha dw would result in a PEC in soil of 21 µg/kg dw for TEHP and 35 µg/kg dw for EHDPP. These estimations are lower than the PECs based on measured concentrations in soil and are not selected in this evaluation.

Outdoor air samples have been analysed using passive samplers in two locations in Australia: Cape Grim (a background site) and Darwin. Both chemicals were below the LODs (0.06 pg/m^3 for TEHP and 1.4 pg/m^3 for EHDPP) at Cape Grim. In Darwin, the mean concentration of EHDPP was 38 pg/m^3, while TEHP was not detected (Rauert et al. 2018). Internationally, the mean concentrations of TEHP in outdoor air are generally in the range <0.06–230 pg/m^3, and they range from <0.06–700 pg/m^3 for EHDPP. These chemicals are typically found in much higher concentrations in airborne particles than in the gaseous phase (Castro-Jiménez Javier et al. 2016; Guo et al. 2017b; Li et al. 2019c; Rauert et al. 2018; Shoeib et al. 2014; Yan et al. 2023). Maximal concentrations of 39,000 and 7,390 pg/m^3 have been measured for TEHP and EHDPP, respectively, in urban or industrial sites (Chen et al. 2020; Syed et al. 2020; Violaki et al. 2024; Zhao et al. 2023). The chemical BEHPP was analysed in air samples from an urban location in China. The mean concentrations of BEHPP were 110 pg/m^3 in PM2.5 particles and 2,810 pg/m^3 in the gas phase. The BEHPP levels were higher than TEHP and EHDPP in this study (Zhao et al. 2023).

Environmental effects

The chemical EHDPP causes long lasting toxic effects in freshwater fish and aquatic invertebrates. No adverse effects to aquatic organisms were observed with TEHP at or below the water solubility of the chemical. In the absence of other information, BEHPP is classified as toxic to aquatic life based on a conservative read across from EHDPP.

The chemical TEHP is harmful to some soil- and sediment-dwelling organisms. Data are not available for BEHPP and EHDPP in these compartments.

In many of the standard aquatic toxicity studies with EHDPP, a commercial sample of the chemical was used, with a typical composition of 92% EHDPP, 4.7% BEHPP, and 3.5% triphenyl phosphate (REACH n.d.-b). The toxicity of triphenyl phosphate (AICIS 2023) may have contributed to the adverse effects to aquatic organisms in these studies. Studies using this technical mixture are noted where relevant.

Some metabolites of the organophosphates in this evaluation, may contribute to adverse effects in aquatic life. The effects of hydroxylated metabolites are discussed in the “Chronic toxicity” and “Endocrine effects” sections below. Degradation or metabolism of the organophosphate triesters in this group to the corresponding diesters and alcohols is expected to reduce the potential for adverse effects to aquatic life. All available aquatic toxicity endpoints for the diester degradants bis(2-ethylhexyl) phosphate and diphenyl phosphate are above 20 mg/L (AICIS 2023; REACH n.d.-c). Based on read across, the toxicity of the mixed aryl-alkyl diester 2-ethylhexyl phenyl phosphate is expected to be similarly low. The alcohol 2-ethylhexan-1-ol does not appear to have significant ecotoxicity based on available standardised screening tests (REACH n.d.-d). The potential release of phenol from BEHPP or EHDPP may contribute to toxic effects to aquatic organisms (REACH n.d.-e).

Effects on aquatic life

Acute toxicity

The following are the most sensitive acute median lethal concentrations (LC50) for fish and median effect concentrations (EC50) on immobilisation for invertebrates and growth rate for algae retrieved from the REACH dossiers for TEHP (REACH n.d.-a) and EHDPP (REACH n.d.-b), from the UK Environmental Agency’s Environmental risk evaluation report on EHDPP (UK EA 2009), and from the literature (Cristale et al. 2013). The half maximal inhibitory concentration (IC50) for the toxicity of EHDPP to STP micro-organisms is also reported in the table (UK EA 2009; UNEP IPCS 2000):

Taxon	Chemical	Endpoint	Method
Fish	TEHP	96 h LC50 > 40 mg/L*	*Oryzias latipes* (Japanese rice fish) Semi-static, measured concentrations HCO-40 dispersant used as vehicle (PEG-40 hydrogenated castor oil) OECD TG 203.
Invertebrate	TEHP	48 h EC50 = 0.74 mg/L*	*Daphnia magna* (water flea) Immobilisation Static, nominal concentrations Solvent (acetone) used as vehicle Standardised 48 h acute test.
Invertebrate	EHDPP	48 h EC50 = 0.15 mg/L*	*D. magna* Immobilisation Static, nominal concentrations Solvent (DMF) used as vehicle American Society for Testing and Materials (ASTM) E729 method. Unnamed technical product tested
Algae	TEHP	72 h EC50 > 0.88 mg/L*	*Desmodesmus subspicatus* (green algae) Growth rate Static, mean measured concentrations No vehicle OECD TG 201
Algae	EHDPP	72 h EC50 = 0.12 mg/L*	*D. subspicatus* (green algae) Growth rate Static, measured (initial) concentrations No vehicle Method equivalent to OECD TG 201 Technical mix ‘Santicizer-141’ tested
STP microflora	TEHP	IC50 > 100 mg/L*	STP biosolids Respiration inhibition ISO 8192
STP microflora	EHDPP	IC50 > 10 g/L*	STP biosolids Respiration inhibition OECD TG 209

* Toxicity endpoint above solubility limit

Many of the tests reported in the table above were conducted using commercial grade impure substances. Many of the tests also indicated evidence of incomplete solvation of the test substance in tests conducted without a solvent vehicle or emulsifier. The acute endpoints reported are therefore not considered to be reliable. However, the results do suggest that the substances are unlikely to have acute ecotoxic effects at or near their respective water solubility limits.

Notable sublethal effects were seen in two acute studies. An LC50 of 3.5 mg/L and an EC50 of 1.8 mg/L for developmental defects were measured in 4-day post fertilisation zebrafish embryos exposed to EHDPP (Alzualde et al. 2018). In a separate study, alterations of the glucose and lipid metabolism were observed in zebrafish larvae exposed to EHDPP at concentrations of 0.10 and 0.20 mg/L for seven days post fertilisation. Some physiological and transcriptomic effects were also observed at 0.020 mg/L EHDPP, the lowest concentration tested in this study (Xu et al. 2023).

Other lethal and sublethal effects of TEHP and EHDPP in zebrafish (*Danio rerio*) embryos, nematodes (*Caenorhabditis elegans*), freshwater flatworms (*Dugesia japonica*), and ciliates (*Tetrahymena pyriformis*) have also been investigated, though no apical effects within water solubility limits were observed (Behl et al. 2015; Behl et al. 2016; Jarema et al. 2015; Noyes et al. 2015; Yoshioka et al. 1985; Zhang et al. 2019).

Data are not available for the acute toxicity of BEHPP to aquatic organisms. The endpoints in the table above and the reported NOECs for these studies are all above the calculated water solubility limit of 2.0 µg/L for BEHPP (US EPA 2017).

Chemicals in this evaluation are not expected to adversely affect the activity of STP micro-organisms based on the result of respiration inhibition tests with TEHP and EHDPP.

Chronic toxicity

The following measured no-observed-effect concentrations (NOEC) and maximum allowable toxicant concentration (MATC) for model organisms across three trophic levels were obtained from the REACH dossiers for TEHP (REACH n.d.-a) and EHDPP (REACH n.d.-b), from the scientific literature (Li et al. 2020), and from the UK EA's Environmental risk evaluation report on EHDPP (UK EA 2009):

Taxon	Chemical	Endpoint	Method
Fish	EHDPP	71 d NOEC = 21 µg/L	*Oncorhynchus mykiss* (rainbow trout eggs and fry) Mortality and behaviour Flow-through, measured concentrations Solvent (dimethylformamide, DMF) used as vehicle Proposed standard practice for conducting toxicity tests with the early life stages of fishes. ASTM, 1980. Technical mix 'Santicizer-141' tested
Fish	EHDPP	100 d MATC = 3.6 µg/L	*Oryzias latipes* (medaka) Reproduction (egg hatch rate) Flow-through, nominal concentrations Solvent (DMSO) used as vehicle
Invertebrate	TEHP	21 d NOEC = 1 mg/L*	*Daphnia magna* (water flea) Reproduction Semi-static, analytically-confirmed nominal concentrations Solvent (DMF) and HCO-40 dispersant (PEG-40 hydrogenated castor oil) used as vehicle OECD TG 211
Invertebrate	EHDPP	21 d NOEC = 18 µg/L	*D. magna* Reproduction Flow-through, measured concentrations Solvent (DMF) used as vehicle Protocol for conducting chronic toxicity tests with the water flea (*Daphnia magna*), EG&G, Bionomics, and ASTM. Technical mix 'Santicizer-141' tested
Algae	TEHP	72 h NOEC = 0.88 mg/L*	*Desmodesmus subspicatus* (green algae) Growth rate Static, mean measured concentrations No vehicle OECD TG 201
Algae	EHDPP	72 h NOEC = 72 µg/L*	*D. subspicatus* (green algae) Growth rate Static, measured (initial) concentrations No vehicle Method equivalent to OECD TG 201 Technical mix 'Santicizer-141' tested

* Toxicity endpoint above solubility limit

The available chronic endpoints for TEHP far exceed the solubility of the chemical in water. For EHDPP, chronic effects below the solubility limit of the chemical were observed in the early life stages test with rainbow trout, reproduction test with medaka, and in the reproduction test with *Daphnia magna* (Li Y et al. 2020; REACH n.d.-b; UK EA 2009).

A study by Li Y et al. (2020) found an EHDPP 100 d medaka egg hatch rate NOEC of 1.6 µg/L and LOEC of 8 µg/L, based on nominal concentrations. The geometric mean of these two values was taken to derive a 100 d MATC of 3.6 µg/L as a representative endpoint (see entry in table above). In the study, recently hatched medaka larvae were exposed to EHDPP at 1.6, 8 and 40 µg/L for 30 days. The male and female fish were then separated and further exposed to EHDPP for 70 days, totalling 100-day exposure. After this duration, the adult males were bred with female fish randomly selected from the control exposure group, and the fertilisation rate and hatch rates were measured, finding effects on both fertilisation and hatch rate with fish from the 8 and 40 µg/L exposure groups. The strongest effect measured was a 22% decrease in hatch rate in the 40 µg/L exposure group.

It should be noted that the test substance concentrations were not well maintained in this test, averaging 30, 104 and 434 ng/L in the 1.6, 8 and 40 µg/L exposure groups, respectively (Li et al. 2020). The authors propose that photodegradation and hydrolytic degradation of EHDPP in water, combined with accumulation of EHDPP into the tissues of the fish, are responsible for the low measured concentrations. The authors also note the presence of several degradants and metabolites of EHDPP in the fish liver tissue, particularly 5-OH-EHDPP. In vitro experiments suggest that 5-OH-EHDPP is more biologically active than the parent substance and may be partly responsible for the observed toxic effects. The nominal concentrations have been used when reporting the endpoints for this study to better represent the range of metabolites and degradants that may have been active in this test. This study also included analysis of biomarkers and hormone levels on exposure to EHDPP and several identified metabolites, which is discussed further in the ‘Endocrine effects’ section below.

In another study effects of EHDPP on zebrafish were investigated, and a 21-day spawn rate EC100 of 50 µg/L can be derived from the reported information (Yang R et al. 2022). The test was conducted according to OECD TG 230 (Short-term screening for estrogenic and androgenic activity) with test substance concentrations of 2.5, 50 and 250 µg/L EHDPP, with the addition of a reproduction endpoint test at the conclusion of the 21 days exposure. After exposure, female fish from each exposure group were transferred to clean water to mate with unexposed male fish, with eggs laid, fertilisation rate and hatching rate measured. No spawning occurred within 7 days for zebrafish from the 50 and 250 µg/L exposure groups. The F1 generation fish from the 2.5 µg/L exposure group were observed for developmental effects, finding a decreased body length at 7 days post-fertilisation (dpf), suggesting some intergenerational exposure effects. It should be noted that test solutions were renewed every 48 h during the exposure period, and the measured concentrations of EHDPP after 48 h were 30–82% of initial concentrations. Analysis of biomarkers and hormone levels on exposure to EHDPP conducted as part of this study are discussed further in the ‘endocrine effects’ section below.

Developmental toxicity effects were observed in the offspring of female Japanese medaka fish exposed to EHDPP for 28 days at nominal concentrations of 1.6, 8.0 and 40 µg/L. The offspring of exposed females mated with unexposed males were assessed for ocular abnormities including eye deformities in the embryos and vision disorders in the larvae. The total incidence of ocular defects was 19, 22, and 37% in the 1.6, 8.0 and 40 µg/L exposure groups, respectively. Antagonistic activity was also observed for EHDPP and its hydroxylated metabolites, 2-ethyl-5-hydroxyhexyl diphenyl phosphate (5-OH-EHDPP) and 2-ethyl-3-hydroxyhexyl diphenyl phosphate (3-OH-EHDPP), in a hybrid in vitro assay with Japanese medaka retinoic acid receptor and retinoic X receptor, which regulate ocular development. In the study of ocular defects in medaka offspring, the measured concentrations of EHDPP in the medium (0.16, 0.41, and 1.2 µg/L) were significantly lower than the nominal concentrations (1.6, 8.0 and 40 µg/L). However, significant uptake of EHDPP in the fish was observed, and metabolites may have contributed to the effects given

their antagonistic activity in the in vitro assay. Consequently, nominal concentrations are considered for the hazard assessment in this evaluation (Li et al. 2021).

Exposure of zebrafish to EHDPP at 35 and 245 µg/L for 21 days caused feeding disorders. Multiple effects were observed in these exposure groups, including increased food intake, increased feeding rate, transcriptomic changes, increased dopamine levels, and increased bodyweight after unrestricted feeding. The effects were greatest in the 35 µg/L exposure group, and no significant effects were observed at 5 µg/L (Yang et al. 2023b).

The solvent DMSO was used as a vehicle in all the studies cited above.

Data are not available for the chronic toxicity of BEHPP to aquatic organisms. All chronic endpoints for TEHP and EHDPP are above the calculated water solubility limit of 2.0 µg/L for BEHPP (US EPA 2017).

Effects on terrestrial life

The following measured endpoints were obtained from the REACH dossier for TEHP (REACH n.d.-a) and the Netherlands' RIVM report on phosphate esters (Verbruggen et al. 2005):

Taxon	Endpoint	Method
Terrestrial plants	14 d EC50 = 748 mg/kg soil dry weight (dw) 14 d NOEC = 37 mg/kg soil dw	*Lycopersicon esculentum* (tomato) fresh weight Nominal concentrations Solvent (acetone) used as vehicle OECD TG 208
Annelids	56 d EC50 > 1,000 mg/kg soil dw (reproduction) 28 d NOEC = 1,000 mg/kg soil dw (mortality and growth)	*Eisenia andrei* (earthworm) Nominal concentrations Solvent (acetone) used as vehicle OECD TG 222
Annelids	14 d NOEC = 562 mg/kg soil dw (weight loss) 14 d NOEC = 1,000 mg/kg soil dw (mortality)	*Eisenia foetida* (earthworm) OECD TG 207
Soil micro-organisms	28 d NOEC = 1,000 mg/kg soil dw	Soil microflora inhibition of total respiration and nitrate formation rate Nominal concentrations No vehicle OECD TG 216 and 217

The chemical TEHP is harmful to tomato plants, and it induces sublethal effects in *E. foetida* earthworms at high concentrations. No adverse effects were observed in standard toxicity tests with *E. andrei* earthworms and soil micro-organisms.

Data are not available for the toxicity of BEHPP and EHDPP to soil-dwelling organisms.

Sublethal hepatotoxic effects were observed in chickens exposed to EHDPP at 800, 1,600, and 3,200 mg/kg body weight in their diet for 14 to 42 days (Yang Y et al. 2022).

Effects on sediment dwelling life

The following measured endpoints were obtained from the REACH dossier for TEHP (REACH n.d.-a):

Taxon	Endpoint	Method
Invertebrates	28 d EC50 = 183 mg/kg sediment dw (emergence rate) 28 d EC50 = 860 mg/kg sediment dw (development rate) 28 d NOEC = 83 mg/kg sediment dw (emergence and development rate)	*Chironomus riparius* (freshwater midge) larvae Measured concentrations Solvent (acetone) used as vehicle OECD TG 218

The chemical TEHP is harmful to the larvae of the freshwater midge *Chironomus riparius*.

Data are not available for the toxicity of BEHPP and EHDPP to sediment-dwelling organisms.

Endocrine effects

The chemical EHDPP shows endocrine activity consistent with an anti-androgenic mode of action in fish and may cause endocrine-related effects on fish gonad development and fish reproduction.

Chemicals TEHP and BEHPP have endocrine activity based on in vitro studies on hamster cells and hybrid yeast-human assays. However, the exposure concentrations are significantly greater than the solubility limits of these chemicals in water. No studies on endocrine effects in fish have been identified for these chemicals.

Two studies on fish found reproductive effects and effects on hormone and biomarker levels consistent with an anti-androgenic mode of action for EHDPP. A third study found reproductive effects and evidence of interaction with the thyroid system.

The first study by Li et al. (2020) studied EHDPP and found effects on reproductive success, incidence of testis-ova, and biomarker and hormone levels in in vitro and in vivo studies with medaka. The reproductive success effects are discussed in the chronic toxicity section above.

In vitro tests identified 5-OH-EHDPP as the principal metabolite of EHDPP in medaka liver microsome cell assay. Both EHDPP and 5-OH-EHDPP were antagonists against the human androgen receptor in recombinant yeast assays, with 5-OH-EHDPP being stronger. Minimal activity against the medaka estrogen receptor was found.

In vivo tests with a transgenic medaka strain found a dose-dependent induction of testis-ova in male fish with exposure to EHDPP at 1.6, 8 and 40 µg/L for 100 days post hatch (Li et al. 2020). The transgenic strain coexpresses green fluorescent protein on promotion of oocyte reporter gene OSP1, allowing convenient monitoring of oocyte cells (and therefore testis-ova) in male gonads (Zhao et al. 2014). After the exposure period, testis-ova were observed

at all exposure concentrations with a dose-dependent increase in both incidence and severity (i.e. the number of oocyte cells detected) (Li et al. 2020). At the highest exposure concentration of 40 µg/L, 48.6% of analysed gonads were testis-ova, suggesting that EHDPP exposure induces effects on sexual development of medaka. Liver tissue analysis of the exposed fish found significant concentrations of degradants and metabolites of EHDPP, particularly 5-OH-EHDPP, which was present at higher concentrations than EHDPP in all exposure groups. The observed effects are consistent with an anti-androgenic mode of action for both EHDPP and 5-OH-EHDPP as identified in in vitro tests. Induction of testis-ova is a listed primary diagnostic for endocrine-related histopathology in fish gonads (OECD 2010).

Plasma hormone levels in males were also monitored in the study by Li et al. (2020), finding repression of testosterone and 11-ketotestosterone (11-KT) in the 40 µg/L exposure group, and an increase of 17β-estradiol (17β-E2) levels in the 8 and 40 µg/L groups. At the highest exposure level, the levels of testosterone and 11-KT were halved and the 17β-E2 had increased fourfold.

In the second study conducted by Yang et al. (2022), EHDPP affected reproduction of adult zebrafish and induced sex-dependent changes in biomarkers related to endocrine activity. The reproductive success endpoint is discussed in the chronic toxicity section above. The test was conducted according to OECD TG 230 (21-day Fish Assay: A Short-Term Screening for Oestrogenic and Androgenic Activity, and Aromatase Inhibition) using test substance concentrations of 2.5, 50 and 250 µg/L. Sex-dependent effects on plasma vitellogenin, testosterone, 11-KT and 17β-E2 were measured, with the most significant effects observed in male fish (Yang et al. 2022).

In males, vitellogenin levels, testosterone levels and 17 β-E2 levels were all significantly elevated in a dose-dependent manner in the 50 and 250 µg/L exposure groups, with a 2-fold, 2.5-fold and 4-fold increase in vitellogenin, testosterone and 17β-E2 respectively at the highest exposure concentration. Plasma concentrations of 11-KT were slightly decreased in the 50 and 250 µg/L exposure group. Lesser effects were observed in female fish, with 11-KT and 17β-E2 levels affected in the same pattern as male fish but at much lower magnitude. Non-monotonic responses were recorded in testosterone and vitellogenin levels in females, which were both depressed in the 2.5 and 50 µg/L exposure group, but not different from the control at 250 µg/L.

These hormone and biomarker level changes were compared to the effects of reference compounds with known endocrine activity. The changes in male fish were consistent with the effects of either an estrogen receptor agonist (dienestrol) or androgen receptor antagonist (flutamide). The effects at 250 µg/L in female fish were again consistent with either dienestrol or flutamide.

In the same study, male and female gonads were excised for analysis of germ cell development. In female fish, oocyte development was slightly inhibited at 50 and 250 µg/L exposure groups, with a decreased proportion of vitellogenic oocytes observed. Non-monotonic effects were seen in male gonads, with a significant decrease in proportion of spermatid cells observed at all exposure concentrations, but with the greatest effect in the 2.5 µg/L exposure group (Yang et al. 2022). It is unclear to what extent the histopathological changes in female gonads contributed to the reproductive effects observed in this study.

An additional fish study found evidence of interaction of EHDPP with the thyroid hormone system. In the laboratory study conducted by Shu et al. (2024), healthy zebrafish embryos were exposed to EHDPP at nominal concentrations of 0.1, 1, 10, and 100 µg/L for 120 h (Shu et al. 2024). The chemical induced multiple statistically significant effects at 1, 10, and

100 µg/L in a concentration-dependent manner. These effects included reduced levels of the thyroid hormones triiodothyronine (T3) and thyroxine (T4), reduced T3/T4 ratios, and increased levels of thyroid-stimulating hormone (TSH). A decrease in T3/T4 is an indicator of thyroid dysfunction. A significant increase in TSH levels was also observed at 0.1 µg/L EHDPP, the lowest concentration tested. The expression of some genes involved in the thyroid endocrine system and the expression of the protein transthyretin, a thyroid hormone carrier, were altered upon exposure to EHDPP in this study.

Exposure to EHDPP affected several developmental endpoints in the zebrafish larvae (Shu et al. 2024). Dose-dependent and statistically significant, but relatively minor effects on survival rate, body length, and malformation rates were observed. The hatch rate was also significantly affected, reducing from 89% in the control to 67% in the 100 µg/L exposure group. The measured concentrations of EHDPP in the medium were lower than the nominal amounts in this study. However, as discussed previously, nominal concentrations are considered here to account for bioaccumulated EHDPP in the fish tissues and for possible effects of its hydroxylated metabolites. Molecular docking modelling was performed to gain insight of the mechanism of endocrine disruption. Molecular docking indicated that EHDPP may compete with T4 to bind to transthyretin and inhibit T4 transport.

The chemical EHDPP also induced endocrine activity in assays with mouse tumour Leydig cells and chicken liver cells (Schang et al. 2016; Shen et al. 2019). However, these effects were typically observed at EHDPP concentrations much higher (0.36–18 mg/L) than in the fish studies above.

The chemical TEHP induced anti-estrogenic activity at concentrations ≥ 0.43 mg/L in Chinese hamster ovary cells. Antagonistic activity against the estrogen receptor *α* was observed in a gene reporter assay with Chinese hamster ovary cells upon exposure to TEHP. The activity was concentration dependent and the lowest observed effect concentration was 0.43 mg/L. Similar effects were observed in a hybrid yeast-human assay (Zhang Q et al. 2014).

Chemicals TEHP and BEHPP exhibited antagonistic activity in a hybrid yeast-human retinoic acid receptor (RAR) assay. In this assay, both chemicals inhibited the β-galactosidase activity induced by all-*trans*-retinoic acid, with half-inhibitory concentrations of 1.1 mg/L and 2.6 mg/l, respectively (Jia et al. 2022).

The solvent DMSO was used as a vehicle in all the studies cited above.

Predicted no-effect concentration (PNEC)

Aquatic organisms

A PNEC for TEHP of 0.14 µg/L (140 ng/L) for aquatic life was derived. In the absence of effects up to the solubility limit of the chemical, the water solubility of TEHP was taken as a worst-case scenario for the PNEC of TEHP in water.

A PNEC for EHDPP of 36 ng/L for aquatic life was derived from the measured reproductive endpoint for fish (100 d MATC = 3.6 µg/L), using an assessment factor of 100. This assessment factor was chosen to be protective of potential intergenerational effects for EHDPP based on evidence such as;

- EHDPP is bioaccumulative with demonstrated maternal transfer.
- In addition to effects on reproduction, EHDPP appears to cause a variety of developmental effects in fish, such as ocular deformity.
- EHDPP is biologically active in receptor activation studies and influences known endocrine activity biomarkers.

Soil-dwelling organisms

A PNEC for TEHP of 3.7 mg/kg dw (3,700 µg/kg dw) for soil-dwelling organisms was derived from the measured plant toxicity endpoint (14 d fresh weight NOEC = 37 mg/kg dw for tomato), using an assessment factor of 10. This assessment factor was selected as long-term toxicity data were available for a producer (plants), a consumer (earthworms), and a decomposer (soil micro-organisms) (EPHC 2009).

Sediment-dwelling organisms

A PNEC for TEHP of 0.83 mg/kg dw (830 µg/kg dw) for sediment-dwelling organisms was derived from the measured toxicity endpoint for *Chironomus riparius* (28 d emergence and development rate NOEC = 83 mg/kg dw), using an assessment factor of 100. This assessment factor was selected as long-term toxicity data were available for one species (EPHC 2009).

A PNEC for EHDPP of 0.225 mg/kg dw (225 µg/kg dw) for sediment-dwelling organisms was derived from the chronic endpoint for aquatic invertebrates using the equilibrium partitioning method. The endpoint for aquatic invertebrates was chosen over the fish or algae endpoints as sediment-dwelling organisms are mostly invertebrates. An assessment factor of 10 was applied to this endpoint. A sediment-water partition partitioning coefficient of 1251 L/kg based on dw was estimated using the calculated K_{OC} (US EPA 2017), and assuming a fraction of organic contents in the sediment of 4% (EPHC 2009). An additional assessment factor of 10 was applied to the resulting PNEC in order to take uptake via ingestion of sediment into account, as the log K_{OW} of EHDPP is above 5 (EPHC 2009).

Categorisation of environmental hazard

The categorisation of the environmental hazards of the assessed chemicals according to domestic environmental hazard thresholds (DCCEEW n.d.) is presented below:

Persistence

Persistent (P). Based on measured degradation studies for TEHP, TEHP is categorised as Persistent.

Not Persistent (Not P). Based on measured degradation studies for EHDPP, chemicals EHDPP and ODPP are categorised as Not Persistent.

No data are available for BEHPP. In the absence of information, BEHPP is categorised as Persistent based on conservative read across from TEHP.

Bioaccumulation

Bioaccumulative (B). Based on high measured log K_{OW} for EHDPP, high calculated log K_{OW} for TEHP and BEHPP, and evidence of bioaccumulation and biomagnification of TEHP and

EHDPP in the field, chemicals TEHP, EHDPP, BEHPP and ODPP are categorised as Bioaccumulative.

Toxicity

Toxic (T). Based on available ecotoxicity values below 1 mg/L and evidence of chronic toxicity and endocrine activity in fish for EHDPP, chemicals EHDPP and ODPP are categorised as Toxic.

Not toxic (Not T). Based on the absence of toxic effects to aquatic life up to the solubility limit, and low toxicity to sediment- and soil-dwelling organisms, the chemical TEHP is categorised as Not Toxic.

No data are available for BEHPP. In the absence of information, BEHPP is categorised as Toxic based on conservative read across from EHDPP.

Environmental hazard classification

The available acute aquatic toxicity information for these chemicals reported in this evaluation was not considered to be suitable for classification purposes. None of these chemicals have been classified for acute aquatic toxicity. Chronic aquatic toxicity classifications have been made with consideration for persistence and potential to bioaccumulate, where relevant.

The GHS classification of TEHP has been made considering that the chemical has no acute toxicity effects up to its water solubility but is persistent and bioaccumulative with log K_{OW} > 4.

The GHS classification of EHDPP and ODPP has been made considering the rapid degradation of these chemicals and considering the 100 d MATC to medaka (3.6 µg/L) as the key endpoint for classification.

Environmental risk characterisation

Based on the PEC and PNEC values determined above, the following Risk Quotients (RQ = PEC ÷ PNEC) have been calculated for the exposure of TEHP in the water, soil, and sediment compartments:

Compartment	PEC	PNEC	RQ
Surface waters	10 ng/L	140 ng/L	0.070
Sediment	530 µg/kg dw	830 µg/kg dw	0.64
Soil	93 µg/kg dw	3,700 µg/kg dw	0.03

The chemical TEHP is not expected to pose a significant risk to the environment. The calculated RQ values for this chemical in surface waters, soil, and sediment are less than 1. Environmental concentrations of TEHP are expected to be below levels likely to cause harmful effects in typical environmental conditions.

Based on the PEC and PNEC values determined in the previous sections, the following Risk Quotients (RQ = PEC ÷ PNEC) have been calculated for the exposure of EHDPP in the water and sediment compartments:

Compartment	PEC	PNEC	RQ
Surface waters	22 ng/L	36 ng/L	0.61
Sediment	64 µg/kg dw	225 µg/kg dw	0.28

The chemical EHDPP is not expected to pose a significant risk to the environment. The calculated RQ values for this chemical in surface waters and sediment are less than 1. Environmental concentrations of EHDPP are expected to be below levels likely to cause harmful effects in typical environmental conditions.

The PNEC for EHDPP in aquatic life was based on a chronic reproduction endpoint for medaka fish. Reduced egg hatching rates were observed after exposure of male medaka to EHDPP for 100 days. While the concentrations of EHDPP in the test medium were not well maintained in this study, accumulation of the chemical in fish tissues led to body burdens comparable to biota levels observed in wild fish in Europe. Monitoring data in biota are not available for EHDPP in Australia, so the risk to aquatic life based on accumulated body burden is uncertain. Additional studies and in vitro experiments showed that EHDPP and its hydroxylated metabolite 5-OH-EHDPP have endocrine activity in fish and suggested that 5-OH-EHDPP may be more biologically active than the parent chemical. These risks were considered in the conservative assessment factor of 100 applied to the pivotal endpoint. Concentrations of hydroxylated metabolites in surface waters are expected to be below levels of concern based on monitoring data in STP influents in Europe.

For EHDPP in sediments, the calculated RQ < 1 indicates that the chemical is not expected to be present in sediments at concentrations that may cause harmful effects. The sediment PEC and PNEC for EHDPP were derived using the equilibrium partitioning method. While the equilibrium partitioning method is a useful tool to estimate RQs for sediment-dwelling organisms, it is considered only as a screen for assessing the risk. Toxicity tests on benthic organisms and Australian sediment monitoring data would support a refined environmental risk assessment for the sediment compartment.

No data regarding the ecotoxicity of EHDPP to soil-dwelling organisms are available. As a result, no RQ for the release of the chemical to soil has been calculated. If more information becomes available, a risk characterisation of EHDPP in soil may be possible. Environmental levels of EHDPP in soil measured internationally are relatively low, suggesting that the risk to soil-dwelling organisms is likely to be low.

As ODPP is considered to be a synonym for EHDPP, the risk characterisation of EHDPP is considered to apply to ODPP.

The chemical BEHPP has been identified as a potentially PBT substance. This categorisation is based on conservative read across from other chemicals in this group, as no hazard or degradation data are available for this chemical. Given its chemical structure and physical and chemical properties, the environmental hazards of BEHPP are expected to lie in between those of TEHP and EHDPP. The worst outcomes from TEHP and EHDPP were conservatively used as read across for each of the P, B, and T categorisations. If ecotoxicity or degradation data become available for BEHPP, this PBT categorisation may be revised. However, based on the provisional PBT categorisation, it is not currently possible to

derive a safe environmental exposure level for this chemical. Therefore, the environmental risks for BEHPP cannot be characterised in terms of a risk quotient.

Due to their persistence, PBT chemicals have the potential to become widely dispersed environmental contaminants. Once in the environment, persistent chemicals that are also highly bioaccumulative pose an increased risk of accumulating in exposed organisms and of causing adverse effects. Importantly, it is difficult or impossible to reverse the adverse effects of PBT chemicals once they have been released to the environment. As a result, these chemicals are considered to be of high concern for the environment.

Based on available international data, the chemical is unlikely to be introduced in Australia except as a component of commercial EHDPP; however, the chemical is likely to be present in some imported articles.

Uncertainty

This evaluation was conducted based on a set of information that may be incomplete or limited in scope. Some relatively common data limitations can be addressed through the use of conservative assumptions (OECD 2019) or quantitative adjustments such as assessment factors (OECD 1995). Others must be addressed qualitatively, or on a case-by-case basis (OECD 2019).

The most consequential areas of uncertainty for this evaluation are;

- Most of the available ecotoxicity studies available for chemicals in this evaluation are not conducted according to standard methodology. In addition, these chemicals are difficult to test due to their very poor solubilities in water. The outcomes of the toxicity categorisation may need to be revised if additional information becomes available.
- Ecotoxicity data for sediment- and soil-dwelling organisms were not available for EHDPP. The risk to benthic organisms was screened using the equilibrium partitioning method. The outcomes of the evaluation may change if additional information becomes available.
- As no hazard data were available for BEHPP, its hazard assessment was conducted using conservative read across from TEHP and EHDPP. The outcomes of this evaluation may change if new information becomes available to indicate that the hazard characteristics of BEHPP are significantly different.
- Limited Australian monitoring data were available for chemicals in this group. Since TEHP and EHDPP were below their limits of detection in STP effluents in the key monitoring study in Australia, additional monitoring information with lower limits of detection would provide a better estimate of the levels of these chemicals in surface waters. Australian monitoring data for sediment and soil would allow for a refined assessment of the risks in these compartments. The outcomes of this evaluation may change if new monitoring information becomes available to indicate that environmental concentrations of TEHP and EHDPP in Australia are different from the predicted concentrations used in this evaluation.
- Chemicals TEHP and tris(1,3-dichloroisopropyl) phosphate (TDCIPP; CAS RN 13674-87-8) have similar molecular weights (434.6 and 430.9 g/mol, respectively) and may not be easily distinguished in monitoring studies. In one study, these chemicals were reported as an inseparable mixture (Gustavsson et al. 2018). The detection of TDCIPP may have been erroneously identified as TEHP in some other monitoring studies.

References

AICIS (Australian Industrial Chemicals Introduction Scheme) (2023) *Triphenyl phosphate and diphenyl phosphate*, AICIS, accessed 14 March 2024.

Alkan N, Alkan A, Castro-Jiménez J, Royer F, Papillon L, Ourgaud M and Sempéré R (2021) 'Environmental occurrence of phthalate and organophosphate esters in sediments across the Gulf of Lion (NW Mediterranean Sea)', *Science of The Total Environment,* **760**, pp 143412, doi:doi.org/10.1016/j.scitotenv.2020.143412.

Allinson M, Cassidy M, Kadokami K and Besley CH (2023) 'In situ calibration of passive sampling methods for urban micropollutants using targeted multiresidue GC and LC screening systems', *Chemosphere,* **311**, pp 136997, doi:doi.org/10.1016/j.chemosphere.2022.136997.

Alzualde A, Behl M, Sipes NS, Hsieh J-H, Alday A, Tice RR, Paules RS, Muriana A and Quevedo C (2018) 'Toxicity profiling of flame retardants in zebrafish embryos using a battery of assays for developmental toxicity, neurotoxicity, cardiotoxicity and hepatotoxicity toward human relevance', *Neurotoxicology and Teratology,* **70**, pp 40-50, doi:doi.org/10.1016/j.ntt.2018.10.002.

Awonaike B, Lei YD and Wania F (2021) 'Precipitation-induced transport and phase partitioning of organophosphate esters (OPEs) in urban and rural watersheds', *Environmental Science: Water Research & Technology,* **7**(11), pp 2106-2115, doi:10.1039/D1EW00329A.

Aznar-Alemany Ò, Sala B, Plön S, Bouwman H, Barceló D and Eljarrat E (2019) 'Halogenated and organophosphorus flame retardants in cetaceans from the southwestern Indian Ocean', *Chemosphere,* **226**, pp 791-799, doi:doi.org/10.1016/j.chemosphere.2019.03.165.

Been F, Bastiaensen M, Lai FY, van Nuijs ALN and Covaci A (2017) 'Liquid Chromatography–Tandem Mass Spectrometry Analysis of Biomarkers of Exposure to Phosphorus Flame Retardants in Wastewater to Monitor Community-Wide Exposure', *Analytical Chemistry,* **89**(18), pp 10045-10053, doi:10.1021/acs.analchem.7b02705.

Been F, Bastiaensen M, Lai FY, Libousi K, Thomaidis NS, Benaglia L, Esseiva P, Delémont O, van Nuijs ALN and Covaci A (2018) 'Mining the Chemical Information on Urban Wastewater: Monitoring Human Exposure to Phosphorus Flame Retardants and Plasticizers', *Environmental Science & Technology,* **52**(12), pp 6996-7005, doi:10.1021/acs.est.8b01279.

Behl M, Hsieh J-H, Shafer TJ, Mundy WR, Rice JR, Boyd WA, Freedman JH, Hunter ES, Jarema KA, Padilla S and Tice RR (2015) 'Use of alternative assays to identify and prioritize organophosphorus flame retardants for potential developmental and neurotoxicity', *Neurotoxicology and Teratology,* **52**, pp 181-193, doi:doi.org/10.1016/j.ntt.2015.09.003.

Behl M, Rice JR, Smith MV, Co CA, Bridge MF, Hsieh J-H, Freedman JH and Boyd WA (2016) 'Editor's Highlight: Comparative Toxicity of Organophosphate Flame Retardants and Polybrominated Diphenyl Ethers to Caenorhabditiselegans', *Toxicological Sciences,* **154**(2), pp 241-252, doi:10.1093/toxsci/kfw162.

Bekele TG, Zhao H, Wang Y, Jiang J and Tan F (2018) 'Measurement and prediction of bioconcentration factors of organophosphate flame retardants in common carp (Cyprinus

carpio)', *Ecotoxicology and Environmental Safety,* **166**, pp 270-276, doi:doi.org/10.1016/j.ecoenv.2018.09.089.

Bekele TG, Zhao H, Wang Q and Chen J (2019) 'Bioaccumulation and Trophic Transfer of Emerging Organophosphate Flame Retardants in the Marine Food Webs of Laizhou Bay, North China', *Environmental Science & Technology,* **53**(22), pp 13417-13426, doi:10.1021/acs.est.9b03687.

Blum KM, Andersson PL, Ahrens L, Wiberg K and Haglund P (2018) 'Persistence, mobility and bioavailability of emerging organic contaminants discharged from sewage treatment plants', *Science of The Total Environment,* **612**, pp 1532-1542, doi:doi.org/10.1016/j.scitotenv.2017.09.006.

Brandsma SH, Leonards PEG, Leslie HA and de Boer J (2015) 'Tracing organophosphorus and brominated flame retardants and plasticizers in an estuarine food web', *Science of The Total Environment,* **505**, pp 22-31, doi:doi.org/10.1016/j.scitotenv.2014.08.072.

Campo J, Lorenzo M, Cammeraat ELH, Picó Y and Andreu V (2017) 'Emerging contaminants related to the occurrence of forest fires in the Spanish Mediterranean', *Science of The Total Environment,* **603-604**, pp 330-339, doi:doi.org/10.1016/j.scitotenv.2017.06.005.

Cao D, Guo J, Wang Y, Li Z, Liang K, Corcoran MB, Hosseini S, Bonina SMC, Rockne KJ, Sturchio NC, Giesy JP, Liu J, Li A and Jiang G (2017) 'Organophosphate Esters in Sediment of the Great Lakes', *Environmental Science & Technology,* **51**(3), pp 1441-1449, doi:10.1021/acs.est.6b05484.

Castro-Jiménez J, González-Gaya B, Pizarro M, Casal P, Pizarro-Álvarez C and Dachs J (2016) 'Organophosphate Ester Flame Retardants and Plasticizers in the Global Oceanic Atmosphere', *Environmental Science & Technology,* **50**(23), pp 12831-12839, doi:10.1021/acs.est.6b04344.

Castro-Jiménez J, Cuny P, Militon C, Sylvi L, Royer F, Papillon L and Sempéré R (2022) 'Effective degradation of organophosphate ester flame retardants and plasticizers in coastal sediments under high urban pressure', *Scientific Reports,* **12**(1), pp 20228, doi:10.1038/s41598-022-24685-6.

Castro G, Sørmo E, Yu G, Sait STL, González SV, Arp HPH and Asimakopoulos AG (2023) 'Analysis, occurrence and removal efficiencies of organophosphate flame retardants (OPFRs) in sludge undergoing anaerobic digestion followed by diverse thermal treatments', *Science of The Total Environment,* **870**, pp 161856, doi:doi.org/10.1016/j.scitotenv.2023.161856.

Celano R, Rodríguez I, Cela R, Rastrelli L and Piccinelli AL (2014) 'Liquid chromatography quadrupole time-of-flight mass spectrometry quantification and screening of organophosphate compounds in sludge', *Talanta,* **118**, pp 312-320, doi:doi.org/10.1016/j.talanta.2013.10.024.

Chen M, Tian J, Gan Z, Wu J, Ding S and Su S (2024a) 'Tissue distribution and trophic transfer of organophosphate triesters and diesters in three marine mammals of the Liaodong Bay and the Northern Yellow Sea', *Journal of Hazardous Materials,* **461**, pp 132694, doi:doi.org/10.1016/j.jhazmat.2023.132694.

Chen Y, Song Y, Chen Y-J, Zhang Y, Li R, Wang Y, Qi Z, Chen Z-F and Cai Z (2020) 'Contamination profiles and potential health risks of organophosphate flame retardants in

PM2.5 from Guangzhou and Taiyuan, China', *Environment International,* **134**, pp 105343, doi:doi.org/10.1016/j.envint.2019.105343.

Chen Y, Xian H, Zhu C, Li Y, Pei Z, Yang R, Zhang Q and Jiang G (2024b) 'The transport and distribution of novel brominated flame retardants (NBFRs) and organophosphate esters (OPEs) in soils and moss along mountain valleys in the Himalayas', *Journal of Hazardous Materials,* **465**, pp 133044, doi:doi.org/10.1016/j.jhazmat.2023.133044.

Cong B, Li S, Liu S, Mi W, Liu S, Zhang Z and Xie Z (2022) 'Source and Distribution of Emerging and Legacy Persistent Organic Pollutants in the Basins of the Eastern Indian Ocean', *Environmental Science & Technology,* **56**(7), pp 4199-4209, doi:10.1021/acs.est.1c08743.

Cristale J, García Vázquez A, Barata C and Lacorte S (2013) 'Priority and emerging flame retardants in rivers: Occurrence in water and sediment, Daphnia magna toxicity and risk assessment', *Environment International,* **59**, pp 232-243, doi:doi.org/10.1016/j.envint.2013.06.011.

Cristale J, Ramos DD, Dantas RF, Machulek Junior A, Lacorte S, Sans C and Esplugas S (2016) 'Can activated sludge treatments and advanced oxidation processes remove organophosphorus flame retardants?', *Environmental Research,* **144**, pp 11-18, doi:doi.org/10.1016/j.envres.2015.10.008.

Cristale J, Dantas RF, De Luca A, Sans C, Esplugas S and Lacorte S (2017) 'Role of oxygen and DOM in sunlight induced photodegradation of organophosphorous flame retardants in river water', *Journal of Hazardous Materials,* **323**, pp 242-249, doi:doi.org/10.1016/j.jhazmat.2016.05.019.

DAWE (Department of Agriculture, Water and Environment) (2022) *Spatio-temporal Trends of Emerging Contaminants in Wastewater*, DAWE.

DCCEEW (Department of Climate Change, Energy, the Environment and Water) (n.d.) *Australian Environmental Criteria for Persistent, Bioaccumulative and/or Toxic Chemicals,* accessed 14 March 2024.

Ding Y, Han M, Wu Z, Zhang R, Li A, Yu K, Wang Y, Huang W, Zheng X and Mai B (2020) 'Bioaccumulation and trophic transfer of organophosphate esters in tropical marine food web, South China Sea', *Environment International,* **143**, pp 105919, doi:doi.org/10.1016/j.envint.2020.105919.

ECHA (European Chemicals Agency) (2020) *Registered substances,* ECHA, accessed 14 March 2024.

ECHA (European Chemicals Agency) (2023) *Guidance on Information Requirements and Chemical Safety Assessment – Chapter R.11: PBT/vPvB assessment*, ECHA, accessed 14 March 2024.

EPHC (Environment Protection and Heritage Council) (2009) *Environmental Risk Assessment Guidance Manual for Industrial Chemicals,* EPHC, accessed 14 March 2024.

Evenset A, Leknes H, Christensen GN, Warner N, Remberger M and Gabrielsen GW (2009) *Screening of new contaminants in samples from the Norwegian Arctic,* Norwegian Pollution Control Authority, accessed 14 March 2024.

Evenset A, Anna O, Harju M and Gabrielsen G (2018) *Settlements on Svalbard as sources for emerging contaminants,* Norwegian Pollution Control Authority, accessed 14 March 2024.

Fu J, Fu K, Gao K, Li H, Xue Q, Chen Y, Wang L, Shi J, Fu J, Zhang Q, Zhang A and Jiang G (2020) 'Occurrence and Trophic Magnification of Organophosphate Esters in an Antarctic Ecosystem: Insights into the Shift from Legacy to Emerging Pollutants', *Journal of Hazardous Materials,* **396**, pp 122742, doi:doi.org/10.1016/j.jhazmat.2020.122742.

Fu J, Fu K, Chen Y, Li X, Ye T, Gao K, Pan W, Zhang A and Fu J (2021) 'Long-Range Transport, Trophic Transfer, and Ecological Risks of Organophosphate Esters in Remote Areas', *Environmental Science & Technology,* **55**(15), pp 10192-10209, doi:10.1021/acs.est.0c08822.

Gadelha JR, Rocha AC, Camacho C, Eljarrat E, Peris A, Aminot Y, Readman JW, Boti V, Nannou C, Kapsi M, Albanis T, Rocha F, Machado A, Bordalo A, Valente LMP, Nunes ML, Marques A and Almeida CMR (2019) 'Persistent and emerging pollutants assessment on aquaculture oysters (Crassostrea gigas) from NW Portuguese coast (Ria De Aveiro)', *Science of The Total Environment,* **666**, pp 731-742, doi:doi.org/10.1016/j.scitotenv.2019.02.280.

Gao X, Huang C, Rao K, Xu Y, Huang Q, Wang F, Ma M and Wang Z (2018) 'Occurrences, sources, and transport of hydrophobic organic contaminants in the waters of Fildes Peninsula, Antarctica', *Environmental Pollution,* **241**, pp 950-958, doi:doi.org/10.1016/j.envpol.2018.06.025.

Gao X, Xu Y, Ma M, Huang Q, Gabrielsen GW, Hallanger I, Rao K, Lu Z and Wang Z (2020) 'Distribution, sources and transport of organophosphorus flame retardants in the water and sediment of Ny-Ålesund, Svalbard, the Arctic', *Environmental Pollution,* **264**, pp 114792, doi:doi.org/10.1016/j.envpol.2020.114792.

Garcia-Garin O, Vighi M, Sala B, Aguilar A, Tsangaris C, Digka N, Kaberi H, Eljarrat E and Borrell A (2020) 'Assessment of organophosphate flame retardants in Mediterranean Boops boops and their relationship to anthropization levels and microplastic ingestion', *Chemosphere,* **252**, pp 126569, doi:doi.org/10.1016/j.chemosphere.2020.126569.

Ginebreda A, Sabater-Liesa L, Rico A, Focks A and Barceló D (2018) 'Reconciling monitoring and modeling: An appraisal of river monitoring networks based on a spatial autocorrelation approach - emerging pollutants in the Danube River as a case study', *Science of The Total Environment,* **618**, pp 323-335, doi:doi.org/10.1016/j.scitotenv.2017.11.020.

Giulivo M, Capri E, Kalogianni E, Milacic R, Majone B, Ferrari F, Eljarrat E and Barceló D (2017) 'Occurrence of halogenated and organophosphate flame retardants in sediment and fish samples from three European river basins', *Science of The Total Environment,* **586**, pp 782-791, doi:doi.org/10.1016/j.scitotenv.2017.02.056.

Gong S, Deng Y, Ren K, Meng W, Ye L, Han C and Su G (2021) 'Newly discovered bis-(2-ethylhexyl)-phenyl phosphate (BEHPP) was a ubiquitous contaminant in surface soils from a typical region, South China', *Science of The Total Environment,* **770**, pp 145350, doi:doi.org/10.1016/j.scitotenv.2021.145350.

Greaves AK and Letcher RJ (2014) 'Comparative Body Compartment Composition and In Ovo Transfer of Organophosphate Flame Retardants in North American Great Lakes Herring

Gulls', *Environmental Science & Technology,* **48**(14), pp 7942-7950, doi:10.1021/es501334w.

Green N, Schlabach M, Bakke T, Brevik E, Dye C, Herzke D, Huber S, Plosz B, Remberger M, Schøyen M, Uggerud H and Vogelsang C (2008) *Screening of selected metals and new organic contaminants 2007. Phosphorus flame retardents, polyfluorinated organic compounds, nitro-PAHs, silver, platinum and sucralose in air, wastewater treatment falcilities, and freshwater and marine recipients*, Norwegian Pollution Control Authority, accessed 14 March 2024.

Grung M, Meland S, Ruus A, Ranneklev S, Fjeld E, Kringstad A, Rundberget JT, Dela Cruz M and Christensen JH (2021) 'Occurrence and trophic transport of organic compounds in sedimentation ponds for road runoff', *Science of The Total Environment,* **751**, pp 141808, doi:doi.org/10.1016/j.scitotenv.2020.141808.

Guo J, Romanak K, Westenbroek S, Hites RA and Venier M (2017a) 'Current-Use Flame Retardants in the Water of Lake Michigan Tributaries', *Environmental Science & Technology,* **51**(17), pp 9960-9969, doi:10.1021/acs.est.7b01294.

Guo J, Venier M, Salamova A and Hites RA (2017b) 'Bioaccumulation of Dechloranes, organophosphate esters, and other flame retardants in Great Lakes fish', *Science of The Total Environment,* **583**, pp 1-9, doi:doi.org/10.1016/j.scitotenv.2016.11.063.

Guo J, Simon K, Romanak K, Bowerman W and Venier M (2018) 'Accumulation of flame retardants in paired eggs and plasma of bald eagles', *Environmental Pollution,* **237**, pp 499-507, doi:doi.org/10.1016/j.envpol.2018.02.056.

Gustavsson J, Wiberg K, Ribeli E, Nguyen MA, Josefsson S and Ahrens L (2018) 'Screening of organic flame retardants in Swedish river water', *Science of The Total Environment,* **625**, pp 1046-1055, doi:doi.org/10.1016/j.scitotenv.2017.12.281.

Gustavsson J, Wiberg K, Nguyen MA, Josefsson S, Laudon H and Ahrens L (2019) 'Seasonal trends of legacy and alternative flame retardants in river water in a boreal catchment', *Science of The Total Environment,* **692**, pp 1097-1105, doi:doi.org/10.1016/j.scitotenv.2019.07.158.

Haglund P (2022) *Screening of new flame retardants in biota,* Swedish Environmental Protection Agency, accessed 14 March 2024.

Hallanger IG, Sagerup K, Evenset A, Kovacs KM, Leonards P, Fuglei E, Routti H, Aars J, Strøm H, Lydersen C and Gabrielsen GW (2015) 'Organophosphorous flame retardants in biota from Svalbard, Norway', *Marine Pollution Bulletin,* **101**(1), pp 442-447, doi:doi.org/10.1016/j.marpolbul.2015.09.049.

Han B, Chen L, Li Y, Yu L, Zhang J, Tao S and Liu W (2022) 'Spatial distribution and risk assessment of 11 organophosphate flame retardants in soils from different regions of agricultural farmlands in mainland China', *Science of The Total Environment,* **842**, pp 156806, doi:doi.org/10.1016/j.scitotenv.2022.156806.

Han X, Hao Y, Li Y, Yang R, Wang P, Zhang G, Zhang Q and Jiang G (2020) 'Occurrence and distribution of organophosphate esters in the air and soils of Ny-Ålesund and London Island, Svalbard, Arctic', *Environmental Pollution,* **263**, pp 114495, doi:doi.org/10.1016/j.envpol.2020.114495.

Harrad S, Brommer S and Mueller JF (2016) 'Concentrations of organophosphate flame retardants in dust from cars, homes, and offices: An international comparison', *Emerging Contaminants,* **2**(2), pp 66-72, doi:doi.org/10.1016/j.emcon.2016.05.002.

Hattori Y, Ishitani H, Kuge Y and Nakamoto M (1981) 'Environmental Fate of Organic Phosphate Esters', *Japan journal of water pollution research,* **4**(3), pp 137-141, doi:10.2965/jswe1978.4.137.

He C, English K, Baduel C, Thai P, Jagals P, Ware RS, Li Y, Wang X, Sly PD and Mueller JF (2018a) 'Concentrations of organophosphate flame retardants and plasticizers in urine from young children in Queensland, Australia and associations with environmental and behavioural factors', *Environmental Research,* **164**, pp 262-270, doi:doi.org/10.1016/j.envres.2018.02.040.

He C, Wang X, Thai P, Baduel C, Gallen C, Banks A, Bainton P, English K and Mueller JF (2018b) 'Organophosphate and brominated flame retardants in Australian indoor environments: Levels, sources, and preliminary assessment of human exposure', *Environmental Pollution,* **235**, pp 670-679, doi:doi.org/10.1016/j.envpol.2017.12.017.

He W, Ding J, Liu W, Zhong W, Zhu L, Zhu L and Feng J (2023) 'Occurrence, bioaccumulation and trophic transfer of organophosphate esters in marine food webs: Evidence from three bays in Bohai Sea, China', *Science of The Total Environment,* **861**, pp 160658, doi:doi.org/10.1016/j.scitotenv.2022.160658.

Hou R, Liu C, Gao X, Xu Y, Zha J and Wang Z (2017) 'Accumulation and distribution of organophosphate flame retardants (PFRs) and their di-alkyl phosphates (DAPs) metabolites in different freshwater fish from locations around Beijing, China', *Environmental Pollution,* **229**, pp 548-556, doi:doi.org/10.1016/j.envpol.2017.06.097.

Huang Q, Hou R, Lin L, Li H, Liu S, Cheng Y and Xu X (2023) 'Bioaccumulation and Trophic Transfer of Organophosphate Flame Retardants and Their Metabolites in the Estuarine Food Web of the Pearl River, China', *Environmental Science & Technology,* **57**(9), pp 3549-3561, doi:10.1021/acs.est.2c05619.

Huang Y, Tan H, Li L, Yang L, Sun F, Li J, Gong X and Chen D (2020) 'A broad range of organophosphate tri- and di-esters in house dust from Adelaide, South Australia: Concentrations, compositions, and human exposure risks', *Environment International,* **142**, pp 105872, doi:doi.org/10.1016/j.envint.2020.105872.

Huber S, Warner NA, Nygård T, Remberger M, Harju M, Uggerud HT, Kaj L and Hanssen L (2015) 'A broad cocktail of environmental pollutants found in eggs of three seabird species from remote colonies in Norway', *Environmental Toxicology and Chemistry,* **34**(6), pp 1296-1308, doi:doi.org/10.1002/etc.2956.

Ishikawa S, Shigezumi K, Yasuda K and Shigemori N (1985) 'Behaviours of organic phosphate esters in several water treatment processes', *Japan journal of water pollution research,* **8**(12), pp 799-807, doi:10.2965/jswe1978.8.799.

Jarema KA, Hunter DL, Shaffer RM, Behl M and Padilla S (2015) 'Acute and developmental behavioral effects of flame retardants and related chemicals in zebrafish', *Neurotoxicology and Teratology,* **52**, pp 194-209, doi:doi.org/10.1016/j.ntt.2015.08.010.

Jia Y, Zhang H, Hu W, Wang L, Kang Q, Liu J, Nakanishi T, Hiromori Y, Kimura T, Tao S and Hu J (2022) 'Discovery of contaminants with antagonistic activity against retinoic acid

receptor in house dust', *Journal of Hazardous Materials,* **426**, pp 127847, doi:doi.org/10.1016/j.jhazmat.2021.127847.

Kang Y, Zhang R, Yu K, Han M, Li H, Yan A, Liu F, Shi J and Wang Y (2023) 'Organophosphate esters (OPEs) in a coral reef food web of the Xisha Islands, South China Sea: Occurrence, trophodynamic, and exposure risk', *Chemosphere,* **313**, pp 137652, doi:doi.org/10.1016/j.chemosphere.2022.137652.

Kim J-W, Isobe T, Chang K-H, Amano A, Maneja RH, Zamora PB, Siringan FP and Tanabe S (2011) 'Levels and distribution of organophosphorus flame retardants and plasticizers in fishes from Manila Bay, the Philippines', *Environmental Pollution,* **159**(12), pp 3653-3659, doi:doi.org/10.1016/j.envpol.2011.07.020.

Kim U-J, Oh JK and Kannan K (2017) 'Occurrence, Removal, and Environmental Emission of Organophosphate Flame Retardants/Plasticizers in a Wastewater Treatment Plant in New York State', *Environmental Science & Technology,* **51**(14), pp 7872-7880, doi:10.1021/acs.est.7b02035.

Kim U-J and Kannan K (2018) 'Occurrence and Distribution of Organophosphate Flame Retardants/Plasticizers in Surface Waters, Tap Water, and Rainwater: Implications for Human Exposure', *Environmental Science & Technology,* **52**(10), pp 5625-5633, doi:10.1021/acs.est.8b00727.

Lassen CL, S; Andersen, LI (1999) *Brominated Flame Retardants - Substance Flow Analysis and Assessment of Alternatives*, accessed 14 March 2024.

Lee H-K, Lee S, Lim J-E and Moon H-B (2020) 'Legacy and novel flame retardants in water and sediment from highly industrialized bays of Korea: Occurrence, source tracking, decadal time trend, and ecological risks', *Marine Pollution Bulletin,* **160**, pp 111639, doi:doi.org/10.1016/j.marpolbul.2020.111639.

Letcher RJ, Morris AD, Dyck M, Sverko E, Reiner EJ, Blair DAD, Chu SG and Shen L (2018) 'Legacy and new halogenated persistent organic pollutants in polar bears from a contamination hotspot in the Arctic, Hudson Bay Canada', *Science of The Total Environment,* **610-611**, pp 121-136, doi:doi.org/10.1016/j.scitotenv.2017.08.035.

Li J, Wang J, Taylor AR, Cryder Z, Schlenk D and Gan J (2019a) 'Inference of Organophosphate Ester Emission History from Marine Sediment Cores Impacted by Wastewater Effluents', *Environmental Science & Technology,* **53**(15), pp 8767-8775, doi:10.1021/acs.est.9b01713.

Li J, Zhang Y, Bi R, Ye L and Su G (2022d) 'High-Resolution Mass Spectrometry Screening of Emerging Organophosphate Esters (OPEs) in Wild Fish: Occurrence, Species-Specific Difference, and Tissue-Specific Distribution', *Environmental Science & Technology,* **56**(1), pp 302-312, doi:10.1021/acs.est.1c05726.

Li R, Gao H, Hou C, Fu J, Shi T, Wu Z, Jin S, Yao Z, Na G and Ma X (2023) 'Occurrence, source, and transfer fluxes of organophosphate esters in the South Pacific and Fildes Peninsula, Antarctic', *Science of The Total Environment,* **894**, pp 164263, doi:doi.org/10.1016/j.scitotenv.2023.164263.

Li T-Y, Bao L-J, Wu C-C, Liu L-Y, Wong CS and Zeng EY (2019b) 'Organophosphate flame retardants emitted from thermal treatment and open burning of e-waste', *Journal of Hazardous Materials,* **367**, pp 390-396, doi:doi.org/10.1016/j.jhazmat.2018.12.041.

Li W, Wang Y and Kannan K (2019c) 'Occurrence, distribution and human exposure to 20 organophosphate esters in air, soil, pine needles, river water, and dust samples collected around an airport in New York state, United States', *Environment International,* **131**, pp 105054, doi:doi.org/10.1016/j.envint.2019.105054.

Li Y, Kang Q, Chen R, He J, Liu L, Wang L and Hu J (2020) '2-Ethylhexyl Diphenyl Phosphate and Its Hydroxylated Metabolites are Anti-androgenic and Cause Adverse Reproductive Outcomes in Male Japanese Medaka (Oryzias latipes)', *Environmental Science & Technology,* **54**(14), pp 8919-8925, doi:10.1021/acs.est.0c02775.

Li Y, Ma H, Chen R, Zhang H, Nakanishi T and Hu J (2021) 'Maternal Transfer of 2-Ethylhexyl Diphenyl Phosphate Leads to Developmental Toxicity Possibly by Blocking the Retinoic Acid Receptor and Retinoic X Receptor in Japanese Medaka (Oryzias latipes)', *Environmental Science & Technology,* **55**(8), pp 5056-5064, doi:10.1021/acs.est.0c06809.

Li Y, Xiong S, Hao Y, Yang R, Zhang Q, Wania F and Jiang G (2022e) 'Organophosphate esters in Arctic air from 2011 to 2019: Concentrations, temporal trends, and potential sources', *Journal of Hazardous Materials,* **434**, pp 128872, doi:doi.org/10.1016/j.jhazmat.2022.128872.

Liu Q, Liggio J, Wu D, Saini A, Halappanavar S, Wentzell JJB, Harner T, Li K, Lee P and Li S-M (2019) 'Experimental Study of OH-Initiated Heterogeneous Oxidation of Organophosphate Flame Retardants: Kinetics, Mechanism, and Toxicity', *Environmental Science & Technology,* **53**(24), pp 14398-14408, doi:10.1021/acs.est.9b05327.

Liu Y-E, Luo X-J, Zapata Corella P, Zeng Y-H and Mai B-X (2019a) 'Organophosphorus flame retardants in a typical freshwater food web: Bioaccumulation factors, tissue distribution, and trophic transfer', *Environmental Pollution,* **255**, pp 113286, doi:doi.org/10.1016/j.envpol.2019.113286.

Liu Y-E, Tang B, Liu Y, Luo X-J, Mai B-X, Covaci A and Poma G (2019b) 'Occurrence, biomagnification and maternal transfer of legacy and emerging organophosphorus flame retardants and plasticizers in water snake from an e-waste site', *Environment International,* **133**, pp 105240, doi:doi.org/10.1016/j.envint.2019.105240.

Liu Y-E, Luo X-J, Liu Y, Zeng Y-H and Mai B-X (2021) 'Bioaccumulation of legacy and emerging organophosphorus flame retardants and plasticizers in insects during metamorphosis', *Journal of Hazardous Materials,* **406**, pp 124688, doi:doi.org/10.1016/j.jhazmat.2020.124688.

Liu Y, Liggio J, Harner T, Jantunen L, Shoeib M and Li S-M (2014) 'Heterogeneous OH Initiated Oxidation: A Possible Explanation for the Persistence of Organophosphate Flame Retardants in Air', *Environmental Science & Technology,* **48**(2), pp 1041-1048, doi:10.1021/es404515k.

Loos R, Carvalho R, António DC, Comero S, Locoro G, Tavazzi S, Paracchini B, Ghiani M, Lettieri T, Blaha L, Jarosova B, Voorspoels S, Servaes K, Haglund P, Fick J, Lindberg RH, Schwesig D and Gawlik BM (2013) 'EU-wide monitoring survey on emerging polar organic contaminants in wastewater treatment plant effluents', *Water Research,* **47**(17), pp 6475-6487, doi:doi.org/10.1016/j.watres.2013.08.024.

Lorenzo M, Campo J, Morales Suárez-Varela M and Picó Y (2019) 'Occurrence, distribution and behavior of emerging persistent organic pollutants (POPs) in a Mediterranean wetland

protected area', *Science of The Total Environment,* **646**, pp 1009-1020, doi:doi.org/10.1016/j.scitotenv.2018.07.304.

Lu Z, Martin PA, Burgess NM, Champoux L, Elliott JE, Baressi E, De Silva AO, de Solla SR and Letcher RJ (2017) 'Volatile Methylsiloxanes and Organophosphate Esters in the Eggs of European Starlings (Sturnus vulgaris) and Congeneric Gull Species from Locations across Canada', *Environmental Science & Technology,* **51**(17), pp 9836-9845, doi:10.1021/acs.est.7b03192.

Ma Y, Cui K, Zeng F, Wen J, Liu H, Zhu F, Ouyang G, Luan T and Zeng Z (2013) 'Microwave-assisted extraction combined with gel permeation chromatography and silica gel cleanup followed by gas chromatography–mass spectrometry for the determination of organophosphorus flame retardants and plasticizers in biological samples', *Analytica Chimica Acta,* **786**, pp 47-53, doi:doi.org/10.1016/j.aca.2013.04.062.

Marklund A, Andersson B and Haglund P (2003) 'Screening of organophosphorus compounds and their distribution in various indoor environments', *Chemosphere,* **53**(9), pp 1137-1146, doi:doi.org/10.1016/S0045-6535(03)00666-0.

Marklund A, Andersson B and Haglund P (2005) 'Organophosphorus Flame Retardants and Plasticizers in Swedish Sewage Treatment Plants', *Environmental Science & Technology,* **39**(19), pp 7423-7429, doi:10.1021/es051013l.

Mata MC, Castro V, Quintana JB, Rodil R, Beiras R and Vidal-Liñán L (2022) 'Bioaccumulation of organophosphorus flame retardants in the marine mussel Mytilus galloprovincialis', *Science of The Total Environment,* **805**, pp 150384, doi:doi.org/10.1016/j.scitotenv.2021.150384.

Matsukami H, Tue NM, Suzuki G, Someya M, Tuyen LH, Viet PH, Takahashi S, Tanabe S and Takigami H (2015) 'Flame retardant emission from e-waste recycling operation in northern Vietnam: Environmental occurrence of emerging organophosphorus esters used as alternatives for PBDEs', *Science of The Total Environment,* **514**, pp 492-499, doi:doi.org/10.1016/j.scitotenv.2015.02.008.

McDonough CA, De Silva AO, Sun C, Cabrerizo A, Adelman D, Soltwedel T, Bauerfeind E, Muir DCG and Lohmann R (2018) 'Dissolved Organophosphate Esters and Polybrominated Diphenyl Ethers in Remote Marine Environments: Arctic Surface Water Distributions and Net Transport through Fram Strait', *Environmental Science & Technology,* **52**(11), pp 6208-6216, doi:10.1021/acs.est.8b01127.

Möller A, Sturm R, Xie Z, Cai M, He J and Ebinghaus R (2012) 'Organophosphorus Flame Retardants and Plasticizers in Airborne Particles over the Northern Pacific and Indian Ocean toward the Polar Regions: Evidence for Global Occurrence', *Environmental Science & Technology,* **46**(6), pp 3127-3134, doi:10.1021/es204272v.

Muir DCG, Yarechewski AL and Grift NP (1989) 'Biodegradation of four triaryl/alkyl phosphate esters in sediment under various temperature and redox conditions∗', *Toxicological & Environmental Chemistry,* **18**(4), pp 269-286, doi:10.1080/02772248909357320.

Na G, Hou C, Li R, Shi Y, Gao H, Jin S, Gao Y, Jiao L and Cai Y (2020) 'Occurrence, distribution, air-seawater exchange and atmospheric deposition of organophosphate esters (OPEs) from the Northwestern Pacific to the Arctic Ocean', *Marine Pollution Bulletin,* **157**, pp 111243, doi:doi.org/10.1016/j.marpolbul.2020.111243.

Nantaba F, Palm W-U, Wasswa J, Bouwman H, Kylin H and Kümmerer K (2021) 'Temporal dynamics and ecotoxicological risk assessment of personal care products, phthalate ester plasticizers, and organophosphorus flame retardants in water from Lake Victoria, Uganda', *Chemosphere,* **262**, pp 127716, doi:doi.org/10.1016/j.chemosphere.2020.127716.

NCBI (National Center for Biotechnology Information) (n.d.-a) *PubChem Compound Summary for CID 6537, Tris(2-ethylhexyl) phosphate,* National Library of Medicine (US), NCBI, accessed 14 March 2024.

NCBI (National Center for Biotechnology Information) (n.d.-b) *PubChem Compound Summary for CID 14716, 2-Ethylhexyl diphenyl phosphate,* National Library of Medicine (US), NCBI, accessed 14 March 2024.

Ng K, Alygizakis N, Nika M-C, Galani A, Oswald P, Oswaldova M, Čirka Ľ, Kunkel U, Macherius A, Sengl M, Mariani G, Tavazzi S, Skejo H, Gawlik BM, Thomaidis NS and Slobodnik J (2023) 'Wide-scope target screening characterization of legacy and emerging contaminants in the Danube River Basin by liquid and gas chromatography coupled with high-resolution mass spectrometry', *Water Research,* **230**, pp 119539, doi:doi.org/10.1016/j.watres.2022.119539.

NICNAS (National Industrial Chemicals Notification and Assessment Scheme) (2016) *2-Ethylhexyl diphenyl phosphate: Human health tier II assessment,* NICNAS, accessed 14 March 2024.

Nordic Council of Ministers (n.d.) *Substances in Preparations in Nordic Countries (SPIN),* Chemical Group, Nordic Council of Ministers, accessed 14 March 2024.

Noyes PD, Haggard DE, Gonnerman GD and Tanguay RL (2015) 'Advanced Morphological — Behavioral Test Platform Reveals Neurodevelopmental Defects in Embryonic Zebrafish Exposed to Comprehensive Suite of Halogenated and Organophosphate Flame Retardants', *Toxicological Sciences,* **145**(1), pp 177-195, doi:10.1093/toxsci/kfv044.

O'Brien JW, Thai PK, Brandsma SH, Leonards PEG, Ort C and Mueller JF (2015) 'Wastewater analysis of Census day samples to investigate per capita input of organophosphorus flame retardants and plasticizers into wastewater', *Chemosphere,* **138**, pp 328-334, doi:doi.org/10.1016/j.chemosphere.2015.06.014.

OECD (Organisation for Economic Co-operation and Development) (1995) *Guidance document for aquatic effects assessment*, OECD, Paris.

OECD (Organisation for Economic Cooperations and Development) (2010) *Guidance document on the diagnosis of endocrine-related histopathology in fish gonads,* OECD, accessed 14 March 2024.

OECD (Organisation for Economic Cooperation and Development) (2011) *Resource compendium of PRTR release estimation techniques, Part 4: summary of techniques for releases from products, version 1.0*, OECD, accessed 14 March 2024.

OECD (The Organisation for Economic Co-operation and Development) (2019) *Guiding Principles and Key Elements for Establishing a Weight of Evidence for Chemical Assessment, Series on Testing and Assessment No. 311, Environment, Health and Safety Division, Environment Directorate*, OECD, accessed 14 March 2024.

OECD (Organisation for Economic Cooperation and Development) (n.d.) *OECD Existing Chemicals Database,* OECD, accessed 14 March 2024.

Ofrydopoulou A, Nannou C, Evgenidou E, Christodoulou A and Lambropoulou D (2022) 'Assessment of a wide array of organic micropollutants of emerging concern in wastewater treatment plants in Greece: Occurrence, removals, mass loading and potential risks', *Science of The Total Environment,* **802**, pp 149860, doi:doi.org/10.1016/j.scitotenv.2021.149860.

Onoja S, Abdallah MA-E and Harrad S (2023) 'Concentrations, spatial and seasonal variations of Organophosphate esters in UK freshwater Sediment', *Emerging Contaminants,* **9**(3), pp 100243, doi:doi.org/10.1016/j.emcon.2023.100243.

Pakalin S, Cole T, Steinkellner J, Nicolas R, Tissier C, Munn S and Eisenreich S (2007) *Review on Production Processes of Decabromodiphenyl Ether (decaBDE) Used in Polymeric Applications in Electrical and Electronic Equipment, and Assessment of the Availability of Potential Alternatives to decaBDE*, European Commission, accessed 14 March 2024.

Pantelaki I and Voutsa D (2021) 'Organophosphate esters in inland and coastal waters in northern Greece', *Science of The Total Environment,* **800**, pp 149544, doi:doi.org/10.1016/j.scitotenv.2021.149544.

Pantelaki I and Voutsa D (2022) 'Occurrence and removal of organophosphate esters in municipal wastewater treatment plants in Thessaloniki, Greece', *Environmental Research,* **214**, pp 113908, doi:doi.org/10.1016/j.envres.2022.113908.

Papachlimitzou A, Barber JL, Losada S, Bersuder P, Deaville R, Brownlow A, Penrose R, Jepson PD and Law RJ (2015) 'Organophosphorus flame retardants (PFRs) and plasticisers in harbour porpoises (Phocoena phocoena) stranded or bycaught in the UK during 2012', *Marine Pollution Bulletin,* **98**(1), pp 328-334, doi:doi.org/10.1016/j.marpolbul.2015.06.034.

Peng X, Chen G, Fan Y, Zhu Z, Guo S, Zhou J and Tan J (2021) 'Lifetime bioaccumulation, gender difference, tissue distribution, and parental transfer of organophosphorus plastic additives in freshwater fish', *Environmental Pollution,* **280**, pp 116948, doi:doi.org/10.1016/j.envpol.2021.116948.

Peverly AA, O'Sullivan C, Liu L-Y, Venier M, Martinez A, Hornbuckle KC and Hites RA (2015) 'Chicago's Sanitary and Ship Canal sediment: Polycyclic aromatic hydrocarbons, polychlorinated biphenyls, brominated flame retardants, and organophosphate esters', *Chemosphere,* **134**, pp 380-386, doi:doi.org/10.1016/j.chemosphere.2015.04.065.

Pintado-Herrera MG, Combi T, Corada-Fernández C, González-Mazo E and Lara-Martín PA (2017) 'Occurrence and spatial distribution of legacy and emerging organic pollutants in marine sediments from the Atlantic coast (Andalusia, SW Spain)', *Science of The Total Environment,* **605-606**, pp 980-994, doi:doi.org/10.1016/j.scitotenv.2017.06.055.

Pintado-Herrera MG, Allan IJ, González-Mazo E and Lara-Martín PA (2020) 'Passive Samplers vs Sentinel Organisms: One-Year Monitoring of Priority and Emerging Contaminants in Coastal Waters', *Environmental Science & Technology,* **54**(11), pp 6693-6702, doi:10.1021/acs.est.0c00522.

Rauert C, Schuster JK, Eng A and Harner T (2018) 'Global Atmospheric Concentrations of Brominated and Chlorinated Flame Retardants and Organophosphate Esters', *Environmental Science & Technology,* **52**(5), pp 2777-2789, doi:10.1021/acs.est.7b06239.

REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) (n.d.-a) *REACH registration dossier for Tris(2-ethylhexyl) phosphate (CAS RN 78-42-2),* European Chemicals Agency website, accessed 14 March 2024.

REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) (n.d.-b) *REACH registration dossier for 2-ethylhexyl diphenyl phosphate (CAS RN 1241-94-7),* European Chemicals Agency website, accessed 14 March 2024.

REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) (n.d.-c) *REACH registration dossier for Bis(2-ethylhexyl) hydrogen phosphate (CAS RN 298-07-7),* European Chemicals Agency website, accessed 14 March 2024.

REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) (n.d.-d) *REACH registration dossier for 2-ethylhexan-1-ol (CAS RN 104-76-7),* European Chemicals Agency website, accessed 14 March 2024.

REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) (n.d.-e) *REACH registration dossier for Phenol (CAS RN 108-95-2),* European Chemicals Agency website, accessed 14 March 2024.

Rede D, Teixeira I, Delerue-Matos C and Fernandes VC (2024) 'Assessing emerging and priority micropollutants in sewage sludge: environmental insights and analytical approaches', *Environmental Science and Pollution Research,* **31**(2), pp 3152-3168, doi:10.1007/s11356-023-30963-1.

Regnery J and Püttmann W (2010) 'Seasonal fluctuations of organophosphate concentrations in precipitation and storm water runoff', *Chemosphere,* **78**(8), pp 958-964, doi:doi.org/10.1016/j.chemosphere.2009.12.027.

Saeger VW, Hicks O, Kaley RG, Michael PR, Mieure JP and Tucker ES (1979) 'Environmental fate of selected phosphate esters', *Environmental Science & Technology,* **13**(7), pp 840-844, doi:10.1021/es60155a010.

Sala B, Giménez J, de Stephanis R, Barceló D and Eljarrat E (2019) 'First determination of high levels of organophosphorus flame retardants and plasticizers in dolphins from Southern European waters', *Environmental Research,* **172**, pp 289-295, doi:doi.org/10.1016/j.envres.2019.02.027.

Salamova A, Hermanson MH and Hites RA (2014) 'Organophosphate and Halogenated Flame Retardants in Atmospheric Particles from a European Arctic Site', *Environmental Science & Technology,* **48**(11), pp 6133-6140, doi:10.1021/es500911d.

Sánchez-Piñero J, Bowerbank SL, Moreda-Piñeiro J, López-Mahía P and Dean JR (2020) 'The occurrence and distribution of polycyclic aromatic hydrocarbons, bisphenol A and organophosphate flame retardants in indoor dust and soils from public open spaces: Implications for human exposure', *Environmental Pollution,* **266**, pp 115372, doi:doi.org/10.1016/j.envpol.2020.115372.

Santín G, Eljarrat E and Barceló D (2016) 'Simultaneous determination of 16 organophosphorus flame retardants and plasticizers in fish by liquid chromatography-tandem mass spectrometry', *Journal of Chromatography A,* **1441**, pp 34-43, doi:doi.org/10.1016/j.chroma.2016.02.058.

Schang G, Robaire B and Hales BF (2016) 'Organophosphate Flame Retardants Act as Endocrine-Disrupting Chemicals in MA-10 Mouse Tumor Leydig Cells', *Toxicological Sciences,* **150**(2), pp 499-509, doi:10.1093/toxsci/kfw012.

Schmidt N, Castro-Jiménez J, Oursel B and Sempéré R (2021) 'Phthalates and organophosphate esters in surface water, sediments and zooplankton of the NW Mediterranean Sea: Exploring links with microplastic abundance and accumulation in the marine food web', *Environmental Pollution,* **272**, pp 115970, doi:doi.org/10.1016/j.envpol.2020.115970.

Shen J, Zhang Y, Yu N, Crump D, Li J, Su H, Letcher RJ and Su G (2019) 'Organophosphate Ester, 2-Ethylhexyl Diphenyl Phosphate (EHDPP), Elicits Cytotoxic and Transcriptomic Effects in Chicken Embryonic Hepatocytes and Its Biotransformation Profile Compared to Humans', *Environmental Science & Technology,* **53**(4), pp 2151-2160, doi:10.1021/acs.est.8b06246.

Shimabuku I, Chen D, Wu Y, Miller E, Sun J and Sutton R (2022) 'Occurrence and risk assessment of organophosphate esters and bisphenols in San Francisco Bay, California, USA', *Science of The Total Environment,* **813**, pp 152287, doi:doi.org/10.1016/j.scitotenv.2021.152287.

Shoeib M, Ahrens L, Jantunen L and Harner T (2014) 'Concentrations in air of organobromine, organochlorine and organophosphate flame retardants in Toronto, Canada', *Atmospheric Environment,* **99**, pp 140-147, doi:doi.org/10.1016/j.atmosenv.2014.09.040.

Shu Y, Yuan J, Hogstrand C, Xue Z, Wang X, Liu C, Li T, Li D and Yu L (2024) 'Bioaccumulation and thyroid endcrione disruption of 2-ethylhexyl diphenyl phosphate at environmental concentration in zebrafish larvae', *Aquatic Toxicology,* **267**, pp 106815, doi:doi.org/10.1016/j.aquatox.2023.106815.

Strobel A, Willmore WG, Sonne C, Dietz R and Letcher RJ (2018) 'Organophosphate esters in East Greenland polar bears and ringed seals: Adipose tissue concentrations and in vitro depletion and metabolite formation', *Chemosphere,* **196**, pp 240-250, doi:doi.org/10.1016/j.chemosphere.2017.12.181.

Struijs J (1996) *SimpleTreat 3.0: a model to predict the distribution and elimination of chemicals by sewage treatment plants*, National Institute of Public Health and the Environment (RIVM).

Su G, Letcher RJ and Yu H (2016) 'Organophosphate Flame Retardants and Plasticizers in Aqueous Solution: pH-Dependent Hydrolysis, Kinetics, and Pathways', *Environmental Science & Technology,* **50**(15), pp 8103-8111, doi:10.1021/acs.est.6b02187.

Sühring R, Diamond ML, Scheringer M, Wong F, Pućko M, Stern G, Burt A, Hung H, Fellin P, Li H and Jantunen LM (2016a) 'Organophosphate Esters in Canadian Arctic Air: Occurrence, Levels and Trends', *Environmental Science & Technology,* **50**(14), pp 7409-7415, doi:10.1021/acs.est.6b00365.

Sühring R, Wolschke H, Diamond ML, Jantunen LM and Scheringer M (2016b) 'Distribution of Organophosphate Esters between the Gas and Particle Phase–Model Predictions vs Measured Data', *Environmental Science & Technology,* **50**(13), pp 6644-6651, doi:10.1021/acs.est.6b00199.

Sühring R, Diamond ML, Bernstein S, Adams JK, Schuster JK, Fernie K, Elliott K, Stern G and Jantunen LM (2021) 'Organophosphate Esters in the Canadian Arctic Ocean', *Environmental Science & Technology,* **55**(1), pp 304-312, doi:10.1021/acs.est.0c04422.

Sundkvist AM, Olofsson U and Haglund P (2010) 'Organophosphorus flame retardants and plasticizers in marine and fresh water biota and in human milk', *Journal of Environmental Monitoring,* **12**(4), pp 943-951, doi:10.1039/B921910B.

Sutton R, Chen D, Sun J, Greig DJ and Wu Y (2019) 'Characterization of brominated, chlorinated, and phosphate flame retardants in San Francisco Bay, an urban estuary', *Science of The Total Environment,* **652**, pp 212-223, doi:doi.org/10.1016/j.scitotenv.2018.10.096.

Syed JH, Iqbal M, Breivik K, Chaudhry MJI, Shahnawaz M, Abbas Z, Nasir J, Rizvi SHH, Taqi MM, Li J and Zhang G (2020) 'Legacy and emerging flame retardants (FRs) in the urban atmosphere of Pakistan: Diurnal variations, gas-particle partitioning and human health exposure', *Science of The Total Environment,* **743**, pp 140874, doi:doi.org/10.1016/j.scitotenv.2020.140874.

UK EA (UK Environment Agency) (2009) *Environmental risk evaluation report: 2-Ethylhexyl diphenyl phosphate (CAS no. 1241-94-7)*, accessed 14 March 2024.

UNECE (United Nations Economic Commission for Europe) (2017) *Globally Harmonized System of Classification and Labelling of Chemicals (GHS), Seventh Revised Edition,* UNECE, accessed 14 March 2024.

UNEP (United Nations Environment Programme) (1987) *The Montreal Protocol on Substances that Deplete the Ozone Layer,* UNEP, Ozone Secretariat, accessed 14 March 2024.

UNEP (United Nations Environment Programme) (2001) *The Stockholm Convention on Persistent Organic Pollutants,* UNEP, Secretariat of the Stockholm Convention, accessed 14 March 2024.

UNEP & FAO (United Nations Environment Programme & Food and Agriculture Organization of the United Nations) (1998) *Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade,* UNEP & FAO, accessed 14 March 2024.

UNEP IPCS (United Nations Environment Progamme, International Programme on Chemical Safety) (2000) *Environmental Health Criteria 218. Flame retardants: Tris(2-butoxyethyl) phosphate, Tris(2-ethylhexyl) phosphate and tetrakis(hydroxymethyl) phosphonium salts*, accessed 14 March 2024.

US EPA (United States Environmental Protection Agency) (2017) *Estimation Programs Interface (EPI) SuiteTM for Microsoft Windows®*, v 4.11, US EPA.

US EPA (United States Environmental Protection Agency) (2020) *2020 Chemical Data Reporting (CDR) data,* US EPA, downloaded 25 May 2023.

Valtris Specialty Chemicals (n.d.) *Valtris Specialty Additives Portfolio – SANTICIZER(R) 141,* accessed 14 March 2024.

van der Veen I and de Boer J (2012) 'Phosphorus flame retardants: Properties, production, environmental occurrence, toxicity and analysis', *Chemosphere,* **88**(10), pp 1119-1153, doi:doi.org/10.1016/j.chemosphere.2012.03.067.

Verbruggen EMJ, Rila JP, Traas TP, Posthuma-Doodeman CJAM and Posthumus R (2005) *Environmental Risk Limits for several phosphate esters, with possible application as flame retardant*, accessed 14 March 2024.

Verreault J, Letcher RJ, Gentes M-L and Braune BM (2018) 'Unusually high Deca-BDE concentrations and new flame retardants in a Canadian Arctic top predator, the glaucous gull', *Science of The Total Environment,* **639**, pp 977-987, doi:doi.org/10.1016/j.scitotenv.2018.05.222.

Violaki K, Castro-Jiménez J, Nenes A, Sempere R and Panagiotopoulos C (2024) 'Spatial and temporal patterns of organophosphate Esters flame retardants and plasticizers in airborne particles over the Mediterranean sea', *Chemosphere,* **348**, pp 140746, doi:doi.org/10.1016/j.chemosphere.2023.140746.

Wang C, Wang P, Zhao J, Fu M, Zhang L, Li Y, Yang R, Zhu Y, Fu J, Zhang Q and Jiang G (2020) 'Atmospheric organophosphate esters in the Western Antarctic Peninsula over 2014–2018: Occurrence, temporal trend and source implication', *Environmental Pollution,* **267**, pp 115428, doi:doi.org/10.1016/j.envpol.2020.115428.

Wang S, Qian J, Zhang B, Chen L, Wei S and Pan B (2023a) 'Unveiling the Occurrence and Potential Ecological Risks of Organophosphate Esters in Municipal Wastewater Treatment Plants across China', *Environmental Science & Technology,* **57**(5), pp 1907-1918, doi:10.1021/acs.est.2c06077.

Wang S, Zheng N, Sun S, Ji Y, An Q, Li X, Li Z and Zhang W (2023b) 'Bioaccumulation of organophosphorus flame retardants in marine organisms in Liaodong Bay and their potential ecological risks based on species sensitivity distribution', *Environmental Pollution,* **317**, pp 120812, doi:doi.org/10.1016/j.envpol.2022.120812.

Wang W, Qing X, Wang J, He T, Fan R and Huang Y (2022) 'Bioaccumulation and potential risk of organophosphate flame retardants in coral reef fish from the Nansha Islands, South China Sea', *Chemosphere,* **287**, pp 132125, doi:doi.org/10.1016/j.chemosphere.2021.132125.

Wang X, Zhong W, Xiao B, Liu Q, Yang L, Covaci A and Zhu L (2019) 'Bioavailability and biomagnification of organophosphate esters in the food web of Taihu Lake, China: Impacts of chemical properties and metabolism', *Environment International,* **125**, pp 25-32, doi:doi.org/10.1016/j.envint.2019.01.018.

Wang Y, Sun H, Zhu H, Yao Y, Chen H, Ren C, Wu F and Kannan K (2018) 'Occurrence and distribution of organophosphate flame retardants (OPFRs) in soil and outdoor settled dust from a multi-waste recycling area in China', *Science of The Total Environment,* **625**, pp 1056-1064, doi:doi.org/10.1016/j.scitotenv.2018.01.013.

Wang Y, Kannan P, Halden RU and Kannan K (2019) 'A nationwide survey of 31 organophosphate esters in sewage sludge from the United States', *Science of The Total Environment,* **655**, pp 446-453, doi:doi.org/10.1016/j.scitotenv.2018.11.224.

Wolschke H, Sühring R, Mi W, Möller A, Xie Z and Ebinghaus R (2016) 'Atmospheric occurrence and fate of organophosphorus flame retardants and plasticizer at the German coast', *Atmospheric Environment,* **137**, pp 1-5, doi:doi.org/10.1016/j.atmosenv.2016.04.028.

Woudneh MB, Benskin JP, Wang G, Grace R, Hamilton MC and Cosgrove JR (2015) 'Quantitative determination of 13 organophosphorous flame retardants and plasticizers in a wastewater treatment system by high performance liquid chromatography tandem mass spectrometry', *Journal of Chromatography A,* **1400**, pp 149-155, doi:doi.org/10.1016/j.chroma.2015.04.026.

Xie J, Pei N, Sun Y, Chen Z, Cheng Y, Chen L, Xie C, Dai S, Zhu C, Luo X, Zhang L and Mai B (2022) 'Bioaccumulation and translocation of organophosphate esters in a Mangrove Nature Reserve from the Pearl River Estuary, South China', *Journal of Hazardous Materials,* **427**, pp 127909, doi:doi.org/10.1016/j.jhazmat.2021.127909.

Xu S, Yu Y, Qin Z, Wang C, Hu Q and Jin Y (2023) 'Effects of 2-ethylhexyl diphenyl phosphate exposure on the glucolipid metabolism and cardiac developmental toxicity in larval zebrafish based on transcriptomic analysis', *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology,* **267**, pp 109578, doi:doi.org/10.1016/j.cbpc.2023.109578.

Yadav IC, Devi NL, Li J and Zhang G (2018a) 'Organophosphate ester flame retardants in Nepalese soil: Spatial distribution, source apportionment and air-soil exchange assessment', *Chemosphere,* **190**, pp 114-123, doi:doi.org/10.1016/j.chemosphere.2017.09.112.

Yadav IC, Devi NL, Li J, Zhang G and Covaci A (2018b) 'Concentration and spatial distribution of organophosphate esters in the soil-sediment profile of Kathmandu Valley, Nepal: Implication for risk assessment', *Science of The Total Environment,* **613-614**, pp 502-512, doi:doi.org/10.1016/j.scitotenv.2017.09.039.

Yan Z, Feng C, Leung KMY, Luo Y, Wang J, Jin X and Wu F (2023) 'Insights into the geographical distribution, bioaccumulation characteristics, and ecological risks of organophosphate esters', *Journal of Hazardous Materials,* **445**, pp 130517, doi:doi.org/10.1016/j.jhazmat.2022.130517.

Yang R, Wang X, Wang J, Chen P, Liu Q, Zhong W and Zhu L (2022) 'Insights into the sex-dependent reproductive toxicity of 2-ethylhexyl diphenyl phosphate on zebrafish (Danio rerio)', *Environment International,* **158**, pp 106928, doi:doi.org/10.1016/j.envint.2021.106928.

Yang R, Ye Y, Chen Y, Yang Y, Yang L, Yao Y, Zhong W and Zhu L (2023a) 'First Insight into the Formation of In Vivo Transformation Products of 2-Ethylhexyl diphenyl phosphate in Zebrafish and Prediction of Their Potential Toxicities', *Environmental Science & Technology,* **57**(1), pp 451-462, doi:10.1021/acs.est.2c05506.

Yang R, Zhang Y, Deng Y, Yang Y, Zhong W and Zhu L (2023b) '2-Ethylhexyl Diphenyl Phosphate Causes Obesity in Zebrafish by Stimulating Overeating via Inhibition of Dopamine Receptor D2', *Environmental Science & Technology,* **57**(38), pp 14162-14172, doi:10.1021/acs.est.3c04070.

Yang Y, Wang X, Zhang H, Li J, Chen J, Yu M, Li G, Zhang R and Ge M (2022) 'Oxidative stress and ferroptosis involved in 2-ethylhexyl diphenyl phosphate -induced hepatotoxicity in chicken', *Chemico-Biological Interactions,* **368**, pp 110216, doi:doi.org/10.1016/j.cbi.2022.110216.

Ye L, Meng W, Huang J, Li J and Su G (2021) 'Establishment of a Target, Suspect, and Functional Group-Dependent Screening Strategy for Organophosphate Esters (OPEs): “Into the Unknown” of OPEs in the Sediment of Taihu Lake, China', *Environmental Science & Technology,* **55**(9), pp 5836-5847, doi:10.1021/acs.est.0c07825.

Ye L and Su G (2022) 'Elevated concentration and high Diversity of organophosphate esters (OPEs) were Discovered in Sediment from Industrial, and E-Waste Recycling Areas', *Water Research,* **217**, pp 118362, doi:doi.org/10.1016/j.watres.2022.118362.

Yoshioka Y, Ose Y and Sato T (1985) 'Testing for the toxicity of chemicals with Tetrahymena pyriformis', *Science of The Total Environment,* **43**(1), pp 149-157, doi:doi.org/10.1016/0048-9697(85)90037-3.

You J, Chen Z-m, Hou X-y, Guo J-s, Wang C-c and Gao J-m (2022) 'Occurrence, potential sources and risks of organophosphate esters in the high-elevation region, Tibet, China', *Science of The Total Environment,* **806**, pp 151348, doi:doi.org/10.1016/j.scitotenv.2021.151348.

Yu Y, Yu X, Zhang D, Jin L, Huang J, Zhu X, Sun J, Yu M and Zhu L (2023) 'Biotransformation of Organophosphate Esters by Rice and Rhizosphere Microbiome: Multiple Metabolic Pathways, Mechanism, and Toxicity Assessment', *Environmental Science & Technology,* **57**(4), pp 1776-1787, doi:10.1021/acs.est.2c07796.

Zhang Q, Lu M, Dong X, Wang C, Zhang C, Liu W and Zhao M (2014) 'Potential Estrogenic Effects of Phosphorus-Containing Flame Retardants', *Environmental Science & Technology,* **48**(12), pp 6995-7001, doi:10.1021/es5007862.

Zhang S, Ireland D, Sipes NS, Behl M and Collins E-MS (2019) 'Screening for neurotoxic potential of 15 flame retardants using freshwater planarians', *Neurotoxicology and Teratology,* **73**, pp 54-66, doi:doi.org/10.1016/j.ntt.2019.03.003.

Zhang Y, Su H, Ya M, Li J, Ho S-H, Zhao L, Jian K, Letcher RJ and Su G (2019) 'Distribution of flame retardants in smartphones and identification of current-use organic chemicals including three novel aryl organophosphate esters', *Science of The Total Environment,* **693**, pp 133654, doi:doi.org/10.1016/j.scitotenv.2019.133654.

Zhang Y, Chen Y, Chen H, Zhang Y, Yang L, Zhong W and Zhu L (2023) 'Direct evidence of the important role of proteins in bioconcentration and biomagnification of PFASs in benthic organisms based on comparison with OPEs', *Science of The Total Environment,* **863**, pp 161012, doi:doi.org/10.1016/j.scitotenv.2022.161012.

Zhang Z, Xu Y, Wang Y, Li Z, Yang C, Rodgers TFM and Tan F (2022) 'Occurrence and distribution of organophosphate flame retardants in the typical soil profiles of the Tibetan Plateau, China', *Science of The Total Environment,* **807**, pp 150519, doi:doi.org/10.1016/j.scitotenv.2021.150519.

Zhao A, Wei C, Xin Y, Wang X, Zhu Q, Xie J, Ma H, Xu J and Wang M (2023) 'Pollution profiles, influencing factors, and source apportionment of target and suspect organophosphate esters in ambient air: A case study in a typical city of Northern China', *Journal of Hazardous Materials,* **444**, pp 130373, doi:doi.org/10.1016/j.jhazmat.2022.130373.

Zhao H, Zhao F, Liu J, Zhang S, Mu D, An L, Wan Y and Hu J (2018) 'Trophic transfer of organophosphorus flame retardants in a lake food web', *Environmental Pollution,* **242**, pp 1887-1893, doi:doi.org/10.1016/j.envpol.2018.07.077.

Zhao Y, Wang C, Xia S, Jiang J, Hu R, Yuan G and Hu J (2014) 'Biosensor medaka for monitoring intersex caused by estrogenic chemicals', *Environ Sci Technol,* **48**(4), pp 2413-20, doi:10.1021/es4052796.

Zheng X, Xu F, Luo X, Mai B and Covaci A (2016) 'Phosphate flame retardants and novel brominated flame retardants in home-produced eggs from an e-waste recycling region in China', *Chemosphere,* **150**, pp 545-550, doi:doi.org/10.1016/j.chemosphere.2015.09.098.