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

Hydroquinone and p-benzoquinone

Evaluation statement

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AICIS evaluation statement

Subject of the evaluation

Hydroquinone and p-benzoquinone

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2,5-Cyclohexadiene-1,4-dione, compound with 1,4-benzenediol (1:1)	106-34-3

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 1,4-benzenediol (hydroquinone), 2,5-cyclohexadiene-1,4-dione (p-benzoquinone), and 2,5-cyclohexadiene-1,4-dione, compound with 1,4-benzendiol (1:1) (quinhydrone). The chemicals are listed on the Australian Inventory of Industrial Chemicals (the Inventory).

Chemicals in this group have been assessed for their risks to the environment according to the following parameters:

- Domestic introduction volume in the range of 100–1000 tonnes per year (t/year) for hydroquinone.
- Default introduction volume of 100 t/year for the remaining chemicals in the evaluation.
- Industrial uses listed in the ‘Summary of Use’ section.

These chemicals have been assessed as a group as they are structurally similar, interconvert in the environment and share similar use patterns.

Summary of evaluation

Summary of introduction, use and end use

Hydroquinone has a reported Australian introduction volume in the range of 100–1000 t/year and reported Australian uses in photochemical reagents and photographic processing, resin, polymer and adhesive manufacturing, and cosmetics. There is currently no specific

information about the introduction, use and end use of p-benzoquinone and quinhydrone in Australia.

Internationally, hydroquinone and p-benzoquinone are predominantly used as polymerisation inhibitors for polyester resins and vinyl monomers, and as intermediates in the manufacture of various stabilisers used in adhesives, polymers and resins, and antioxidants used by the rubber and food industries. Hydroquinone is used as a reducing agent in photographic developers, although evidence points to a substantial decline in this use pattern over recent years.

Based on the reported Australian and international use patterns, the assessed industrial end use categories for these chemicals are:

- Adhesive and sealant products
- Arts, crafts and hobby products
- Personal care products – limited environmental release
- Plastic and polymer products
- Construction products not covered by other end uses
- Ink, toner and colourant products
- Personal care products not covered by other end uses
- Photographic products
- Water treatment products.

Reported volumes of hydroquinone from international jurisdictions indicate annual use volumes of up to 100 000 tonnes (t) in the European Economic Area (EEA), up to 44 643 tonnes (100 000 000 lb) in the United States of America (USA), and up to 14 789 t in Japan. Between 10 and 100 t of p-benzoquinone is used in the EEA each year.

No current domestic or international use or introduction information was identified for quinhydrone. It does not appear to have widespread industrial use.

Environment

Summary of environmental hazard characteristics

According to domestic environmental hazard thresholds and based on the available data, the chemicals in this group are:

- Not persistent (not P)
- Not bioaccumulative (not B)
- Toxic (T).

Environmental hazard classification

The chemicals in this group 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 evaluation does not consider classification of physical and health hazards.

For hydroquinone (CAS RN 123-31-9):

Environmental Hazard	Hazard Category	Hazard Statement
Hazardous to the aquatic environment (acute / short-term)	Aquatic Acute 1	H400: Very toxic to aquatic life
Hazardous to the aquatic environment (long-term)	Aquatic Chronic 1	H410: Very toxic to aquatic life with long lasting effects

For p-benzoquinone (CAS RN 106-51-4):

Environmental Hazard	Hazard Category	Hazard Statement
Hazardous to the aquatic environment (acute / short-term)	Aquatic Acute 1	H400: Very toxic to aquatic life

The environmental hazard classification of quinhydrone (CAS RN 106-34-3) has not been determined as part of this evaluation.

Summary of environmental risk

The chemicals in this group are not persistent (not P) and not bioaccumulative (not B), and toxic (T) according to Australian categorisation criteria. The environmental fate of these chemicals is linked. Hydroquinone and p-benzoquinone are expected to interconvert in the environment through biotic and abiotic processes. Quinhydrone is an addition complex of hydroquinone and p-benzoquinone that is expected to dissociate to these 2 components in the environment. Due to its much higher use volume, environmental emissions of hydroquinone are expected to be the main factor determining the concentration of chemicals in this group.

Hydroquinone and p-benzoquinone have similar primary industrial uses as intermediates and stabilisers in vinyl monomers and unsaturated polyester resins. Hydroquinone is also used as a reducing agent for photographic processing, though this use pattern is expected to have declined significantly in recent years. Hydroquinone has uses in cosmetic products, but these uses are regulated in Australia and are generally expected to be only a minor proportion of the total use volume.

Limited environmental release of the chemicals in this evaluation is expected. The chemicals are expected to be consumed during use as intermediates and stabilisers. Use in adhesive products may result in limited releases to air and soil. Some release to STPs may occur due to minor uses of the chemicals in cosmetics or photographic processing; however, considering historical Australian introduction volume data for hydroquinone and standard modelling approaches, typical concentrations in STP effluent are expected to be low. There is some evidence to suggest that raw effluent from manufacturing or reformulation facilities may contain relatively high concentrations of hydroquinone, but wastewater treatment processes are expected to mitigate these releases significantly.

Based on the available assessed hazard and exposure characteristics, including industry reported data held by AICIS, the chemicals reported in this evaluation are not expected to pose a significant risk to the environment.

Conclusions

The conclusions of this evaluation are based on the information described in this evaluation statement.

The Executive Director is satisfied that the identified environmental risks can be managed within existing risk management frameworks. This is provided that all requirements are met under environmental, workplace health and safety and poisons legislation as adopted by the relevant state or territory.

Note: Obligations to report additional information about hazards under *section 100* of the *Industrial Chemicals Act 2019* apply.

Supporting information

Rationale

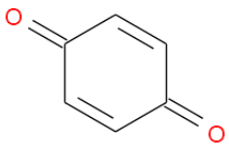
This evaluation considers the environmental risks associated with the industrial uses of hydroquinone, p-benzoquinone and quinhydrone in Australia. Hydroquinone and p-benzoquinone interconvert in the environment, while quinhydrone is a complex of hydroquinone and p-benzoquinone that largely dissociates into its components upon dissolution in water. Therefore, the concentrations of each chemical in the environment may be influenced by emissions of any of the three chemicals in this evaluation.

The Evaluation Selection Analysis (ESA) of hydroquinone and p-benzoquinone found evidence of high toxicity to aquatic life and potential for widespread environmental exposure. This evaluation includes a refinement of the risk characterisation and more detailed assessment of the available hazard and exposure data.

Chemical identity

Chemicals in this group contain a common six-membered ring structure functionalised by 2 oxygen-containing substituents in a *para*-arrangement. Hydroquinone consists of a benzene ring substituted by 2 hydroxyl groups, while p-benzoquinone is the oxidised derivative of hydroquinone, characterised by a cyclic diketone structure. Quinhydrone is a 1:1 complex of hydroquinone and p-benzoquinone.

CAS No.	123-31-9
Chemical name	1,4-Benzenediol
Synonyms	Hydroquinone (INCI name) quinol 1,4-dihydroxybenzene p-dihydroxybenzene p-benzenediol 4-hydroxyphenol hydroquinol benzoquinol
Structural formula	
Molecular formula	$C_6H_6O_2$
Molecular weight (g/mol)	110.11
SMILES	OC1=CC=C(O)C=C1
Chemical description	Appears as an off-white solid.

CAS No.	106-51-4
Chemical name	2,5-Cyclohexadiene-1,4-dione
Synonyms	p-benzoquinone quinone 1,4-quinone 1,4-benzoquinonecyclohexa-2,5-diene-1,4-dione
Structural formula	
Molecular formula	$C_6H_4O_2$
Molecular weight (g/mol)	108.09
SMILES	O=C1C=CC(=O)C=C1
Chemical description	Appears as a yellow solid.

CAS No.	106-34-3
Chemical name	2,5-Cyclohexadiene-1,4-dione, compound with 1,4-benzenediol (1:1)
Synonyms	quinhydrone green hydroquinone p-benzoquinhydrone
Molecular formula	$C_{12}H_{10}O_4$
Molecular weight (g/mol)	218.21
SMILES	OC1=CC=C(O)C=C1.O=C1C=CC(=O)C=C1
Chemical description	Equimolar complex formed from hydroquinone and p-benzoquinone. Appears as a green solid.

Relevant physical and chemical properties

The physical and chemical property data for 1,4-benzenediol (hydroquinone) and 2,5-cyclohexadiene-1,4-dione (p-benzoquinone) were retrieved from the registration dossiers for hydroquinone and p-benzoquinone submitted under the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) legislation in the European Union (EU) (REACHa; REACHb). The Henry's Law constant for hydroquinone was calculated in EPISuite 4.11 using the measured value for water solubility and the calculated value for vapour pressure (US EPA 2017). The Henry's Law constant for p-benzoquinone was calculated in EPISuite 4.11 using the measured values for water solubility and vapour pressure.

Chemical	Hydroquinone	p-Benzoquinone
Physical form	Solid	Solid
Melting point	172.3°C (exp.)	112.5°C (exp.)
Boiling point	287°C (exp.)	160°C decomposition (exp.)
Vapour pressure	3.2 x 10^{-3} Pa at 25°C (calc.)	3.9 Pa at 25°C (exp.)
Water solubility	72 g/L at 25°C (exp.)	14.7 g/L at 20°C (exp.)
Henry's law constant	4.89 x 10^{-6} Pa·m^3/mol (calc.)	2.87 x 10^{-2} Pa·m^3/mol (calc.)
Ionisable in the environment?	Yes	No
pKa	pka1 = 9.91 at 20°C (exp.) pka2 =11.56 at 20°C (exp.)	N/A
log K_{OW}	0.59 at 20–25°C (exp.)	0.2 at 23°C (exp.)

Chemicals in this group are solids at room temperature and pressure. They are readily soluble in water. Hydroquinone is expected to be partially deprotonated in basic environments. It interconverts with p-benzoquinone through an oxidation-reduction mechanism via a semibenzoquinone radical (Hudnall 2000). The experimental vapour pressure and estimated Henry's law constant indicate that hydroquinone is slightly volatile from water, wet and dry soils while p-benzoquinone is moderately volatile. The members of this group are hydrophilic based on the logarithmic octanol-water partition coefficients (log K_{OW}). At 4 grams per litre (g/L), the solubility of quinhydrone is slightly lower than hydroquinone and p-benzoquinone while its log K_{OW} is comparable at 0.16 (Sigma-Aldrich 2022).

Introduction and use

Australia

Based on information reported to the former National Industrial Chemicals Notification and Assessment Scheme (NICNAS) under previous mandatory and/or voluntary calls for information, the annual introduction volume of hydroquinone is in the range of 100–1000 t. Hydroquinone has reported Australian uses in resin and polymer manufacturing,

photochemical reagents and in photographic processing, stabilisers in resins used by the fibreglass industry and in adhesive manufacturing (NICNAS 2014).

Hydroquinone is currently available as an active pharmaceutical or excipient ingredient in biological products containing human or animal cells and microbiota, export only, over the counter and prescription medicines (TGA). As an excipient ingredient it is also available for use in devices, including medical X-ray equipment. The chemical is reportedly used as depigmenting agent in topical therapeutic products. These non-industrial uses are outside the parameters of this evaluation.

No specific Australian use information has been identified for p-benzoquinone and quinhydrone.

International

Hydroquinone is an Organisation for Economic Co-operation and Development (OECD) High Production Volume (HPV) chemical, indicating a use volume greater than or equal to 1000 t/year in at least one member country or region (OECD). The global production volume was estimated at 35 000 t in 1992 (OECD 2002). Aggregated production volumes of 4536–45 359 t/year were reported in the USA between 2016 and 2019 (US EPA 2020), while use volumes of 11 738–14 789 t/year were reported in Japan between 2016 and 2020 (NITE). Use volumes in the European Economic Area (EEA) are currently between 10 000 and 100 000 t/year (REACHa). The cumulative volume used in Nordic countries has declined from a peak volume of 417 t in 2001 to 13.3 t in 2019 (SPIN).

The chemical, p-benzoquinone appears to be used at much lower volumes than hydroquinone worldwide. The registered use volume under REACH is in the range of 10–100 t/year (REACHb); however, it may have a significant additional use volume under its separate registration as an intermediate.

Hydroquinone has significant use as an intermediate. A large proportion is consumed in the manufacture of antioxidants and antiozonants used in rubber and food, and additive stabilisers used for vinyl monomers and resins (Hudnall 2000). Other chemicals manufactured from hydroquinone include dyes, polymers, agrochemicals and stabilisers used in inks and coatings (REACHa). Hydroquinone has reported use in cosmetic nail products, face cleansers and moisturisers (NCBI; US EPAb). It is also used as a coupling agent in oxidative hair dye preparations (Associates). It is authorised for use (with a specific migration limit of 0.6 milligrams per kilogram of food) in food packaging contact materials under Annex I of Regulation (EU) No 10/2011 (EC 2011).

Hydroquinone has use as a reducing agent in photographic developers for black and white film, lithography, photochemical machining, microfilm and X-ray film (Hudnall 2000). In 1987, this represented the largest demand (37%) in the global market for hydroquinone (Hudnall 2000). However, current use patterns point to a decline in photographic processing activities over recent years. For example, the volume of hydroquinone reportedly used in “reprographic agents” and “photochemicals” in Nordic countries fell from 211.6 t in 2002 (71% of the total use volume for that year) to less than 3 t/year in total from 2017 (SPIN). This is consistent with the declining use of traditional film in favour of digital image formats across consumer (Lucas Jr and Goh 2009), medical and industrial sectors (Nsengiyumva et al. 2021; Seco et al. 2014).

Both hydroquinone and p-benzoquinone are used as additive stabilisers to prevent free radical polymerisation in vinyl monomers and unsaturated polyester resins during production, processing and storage (Hudnall 2000). Hydroquinone is also used to stabilise acrylic

adhesives and to inhibit corrosion in water cooling towers (Associates; Hudnall 2000; OECD 2002).

The chemical p-benzoquinone is reportedly used as a tanning agent for leather making (NCBI), as a bleaching agent and intensifier in holography (Bjelkhagen et al. 1991), and has reported use in paints, construction materials and adhesives (REACHb; SPIN). It is also used as a catalyst in the manufacture of mequinol (CAS RN 150-76-5) (Gambarotti et al. 2013), and is used as an intermediate in the manufacture of biocides and pharmaceuticals (NCBI).

There are no reported international uses or use volumes for quinhydrone. It is expected to have specialist laboratory uses only; for example in the preparation of the quinhydrone electrode used for pH determination (Yuqing et al. 2005).

Existing Australian regulatory controls

Environment

The industrial uses of the chemicals in this group are not subject to any specific national environmental regulations.

Public

Hydroquinone is listed on the *Poisons Standard, Standard for the Uniform Scheduling of Medicines and Poisons* (SUSMP) *as follows* (TGA 2022).

Schedule 2

HYDROQUINONE (excluding monobenzone and alkyl ethers of hydroquinone included in Schedule 4) in preparations for human external therapeutic or cosmetic use containing 2 per cent or less of hydroquinone **except**:

a) in hair preparations containing 0.3 per cent or less of hydroquinone; or

b) in cosmetic nail preparations containing 0.02 per cent or less of hydroquinone.

Schedule 4

HYDROQUINONE (other than its alkyl ethers separately specified in this Schedule) in preparations for human therapeutic or cosmetic use **except**:

a) when included in Schedule 2; or

b) in hair preparations containing 0.3 per cent or less of hydroquinone; or

c) in cosmetic nail preparations containing 0.02 per cent or less of hydroquinone.

Schedule 6

HYDROQUINONE **except**:

a) when included in Schedule 2 or 4; or

b) in preparations containing 10 per cent or less of hydroquinone.

International regulatory status

United Nations

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

OECD

Hydroquinone was sponsored by the USA under the Cooperative Chemicals Assessment Programme (CoCAP). The 3rd Screening Information Data Set (SIDS) Initial Meeting Assessment (SIAM 3) agreed that the chemical was a low priority for further work (OECD). A SIDS Initial Assessment Report (SIAR) published in 2002 concluded that processing sites, such as industrial photography, could present local environmental concern based on exposure modelling (OECD 2002).

Environmental exposure

The major uses of hydroquinone and p-benzoquinone as intermediates and as polymerisation inhibitors in monomers, resins and adhesives are not expected to result in significant release to the environment due to consumption of the parent chemical during use. Uses in photographic processing and cosmetics may result in release to wastewater but this is expected to represent a small proportion of the total use volume. Limited releases of chemicals in this group to air and soil are anticipated due to the use of hydroquinone in adhesives.

The chemicals in this evaluation have similar use patterns; however, environmental releases of hydroquinone are expected to dominate due to its larger total use volume. This is consistent with data retrieved from the United States Environmental Protection Agency (US EPA) toxics release inventory (TRI), which reports production related hydroquinone wastes in the USA of 1960–2324 t/year between 2015 and 2020, as opposed to 25–83 t/year reported for p-benzoquinone (US EPAa). Due to interconversion in the environment, emissions resulting from the industrial use of hydroquinone are considered the main factor in determining environmental concentrations of p-benzoquinone and quinhydrone.

Hydroquinone and p-benzoquinone are primarily used as intermediates in the manufacture of other substances; including antioxidants used by the rubber industry, dyes and pigments, stabilisers and agrochemicals (Hudnall 2000). As use in these processes results in consumption of the chemical, emissions are expected to be limited (EPHC 2009).

The use of chemicals in this group for photographic processing is not expected to contribute significantly to environmental releases in Australia. While photographic processing represented a large proportion of hydroquinone use historically (Hudnall 2000), evidence suggests that the use of chemicals in this area has greatly declined. The use of hydroquinone in photographic developers may also include significant non-industrial use in medical image development, while waste generated by industrial sources is expected to be disposed of as hazardous waste (Latimer 2021). DIY and hobbyist use of black and white developers and holographic bleaching agents may result in sporadic releases of hydroquinone and p-benzoquinone to wastewater, but total emissions are expected to be insignificant (OECD 2002).

Chemicals in this group are widely used as polymerisation inhibitors during the manufacture, storage and processing of vinyl monomers and unsaturated polyester resins (Hudnall 2000). Hydroquinone inhibits polymerisation by reducing aerobically produced peroxy radicals to nonradical products, during which it is expected to be oxidised to semibenzoquinone radicals and p-benzoquinone (Nesvadba 2012; Ramis and Salla 1995). p-Benzoquinone is a mild polymerisation inhibitor, reacting with free radicals to form other inhibitory by-products and residues (Novák 1988). These uses are not expected to cause significant environmental release as the chemicals are consumed during use. Emissions of residual, unreacted inhibitor from cured plastics are expected to be negligible, although limited releases to soil and wastewater may result from clean-up and equipment maintenance activities.

Hydroquinone is also used as a stabiliser in acrylic adhesives, extending the shelf life of these products by preventing polymerisation in the container (Associates; OECD 2015). In radical activated products, such as 2-part methyl methacrylate adhesives, hydroquinone is expected to be consumed upon curing. Releases of residual unreacted hydroquinone and p-benzoquinone impurities are likely to be low. By contrast, hydroquinone is not expected to participate in the curing of moisture activated adhesives, such as cyanoacrylate superglues, which undergo anionic polymerisation (Raja 2016). Therefore, releases of hydroquinone to soils and wastewater may result from leaching, abrasion and wear over the lifetime of these products. Releases to wastewater, soil and air may also occur during application and clean-up of adhesive products or during equipment maintenance at industrial sites (OECD 2015).

The use of hydroquinone in cosmetic products will result in releases to wastewater. However, these uses are expected to account for a negligible proportion of the total use volume of hydroquinone in Australia. In Australia, the use of hydroquinone in cosmetic products is restricted (TGA 2022).

Potentially emissive uses of chemicals in this group in leather tanning and water treatment are expected to account for a minor fraction of the total use volumes in Australia. Environmental release of quinhydrone due to its use in academic laboratories is expected to be negligible given that chemical wastes generated by these facilities are disposed of as hazardous waste.

Environmental fate

The chemicals in this group will be released to wastewater, soils and air as a result of their industrial uses. Water is expected to be the major affected compartment. Hydroquinone and p-benzoquinone are expected to degrade in the environment.

Partitioning

Hydroquinone is readily soluble in water while its low vapour pressure and Henry's Law constant indicate slight volatility. p-Benzoquinone has a moderate vapour pressure and its Henry's Law constant indicates moderate volatility from water. The calculated octanol-soil partition coefficients (K_{OC}) of 41–241 L/kg are consistent with moderate-high mobility in soils for hydroquinone and p-benzoquinone, respectively (US EPA 2017). Quinhydrone is slightly volatile and readily soluble in water.

Calculations using a standard multimedia partitioning (fugacity) model, parameterised for equal and continuous emissions of the chemicals to water, soil and air (level III approach), predict that hydroquinone and p-benzoquinone will mainly partition to soil (69.5–82.3%) then water (17.5–28.7%) upon release to the environment (US EPA 2017). Calculations parameterised for exclusive emissions to water predict that the chemicals will remain in this

compartment upon release (>98%), while releases to air are expected to partition to soil. Therefore, quinhydrone is expected to accumulate in water and soil.

Degradation

Chemicals in this group are expected to degrade in the environment.

Hydroquinone readily oxidises in the environment. This involves the initial loss of an electron and proton to form a semibenzoquinone radical, with subsequent oxidation and proton elimination yielding p-benzoquinone (Hudnall 2000). Chemical reduction of p-benzoquinone recovers hydroquinone (Isaacs and Van Eldik 1997). Oxidation is accelerated in sunlit water, where hydroquinone has a conservatively estimated photo-oxidation half life of 20 hours (2, 10 hour days) (REACHa). p-Benzoquinone reacts with hydroquinone to form the dark green quinhydrone complex. It also reacts with water forming hydroxyquinol (CAS RN 533-73-3) (Hudnall 2000), which readily oxidises to 2-hydroxy-1,4-benzoquinone (CAS RN 2474-72-8) (Zhang L et al. 1996), contributing to the formation of humic acids in the environment (Devillers et al. 1990).

The chemicals in this group are expected to degrade rapidly in air. The half life for the reaction of volatilised hydroquinone with photochemically produced hydroxyl radicals is estimated to be 5.5 hours (US EPA 2017). p-Benzoquinone has a longer estimated half life of 28.4 hours due to reaction with hydroxyl radicals and 78.6 hours due to reaction with ozone.

Hydroquinone is expected to biodegrade rapidly in environmental waters. In a study conducted according to OECD Test Guideline (TG) 301C, hydroquinone was found to be readily biodegradable, with 70% biodegradation measured after 14 days. In a separate Sturm test, 82% degradation over 28 days was measured by carbon dioxide evolution in acclimated inoculum (Gerike and Fischer 1979). In a third closed bottle test, 81% degradation after 30 days was measured by theoretical biological oxygen demand (ThOD) (Gerike and Fischer 1979).

In a study on p-benzoquinone conducted according to OECD TG 301A, 56% degradation was measured by dissolved organic carbon (DOC) removal over the 28 day test duration (REACHb). While the chemical did not meet the 10 day window criterion for ready biodegradability, it is not persistent according to domestic categorisation criteria (EPHC 2009).

Hydroquinone and p-benzoquinone appear to degrade by similar microbial degradation pathways. Under aerobic conditions, hydroquinone degrades via ring cleavage to β-ketoadipic acid before mineralisation (Enguita and Leitão 2013). In gram-negative bacteria such as *Pseudomonas*, p-benzoquinone is channelled to the β-ketoadipate pathway following enzymatic reduction to hydroquinone (Spain and Gibson 1991; Zhang J-J et al. 2009; Zhang S et al. 2012). Hydroquinone also biodegrades under anaerobic conditions, yielding carbon dioxide and methane (Enguita and Leitão 2013; Young and Rivera 1985).

Hydroquinone and p-benzoquinone are expected to degrade in soils. In a non-guideline study using black chernozem soil spiked with hydroquinone, complete primary degradation to an unknown transformation product was observed after 24 hours (REACHa). Similarly, hydroquinone and p-benzoquinone were rapidly degraded in scrub soil obtained from beneath wild Floridian *Polygonella* shrubs (Weidenhamer and Romeo 2004).

Quinhydrone is expected to dissociate in environmental waters, forming hydroquinone and p-benzoquinone (Michaelis and Granick 1944). Since these chemicals degrade in the environment, quinhydrone is not expected to be persistent.

Bioaccumulation

The chemicals in this group have low potential to bioaccumulate in aquatic life.

The experimental log K_{OW} values for members of this group do not exceed the domestic categorisation threshold of a bioaccumulation hazard to aquatic life (log K_{OW} ≥4.2).

Environmental transport

Chemicals in this group are not expected to undergo long range transport based on their short half lives in the environment.

Predicted environmental concentration (PEC)

A PEC has not been estimated for chemicals identified in this evaluation. Based on the identified use patterns and taking into consideration historical Australian volume data for hydroquinone and standard exposure modelling approaches, typical concentrations in STP effluent are expected to be low. There is some evidence to suggest that raw effluent from manufacturing or reformulation facilities may contain relatively high concentrations of hydroquinone, but wastewater treatment processes are expected to mitigate these releases significantly.

No Australian or international environmental monitoring data were identified for the chemicals in this evaluation. The major identified uses of hydroquinone and p-benzoquinone are expected to result in minimal environmental release. Emissive uses, for example in cosmetic products, appear to represent a small fraction of the total use volume. Therefore, emissions from STPs are not expected to be significant.

Point source emissions from reformulation and other industrial facilities may represent the most concerning exposure scenario for chemicals in this group. Raw wastewater generated by a chemical production facility in Ravenna, Italy reportedly contained up to 50 mg/L hydroquinone, though it appeared to be effectively removed by STP treatment (Guerra 2001). Other historical studies conducted in the USA surveyed surface waters receiving industrial facility effluents for organic contaminants (OECD 2002). The resulting contaminant libraries did not list hydroquinone or p-benzoquinone, indicating they were not detected in any facility effluent streams.

Environmental effects

Effects on Aquatic Life

Chemicals in this group are toxic to aquatic organisms across all trophic levels.

In several standard tests with hydroquinone, loss of test substance concentration and formation of degradants including p-benzoquinone has been noted (ECHA 2017). Therefore, there is the potential that the effects of p-benzoquinone contribute to the outcome of tests with hydroquinone.

Acute toxicity

The following measured median effective concentration (EC50) and median lethal concentration (LC50) values for freshwater fish and algae were retrieved from the REACH

registration dossiers for hydroquinone and p-benzoquinone (REACHa; REACHb). The EC50 values of hydroquinone and p-benzoquinone to *Daphnia* were sourced from a literature study (Shim et al. 2009):

Taxon	Endpoint	Method
Fish	Hydroquinone: 96 h LC50 = 0.638 milligrams per litre (mg/L)	*Oncorhynchus mykiss* (rainbow trout) OECD TG 203 Flow-through
Invertebrate	Hydroquinone: 48 h EC50 = 0.080 mg/L	*Daphnia magna* (water flea) OECD TG 202 Immobilisation Static
	p-Benzoquinone: 48 h EC50 = 0.059 mg/L	Water flea OECD TG 202 Immobilisation Static
Algae	Hydroquinone: 72 h EC50 = 0.33 mg/L	*Raphidocelis subcapitata* (green algae) OECD TG 201 Growth rate Static
	p-Benzoquinone: 72 h EC50 = 1.5 mg/L	*Desmodesmus subspicatus* OECD TG 201 Growth inhibition Static

Chronic toxicity

The following measured no-observed-effect concentrations (NOEC) values were retrieved from the REACH registration dossier for hydroquinone (REACHa):

Taxon	Endpoint	Method
Fish	32 d NOEC ≥ 0.066mg/L	*Pimephales promelas* (fathead minnow) OECD TG 210 Reproduction Flow-through
Invertebrates	21 d NOEC = 0.0057 mg/L	*Daphnia magna* water flea OECD TG 211 Reproduction Semi-static
Algae	72 h NOEC = 0.019 mg/L	*Raphidocelis subcapitata* (green algae) OECD TG 201 Growth rate Static

Toxicity to microorganisms

The following EC50 for microorganisms were taken from the REACH registration dossier for hydroquinone (REACHa) and from a literature study of p-benzoquinone (King and Painter 1985):

Taxon	Endpoint	Method
Activated sludge	Hydroquinone: 2 h EC50 = 71 mg/L	Non-guideline study Respiration inhibition Static
	p-Benzoquinone: 3 h EC50 = 12 mg/L (unacclimatised) 30 mg/L (acclimatised)	OECD TG 209 Respiration inhibition Static

Predicted no-effect concentration (PNEC)

A freshwater PNEC of 0.57 micrograms per litre (µg/L) for hydroquinone was derived from the measured chronic ecotoxicity endpoint for invertebrates (21 d NOEC = 0.0057 milligrams per litre) using an assessment factor of 10. This assessment factor was selected as reliable chronic ecotoxicity data are available over three trophic levels.

The freshwater PNEC for hydroquinone is considered sufficiently representative of p-benzoquinone.

A PNEC was not determined for quinhydrone.

Categorisation of environmental hazard

The categorisation of the environmental hazards of the assessed chemical according to domestic environmental hazard thresholds is presented below:

Persistence

Not persistent (not P). Based on results from standard biodegradability tests that show ready biodegradability, the chemicals in this evaluation are categorised as not persistent.

Bioaccumulation

Not bioaccumulative (not B). Based on measured log K_{OW} and a hydroquinone fish bioaccumulation factor (BAF) that do not exceed domestic thresholds, the chemicals in this evaluation are categorised as not bioaccumulative.

Toxicity

Toxic (T). Based on available ecotoxicity values below 1 mg/L and evidence of high chronic toxicity, hydroquinone and p-benzoquinone are categorised as toxic. Quinhydrone is considered toxic given that it dissociates to toxic chemicals in water.

Environmental risk characterisation

Based on the assessed hazard and exposure characteristics, including industry reported data held by AICIS, the chemicals in this evaluation are not expected to pose a significant risk to the environment.

Risk quotients have not been determined for the chemicals in this evaluation. The major identified uses are not expected to result in significant release to the environment. More emissive use patterns appear to represent a minority of the total use volume of the chemicals.

Point source emissions from manufacturing or reformulation facilities are the most concerning release scenario for these chemicals, but international monitoring studies suggest that treatment of industrial effluent is effective at removal of the chemicals from waste streams.

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 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:

- There are no Australian monitoring data for the chemicals in this group. The risk profile of hydroquinone and p-benzoquinone may change should Australian monitoring data become available to indicate that the chemicals are present in Australian surface waters at concentrations above the level of concern.
- There are insufficient ecotoxicity data to fully characterise the acute and chronic toxicity of this group of chemicals to sediment and soil-dwelling organisms. Additional reliable ecotoxicity data may change the outcome of the evaluation.

References

DeLima Associates (n.d.) *Consumer Product Information Database,* DeLima Associates website, accessed July 2022.

Bjelkhagen HI, Phillips NJ and Wang C (1991) 'Chemical symmetry: developers that look like bleach agents for holography', *Practical Holography V,* **1461**, pp 321-328, doi:10.1117/12.44743.

Devillers J, Boule P, Vasseur P, Prevot P, Steiman R, Seigle-Murandi F, Benoit-Guyod JL, Nendza M, Grioni C and Dive D (1990) 'Environmental and health risks of hydroquinone', *Ecotoxicology and Environmental Safety,* **19**(3), pp 327-354, doi:10.1016/0147-6513(90)90035-4.

EC (European Commission) (2011) *Regulation No 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food*, EC website, accessed July 2022.

ECHA (European Chemicals Agency) (2017) *Substance evaluation conclusion for Hydroquinone*, ECHA, accessed May 2022.

Enguita FJ and Leitão AL (2013) 'Hydroquinone: environmental pollution, toxicity, and microbial answers', *BioMed Research International,* **2013**, doi:10.1155/2013/542168.

EPHC (Environment Protection and Heritage Council) (2009) *Environmental Risk Assessment Guidance Manual for Industrial Chemicals,* EPHC, accessed June 2022.

Gambarotti C, Melone L, Punta C and Shisodia SU (2013) 'Selective monoetherification of 1, 4-hydroquinone promoted by NaNO2', *Current Organic Chemistry,* **17**(10), pp 1108-1113, doi:10.2174/1385272811317100011.

Gerike P and Fischer WK (1979) 'A correlation study of biodegradability determinations with various chemicals in various tests', *Ecotoxicology and Environmental Safety,* **3**(2), pp 159-173, doi:10.1016/0147-6513(79)90009-5.

Guerra R (2001) 'Ecotoxicological and chemical evaluation of phenolic compounds in industrial effluents', *Chemosphere,* **44**(8), pp 1737-1747, doi:10.1016/S0045-6535(00)00562-2.

Hudnall PM (2000) 'Hydroquinone', *Ullmann's Encyclopedia of Industrial Chemistry*, doi:10.1002/14356007.a13_499.

Isaacs NS and Van Eldik R (1997) 'A mechanistic study of the reduction of quinones by ascorbic acid', *Journal of the Chemical Society, Perkin Transactions 2,* (8), pp 1465-1468, doi:10.1039/A701072I.

King EF and Painter HA (1985) 'The effect of acclimatisation on the toxicity of chemicals to activated sludge microorganisms', *Environmental Pollution Series A, Ecological and Biological,* **39**(3), pp 267-280, doi:10.1016/0143-1471(85)90101-1.

DAWE (The Department of Agriculture, Water and the Environment) (2021) *Hazardous Waste in Australia 2021*, DAWE website, accessed May 2022.

Lucas Jr HC and Goh JM (2009) 'Disruptive technology: How Kodak missed the digital photography revolution', *The Journal of Strategic Information Systems,* **18**(1), pp 46-55, doi:10.1016/j.jsis.2009.01.002.

Michaelis L and Granick S (1944) 'Molecular compounds of the quinhydrone type in solution', *Journal of the American Chemical Society,* **66**(6), pp 1023-1030, doi:10.1021/ja01234a057.

NCBI (National Center for Biotechnology Information) (n.d.) *PubChem,* NCBI website, accessed May 2022.

Nesvadba P (2012) 'Radical polymerization in industry', *Encyclopedia of Radicals in Chemistry, Biology and Materials*, doi:10.1002/9781119953678.rad080.

NICNAS (National Industrial Chemicals Notification and Assessment Scheme) (2014) *IMAP Single Assessment Report – 1,4-Benzenediol: Human health tier II assessment,* NICNAS, accessed May 2022.

NITE (National Institute of Technology and Evaluation) (n.d.) *Japan CHEmicals Collaborative Knowledge Database,* NITE website, accessed May 2022.

Novák J (1988) 'Inhibitors for unsaturated polyesters and varnishes prepared from them', *Progress in Organic Coatings,* **16**(3), pp 231-253, doi:doi.org/10.1016/0033-0655(88)80018-9.

Nsengiyumva W, Zhong S, Lin J, Zhang Q, Zhong J and Huang Y (2021) 'Advances, limitations and prospects of nondestructive testing and evaluation of thick composites and sandwich structures: A state-of-the-art review', *Composite Structures,* **256**, pp 112951, doi:10.1016/j.compstruct.2020.112951.

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

OECD (Organisation for Economic Cooperation and Development) (2002) *Screening Information DataSet for Hydroquinone*, OECD, accessed May 2022.

OECD (Organisation for Economic Cooperation and Development) (2015) *Emission Scenario Document on the Use of Adhesives*, OECD, accessed July 2022.

OECD (Organisation for Economic Cooperation 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 July 2022.

OECD (Organisation for Economic Cooperation and Development) (n.d.) *OECD Existing Chemicals Database,* OECD, accessed May 2022.

Raja PR (2016) 'Cyanoacrylate adhesives: A critical review', *Reviews of Adhesion and Adhesives,* **4**(4), pp 398-416, doi:10.7569/RAA.2016.097315.

Ramis X and Salla JM (1995) 'Effect of the inhibitor on the curing of an unsaturated polyester resin', *Polymer,* **36**(18), pp 3511-3521, doi:10.1016/0032-3861(95)92023-8.

REACH(a) (Registration, Evaluation, Authorisation and Restriction of Chemicals) (n.d.) *Registered dossier for CAS No. 123-31-9,* European Chemicals Agency website, accessed April 2022.

REACH(b) (Registration, Evaluation, Authorisation and Restriction of Chemicals) (n.d.) *Registered dossier for CAS No. 106-51-4,* European Chemicals Agency website, accessed May 2022.

Seco J, Clasie B and Partridge M (2014) 'Review on the characteristics of radiation detectors for dosimetry and imaging', *Physics in Medicine and Biology,* **59**(20), pp R303, doi:10.1088/0031-9155/59/20/R303.

Shim S, Jo H and Jung J (2009) 'Toxicity identification of gamma-ray treated phenol and chlorophenols', *Journal of Radioanalytical and Nuclear Chemistry,* **280**(1), pp 41-46, doi:10.1007/s10967-008-7388-z.

Sigma-Aldrich (2022) *Safety Data Sheet for Quinhydrone*, Sigma-Aldrich, accessed July 2022.

Spain JC and Gibson DT (1991) 'Pathway for biodegradation of p-nitrophenol in a Moraxella sp', *Applied and Environmental Microbiology,* **57**(3), pp 812-819, doi:10.1128/aem.57.3.812-819.1991.

SPIN (Substances in Preparation in Nordic Countries) (n.d.) *SPIN Database,* SPIN website, accessed May 2022.

TGA (Therapeutic Goods Administration) (2022) *Standard for the Uniform Scheduling of Medicines and Poisons No. 36 (Poisons Standard June 2022)*, TGA, accessed June 2022.

TGA (Therapeutic Goods Administration) (n.d.) *Ingredient Summary for Hydroquinone,* TGA, accessed June 2022.

UNECE (United Nations Economic Commission for Europe) (2017) *Globally Harmonized System of Classification and Labelling of Chemicals (GHS), Seventh Revised Edition,* UNECE, accessed May 2022.

UNEP (United Nations Environment Programme) (1987) *The Montreal Protocol on Substances that Deplete the Ozone Layer,* UNEP, Ozone Secretariat, accessed June 2022.

UNEP (United Nations Environment Programme) (2001) *The Stockholm Convention on Persistent Organic Pollutants,* UNEP, Secretariat of the Stockholm Convention, accessed June 2022.

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 June 2022.

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

US EPA (United States Environmental Protection Agency) (2020) *2020 CDR Industrial Processing and Use (May 2022),* US EPA, downloaded June 2022.

US EPA(a) (United States Environmental Protection Agency) (n.d.) *Toxics Release Inventory,* US EPA website, accessed June 2022?

US EPA(b) (United States Environmental Protection Agency) (n.d.) *CPDat Record for Hydroquinone (CAS RN 123-31-9),* US EPA, accessed July 2022.

Weidenhamer JD and Romeo JT (2004) 'Allelochemicals of Polygonella myriophylla: chemistry and soil degradation', *Journal of Chemical Ecology,* **30**(5), pp 1067-1082, doi:10.1023/B:JOEC.0000028468.97851.7a.

Young L and Rivera MD (1985) 'Methanogenic degradation of four phenolic compounds', *Water Research,* **19**(10), pp 1325-1332, doi:10.1016/0043-1354(85)90189-7.

Yuqing M, Jianrong C and Keming F (2005) 'New technology for the detection of pH', *Journal of Biochemical and Biophysical Methods,* **63**(1), pp 1-9, doi:10.1016/j.jbbm.2005.02.001.

Zhang J-J, Liu H, Xiao Y, Zhang X-E and Zhou N-Y (2009) 'Identification and characterization of catabolic para-nitrophenol 4-monooxygenase and para-benzoquinone reductase from Pseudomonas sp. strain WBC-3', *Journal of Bacteriology,* **191**(8), pp 2703-2710, doi:10.1128/JB.01566-08.

Zhang L, Bandy B and Davison AJ (1996) 'Effects of metals, ligands and antioxidants on the reaction of oxygen with 1,2,4-benzenetriol', *Free Radical Biology and Medicine,* **20**(4), pp 495-505, doi:10.1016/0891-5849(95)02089-6.

Zhang S, Sun W, Xu L, Zheng X, Chu X, Tian J, Wu N and Fan Y (2012) 'Identification of the para-nitrophenol catabolic pathway, and characterization of three enzymes involved in the hydroquinone pathway, in pseudomonas sp. 1-7', *BMC Microbiology,* **12**(1), pp 1-11, doi:10.1186/1471-2180-12-27.