Review of potential health hazards associated with industrial effluents

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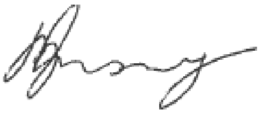

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. EXECUTIVE SUMMARY

Industrial effluent refers to the liquid waste produced by businesses which may be discharged to the municipal wastewater/sewer network (referred to as trade waste in New Zealand), or directly to receiving waters. The composition of these effluents is highly variable and dependent on the industry they arise from.

Many pollutants identified in industrial effluents are known to pose a health hazard. The purpose of this report is to provide an overview of those contaminants of most concern for human health based on international grey and published literature. Given the variety of conventional and advanced wastewater treatment processes which may be employed by industries to pre-treat their effluent before it is discharged to the municipal sewer network or receiving waters, and the variable removal efficiency of these different processes, this report primarily considers the presence of the contaminants in untreated effluents. As such, no assertion is made that the contaminants of interest will be present in treated effluent.

Selection of contaminants for inclusion in this report was informed by review of international published and grey literature and reports on emerging contaminants of potential concern for New Zealand[1] (Stewart et al 2016). Candidate contaminants were assessed on two criteria: 1) the likelihood that the contaminant poses a substantial health hazard, and 2) the contaminant has been detected in untreated industrial effluents internationally. Where there is a substantial residential source known to contribute to presence of the contaminant in wastewater, the relative contribution from industrial effluents was evaluated to assess whether industrial contribution warranted further assessment.

For the purposes of this report, the contaminants considered have been grouped into seven broad classes: endocrine disrupting compounds (EDCs), heavy metals and metalloids, per- and polyfluoroalkyl substances (PFAS), pharmaceuticals, pesticides, microplastics, and contaminants of specific concern for tikanga Māori. For each contaminant, an overview of the potential health concerns associated with exposure is provided. Those risks specifically associated with inhalation are not discussed due to contaminated effluents providing little opportunity for exposure via this route. For many contaminants, the exact health hazard they pose is still unclear and may be under debate.

A variety of approaches were utilised to identify industries whose effluents have been associated with the chosen contaminants. An initial search was performed to identify

[1]https://www.watercare.co.nz/CMSPages/GetAzureFile.aspx?path=~%5Cwatercarepublicweb%5Cmedia%5Cwatercare-media-library%5Comaha%5Comahawwtpemergingcontaminantspresentation.pdf&hash=9b396b7f4c7cc9bfb4f76701eecee433a81fb84b5a3b8a0d9375f5a182736b5c Accessed 30 November 2021

published and grey literature assessing the presence or removal of the chosen contaminants in industrial effluents. International pollutant release databases were also interrogated to identify industries who reported on-site release of that contaminant to water, or transfer to a public wastewater network. The United States (US) Environmental Protection Agency (EPA) Effluent Limitations Guidelines (ELGs) and Standards Database was also interrogated to identify industries with discharge limitations for the chosen contaminants, as an indicator that effluents from those industries likely contain that contaminant. For some contaminants, little information about their presence in industrial effluents was available. However, this may be due to a lack of publicly available studies or monitoring information assessing their presence, rather than their complete absence from industrial effluents.

Where possible, an overview of international discharge limitations and any other relevant regulation is provided. Very little consolidated information was available on international discharge limits and for several emerging contaminants no information on discharge limits could be found.

This report serves to identify those contaminants of concern which warrant further investigation in the Aotearoa New Zealand context. Further work will be required to assess the presence, and removal, of these contaminants in industrial effluent in New Zealand, and to assess what regulation, if any, exists for these contaminants.

2. INTRODUCTION

2.1 BACKGROUND

During the normal course of business, industries generate a variety of waste streams which need to be appropriately disposed of. Liquid wastes that are discharged by businesses to either the municipal/public wastewater network or direct to receiving waters, are referred to internationally as industrial effluents. In New Zealand, those wastes discharged by businesses specifically to the municipal wastewater network are referred to as trade waste (Figure 1).

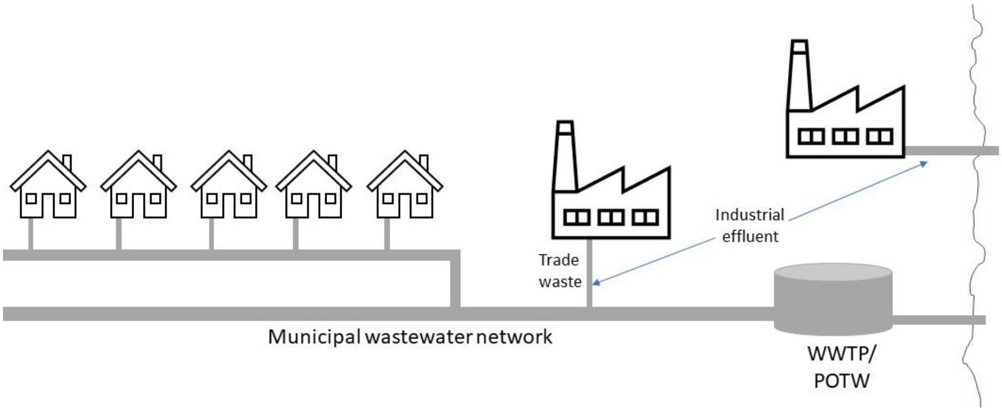

Figure 1 Schematic showing trade waste and industrial effluent

WWTP, wastewater treatment plant; POTW, publicly owned treatment works.

Many industrial activities generate effluents contaminated with a variety of substances that may pose human health hazard. These effluents are often treated on-site to reduce contaminant concentrations, before being discharged to the municipal wastewater network or to receiving waters. Many countries have regulations specifying concentration limits for a range of potentially harmful contaminants to limit their presence in discharged effluents to tolerable levels. In New Zealand, these limits are specified in Trade Waste By-Laws set by each territorial authority and modelled on the Model General Bylaw for Trade Waste (Standards New Zealand 2004). Additionally, as sewage sludge, or "the unstabilised organic solid material settled out from domestic and industrial wastewater during the treatment process" (Water New Zealand 2017) may be applied to land and therefore pose a potential health hazard, concentration limits for a range of contaminants are set in the 2003 Guidelines for the Safe Application of Biosolids to Land in New Zealand (the 2003 Biosolids Guidelines) (NZWWA 2003). These guidelines are currently under revision and are referenced in this report as the draft Guidelines for Beneficial Use of Organic Material on Productive

Land (Water New Zealand 2017). Metal concentration limits specified in these draft guidelines correspond to the ‘grade B’ biosolids limits specified in the 2003 Biosolids Guidelines and “are used as a minimum product quality criteria”. However, these draft guidelines also propose limits for nonylphenol and its ethoxylates, and the phthalate DEHP which are not included in the 2003 Biosolids Guidelines. The draft guidelines note that “untreated sewage sludge would not meet the stabilisation and/or contaminant grades defined in the Guide and cannot be beneficially used without further treatment and stabilisation” (Water New Zealand 2017). Regional Councils are responsible for controlling the application of biosolids to land in New Zealand, and the 2003 Biosolids Guidelines note that “Local authorities may wish to set more stringent requirements than those recommended here if this is appropriate to their local environment and community requirements, or indicated in regional policy objectives” (NZWWA 2003). Concentrations limits set for the contaminants covered in this report in the Model General Bylaw for Trade Waste and draft Guidelines for Beneficial Use of Organic Material on Productive Land are summarised in Appendix Table 29.

In the almost eighteen years since the last Trade Waste Standard was released (2004), several new contaminants of concern have emerged for which no discharge limits are currently set. Additionally, knowledge around the risks posed by previously known contaminants will also have improved. To fully address the potential health hazard posed by contaminants present in trade waste in New Zealand, those contaminants that pose health hazard need to first be identified and the risk they pose appropriately assessed. However, due to limited local information, the first step in this process is dependent on international data. To this end, this report serves to identify those contaminants of the most concern for human health reported in industrial effluents internationally and provides a broad overview of the industries whose untreated waste streams have been found to contain those contaminants.

Selection of contaminants of the most concern for human health for inclusion in this report was guided by review of international published and grey literature and reports on emerging contaminants of potential concern in New Zealand[2] (Stewart et al 2016). Candidate contaminants were first assessed to determine if they pose a substantial health hazard, noting that for many emerging contaminants the health risks are not yet fully understood. Potential candidates were then evaluated to determine what is known about their presence in industrial effluents. Those contaminants for which there are substantial residential sources contributing to levels in municipal wastewater were further evaluated to determine whether industrial contributions were sufficient to warrant inclusion in this report.

[2] https://www.watercare.co.nz/CMSPages/GetAzureFile.aspx?path=~%5Cwatercarepublicweb%5Cmedia%5Cwatercare-media-library%5Comaha%5Comahawwtpemergingcontaminantspresentation.pdf&hash=9b396b7f4c7cc9bfb4f76701eecee433a81fb84b5a3b8a0d9375f5a182736b5c Accessed 30 November 2021

Contaminants selected for inclusion in this report were grouped into seven classes: endocrine disrupting compounds (EDCs), heavy metals and metalloids, per- and polyfluoroalkyl substances (PFAS), pharmaceuticals, pesticides, microplastics, and contaminants of specific concern for tikanga Māori. It is important to note that there is some overlap between these classes, with PFAS, for example, proposed to have endocrine disrupting effects[3]. It is also important to note that the suite of contaminants included in this report is by no means a comprehensive collection of all contaminants of potential health concern present in industrial effluents and represents our best efforts to identify those contaminants of most concern.

2.2 APPROACH AND SCOPE

This report represents Stage One of an analysis of the potential human health hazards posed by trade waste in New Zealand. In this first stage, an international focus is taken to assess what contaminants of potential health concern are present in industrial effluents based on scientific publications and grey literature. Key aspects covered in this review include:

- Selection of a priority list of contaminants of potential concern for human health identified in industrial effluents internationally.
- Broad overview of the potential health hazards associated with exposure to the priority contaminants.
- General overview of the industries whose effluents have been associated with the priority contaminants internationally.
- Where possible, comment is made on discharge limits or regulations set for the priority contaminants in international guidelines.

Potential health risks associated with workplace exposure are outside the scope of this report, as this is a WorkSafe responsibility. Hazards posed to the environment are also outside the scope of this report, as this is the responsibility of the Ministry for the Environment.

2.3 CONTAMINANTS CONSIDERED BUT NOT INCLUDED IN THIS REPORT

Aside from the seven classes of contaminants covered in this report, several additional contaminants were considered for inclusion but omitted due to reasons detailed below:

- Triclosan: this broad-spectrum antimicrobial agent was omitted due to substantial residential sources (eg, personal care products, cosmetics)

[3] https://www.endocrine.org/topics/edc/what-edcs-are/common-edcs/pfas Accessed 19 January 2022

contributing to levels present in municipal wastewater and lack of sufficient data on human health effects[4].

- Musk fragrances: the two polycyclic musk fragrances, galaxolide and tonalide, were considered for inclusion in this report but omitted as residential sources are noted to be the major contributor of these chemicals to wastewater, with industrial sources considered minor (Clara et al 2011).
- Flame retardants: two classes of flame retardants were considered – brominated flame retardants (BFRs) and organophosphate flame retardants (OPFRs). These chemicals were omitted due to the known contribution of residential sources to levels of these chemicals in municipal wastewater and insufficient data on the human health effects of OPFRs (Pantelaki & Voutsa 2019, Schreder & La Guardia 2014). Residential laundry wastewater has been suggested to be a primary source of these chemicals into the municipal wastewater network (Schreder & La Guardia 2014). These chemicals are found in household dusts which are thought to adhere to clothing and be removed during washing (Schreder & La Guardia 2014).

[4] https://www.epa.govt.nz/assets/Uploads/Documents/Everyday-Environment/Publications/Triclosan-fact-sheet-Dec16.pdf Accessed 16 March 2022

3. ENDOCRINE DISRUPTING COMPOUNDS

Endocrine disrupting compounds are chemicals that interfere with normal hormone signalling by affecting hormone biosynthesis, metabolism, or action (Diamanti-Kandarakis et al 2009). These are a diverse group of chemicals which can be found in the environment, in our food, and in a range of consumer products. Due to their effect on hormone signalling, EDCs have been recognised as an area of concern for public health and have been linked to a range of health problems, although varied effects have been reported and the health hazard posed by these chemicals is an area of debate (as discussed in Zoeller et al (2014)). The usage of many EDCs is regulated, although this varies around the world (Diamanti-Kandarakis et al 2009). Given the widespread exposure to many EDCs through food, consumer products and pharmaceuticals (eg, birth control medication), substantial levels are often found in municipal wastewater due to human excretion or activity (eg, domestic cleaning or personal care products going down the drain). As such, this section will focus on those EDCs which have been shown in international literature to have substantial presence in industrial effluents, with the acknowledgement that the load reaching municipal WWTPs will often have a considerable residential contribution.

3.1 NONYLPHENOL AND NONYLPHENOL ETHOXYLATES

Nonylphenol is a synthetic alkylphenol composed of a phenol group with a nine-carbon tail. Nonylphenol is used in production of antioxidants and lubricating oil additives, but the majority is used to produce nonylphenol ethoxylate surfactants (Soares et al 2008). These surfactants are widely used industrially, commercially, and domestically in a variety of products including detergents and cleaning products, degreasers, emulsifiers, wetting and de-wetting agents, cosmetics, and paints (Environment Canada & Health Canada 2001, Soares et al 2008). Due to their widespread usage, substantial levels of nonylphenol ethoxylates enter wastewater systems from both industrial and residential sources. Nonylphenol is hydrophobic and has low solubility in water so much of the nonylphenol load in wastewater accumulates in the sludge, or in sediments when discharged to aquatic environments (Soares et al 2008). Nonylphenol and its ethoxylates are highly persistent in the environment, with nonylphenol ethoxylates in sediments estimated to have a half-life of more than 60 years (Shang et al 1999). These chemicals are also known to bioaccumulate within aquatic organisms (Ahel et al 1993, Gautam et al 2015), and have been detected in human breast milk (Sise & Uguz 2017). Nonylphenol ethoxylates have been noted to be less toxic and less persistent than nonylphenol but can degrade to produce nonylphenol in the environment[5].

3.1.1 Health effects

Nonylphenol is structurally similar to the female sex hormone 17β-estradiol, and as such competes for binding to the estrogen receptor, potentially disrupting normal hormone signalling (reviewed in Soares et al (2008)). The health effects of nonylphenol and its ethoxylates are covered in the Cressey (2018) risk assessment recently prepared for the Ministry of Health. In brief, evidence from studies of laboratory animals indicated that nonylphenol can cause reproductive effects, and may affect the immune and nervous systems (Cressey 2018). However, further studies are needed to fully evaluate the effects of these chemicals on human health. Although, these analyses will be confounded by the "ubiquitous nature of nonylphenol in the environment" (Cressey 2018). Recommended exposure limits for nonylphenol and its ethoxylates have been established by the Danish Veterinary and Food Administration (DVFA) (Nielsen et al 2000) and European Commission (EC) (European Commission 2002) as summarised in Table 1. In their risk assessment of nonylphenol and 4-nonylphenol the EC noted there was no useful human data available on which to evaluate the effects of human exposure so they established their oral exposure limit (tolerable daily intake, TDI) on the lowest observed adverse effect level (LOAEL) for repeated dose toxicity from animal studies (European Commission 2002).

Table 1 Recommended exposure limits for nonylphenol and its ethoxylates

Substance	TDI DVFA (µg/kg bw/day)	LOAEL DVFA (mg/kg bw/day)	LOAEL EC (mg/kg bw/day)
Nonylphenol	5	15	15 (Nonylphenol and 4-nonylphenol)
Nonylphenol ethoxylates	13	40	-

TDI, tolerable daily intake; LOAEL, lowest observed adverse effect level; DVFA, Danish Veterinary and Food Administration; EC, European Commission.

3.1.2 Industrial effluent sources

Nonylphenol ethoxylates have been employed widely in the textile industry in a variety of different processes including during wool scouring, bleaching, washing, dyeing, and printing (Ho & Watanabe 2017). In Canada, the textile industry has been suggested to

[5] https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-management-nonylphenol-and-nonylphenol-ethoxylates#address Accessed 3 November 2021.

be a major source of nonylphenol ethoxylates entering the environment (Environment Canada and Health Canada, 2001). Concentrations of nonylphenol in textile mill effluent discharged to the municipal wastewater treatment plant were found to range from 0.23 - 26 μg/L and concentrations for a variety of different nonylphenol ethoxylates ranged from < 0.45 - 5800 μg/L (Environment Canada and Health Canada, 2001). Nonylphenol and its ethoxylates have also been reported in untreated textile plant effluent in Belgium (Loos et al 2007). In Vietnam, nonylphenol and its ethoxylates have been detected in effluents from both cotton and synthetic fibre factories (Ho & Watanabe 2017). These chemicals have also been detected in wastewater discharge from a textile factory in Indonesia (Brigden et al 2013), and in effluent from several textile factories in China (He et al 2020). Nonylphenol has also been detected in effluent from the textile treatment industry in France (Bergé et al 2014) and a textile factory in Greece (Pothitou & Voutsa 2008).

Nonylphenol ethoxylates are also used in wetting of pulp fibres by pulp and paper mills (Groshart et al 2001) and effluent from mills may contain both nonylphenol and nonylphenol ethoxylates. Indeed, in Canada, effluent from pulp and paper mills is noted to be a major source of these chemicals entering the environment, with concentrations of nonylphenol in effluent discharged to the municipal WWTP (since 1998) ranging from < 0.10 – 4.3 μg/L and nonylphenol ethoxylate concentrations ranging from < 0.10 – 36 μg/L (Environment Canada & Health Canada 2001, Lee & Peart 1999). Nonylphenol and its ethoxylates have also been reported in effluent from paper mills in the United States (Michigan Pulp and Paper Environmental Council & Michigan Department of Environmental Quality 2000), and nonylphenol has been found in paper mill effluents in Slovenia (Balabanic & Klemencic 2011).

Although textile and pulp and paper mills are the industries whose effluent has been most associated with nonylphenol and its ethoxylates, effluent from other industries have also been shown to contain these chemicals. In the leather industry, nonylphenol ethoxylates are used during wet degreasing of hides (Groshart et al 2001), and both nonylphenol and its ethoxylates have been found in effluent from tanneries in Argentina (Labunska et al 2011) and Greece (Pothitou & Voutsa 2008). In Greece, nonylphenol and its ethoxylates were found in substantial amounts in tannery wastewaters (dissolved concentrations of 50 - 430 μg/L), and it was suggested that tannery effluents may be a "significant source of these compounds to the aquatic and terrestrial environment" (Pothitou & Voutsa 2008). Nonylphenol ethoxylates have also been found in wastewater from a commercial laundry in Brazil (Braga & Varesche 2014). The importance of laundry/dry-cleaning wastewater as a source of these chemicals is also evidenced by the specification of maximum limits for their discharge to the municipal sewer in the Toronto Dry Cleaner and Commercial Laundry Facilities Pollution Prevention Plan[6]. In a study of wastewaters from a range of different

[6] http://wx.toronto.ca/inter/clerks/fit.nsf/0/d1a95054bccf36af8525808a0066bfa3/$File/Dry%2BCleaner%2Band%2BCommercial%2BLaundry%2BP2%2BForm_v3.1%2B(unlocked).pdf Accessed 9 November 2021

industries in France, nonylphenol was found in effluents from the pharmaceutical, cosmetics, and transportation maintenance industries, as well as in effluent from drinking-water treatment and universities (Bergé et al 2014). Nonylphenol and its ethoxylates have also been detected in Canada in effluent produced by funeral homes during the embalming process (Kleywegt et al 2019).

Interrogation of international pollutant release databases for information on release of nonylphenol or its ethoxylates either to water or to a wastewater network revealed some additional insight into those industries whose effluent may be contaminated with these chemicals. Information from these databases is summarised in Table 2 and expanded in Appendix Table 30. Several industries within the chemicals sector were highlighted as potential sources of nonylphenols contaminated effluents. These include soap and other detergents manufacturers, paint and coating manufacturers, and plastics material and resin manufacturers. Dairy product manufacturers were also identified as potential sources, as were facilities involved in manufacture of metal cans.

A broad overview of removal of nonylphenol and nonylphenol ethoxylates from wastewater has suggested that the efficiency at which these chemicals are removed is highly variable (Bina et al 2018, Gao et al 2017). However, more detailed assessment of what is known about the removal of these chemicals by different treatment processes is required.

3.1.3 Discharge limits and regulation

Little information was identified on discharge limits for nonylphenol and its ethoxylates in industrial effluents. In the European Union (EU), there is a maximum allowable concentration of 2 μg/L for nonylphenols in surface waters under Directive 2008/105/EC. The marketing and usage of nonylphenol and its ethoxylates is highly restricted in the EU under Directive 2003/53/EC. This directive specifies that these chemicals may not be used in manufacturing of pulp and paper in concentrations equal to or higher than 0.1% by mass, and only used in textile and leather processing at concentrations equal to or higher than 0.1% by mass where there is no release to wastewater or in systems where the wastewater is pre-treated to completely remove the organic fraction prior to biological wastewater treatment. In industrial/institutional cleaning these chemicals may only be used in concentrations equal to or higher than 0.1% by mass in controlled dry-cleaning/cleaning systems where the washing liquid is either recycled or incinerated. In Canada both nonylphenol and its ethoxylates are classified as toxic substances under Schedule 1 of the Canadian Environmental Protection Act, 1999[7]. The Toronto Dry Cleaner and Commercial Laundry Facilities Pollution Prevention Plan specifies a maximum concentration of 0.02 mg/L for

[7] https://www.canada.ca/en/environment-climate-change/services/management-toxic-substances/list-canadian-environmental-protection-act/nonylphenol-ethoxylates.html
Accessed 9 November 2021

nonylphenol and 0.2 mg/L for nonylphenol ethoxylates discharged to the municipal wastewater network[8].

Table 2 Summary of discharges of nonylphenol and its ethoxylates reported in pollutant release databases

US Toxics Release Inventory 2020[9]			
Substance	**TRI Industry sector**	**Number of facilities[1]**	**Total discharged to surface waters (kg)**
Nonylphenol	Chemicals	3	24
Nonylphenol ethoxylates	Other	1	515
	Chemicals	4	82
Substance	**TRI Industry sector**	**Number of facilities[1]**	**Total transferred to POTW (kg)**
Nonylphenol	Chemicals	4	25
Nonylphenol ethoxylates	Chemicals	30	11,744
	Food	4	906
	Fabricated metals	2	86
	Petroleum	1	3.6
Canadian National Pollutant Release Inventory 2017[10]			
Substance	**Industry sector**	**Number of facilities[1]**	**Total discharged to water (kg)**
Nonylphenol and its ethoxylates	Chemicals	1	1.3

[1]Number who discharged/transferred 1 kg or more per year, excluding WWTPs and hazardous waste treatment and disposal facilities. TRI, toxics release inventory; POTW, publicly owned treatment works. Summarised from Table 30.

In the United States, the Environmental Protection Agency (EPA) has proposed a Significant New Use Rule (SNUR) which requires Agency review before manufacturers can start or resume usage of fifteen different nonylphenols/nonylphenol ethoxylates, allowing the EPA to limit any new or resumed uses, if necessary[11]. There

[8]http://wx.toronto.ca/inter/clerks/fit.nsf/0/d1a95054bccf36af8525808a0066bfa3/$File/Dry%2BCleaner%2Band%2BCommercial%2BLaundry%2BP2%2BForm_v3.1%2B(unlocked).pdf Accessed 9 November 2021
[9]https://enviro.epa.gov/triexplorer/release_chem?p_view=USCH&trilib=TRIQ1&sort=_VIEW_&sort_fmt=1&state=All+states&county=All+counties&chemical=All+chemicals&industry=ALL&year=2020&tab_rpt=1&fld=RELLBY&fld=TSFDSP Accessed 7 December 2021
[10] https://pollution-waste.canada.ca/national-release-inventory/archives/index.cfm?lang=En Accessed 7 December 2021
[11] https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-management-nonylphenol-and-nonylphenol-ethoxylates Accessed 9 November 2021

is also an on-going voluntary phase-out of the usage of nonylphenol ethoxylates in industrial laundry detergents[12].

Preliminary assessment of the New Zealand context has identified that nonylphenol and its ethoxylates are currently being considered under the draft Water New Zealand Guidelines for Beneficial Use of Organic Materials on Productive Land, with a proposed concentration limit of 50 mg/kg dry weight (Water New Zealand 2017). These chemicals are not specified in the New Zealand Model General Bylaw for Trade Waste (Standards New Zealand 2004). However, it does list phenolic compounds, with a maximum concentration of 50 g/m^3.

3.2 BISPHENOL A

Bisphenol A (BPA), or 4’4-isopropylidenediphenol, is a synthetic chemical mainly used in the production of epoxy resins and polycarbonate plastics[13], including food containers (Cressey 2018).

3.2.1 Health effects

Bisphenol A is a known EDC that mimics 17β-estradiol and binds to estrogen receptors (Rubin 2011). It can also interact with the androgen and thyroid hormone receptors in vivo (Ma et al 2019). Bisphenol A is classified by the New Zealand Environmental Protection Authority as “suspected of damaging fertility or the unborn child”[14]. In 2015, the European Food Safety Authority (EFSA) reduced the TDI of BPA from 50 to 4 μg/kg body weight/day[15], and are proposing to further reduce it to 0.04 ng/kg body weight/day[16]. In 2008, the United States Food and Drug Administration set an intake limit of 5 μg/kg body weight/day based on systemic effects[17]. Based on recent studies showing effects at concentrations as low as 2.5 μg/kg body weight/day (Heindel et al 2020) it has been proposed that the TDI should “probably” be only 2.5 ng/kg body weight/day[18].

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[12] https://www.epa.gov/saferchoice/design-environment-safer-detergents-stewardship-initiative Accessed 9 November 2021
[13] https://www.niehs.nih.gov/health/topics/agents/sya-bpa/index.cfm Accessed 9 November 2021
[14] https://www.epa.govt.nz/database-search/chemical-classification-and-information-database-ccid/view/B41EC9A7-D80E-41DF-A353-4AF0DCA80AC4 Accessed 14 December 2021
[15] https://www.efsa.europa.eu/en/topics/topic/bisphenol Accessed 9 November 2021
[16] https://www.efsa.europa.eu/en/news/bisphenol-efsa-draft-opinion-proposes-lowering-tolerable-daily-intake Accessed 2 May 2022
[17] https://www.epa.gov/sites/default/files/2015-09/documents/bpa_action_plan.pdf Accessed 5 November 2021
[18] https://www.cmu.edu/news/stories/archives/2020/august/bpa-standards.html Accessed 9 November 2021

3.2.2 Industrial effluent sources

Given the widespread usage of BPA in food and beverage packaging, and the subsequent absorption by exposed individuals, it is inevitable that there will be a residential contribution to BPA loads reaching the municipal WWTP. However, international literature has shown that effluent from some industries contain substantial BPA levels which must be considered. Indeed, a study conducted in Detroit, USA suggested the main source of BPA into the municipal sewer network was industry inputs (Santos et al 2016).

Effluent from paper mills in Slovenia, Austria, Canada, and sludge from paper mills in Korea have been shown to contain BPA (Balabanic & Klemencic 2011, Fuerhacker 2003, Lee & Peart 2000, Lee et al 2015). Bisphenol A has also been detected in effluents from the textile (Lee & Peart 2000, Pothitou & Voutsa 2008) and tanning (Pothitou & Voutsa 2008) industries. Additionally, BPA has also been detected in wastewaters from the metal/wood manufacturing, chemical, dry-cleaning/cloth washing, plastics (Fuerhacker 2003, Lee & Peart 2000) and petrochemical (Mirzaee et al 2019) industries.

Bisphenol A was not present in the Australian or US pollutant release databases, and the Canadian database contained only a single entry which was for a WWTP.

3.2.3 Discharge limits and regulation

Since 2012, all Canadian facilities that manufacture or use BPA in quantities greater than 100 kg per year, and whose effluent at the final discharge point contains BPA, are required to prepare and implement BPA pollution prevention plans[19]. An effluent release target concentration for BPA in industrial effluents in Canada is set at 1.75 μg/L[20]. In the United States, the EPA has established a BPA action plan[21], although there does not appear to be a discharge concentration limit. Bisphenol A is not listed in the New Zealand Model General Bylaw for Trade Waste (Standards New Zealand 2004).

[19] https://www.canada.ca/en/environment-climate-change/services/pollution-prevention/planning-notices/performance-results/bisphenol-a-industrial-effluents-overview.html Accessed 9 November 2021
[20] https://www.canada.ca/en/environment-climate-change/services/evaluating-existing-substances/federal-environmental-quality-guidelines-bisphenol-a.html Accessed 9 November 2021
[21] https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-management-bisphenol-bpa Accessed 9 November 2021

3.3 PHTHALATES

Phthalates, often also known as phthalate plasticizers, are chemicals used in manufacturing to make products more durable and flexible, or for their solvent properties[22]. They have been used in a wide variety of products including vinyl flooring, plastic packaging, medical tubing, and even personal care products such as shampoos, hair sprays, soaps[23] and cosmetics[24]. Phthalates are diesters of 1,2-benzenedicarboxylic (phthalic) acid, with a wide variety of derivatives based on differences in the ester side chains. Common examples include DMP (dimethyl phthalate), DEP (diethyl phthalate), DBP (di-*n*-butyl phthalate), BBP (benzyl butyl phthalate), DiBP (di-iso butylphthalate), DCHP (dicyclohexyl phthalate), DOP (di-*n*-octyl phthalate), and DEHP (di(2-ethylhexyl) phthalate)[25]. This review will focus on four phthalates with recognised health effects identified in industrial effluents: DEHP, DBP, DiBP and BBP.

3.3.1 Health effects

One of the most commonly recognised health effects of phthalates is known as phthalate syndrome and refers to the ability of some phthalates to interfere with androgen biosynthesis, leading to disruption of male sexual differentiation (CHAP 2014, National Research Council 2008). The health risks posed by all four phthalates considered in this report (DEHP, DBP, DiBP and BBP) were previously assessed in a report prepared for the Ministry of Health, with all four noted as having “reproductive or developmental toxicity (antiandrogenic) concerns” (Ashworth & Chappell 2015). Both DEHP and BBP were also assessed in the Cressey (2018) report prepared for the Ministry of Health. Di-iso butylphthalate (DiBP) is classified by the New Zealand Environmental Protection Authority as “suspected of damaging fertility or the unborn child” based on animal studies[26]. Similarly, DBP is classified by the EPA as a chemical which “may damage fertility or the unborn child” based on animal studies[27]. Recommended exposure limits set by US EPA and EFSA are provided in Table 3. The

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22 https://www.nap.edu/resource/12528/phthalates_final.pdf Accessed 8 November 2021
23 https://www.cdc.gov/biomonitoring/Phthalates_FactSheet.html Accessed 9 November 2021
24 https://www.fda.gov/cosmetics/cosmetic-ingredients/phthalates#pht Accessed 9 November 2021
25 https://www.nap.edu/resource/12528/phthalates_final.pdf Accessed 8 November 2021
26 https://www.epa.govt.nz/database-search/chemical-classification-and-information-database-ccid/view/1D671A8C-C16B-4F05-8BB5-0336C055D877 Accessed 14 December 2021
27 https://www.epa.govt.nz/database-search/chemical-classification-and-information-database-ccid/view/F1CAD33D-608F-4C22-BCCF-98BA3726559D Accessed 14 December 2021

EFSA has set a group TDI for phthalates of 0.05 mg/kg bw/day, with DEHP as the index compound and the potency of other phthalates expressed relative to DEHP[28].

Table 3 Health effects and intake limits for phthalates

Compound	RfD US EPA (μg/kg bw/day)	RPF EFSA[29]
DEHP	20[30]	1
DBP	100[31]	5
DiBP	-	-
BBP	200[32]	0.1

DEHP, di(2-ethylhexyl) phthalate; DBP, di-*n*-butyl phthalate; DiBP, di-iso butylphthalate; BBP, benzyl butyl phthalate; RfD, reference dose; RPF, relative potency factor.

3.3.2 Industrial effluent sources

As noted by Bergé et al (2014), studies of industrial contributions of phthalates to the environment are extremely limited. Effluent from pulp and paper mills in Slovenia has been found to contain DBP, BBP and DEHP (Balabanic & Klemencic 2011). Additionally, effluent from tanneries in Argentina and India were found to contain DEHP, DBP, DiBP and BBP (Alam et al 2010, Bharagava et al 2018, Labunska et al 2011). In an analysis of the presence of DBP, BBP, and DEHP in industrial effluents in France, Bergé et al (2014) reported all three esters in effluent from the textile, pharmaceutical, aerospace, garbage disposal, vehicle cleaning, cosmetics, surface treatment, metallurgy, and transportation maintenance industries, as well as in effluent from drinking-water treatment and universities. Di-iso butylphthalate has also been reported in effluents from a turkey processing plant (Buyukada 2019).

Interrogation of international pollutant release databases for information on release of DEHP, BBP, DBP and DiBP either to water or to a wastewater network provided little additional insight into those industries whose effluent may be contaminated with these chemicals. Not all the phthalates were present in these databases. For those that were, no discharges to water were identified for DEHP or DBP in Australia in 2019/2020[33], DEHP and BBP in Canada in 2017, or DBP in the US in 2020. Results

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[28] https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/j.efsa.2019.5838 Accessed 2 May 2022
[29] https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/j.efsa.2019.5838 Accessed 2 May 2022
[30] https://iris.epa.gov/ChemicalLanding/&substance_nmbr=14 Accessed 14 December 2021
[31] https://iris.epa.gov/ChemicalLanding/&substance_nmbr=38 Accessed 14 December 2021
[32] https://iris.epa.gov/ChemicalLanding/&substance_nmbr=293 Accessed 14 December 2021
[33] http://www.npi.gov.au/npidata/action/load/browse-search/criteria/browse-type/Substance/year/2020 Accessed 14 January 2022

for discharge of DEHP reported in the US TRI database are summarised in Table 4. This identifies the plastics and resin manufacturing industries as potentially important sources of DEHP contaminated effluents.

Table 4 Discharges of DEHP reported to the US Toxics Release Inventory in 2020

US Toxics Release Inventory 2020		
Primary industry associated with facility[1]	**TRI Industry sector**	**Discharge to surface waters (kg)[2]**
Plastics material and resin manufacturing	Chemicals	179
All other rubber product manufacturing	Plastics and rubber	2.7
Custom compounding of purchased resins	Chemicals	1.8
Custom compounding of purchased resins	Chemicals	0.9
Primary industry associated with facility[1]	**TRI Industry sector**	**Transfer to POTW (kg)[2]**
Surgical appliance and supplies manufacturing	Miscellaneous manufacturing	2.3
Plastics material and resin manufacturing	Chemicals	0.5

TRI, toxics release inventory; POTW, publicly owned treatment works. [1]Based on the North American Industry Classification System (NAICS). [2]Converted from pounds. Excludes WWTPs and hazardous waste treatment and disposal facilities.

3.3.3 Discharge limits and regulation

Although regulations exist with respect to phthalate levels in toys, childcare items, cosmetics, etc, little information is available on discharge limits for these chemicals in wastewater[34]. Limits are set for discharge of DEHP, BBP and DBP under the US EPA ELGs[35]. These limits vary by point source category and are summarised in Table 5.

In Australia, DEHP, DBP and BBP have been declared Priority Existing Chemicals by the National Industrial Chemicals Notification and Assessment Scheme (NICNAS, now the Australian Industrial Chemicals Introduction Scheme, AICIS)[36]. Preliminary

[34] https://www.ec.gc.ca/ese-ees/default.asp?lang=En&n=E00E9A1F-1 Accessed 8 November 2021
[35] https://owapps.epa.gov/elg/ Accessed 14 January 2022
[36] https://www.industrialchemicals.gov.au/chemical-information/search-assessments-keywords?keywords=phthalate Accessed 8 November 2021

analysis of the New Zealand context has identified that DEHP is currently being considered under the draft Water New Zealand Guidelines for Beneficial Use of Organic Materials on Productive Land, with a proposed concentration limit of 100 mg/kg dry weight (Water New Zealand 2017).

Table 5 Summary of US EPA effluent limits for phthalate compounds

Substance	Point source category	Daily maximum concentration (mg/L)	Max monthly average (mg/L)
DEHP	Organic chemicals, plastics and synthetic fibers	0.258 – 0.279	0.095 – 0.103
	Centralised waste treatment	0.215 – 0.267	0.101 – 0.158
BBP	Centralised waste treatment	0.188	0.0887
DBP	Organic chemicals, plastics and synthetic fibers	0.043 – 0.057	0.020 – 0.027

DEHP, di(2-ethylhexyl) phthalate; BBP, benzyl butyl phthalate; DBP, di-*n*-butyl phthalate.

3.4 DIOXINS

Although the term dioxin technically refers to 2,3,7,8- tetrachlorodibenzo-*p*-dioxin (TCDD), it is generally used to refer to chemicals within the polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) and may include some dioxin-like polychlorinated biphenyls (PCBs)[37]. All three of these classes are Annex C persistent organic pollutants (POPs) under the Stockholm Convention[38]. This means that signatories must take actions to reduce their unintentional release, with the goal of minimisation, and where possible elimination. Dioxins are mainly produced as unwanted by-products of industrial processes where chlorine is present, including by pulp and paper mills, herbicide/pesticide manufacturing and smelting[39]. These chemicals generally have high sorption potential so associate with particulate matter, ending up in the sludge where they may accumulate to high levels (Urbaniak & Wyrwicka 2017).

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[37] https://www.who.int/news-room/fact-sheets/detail/dioxins-and-their-effects-on-human-health Accessed 9 November 2021

[38] http://www.pops.int/TheConvention/ThePOPs/AllPOPs/tabid/2509/Default.aspx Accessed 8 November 2021

[39] https://www.who.int/news-room/fact-sheets/detail/dioxins-and-their-effects-on-human-health Accessed 9 November 2021

3.4.1 Health effects

The toxicity of dioxins varies, with each having a toxic equivalency factor (TEF) indicating its toxicity relative to TCDD, with the total 'dioxin-like' toxicity of a mixture being determined from their concentrations multiplied by the respective TEFs (Ministry of Health 2020). The health risks posed by dioxin exposure have been covered in a recent report by the Ministry of Health (Ministry of Health 2020). However, this report notes that the health effects of dioxins are "still not completely understood".

Recommended exposure limits set by the US EPA, EFSA, Joint Food and Agriculture Organization of the United Nations (FAO)/WHO Expert Committee on Food Additives (JECFA), and New Zealand Ministry of Health are provided in Table 6. It is worth noting that the limit set by EFSA in 2018 is seven times lower than the previous limit set in 2001[40].

Table 6 Recommended exposure limits for dioxins and dioxin-like compounds

RfD US EPA 2012[41] (pg/kg bw/day)	TWI EFSA 2018[42] (pg/kg bw/week)	PTMI JECFA[43] 2002 (pg/kg bw/month)	TMI New Zealand MoH 2002[1] (pg/kg bw/month)
0.7 (for TCDD)	2	70	30

RfD, reference Dose; TWI, tolerable weekly intake; PTMI, provisional tolerable monthly intake; TMI, tolerable monthly intake. [1]Ministry of Health (2020).

3.4.2 Industrial effluent sources

Given the status of dioxins as POPs, most industrial countries have taken steps to reduce the release of these toxins. However, there have been few studies of the sources of dioxin release into aquatic environments, and it has been suggested that effluent from industrial processes involving chlorine or chlorination should be assessed for PCDD and PCDF release (Kawamoto & Weber 2021). Historically, pulp and paper mills that perform chlorine bleaching have been shown to contain dioxins in their effluent and sludge (Nakamata & Ohi 2003, Whittemore et al 1990), although changes in the bleaching process can reduce dioxin production (Axegård 2019). Preliminary assessment of the New Zealand context has shown that dioxins have been reported

[40] https://www.efsa.europa.eu/en/press/news/dioxins-and-related-pcbs-tolerable-intake-level-updated Accessed 14 December 2021
[41]https://iris.epa.gov/ChemicalLanding/&substance_nmbr=1024 Accessed 14 December 2021
[42]https://www.efsa.europa.eu/en/press/news/dioxins-and-related-pcbs-tolerable-intake-level-updated Accessed 9 November 2021
[43] https://cdn.who.int/media/docs/default-source/food-safety/dioxins.pdf?sfvrsn=4bcd5f4d_1 Accessed 11 July 22

in waste produced by the pulp and paper industry, and these absorb onto suspended solids ending up in the sludge[44].

In a recent Japanese study, dioxins were found in the effluent from industries involved in manufacture of caprolactam (a nylon intermediate), acetylene, alumina fibres, chlorobenzene, vinyl chloride, 2,3-dichloro-1,4-naphthoquinone, 4-chloro sodium hydrogen phthalate, and organic pigments (eg, dioxazine violet) (Kawamoto & Weber 2021). A US study also identified dioxins in effluents from a range of chemical sector industries, including those involved in production of plastics materials/synthetic resins/non-volatile elastics; industrial organic chemicals; cyclic organic crudes, dyes and pigments; pesticides and agricultural chemicals; and petroleum (Sappington et al 2015). Polychlorinated biphenyls have also been detected in effluent produced by funeral homes during the embalming process (Kleywegt et al 2019).

Interrogation of international pollutant release databases for information on release of dioxins or PCBs to water or to a wastewater network provided some additional insight into industries whose effluent may be contaminated with these chemicals (Table 7). Of note is the potential importance of petroleum refineries.

Preliminary assessment of removal of these chemicals from wastewater has revealed substantial levels may be present after treatment (Urbaniak & Wyrwicka 2017).

3.4.3 Discharge limits and regulation

It has been noted that there are often no specific regulations regarding release of dioxins into aquatic environments (Kawamoto & Weber 2021). In Japan, however, the release of PCDD/PCDFs in industrial water is limited to 10 pg TEQ (toxic equivalent)/L (Kawamoto & Weber 2021). In Canada, pulp and paper mills are prohibited from releasing 2,3,7,8-TCDD and 2,3,7,8-TCDF into the environment under the Canadian Environmental Protection Act, 1999[45]. A limit of less than 10 pg/L per day is set for discharge of 2,3,7,8-TCDD and 2,3,7,8-TCDF by the pulp, paper and paperboard point source category under the US EPA ELGs[46].

In New Zealand, a maximum concentration of 0.002 g/m^3 (2 μg/L) is specified for PCBs in the Trade Waste Standard (Standards New Zealand 2004). Under the 2003 Biosolids Guidelines, concentration limits are set for total PCBs (0.2 mg/kg dry weight for 'grade a' and 'grade b' biosolids) and total dioxin TEQ (0.00003 and 0.00005 mg/kg dry weight for 'grade a' and 'grade b' biosolids respectively) (NZWWA 2003). However, in the draft Guidelines for Beneficial Use of Organic Materials on Productive Land these limits are removed as it is proposed that these guidelines "only measure

44 https://environment.govt.nz/assets/Publications/Files/2018-update-dioxin-emission-inventory-report-april-2019.pdf Accessed 9 November 2021
45 https://laws.justice.gc.ca/eng/regulations/SOR-92-267/FullText.html Accessed 9 November 2021
46 https://owapps.epa.gov/elg/ Accessed 11 January 2022

emerging organic contaminants, not historical banned substances eg, dioxins" (Water New Zealand 2017).

Table 7 Discharge of dioxins and polychlorinated biphenyls reported in pollutant release databases

US Toxics Release Inventory 2020			
Substance	**Primary industry associated with facility[1]**	**TRI Industry sector**	**Discharge to surface waters (kg)[2]**
Dioxin and dioxin-like substances	All other basic organic chemical manufacturing All other pipeline transportation	Chemicals	0.9
Polychlorinated biphenyls	Petroleum refineries	Petroleum	5.0
	Petroleum refineries	Petroleum	2.3
	Secondary smelting, refining, and alloying of nonferrous metal (except copper and aluminium)	Primary metals	0.5
Australian National Pollutant Inventory 2019-2020[47]			
Substance	**Primary ANZSIC class**	**Primary ANZSIC group**	**Discharged to water (kg)**
Polychlorinated dioxins and furans (TEQ)	Pulp, paper and paperboard manufacturing	Pulp, paper and paperboard manufacturing	0.00015

TRI, toxics release inventory; ANZSIC, Australian and New Zealand Standard Industrial Classification; TEQ, toxic equivalent. [1]Based on the North American Industry Classification System (NAICS). [2]Converted from pounds. Excludes WWTPs and hazardous waste treatment and disposal facilities.

[47] http://www.npi.gov.au/npidata/action/load/browse-search/criteria/browse-type/Substance/year/2020 Accessed 14 December 2021

4. HEAVY METALS AND METALLOIDS

Heavy metals refers to metallic elements of high density (at least five times denser than water) (Tchounwou et al 2012). These elements are well known contaminants present in wastewater, and industrial effluents may contain a variety of heavy metals including cadmium, chromium, lead, nickel, copper, zinc, and the metalloid arsenic (Wang 2018). These elements are known to be present in sewage sludge and biosolids. In 2014, the Centre for Integrated Biowaste Research conducted a review of heavy metal contaminants in biowaste including assessment of international guideline concentrations (Esperschütz & Robinson 2014). Concentration limits are set for several heavy metals in the draft Guidelines for Beneficial Use of Organic Materials on Productive Land (Water New Zealand 2017), corresponding to the 'grade B' biosolids limits set in the 2003 Biosolids Guidelines (NZWWA 2003). This section will provide an overview of industrial effluent sources, and effluent discharge limits, associated with those heavy metals covered in the Water New Zealand guidelines of potential concern for human health (cadmium, chromium, lead, mercury, and arsenic), based on international literature. A brief overview of the health effects associated with each element will also be provided.

4.1 CADMIUM

Cadmium (Cd) is a non-essential, toxic heavy metal naturally found in trace amounts in the environment. It is present in phosphate rock, the key ingredient of superphosphate fertiliser, and it is "not possible to economically remove cadmium from the end product" using currently available methodologies[48]. Given the widespread usage of fertiliser in New Zealand, there will be a potentially substantial agricultural contribution to cadmium in the environment, although the fertiliser industry has voluntarily limited cadmium concentration in fertilisers since the late 1990s, and the New Zealand Ministry for Primary Industries has noted that cadmium concentrations are "relatively low in New Zealand soils"[49]. Aside from this agricultural contribution, it is important to consider the potential contribution of cadmium-contaminated industrial effluents to environmental cadmium levels. As such, this section provides an overview of those industries identified internationally as producing cadmium-contaminated effluents. Cadmium has been identified in the draft Water New Zealand Guidelines for Beneficial Use of Organic Materials on Productive Land as being one of the three

[48] https://ballance.co.nz/medias/Cadmium-in-fertilisers.pdf?context=bWFzdGVyfERvY3VtZW50c3w2NTcyMzB8YXBwbGljYXRpb24vcGRmfGhhMy9oYjQvODgwMjY1NjE5MDQ5NC5wZGZ8MmQ5ODM5YTY4ZWNjY2IwOGJmZDhjMzZjMDQxMDVmNzVjZGZkYzI3OWJiMDI5NWNkYmFiMDUxOWU5NjVhNTYxMA Accessed 15 December 2021
[49] https://www.mpi.govt.nz/funding-rural-support/environment-and-natural-resources/land-and-soil-health/monitoring-cadmium-in-nz-soils/ Accessed 15 December 2021

heavy metals potentially present in organic materials of the most concern for human health (Water New Zealand 2017), and has been suggested to be one of the most toxic heavy metals present in industrial effluents (Velusamy et al 2021).

4.1.1 Health effects

Cadmium is toxic even at very low exposure levels and has been associated with damage to the kidneys, where it accumulates with a half-life of around 15 years ('t Mannetje et al 2018). Results from the 2014-2016 New Zealand biological monitoring programme identified cadmium in urine from 89% of adult participants and 53% of child participants. The geometric mean adult urinary cadmium concentration was comparable with data from the US and Europe (DEMOCOPHES study) and lower than reported for Spain, Korea and Canada, and the child geometric mean was comparable to that of Europe (DEMOCOPHES study) and lower than reported for Canada ('t Mannetje et al 2018).

Recommended exposure limits set by the Dutch National Institute for Public Health and the Environment (RIVM), US EPA, US Agency for Toxic Substances and Disease Registry (ATSDR), Joint FAO/WHO Expert Committee on Food Additives (JECFA), EFSA, and Food Standards Australia New Zealand (FSANZ) are provided in Table 8.

Table 8 Recommended exposure limits for cadmium

TDI RIVM 2001[1] (μg/kg bw/day)	RfD US EPA[50] (μg/kg bw/day)	MRL ATSDR 2012[51] (μg/kg bw/day)	PTMI JECFA 2013[52] (μg/kg bw/month)	TWI EFSA 2009[53] (μg/kg bw/week)	PTMI FSANZ[2] (μg/kg bw/month)
0.5 (oral)	0.5 (water) 1 (food)	0.1 (chronic oral)	25	2.5	25

RfD, reference dose; MRL, minimum risk level; PTMI, provisional tolerable monthly intake; TWI, tolerable weekly intake, RIVM, Dutch National Institute for Public Health and the Environment; EPA, Environmental Protection Agency; ATSDR, Agency for Toxic Substances and Disease Registry; JECFA, Joint FAO/WHO Expert Committee on Food Additives; EFSA, European Food Safety Authority; FSANZ, Food Standards Australia New Zealand. [1]Baars et al (2001); [2]Food Standards Australia New Zealand (2011), based on PTMI set by JECFA.

[50]https://cfpub.epa.gov/ncea/iris2/chemicallanding.cfm?substance_nmbr=141 Accessed 8 December 2021
[51]https://wwwn.cdc.gov/TSP/MRLS/mrlslisting.aspx Accessed 8 December 2021
[52]https://apps.who.int/food-additives-contaminants-jecfa-database/chemical.aspx?chemID=1376 Accessed 8 December 2021
[53]https://www.efsa.europa.eu/en/news/efsa-sets-lower-tolerable-intake-level-cadmium-food Accessed 8 December 2021

4.1.2 Industrial effluent sources

Cadmium is employed in a variety of industries including the textile, electronics, electroplating, chemical, metal-finishing and metallurgical industries, and those involved in manufacture of batteries, pigments, ceramics, insecticides, televisions, solders, steel and photography plastics (Velusamy et al 2021). Studies assessing methods for removal of cadmium from industrial effluents have highlighted potential cadmium contamination in effluents from a variety of these industries including the paint (Malakootian et al 2009), metal processing (Slater et al 1987), and battery industries (Shahriari et al 2019). A study of cadmium removal from effluent from a brewery in Nigeria has also highlighted its presence in this waste stream (Ogbiye et al 2018).

Interrogation of international pollutant release databases for information on release of cadmium and its compounds either direct to water or to a wastewater network provided additional insight into those industries whose effluent may be contaminated with these chemicals, as summarised in Table 9 and expanded in Appendix Table 31.

Table 9 Summary of discharges of cadmium or its compounds reported in pollutant release databases

US Toxics Release Inventory 2020			
Substance	**TRI Industry sector**	**Number of facilities[1]**	**Total discharged to surface waters (kg)[2]**
Cadmium compounds	Metal mining	1	254
	Primary metals	5	202
	Chemicals	1	36
Canadian National Pollutant Release Inventory 2017			
Substance	**Industry sector**	**Number of facilities[1]**	**Total released to water (kg)**
Cadmium and its compounds	Paper	25	758
	Primary metals	5	369
	Metal mining	3	161
	Coal mining	2	30
	Petroleum	1	19
Australian National Pollutant Inventory 2019-2020			
Substance	**Industry sector**	**Number of facilities[1]**	**Total emission to water (kg)**
Cadmium and compounds	Primary metals	3	2,512
	Metal mining	5	375
	Chemicals	1	22

TRI, toxics release inventory. [1]Number who discharged/transferred 10 kg per year or more, excluding WWTPs and hazardous waste treatment and disposal facilities; [2]converted from pounds.

These data highlight the importance of the metal (primary and mining) and paper industries, in particular, as potential sources of cadmium contaminated effluents. The importance of the metal industry was also highlighted by the Australian NICNAS (now AICIS), who reported cadmium in wastewaters from a zinc refinery, although this was reported to typically be substantially below regulatory limits[54].

The US EPA has set discharge limits for cadmium from several point source categories including the electroplating, inorganic chemicals manufacturing, nonferrous metals manufacturing, metal finishing, oil and gas extraction, centralised waste treatment, ore mining and dressing, transportation equipment cleaning, waste combustors, battery manufacturing, electrical and electronic components, and nonferrous metals forming and metal powders industries[55] highlighting the likely presence of cadmium in effluents from these industries.

4.1.3 Discharge limits and regulation

As detailed above, the US EPA has set discharge limits for cadmium in effluents from several point source categories[56], with limits varying by category, as summarised in Table 10.

Table 10 Summary of US EPA discharge limits for cadmium

Point source category	Daily maximum concentration (μg/L)	Monthly average[1] (μg/L)	Max monthly average (μg/L)
Electroplating	1200		
Inorganic chemicals manufacturing	840	280	
Metal finishing	110 – 690	70 – 260	
Centralized waste treatment	17.2 – 782		10.2 – 163
Ore mining and dressing	100	50	
Transportation equipment cleaning	20		
Waste combustors	71		26
Electrical and electronic components	60 – 550		30 – 260

[1]Average of daily values for 30 consecutive days. All categories with per litre limits.

[54]https://www.industrialchemicals.gov.au/sites/default/files/Cadmium%20metal%20and%20cadmium%20oxide_%20Environment%20tier%20II%20assessment.pdf Accessed 2 December 2021
[55] https://owapps.epa.gov/elg/ Accessed 2 December 2021
[56] https://owapps.epa.gov/elg/ Accessed 2 December 2021

In Australia, cadmium emissions from sites where it is refined are regulated by state legislature[57]. In Tasmania, an Environmental Protection Notice issued under the Environmental Management and Pollution Control Act (1994) limits cadmium emissions from a zinc refinery in Hobart discharged direct to surface waters to 30 μg/L (with a threshold limit of 70 μg/L). In South Australia, emissions from the Port Pirie smelter are regulated under the Environmental Protection Act (1993) through a license issued by the South Australian EPA which sets a cadmium target threshold of 230 μg/L and reportable limit of 615 μg/L.

In New Zealand, the maximum concentration of cadmium permissible under the Model General Bylaw for Trade Waste (Standards New Zealand 2004) is 0.5 g/m^3 (equivalent to 500 μg/L). Under the draft Water New Zealand Guidelines for Beneficial Use of Organic Materials on Productive Land the proposed concentration limit for cadmium is 10 mg per kg of dry weight (Water New Zealand 2017), corresponding to the ‘grade B’ biosolids limit specified in the 2003 Biosolids Guidelines (NZWWA 2003).

4.2 CHROMIUM

Elemental chromium (Cr) is never found in nature, but rather it exists in a variety of oxidation states, with chromium III being the most stable followed by chromium VI (Wilbur et al 2012). Chromium III occurs naturally and is an essential nutrient. Chromium VI, in comparison, is highly toxic and seldom occurs naturally as it is readily reduced to chromium III (US Environmental Protection Agency 1984). Chromium VI is produced via anthropogenic activities and once it enters water is relatively stable due to the generally low level of reducing matter (US Environmental Protection Agency 1984, Wilbur et al 2012).

4.2.1 Health effects

Chromium VI exposure has been associated with cancer development and effects on the respiratory system and kidneys ('t Mannetje et al 2018). The health effects of chromium III are less well studied partly because studies are confounded by concomitant chromium VI exposure (Wilbur et al 2012). Results from the 2014-2016 New Zealand biological monitoring programme identified chromium in urine from 59% of adult and 44% of child participants. The geometric mean chromium concentration was “considerably lower than the most recent results reported for France and Belgium” ('t Mannetje et al 2018). However, due to a lack of reported geometric means the levels could not be compared with those of the US or Canada.

[57]https://www.industrialchemicals.gov.au/sites/default/files/Cadmium%20metal%20and%20cadmium%20oxide_%20Environment%20tier%20II%20assessment.pdf Accessed 2 December 2021

Recommended exposure limits set by RIVM, US EPA, the EFSA panel on Contaminants in the Food Chain (EFSA CONTAM), International Programme on Chemical Safety (IPCS), and US ATSDR are provided in Table 11.

Table 11 Recommended exposure limits for chromium III and VI

	TDI RIVM[1] (µg/kg bw/day)	RfD US EPA 1998 (µg/kg bw/day)	TDI EFSA CONTAM[2] (µg/kg bw/day)	TDI IPCS[3] (µg/kg bw/day)	MRL[5] ATSDR 2012[58] (µg/kg bw/day)
Cr III	5 (water soluble) 5000 (insoluble)	1500[59] (insoluble)	300		
Cr VI	5* (oral)	3[60] (oral)		0.9 (oral)	0.9 (chronic oral)

TDI, tolerable daily intake; RfD, reference dose; MRL, minimum risk level; RIVM, Dutch National Institute for Public Health and the Environment; EPA, Environmental Protection Agency; EFSA CONTAM, European Food Safety Authority panel on Contaminants in the Food Chain; IPCS, International Programme on Chemical Safety; ATSDR, Agency for Toxic Substances and Disease Registry. [1]Baars et al (2001); [2]European Food Safety Authority (2014); [3]World Health Organization and International Programme on Chemical Safety (2013). *Provisional Maximum Permissible Risk, non-carcinogenic effects.

4.2.2 Industrial effluent sources

Chromium has been identified as a contaminant in effluent from a variety of different industries, including tanneries, textile, metal finishing and electroplating, pigment production, wood preservation and fertiliser industries (Dermentzis et al 2011, Verma et al 2013). The textile, leather tanning, and electroplating industries were identified by the US ATSDR as releasing large amounts of chromium into surface waters[61]. Untreated effluent produced by the electroplating industry often contains very high levels of chromium (reportedly up to 2,500 mg/L of the highly toxic chromium VI) (Dermentzis et al 2011). Effluents from the electroplating industry must therefore be efficiently treated to remove chromium prior to discharge. Very high levels of chromium

[58]https://wwwn.cdc.gov/TSP/MRLS/mrlslisting.aspx Accessed 8 December 2021
[59] https://iris.epa.gov/ChemicalLanding/&substance_nmbr=28 Accessed 14 December 2021
[60] https://iris.epa.gov/ChemicalLanding/&substance_nmbr=144 Accessed 14 December 2021
[61]https://www.atsdr.cdc.gov/csem/chromium/where_is_chromium_found.html#:~:text=Electroplating%2C%20leather%20tanning%2C%20and%20textile,entry%20into%20bodies%20of%20water. Accessed 10 November 2021

(0.2 to more than 14 mg/L) have also been found in effluent from leather tanneries in Argentina (Labunska et al 2011) and substantial chromium concentrations have been reported in textile dying wastewaters (Çetin et al 2008).

A recent publication on chromium pollution in EU waters identified the energy sector as the major contributor of chromium to water in 2017, followed by the waste and wastewater management sector, production and processing of metals, the chemical industry, mineral industry and paper and wood production processing (Figure 2) (Tumolo et al 2020).

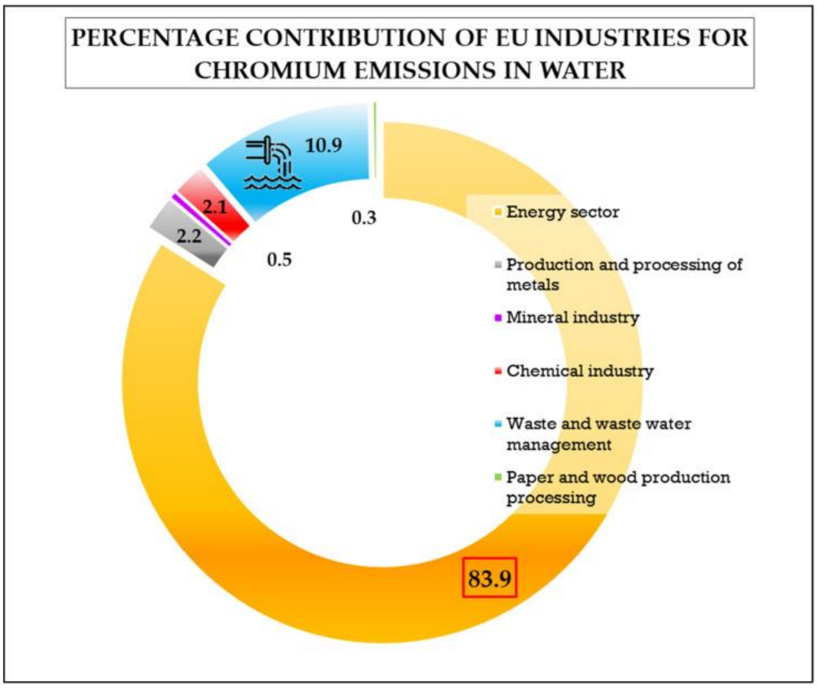

Figure 2 Chromium emissions in European Union waters by industrial sector

Reproduced from Tumolo et al (2020). Data from 2017 released by the European Environmental Agency.

Interrogation of international pollutant release databases for information on release of chromium and its compounds either direct to water or to a wastewater network provided valuable additional insight, as summarised in Table 12 and expanded in Appendix Table 32. These data emphasise the importance of the energy sector as a potentially major source of chromium contaminated effluents, with fossil fuel electricity generation facilities reported to discharge large amounts of chromium compounds. The metal sector (mining, primary metal, and fabricated metal industries) was also identified as a major contributor of chromium and its compounds to surface waters and wastewater. Several leather industry facilities were also reported in the US database to have transferred large amounts of chromium compounds to POTWs, again emphasising the importance of this industry as a potential source of chromium-contaminated effluents.

Table 12 Summary of discharges of chromium or its compounds reported in pollutant release databases

US Toxics Release Inventory 2020			
Substance	**TRI Industry sector**	**Number of facilities**[1]	**Total discharged to surface waters (kg)**[2]
Chromium	Nonmetallic mineral product	2	6,580
	Primary metals	8	395
	Petroleum	2	333
	Fabricated metals	3	273
	Machinery	3	169
	Chemical	2	110
	Transport equipment	5	102
Chromium compounds	Electricity generation	32	8,640
	Primary metals	36	3,652
	Paper	6	1,627
	Chemicals	15	1,010
	Petroleum	8	374
	Metal mining	1	227
	Fabricated metals	2	80
	Wood products	4	60
	Transportation equipment	3	59
	Plastics and rubber	1	45
Substance	**TRI Industry sector**	**Number of facilities**[1]	**Total transferred to POTW (kg)**[2]
Chromium	Fabricated metals	7	2,428
	Primary metals	8	511
	Machinery	3	143
	Food	1	88
	Furniture	2	57
	Chemicals	1	37
	Transportation equipment	3	35
	Leather	1	30
	Miscellaneous manufacturing	1	25
	Nonmetallic mineral product	1	11
Chromium compounds	Leather	5	1,795
	Fabricated metals	22	774
	Transportation equipment	7	202
	Chemicals	6	140
	Machinery	1	113
	Electricity generation	1	64

	Plastics and rubber	1	39
	Miscellaneous manufacturing	1	12
	Primary metals	1	11
	Other	1	10
Australian National Pollutant Inventory 2019-2020			
Substance	**Industry sector**	**Number of facilities[1]**	**Total emission to water (kg)**
Chromium III compounds	Metal mining	9	1,611
	Primary metals	3	170
	Chemical	5	120
	Electricity generation	2	58
	Oil and gas extraction	1	56
	Paper	1	51
	Water transport services	1	17
	Mining (other)	1	16
Chromium VI compounds	Chemical	3	31
	Metal mining	1	26
	Coal mining	3	14
	Oil and gas extraction	3	13
	Petroleum	1	7
Substance	**Industry sector**	**Number of facilities[1]**	**Total transferred to off-site sewerage (kg)**
Chromium III compounds	Electricity generation	1	170
	Water transport support services	1	55

TRI, toxics release inventory; POTW, publicly owned treatment works. [1]Number who discharged/transferred 10 kg or more total chromium or 1 kg or more chromium VI per year, excluding WWTPs and hazardous waste treatment and disposal facilities; [2]converted from pounds.

Several paper industry facilities were also identified as substantial contributors of chromium-contaminated effluents. A cement manufacturer was reported to have discharged the most chromium to surface waters in the US during 2020 (20x more than the next highest facility). Chromium VI may be present at trace amounts in cement due to its presence in raw materials used in cement production (Eštoková et al 2012).

The US EPA has also set concentration limits for total chromium[62] and chromium VI[63] present in discharges from several point source categories under the ELGs, highlighting these industries as potential sources of chromium contaminated effluents. For total chromium, these point source categories include textile mills, electroplating, organic chemicals, plastics and synthetic fibers, inorganic chemicals manufacturing, petroleum refining, iron and steel manufacturing, nonferrous metals manufacturing,

[62] https://owapps.epa.gov/elg/results Accessed 16 December 2021
[63] https://owapps.epa.gov/elg/results Accessed 16 December 2021

steam electric power generating, ferroalloy manufacturing, leather tanning and finishing, rubber manufacturing, timber products processing, metal finishing, centralised waste treatment, transportation equipment cleaning, waste combustors, landfills, battery manufacturing, coil coating, porcelain enamelling, aluminium forming, copper forming, electrical and electronic components, and nonferrous metals forming and metal powders. For chromium VI, these categories include inorganic chemicals manufacturing, petroleum refining, iron and steel manufacturing, and ferroalloy manufacturing.

4.2.3 Discharge limits and regulation

The EU has not proposed any universal limits for discharge of chromium III or VI to water, but member states must report any discharges of more than 50 kg per year to a specific water body (Vaiopoulou & Gikas 2020). Discharge limits vary between member states, with a maximum limit for discharge to water of 5 mg/L for total chromium and 1 mg/L for chromium VI, as summarised in Table 13.

As mentioned above, in the US, limits are set for total chromium and chromium VI under the ELGs[64]. For chromium VI, the only point source category with per litre limitations is inorganic chemicals manufacturing which has daily maximum limits of 0.11 – 0.25 mg/L and monthly average limits of 0.06 – 0.09 mg/L. The limits for total chromium discharge vary by point source category, as summarised in Table 14.

Table 13 Discharge limits for chromium in European Union member states

Member State	Austria [1]	Belgium [1,2,3]	Croatia [3]	Cyprus [4]	Czech Republic [1,2]	Denmark [3]
Total Cr	0.5–3	0.5–5	1–4	0.5	0.5–1	0.001–0.3
Cr (VI)	-	0.1–1	0.1	0.1	0.1–0.3	-
Member State	**Estonia [4]**	**Finland [4]**	**France**	**Germany [1]**	**Greece [3,*]**	**Hungary [1,3]**
Total Cr	0.5	0.7	0.5	0.1–0.5	0.6–1.5	0.2–1
Cr (VI)	0.1	0.2	0.1	0.05–0.5	-	0.1–0.5
Member State	**Ireland**	**Italy [3]**	**Lithuania [3]**	**Luxembourg**	**Malta**	**The Netherlands [1]**
Total Cr	0.5	2–4	-	0.5	0.5	0.5
Cr (VI)	0.1	0.2	0.1–0.2	0.1	0.1	0.1–2
Member State	**Norway**	**Poland [1]**	**Portugal**	**Sweden [4]**	**Slovak Republic [1]**	**Slovenia [1]**
Total Cr	-	-	2	0.5	0.5–1	0.5–1
Cr (VI)	0.05	0.05–0.5	0.1	0.1	0.1	0.1
Member State	**Spain**	**Sweden [4]**	-	-	-	-
Total Cr	5	0.5	-	-	-	-
Cr (VI)	0.3	0.1	-	-	-	-

[1] Discharge limit varies depending on industrial type; [2] regional policy; [3] limit depends on the type of receiving water body; [4] case-specific regulation; * average monthly discharge limit (average daily discharge is double).

Reproduced from Tumolo et al (2020). Values all mg/L.

[64] https://owapps.epa.gov/elg/ Accessed 6 December 2021

In New Zealand, the maximum concentration of chromium permissible under the Model General Bylaw for Trade Waste (Standards New Zealand 2004) is 5 g/m^3 (equivalent to 5 mg/L). Under the draft Water New Zealand Guidelines for Beneficial Use of Organic Materials on Productive Land the proposed concentration limit for chromium is 1500 mg per kg of dry weight (Water New Zealand 2017), corresponding to the 'grade B' biosolids limit specified in the 2003 Biosolids Guidelines (NZWWA 2003). No distinction is made between total chromium and chromium VI in these regulations. However, it is noted in the Trade Waste Standard that for discharges where chromium III is known to make up a large proportion of the discharge, higher discharge concentration limits may be acceptable.

Table 14 Summary of US EPA discharge limits for total chromium

Point source category	Daily maximum concentration (mg/L)	Monthly average[1] (mg/L)	Max monthly average (mg/L)
Electroplating	7		
Organic chemicals, plastics and synthetic fibers	2.77		1.11
Inorganic chemicals manufacturing	0.23 - 3	0.12 – 1.2	
Petroleum refining	1		
Steam electric power generation	0.2	0.2	
Leather tanning and finishing	12 - 19		8 – 12
Timber products processing	4		
Metal finishing	2.77	1.71	
Centralised waste treatment	0.167 – 15.5		0.0522 – 3.07
Transportation equipment cleaning	0.42		
Waste combustors	0.025		0.014
Landfills	1.1		0.46
Porcelain enamelling	0.42		0.17
Electrical and electronic components	0.56 – 0.65		0.26 – 0.30

[1]Average of daily values for 30 consecutive days. All categories with per litre limits.

4.3 LEAD

Lead (Pb) is a non-essential metal found in trace amounts in the environment. Historically, it has been extensively used in a variety of products including petrol, paints, batteries, ceramics, cosmetics, and plumbing pipes and materials[65]. However,

[65] https://www.epa.gov/lead/learn-about-lead Accessed 16 December 2021

due to its toxicity, many historic uses have been phased out, including its addition to petrol which was banned in New Zealand in 1996[66], usage in solder of cans used for canned food (Pickston et al 1985), and its usage in other than special-purpose paints used in New Zealand[67].

4.3.1 Health effects

Lead (Pb) exposure in adults has been associated with a range of adverse health effects including decreased renal function, reduced fertility, increased blood pressure and neurocognitive effects ('t Mannetje et al 2018). Lead exposure in children has been noted to be of particular concern as it has been reported to cause neurodevelopmental effects even at low exposure levels, with the US Centers for Disease Control (CDC) indicating there is no safe level of blood lead in children ('t Mannetje et al 2018). Results from the 2014-2016 New Zealand biological monitoring programme identified lead in blood from all participants (adult and children), although none had levels above the then notifiable level of 100 μg/L (the notifiable limit is now 0.24 μmol/L[68]). The geometric mean concentrations for adults and children were comparable to those of the US and Canada, although their levels have been decreasing with the most recent results below that of New Zealand, possibly due to leaded petrol being phased out in North America more than a decade before New Zealand ('t Mannetje et al 2018). Lead was identified in the Water New Zealand Guidelines for Beneficial Use of Organic Materials on Productive Land as one of the three heavy metals potentially present in organic materials of the most concern for human health (Water New Zealand 2017).

The Dutch National Institute for Public Health and the Environment has established a recommended exposure limit of 3.6 μg/kg bw/day for oral lead exposure (Baars et al 2001). A provisional tolerable weekly intake of 25 μg/kg bw/week established by JECFA was withdrawn in 2011 as it "could no longer be considered health protective"[69].

4.3.2 Industrial effluent sources

Lead is a well-established industrial contaminant, and lead levels in untreated industrial effluents may reach 200-500 mg/L (Arbabi et al 2015). Lead is used in a wide variety of industries including production of acid batteries, printed circuit boards,

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[66] https://www.beehive.govt.nz/release/petrol-and-diesel-delivering-quality Accessed 16 December 2021
[67] https://www.health.govt.nz/your-health/healthy-living/environmental-health/hazardous-substances/removing-lead-based-paint Accessed 16 December 2021
[68] https://www.health.govt.nz/news-media/news-items/reduction-blood-lead-notification-level Accessed 29 April 2022
[69] https://apps.who.int/food-additives-contaminants-jecfa-database/chemical.aspx?chemID=3511 Accessed 15 December 2021

ammunition, ceramics, and glass, metal plating and finishing, and the paint and pigment manufacturing industry, and wastewaters from these industries may contain high lead concentrations[70].

In the US, the iron and steel manufacturing and pulp and paper industries were identified by the EPA as dischargers of lead-contaminated effluents (US Environmental Protection Agency 2018). Lead has also been found in wastewaters from the paint (Malakootian et al 2009) and textile industries (Muhammd 2018), and a brewery (Muhammd 2018).

Interrogation of international pollutant release databases for information on release of lead and its compounds either direct to water or to a wastewater network provided additional insight, as summarised in Table 15 and expanded in Appendix Table 33. These data emphasise the importance of the metal (mining, primary and fabricated metals) and paper industries as sources of lead-contaminated effluents. It also highlighted the potential importance of the chemical, electricity generation (fossil fuel electric power generation) and petroleum industries as potential sources of lead-contaminated effluents. Similar to chromium, the highest reported lead discharger in the US database for 2020 was a cement manufacturer.

The US EPA has set limits for lead in discharges from several point source categories under the ELGs[71], highlighting them as potential sources of lead contaminated effluents. These categories include electroplating, organic chemicals, plastics and synthetic fibers, inorganic chemicals manufacturing, iron and steel manufacturing, nonferrous metals manufacturing, glass manufacturing, rubber manufacturing, metal finishing, centralised waste treatment, ore mining and dressing, transportation equipment cleaning, waste combustors, pesticide chemicals, battery manufacturing, metal molding and casting (foundries), porcelain enamelling, copper forming, electrical and electronic components, and nonferrous metals forming and metal powders.

4.3.3 Discharge limits and regulation

As mentioned above, limits are set for lead under the US EPA ELGs, as summarised in Table 16.

In Tasmania, Environmental Protection Notice 7043/4 issued by the Tasmanian Environment Protection Authority limits lead concentrations in discharge from a Hobart zinc smelter to 0.20 mg/L, and concentrations must be monitored daily (Nyrstar 2018).

[70] https://www.samcotech.com/acceptable-lead-levels-in-wastewater-removal/ Accessed 10 November 2021
[71] https://owapps.epa.gov/elg/results Accessed 16 December 2021

Table 15 Summary of discharges of lead or its compounds reported in pollutant release databases

US Toxics Release Inventory 2020			
Substance	**TRI Industry sector**	**Number of facilities[1]**	**Total discharged to surface waters (kg)[2]**
Lead	Nonmetallic mineral product	1	4,299
	Chemicals	7	578
	Primary metals	6	203
	Transportation equipment	5	183
	Paper	5	130
	Beverages	1	71
	Wood products	1	19
	Fabricated metals	1	16
	Other	1	13
	Electrical equipment	1	11
Lead compounds	Paper	16	5,121
	Primary metals	6	2,339
	Electric utilities	5	2,094
	Metal mining	3	806
	Other	2	495
	Chemicals	3	382
	Fabricated metals	2	280
	Petroleum	1	108
Substance	**TRI Industry sector**	**Number of facilities[1]**	**Total transferred to POTW (kg)[2]**
Lead	Furniture	3	196
	Petroleum	2	125
	Computer/electronics products	1	86
	Paper	2	26
	Primary metals	1	19
	Other	1	16
	Printing	1	11
	Transportation equipment	1	11
Lead compounds	Primary metals	5	182
	Plastics and rubber	1	152
	Paper	3	140
	Fabricated metals	3	57
	Electric utilities	2	30
	Petroleum	2	29
	Chemicals	2	26
	Machinery	1	18

	Transportation equipment	1	11
	Food	1	10
	Nonmetallic mineral product	1	10
Canadian National Pollutant Release Inventory 2017			
Substance	**Industry sector**	**Number of facilities[1]**	**Total released to water (kg)**
Lead and its compounds	Primary metals	9	1,820
	Paper	30	1,411
	Metal mining	10	969
	Petroleum	3	248
	Water transport services	1	65
	Fabricated metals	2	34
	Coal mining	1	22
	Electronics	1	22
	Oil and gas extraction	1	14
Australian National Pollutant Inventory 2019-2020			
Substance	**Industry sector**	**Number of facilities[1]**	**Total emission to water (kg)**
Lead and compounds	Primary metals	6	20,387
	Metal mining	13	7,638
	Petroleum	1	110
	Electricity generation	1	59
	Chemicals	2	60
	Oil and gas extraction	1	10
Substance	**Industry sector**	**Number of facilities[1]**	**Total transferred to off-site sewerage (kg)**
Lead and compounds	Primary metals	1	87
	Water transport services	1	30
	Chemicals	1	11

TRI, toxics release inventory; POTW, publicly owned treatment works. [1]Number who discharged/transferred 10 kg or more per year (100 kg for lead compounds discharged to surface waters in US), excluding WWTPs and hazardous waste treatment and disposal facilities; [2]converted from pounds.

Table 16 Summary of US EPA discharge limits for lead

Point source category	Daily maximum concentration (mg/L)	Monthly average[1] (mg/L)	Max monthly average (mg/L)
Electroplating	0.6		
Organic chemicals, plastics and synthetic fibers	0.69		0.32
Inorganic chemicals manufacturing	0.18 – 3.4	0.048 – 1.4	
Glass manufacturing	0.2	0.1	
Metal finishing	0.69	0.43	
Centralised waste treatment	0.222 – 1.32		0.16 – 0.283
Ore mining and dressing	0.6	0.3	
Transportation equipment cleaning	0.14		
Waste combustors	0.057		0.032
Pesticide chemicals	0.69	0.32	
Metal molding and casting (foundries)	0.53 – 0.79		0.26 – 0.39
Porcelain enamelling	0.15		0.13
Electrical and electronic components	0.72 – 1.12		0.27 – 0.41

[1]Average of daily values for 30 consecutive days. All categories with per litre limits.

The maximum concentration of lead permitted in New Zealand under the Model General Bylaw for Trade Waste (Standards New Zealand 2004) is 10 g/m^3 (equivalent to 10 mg/L). Under the draft Water New Zealand Guidelines for Beneficial Use of Organic Materials on Productive Land the proposed concentration limit for lead is 300 mg per kg of dry weight (Water New Zealand 2017), corresponding to the 'grade B' biosolids limit specified in the 2003 Biosolids Guidelines (NZWWA 2003).

4.4 MERCURY

Mercury (Hg) is a highly toxic, non-essential element which together with its salts has been used in a variety of industrial and residential products, including fluorescent light bulbs, electrical switches, pigments, personal care products[72], thermometers, batteries, and dental amalgams[73]. However, due to its effects on human health, and its persistence in the environment, its usage in many applications is being phased out (Crossett 2011). Mercury can enter the wastewater network from a variety of sources and the majority ends up in the sewage sludge, which is potentially problematic when this is used as fertiliser (Suess et al 2020).

[72]https://www.epa.gov/mercury/basic-information-about-mercury Accessed 6 December 2021
[73]https://p2infohouse.org/ref/04/03851/paper.pdf Accessed 6 December 2021

4.4.1 Health effects

The health effects of mercury exposure vary depending on the elemental form an individual is exposed to (elemental, inorganic, organic) (Ministry of Health 2021). Mercury is known to affect "many organic systems", including the kidneys, brain, and skin, and can accumulate in the human body (Ministry of Health 2021). Additionally, both elemental and organic mercury can cross the blood-brain and placental barriers, allowing accumulation in the brain and developing foetus (Ministry of Health 2021). Neurological effects are the most common adverse effects of mercury exposure, with the developing foetus being the most vulnerable group (ATSDR 1999, JECFA 2007).

Results from the 2014-2016 New Zealand biological monitoring programme identified mercury in blood from 99% of adult and 93% of child participants. Both the adult and child geometric means were higher than those of the US, Canada, and Germany. The adult geometric mean was comparable to that of France and lower than that of Korea, whilst the child geometric mean was comparable to that of Italy ('t Mannetje et al 2018).

Mercury has been identified in the Water New Zealand Guidelines for Beneficial Use of Organic Materials on Productive Land as one of the three heavy metals potentially present in organic materials of the most concern for human health (Water New Zealand 2017). Recommended exposure limits set by RIVM, US ATSDR, JECFA, and US EPA are provided in Table 17.

Table 17 Recommended exposure limits for mercury

TDI RIVM 2001[1] (µg/kg bw/day)	MRL ATSDR 1999[74] (µg/kg bw/day)	PTWI JECFA 2011 (µg/kg bw/week)	RfD US EPA 2001[75] (µg/kg bw/day)
2 (inorganic, oral) 0.1 (organic, oral)	0.3 (methylmercury, chronic oral)	4 (inorganic)[76] 1.6 (methylmercury)[77]	0.1 (methylmercury, oral)

TDI, tolerable daily intake; MRL, minimum risk level; PTWI, provisional tolerable weekly intake; RfD, reference dose; RIVM, Dutch National Institute for Public Health and the Environment; ATSDR, Agency for Toxic Substances and Disease Registry; JECFA, Joint FAO/WHO Expert Committee on Food Additives; EPA, Environmental Protection Agency. [1]Baars et al (2001).

[74]https://wwwn.cdc.gov/TSP/MRLS/mrlslisting.aspx Accessed 8 December 2021
[75]https://iris.epa.gov/ChemicalLanding/&substance_nmbr=73 Accessed 15 December 2021
[76]https://apps.who.int/food-additives-contaminants-jecfa-database/chemical.aspx?chemID=1806 Accessed 8 December 2021
[77] https://apps.who.int/food-additives-contaminants-jecfa-database/chemical.aspx?chemID=3083 Accessed 14 January 2022

4.4.2 Industrial effluent sources

In 2008, dental practice wastes in the US were estimated to contribute around 50% of the mercury present in municipal wastewater networks (Bender 2008). Indeed, dental practices have been identified by the US EPA as the main source of mercury entering POTWs, and in 2017 they effected pre-treatment standards for effluents from dental practices entering POTWs to reduce the discharge of mercury[78]. This involves the use of amalgam separators to remove amalgam from the effluents before they are discharged to the municipal network[79].

Interrogation of international pollutant release databases for information on release of mercury or its compounds either to water or to a wastewater network revealed some additional insight into those industries whose effluent may be contaminated with these chemicals. Information from these databases is summarised in Table 18, and expanded in Appendix Table 34.

These data identified the paper, electric utilities, and metal sectors (mining, primary and fabricated metals) as potentially important with respect to mercury contaminated effluents. A cement manufacturer discharged the most mercury to surface waters in the US during 2020.

The US EPA has set limits for mercury present in discharges from several point source categories under the ELGs, highlighting these industries as potential sources of mercury contaminated effluents[80]. These include inorganic chemicals manufacturing, nonferrous metals manufacturing, steam electric power generating, oil and gas extraction, centralised waste treatment, ore mining and dressing, transportation equipment cleaning, waste combustors and battery manufacturing.

4.4.3 Discharge limits and regulation

Mercury is recognised as a priority hazardous substance in many countries around the world and is covered by the Minamata Convention which aims to reduce global mercury emissions (Suess et al 2020). New Zealand signed the Convention in 2013 but has yet to ratify it[81].

[78]https://www.epa.gov/eg/dental-effluent-guidelines Accessed 6 December 2021
[79]https://www.epa.gov/mercury/what-epa-doing-reduce-mercury-pollution-and-exposures-mercury Accessed 6 December 2021
[80] https://owapps.epa.gov/elg/results Accessed 6 December 2021
[81]https://environment.govt.nz/what-government-is-doing/international-action/minamata-convention-on-mercury/ Accessed 14 January 2022

Table 18 Summary of discharges of mercury or its compounds reported in pollutant release databases

US Toxics Release Inventory 2020			
Substance	**TRI Industry sector**	**Number of facilities[1]**	**Total discharged to surface waters (kg)[2]**
Mercury	Non-metallic mineral product	1	303
	Primary metals	1	60
	Electric utilities	2	19.5
	Fabricated metals	1	3.6
Mercury compounds	Other	1	662
	Metal mining	1	300
	Paper	7	172
	Petroleum	3	96
	Electric utilities	13	60
	Primary metals	5	52
	Chemicals	6	28
Substance	**TRI Industry sector**	**Number of facilities[1]**	**Total transferred to POTW (kg)[2]**
Mercury	Primary metals	1	5.4
	Petroleum	1	2.7
Mercury compounds	Petroleum	1	4.5
	Other	1	4.5
	Chemicals	1	4.5
Australian National Pollutant Inventory 2019-2020			
Substance	**Industry sector**	**Number of facilities[1]**	**Total emission to water (kg)**
Mercury and compounds	Primary metals	2	26
	Water supply, sewerage and drainage services	1	9
	Oil and gas extraction	2	3.9
	Metal mining	2	3.7
	Industry sector	**Number of facilities[1]**	**Total transferred to off-site sewerage (kg)**
	Water transport support services	1	1.2
Canadian National Pollutant Release Inventory 2017			
Substance	**Industry sector**	**Number of facilities[1]**	**Total released to water (kg)**
Mercury and its compounds	Paper	6	16.5
	Primary metals	2	12
	Metal mining	3	4.5

TRI, toxics release inventory; POTW, publicly owned treatment works. [1]Number who discharged/transferred 1 kg or more per year, excluding WWTPs and hazardous waste treatment and disposal facilities; [2]converted from pounds.

In Tasmania, Environmental Protection Notice 7043/4 issued by the Tasmanian Environment Protection Authority limits mercury concentrations in discharge from a Hobart zinc smelter to 10 μg/L, and concentrations must be monitored daily (Nyrstar 2018). In the US, limits are set for mercury under the EPA ELGs[82]. Limits for the different point source categories are summarised in Table 19.

Table 19 Summary of US EPA discharge limits for mercury

Point source category	Daily maximum concentration (μg/L)	Monthly average[1] (μg/L)	Max monthly average (μg/L)
Inorganic chemicals manufacturing	110	48	
Steam electric power generating	0.0018 – 0.788	0.0013 – 0.356	
Centralised waste treatment	0.641 –17.2		0.246 – 6.47
Ore mining and dressing	2	1	
Transportation equipment cleaning	1.3 –3.1		
Waste combustors	2.3		1.3

[1]Average of daily values for 30 consecutive days. All categories with per litre limits.

The maximum concentration of mercury permissible in New Zealand under the Model General Bylaw for Trade Waste (Standards New Zealand 2004) is 0.05 g/m^3 (equivalent to 50 μg/L). Under the draft Water New Zealand Guidelines for Beneficial Use of Organic Materials on Productive Land the proposed limit for mercury is 7.5 mg per kg of dry weight (Water New Zealand 2017), corresponding to the 'grade B' biosolids limit specified in the 2003 Biosolids Guidelines (NZWWA 2003).

4.5 ARSENIC

Arsenic (As) is a metalloid, which is a chemical with intermediate properties between those of metal and non-metal elements. Historically, arsenic and its compounds have been used in a wide variety of industrial applications including in pharmaceuticals, pesticides, and other agricultural products (IARC working group on the evaluation of carcinogenic risks to humans 2012). Although many of its historic uses have been stopped largely owing to its well-known toxic nature, it is still used industrially in a range of processes including as an alloying agent in the metal industry, in the leather industry during tanning of hides, and during manufacture of pigments, glass, metal adhesives, paper, ammunition and wood preservatives[83].

[82]https://owapps.epa.gov/elg/results Accessed 6 December 2021
[83] https://www.who.int/news-room/fact-sheets/detail/arsenic Accessed 8 December 2021

4.5.1 Health effects

Arsenic exists in two main forms – organic and inorganic, with inorganic arsenic being highly toxic and organic arsenic considered less harmful[84,85]. Arsenic is known to be carcinogenic, and chronic oral exposure to moderate amounts of arsenic has been associated with development of various cancers including skin, bladder, and lung cancer[86,87]. Long-term exposure to moderate levels has also been associated with damage to the kidneys, liver, heart, nerves, blood and blood vessels[88].

Results from the 2014-2016 New Zealand biological monitoring programme identified inorganic arsenic in urine from 79% of adult and 74% of child participants and organic arsenic (specifically arsenobetaine) in 68% of adult and 53% of child participants ('t Mannetje et al 2018). Arsenobetaine is the predominant form of arsenic in fish, with fish being the main contributor to dietary arsenic exposure. Adult urinary arsenobetaine concentrations were approximately double that of the US, but lower than countries known to consume high levels of fish such as Japan and Spain ('t Mannetje et al 2018). No comparisons of the child levels were made.

Recommended exposure limits proposed by RIVM, US EPA, and the US ATSDR are provided in Table 20. It is also important to note that JECFA withdrew its PTWI for inorganic arsenic in 2010 and did not establish a new tolerable intake level (JECFA 2011), and the EFSA CONTAM panel did not set a PTWI due to the carcinogenicity of arsenic (EFSA Panel on Contaminants in the Food Chain 2009).

Table 20 Recommended exposure limits for arsenic

TDI RIVM[1] (µg/kg bw/day)	RfD US EPA 1991[89] (µg/kg bw/day)	MRL ATSDR 2007[90] (µg/kg bw/day)
1 (inorganic; oral)	0.3 (inorganic, oral)	0.3 (chronic oral)

TDI, tolerable daily intake; RfD, reference dose; MRL, minimum risk level; RIVM, Dutch National Institute for Public Health and the Environment; EPA, Environmental Protection Agency; ATSDR, Agency for Toxic Substances and Disease Registry. [1]Baars et al (2001).

[84] https://www.health.govt.nz/your-health/healthy-living/environmental-health/hazardous-substances/arsenic-and-health#healtheffects Accessed 15 December 2021
[85] https://www.who.int/news-room/fact-sheets/detail/arsenic Accessed 8 December 2021
[86] https://www.health.govt.nz/your-health/healthy-living/environmental-health/hazardous-substances/arsenic-and-health#healtheffects Accessed 15 December 2021
[87] https://www.who.int/news-room/fact-sheets/detail/arsenic Accessed 8 December 2021
[88] https://www.health.govt.nz/your-health/healthy-living/environmental-health/hazardous-substances/arsenic-and-health#healtheffects Accessed 15 December 2021
[89] https://iris.epa.gov/ChemicalLanding/&substance_nmbr=278 Accessed 8 December 2021
[90] https://wwwn.cdc.gov/TSP/MRLS/mrlslisting.aspx Accessed 8 December 2021

4.5.2 Industrial effluent sources

Arsenic commonly occurs as an impurity in metal ores and is a known problem for the metals and mining industries. Many studies have assessed different methodologies for removal of arsenic from wastewaters produced by these industries (Basha et al 2008, Jiang et al 2014, Langsch et al 2012, Luo et al 2010, Xie et al 2020). Data obtained from interrogation of international pollutant release databases emphasised the importance of the metal (primary, fabricated and mining) and paper industries as potential sources of arsenic contamination (Table 21 and Appendix Table 35).

It also highlighted the importance of the fossil fuel electric power generation industries as potential sources of arsenic contaminated effluents. In the US, the steam electric power generating ELGs which regulate the amount of arsenic permitted in effluents from this industry is being reviewed and strengthened[91].

The US EPA has set limits for arsenic present in discharges from several other point source categories, highlighting them as potential sources of arsenic contaminated effluents[92]. These include inorganic chemicals manufacturing, nonferrous metals manufacturing, steam electric power generating, timber products processing, centralised waste treatment, ore mining and dressing, waste combustors, landfills, and electrical and electronic components.

4.5.3 Discharge limits and regulation

In Tasmania, Environmental Protection Notice 7043/4 issued by the Tasmanian Environment Protection Authority limits arsenic concentrations in discharge from a Hobart zinc smelter to 0.25 mg/L, and concentrations must be monitored every six months (Nyrstar 2018). In China, the maximum concentration of arsenic in mining wastewater is 100 μg/L (Xie et al 2020).

As mentioned above, limits are set for arsenic under the US EPA ELGs[93], as summarised in Table 22.

The maximum concentration of arsenic permissible in New Zealand under the Model General Bylaw for Trade Waste (Standards New Zealand 2004) is 5 g/m^3 (equivalent to 5 mg/L). Under the draft Water New Zealand Guidelines for Beneficial Use of Organic Materials on Productive Land the proposed limit for arsenic is 30 mg per kg of dry weight (Water New Zealand 2017), corresponding to the ‘grade B’ biosolids limit specified in the 2003 Biosolids Guidelines (NZWWA 2003).

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[91] https://www.epa.gov/newsreleases/epa-announces-intent-bolster-limits-water-pollution-power-plants Accessed 9 December 2021

[92] https://owapps.epa.gov/elg/results Accessed 6 December 2021

[93] https://owapps.epa.gov/elg/ Accessed 6 December 2021

Table 21 Summary of discharges of arsenic or its compounds reported in pollutant release databases

US Toxics Release Inventory 2020			
Substance	**TRI Industry sector**	**Number of facilities[1]**	**Total Discharge to surface waters (kg)[2]**
Arsenic	Chemicals	1	1,789
	Fabricated metals	1	76
	Primary metals	1	10
Arsenic compounds	Electric utilities	26	3,617
	Chemicals	6	694
	Primary metals	4	442
	Metal mining	3	156
	Wood products	7	167
Substance	**TRI Industry sector**	**Number of facilities[1]**	**Total Transfer to POTW (kg)[2]**
Arsenic	Primary metals	1	346
	Machinery	1	29
Arsenic compounds	Primary metals	2	123
Australian National Pollutant Inventory 2019-2020			
Substance	**Industry sector**	**Number of facilities[1]**	**Total emission to water (kg)**
Arsenic and compounds	Metal mining	17	3,949
	Primary metals	6	1,908
	Electricity generation	5	218
	Oil and gas extraction	3	148
	Coal mining	2	92
	Chemicals	2	89
	Mining (other)	1	76
	Water transport support services	1	72
	Petroleum	2	45
	Industry sector	**Number of facilities[1]**	**Total transferred to off-site sewerage (kg)**
	Primary metals	1	170
	Water transport support services	1	28
Canadian National Pollutant Release Inventory 2017			
Substance	**Industry sector**	**Number of facilities[1]**	**Total released to water (kg)**
Arsenic and its compounds	Paper	27	2,229
	Metal mining	20	1,935
	Primary metals	8	1,731
	Petroleum	3	131
	Electric utilities	2	42
	Coal mining	2	29

	Mining (other)	1	24
	Chemicals	1	11

TRI, toxics release inventory; POTW, publicly owned treatment works. [1]Number who discharged/transferred 10 kg or more per year, excluding WWTPs and hazardous waste treatment and disposal facilities; [2]converted from pounds.

Table 22 Summary of US EPA discharge limits for arsenic

Point source category	Daily maximum concentration (mg/L)	Monthly average[1] (mg/L)	Max monthly average (mg/L)
Inorganic chemicals manufacturing	3	1	
Steam electric power generating	0.004 – 0.018	0.008	
Timber products processing	4		
Centralised waste treatment	0.0993 –2.95		0.0199 – 1.33
Ore mining and dressing	1	0.5	
Waste combustors	0.084		0.072
Landfills	1.1		0.54
Electrical and electronic components	2.09	0.83	

[1]Average of daily values for 30 consecutive days. All categories with per litre limits.

5. PER- AND POLYFLUOROALKYL SUBSTANCES

Per- and poly-fluoroalkyl substances are a large family of man-made chemicals in use internationally since the 1950s[94]. Due to the resistance of many of these substances to water, grease, oil and heat they have been extensively used in the production of a variety of products including stain- and water-resistant fabrics and carpets, paints, aviation hydraulic fluids, cleaning products, insect baits, firefighting foams, and in the electroplating and electronics industries[95,96]. However, concerns arose due to the observation that these chemicals are resistant to degradation, persist in the environment for long periods of time and bioaccumulate in tissues[97]. The most well-known PFAS are perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), but more than 3000 other PFAS also exist (Wang et al 2017). Both PFOS and PFOA are classified as POPs under the Stockholm Convention[98]. Perfluorooctanoic acid and its related compounds are classified as annex A chemicals, and as such measures much be taken to eliminate their production and usage, whilst PFOS and its related compounds are annex B chemicals, with signatories required to take steps to restrict their production and usage. Despite several PFAS being phased out of use they are still persistent in the environment and are often referred to as 'legacy' PFAS (Brase et al 2021). Additionally, new PFAS are emerging to replace PFOS, PFOA, and other phased-out PFAS, with considerable knowledge gaps around the environmental fate of, and health hazard posed by, these new substances (Brase et al 2021).

Per- and poly-fluoroalkyl substances are found both in effluent and biosolids produced by WWTPs. A recent review by the New Zealand Environmental Protection Authority summarised typical PFOS and PFOA concentrations found in wastewater influent, effluent and biosolids from several countries around the world, and noted that no data were available for New Zealand (Dawson 2018). These substances can enter the wastewater network from both residential and industrial sources, with residential sources suggested to be the most substantial (Rumsby 2018). Additionally, some precursor compounds can undergo transformation to produce PFAS during

[94] https://environment.govt.nz/what-government-is-doing/areas-of-work/land/per-and-poly-fluoroalkyl-substances-pfas/about-pfas/ Accessed 24 November 2021
[95] https://www.fda.gov/food/chemical-contaminants-food/and-polyfluoroalkyl-substances-pfas#:~:text=Many%20PFAS%20are%20resistant%20to,%2C%20and%20fire%2Dfighting%20foams Accessed 24 November 2021
[96] https://environment.govt.nz/assets/publications/International-action/table-pops-description-use-nz_0.pdf Accessed 24 November 2021
[97] https://environment.govt.nz/what-government-is-doing/areas-of-work/land/per-and-poly-fluoroalkyl-substances-pfas/history-of-pfas-globally-and-in-nz/ Accessed 24 November 2021
[98] http://www.pops.int/TheConvention/ThePOPs/AllPOPs/tabid/2509/Default.aspx Accessed 24 November 2021

wastewater treatment, adding to the load of PFAS discharged by the WWTP (Lenka et al 2021).

5.1 HEALTH EFFECTS

The health effects of exposure to PFAS are still not fully characterised. Exposure to PFOS and PFOA is not deemed to pose an acute health risk[99]. Effects on serum cholesterol levels and immune effects have been used as the basis for establishing chronic exposure limits. However, these chemicals have long half lives in the body (estimated at 3.4 and 2.7 years for PFOS and PFOA respectively) (Li et al 2018).

Recommended exposure limits for PFOS and PFOA proposed by EFSA, FSANZ and the US EPA are provided in Table 23.

Table 23 Recommended exposure limits for PFOS and PFOA

Substance	TWI EFSA[100] 2020 (ng/kg bw/week)	TDI FSANZ 2017[101] (ng/kg bw/day)	Draft RfD US EPA[102] 2022 (ng/kg bw/day)[#]
PFOS	4.4*	20	0.0079 (chronic oral)
PFOA		160	0.0015 (chronic oral

TDI, tolerable daily intake; TWI, tolerable weekly intake; RfD, reference dose. PFOS, perfluorooctane sulfonate; PFOA, perfluorooctanoic; EFSA, European Food Safety Authority; FSANZ, Food Standards Australia New Zealand; US EPA, United States Environmental Protection Agency. *A group TWI for PFAS based on assessment of PFOA, PFOS, perfluorononanoic acid (PFNA) and perfluorohexane sulfonic acid (PFHxS).

5.2 INDUSTRIAL EFFLUENT SOURCES

One of the main industries utilising PFAS is the textile industry, which was reported to account for around 50% of the global usage of PFAS in 2015 (Ministry of Environment and Food & The Danish Environmental Protection Agency 2015). These substances are used by the textile industry in flame retardant clothing and to impart water, oil and dirt resistance into fabrics and carpets (Tonkin and Taylor Ltd 2018). A substantial proportion of those PFAS used by textile manufacturers which do not end up in the final product have been suggested to ultimately be discharged to WWTPs (Yiliqi et al

[99] https://environment.govt.nz/what-government-is-doing/areas-of-work/land/per-and-poly-fluoroalkyl-substances-pfas/information/ Accessed 7 December 2021
[100] https://www.efsa.europa.eu/en/news/pfas-food-efsa-assesses-risks-and-sets-tolerable-intake Accessed 11 July 2022
[101] https://www.foodstandards.gov.au/consumer/chemicals/Pages/Perfluorinated-compounds.aspx Accessed 11 July 2022
[102] https://www.epa.gov/system/files/documents/2022-06/technical-factsheet-four-PFAS.pdf Accessed 12 July 2022

2021). The US EPA has identified PFAS (including legacy PFAS) in wastewater discharged to publicly owned wastewater treatment works by textile mills, and indicated that most textile mills do not monitor for PFAS (US Environmental Protection Agency 2021). In their report on potential sources of PFAS contamination in New Zealand prepared for Environment Canterbury, Tonkin and Taylor Ltd indicated that the extent of PFAS usage in the New Zealand textile industry is unclear, and further work is needed to clarify how effluents are managed (Tonkin and Taylor Ltd 2018).

Per- and poly-fluoroalkyl substances have also been used in the metal plating industry, particularly as mist suppressants to prevent emission of toxic metal fumes from metal plating and finishing baths[103]. Although, the usage of PFOS as a mist suppressant has been banned by the US EPA since 2016[104]. PFAS have been identified in effluent discharged from chromium electroplating facilities to both surface waters and publicly owned WWTPs in the US (US Environmental Protection Agency 2021). The US EPA could not identify any facilities with PFAS limitations or pre-treatment standards set in their discharge permits and most were not monitoring PFAS levels in their discharge, although some were using specialised treatment processes to reduce PFAS concentrations (US Environmental Protection Agency 2021). Interestingly, PFOS has been detected in effluent from chrome plating facilities in Michigan despite this chemical not being used for around 5 years, indicating the PFOS detected was from historical usage (Michigan Department of Environment Great Lakes and Energy 2020). Untreated chrome plating effluent has also been shown to contain a variety of other PFAS (Michigan Department of Environment Great Lakes and Energy 2020). However, more than half of the chrome plating facilities assessed by the Michigan Department of Environment, Great Lakes and Energy (EGLE) were pre-treating their effluent for PFOS (Michigan Department of Environment Great Lakes and Energy 2020). Both PFOS and PFOA, as well as several other PFAS, have also recently been reported in wastewaters from the electroplating industry in China (Jiawei et al 2019). Tonkin and Taylor found no information on the amount of PFOS used by the metal plating and etching industry in New Zealand prior to its lawful use ending in 2011 (Tonkin and Taylor Ltd 2018). However, they indicated that PFAS-containing substitutes are likely in current usage. They also noted that internationally plating bath effluents have been shown to contain high levels of PFAS, with inappropriate disposal presenting a potentially substantial source for PFAS contamination (Tonkin and Taylor Ltd 2018). However, further work is needed to assess the level of PFAS in effluent from these facilities in New Zealand.

[103] https://hrpassociates.com/uploads/files/Metal_Plating_Fact_Sheet.pdf?v=1623863694814#:~:text=PFAS%20have%20been%20used%20in,emissions%20of%20toxic%20metal%20fumes. Accessed 24 November 2021
[104] https://hrpassociates.com/uploads/files/Metal_Plating_Fact_Sheet.pdf?v=1623863694814#:~:text=PFAS%20have%20been%20used%20in,emissions%20of%20toxic%20metal%20fumes. Accessed 24 November 2021

Another industry whose effluents have been found to contain PFAS is the pulp and paper industry. The US EPA has identified PFAS (including legacy PFAS) in wastewater discharged to both surface waters and publicly owned wastewater treatment works by pulp, paper and paperboard facilities (US Environmental Protection Agency 2021). They did not identify any facilities with limits or pre-treatment standards for PFAS in their wastewater discharge permits and very few monitored for PFAS in their discharge (US Environmental Protection Agency 2021). The recent Tonkin and Taylor report noted that they "identified limited monitoring data specifically related to potential environmental discharges of PFAS from paper and pulp mills" (Tonkin and Taylor Ltd 2018). They noted that further work was required to confirm that PFAS are used by paper mills in New Zealand and site-specific monitoring data needs to be obtained.

The semiconductor and electronics industries have also been associated with PFAS discharge, with high PFOS concentrations (up to 0.13 mg/L) found in semiconductor wastewaters and PFOA, PFOS and a number of other PFAS found in raw effluents from electronics plants in Taiwan (Lin et al 2009). In their 2018 report, Tonkin and Taylor noted that further work is needed to assess the usage of PFAS in these industries in New Zealand (Tonkin and Taylor Ltd 2018).

A recent study assessing PFAS levels in industrial wastewaters from a range of facilities in South Korea identified the highest levels in samples from the advanced electronic, metal, polymer and textile industries (Kim et al 2021). Samples from the advanced electronic and textile industries contained the highest PFOS, and samples from the metal and textile industries contained the highest PFOA.

Perfluorooctane sulfonate has historically been used in foams for fighting hydrocarbon fuel fires such as those involving aviation fuel[105]. PFOS-based firefighting foams were banned in New Zealand in 2006 under the Hazardous Substances and New Organisms (HSNO) Act Fire Fighting Chemicals Group Standard[106]. However, due to the persistence of these chemicals, firefighting equipment (eg, trucks) which once contained PFOS-based foam may still be contaminated, resulting in PFOS-contaminated wastewater when these equipment are cleaned (Dawson 2018). As such, wastewater from sites such as fire stations and airports which have used PFOS-based foams in the past present potential risk of PFOS-contaminated wastewater.

Interrogation of international pollutant release databases for information on release of PFAS revealed little additional insight into those industries whose effluent may be contaminated with these substances. However, it should be noted that there may be

[105] https://www.epa.govt.nz/news-and-alerts/alerts/managing-fire-fighting-foams-manufactured-with-pfas-chemicals/#:~:text=PFOS%20was%20used%20to%20make,fuels%2C%20such%20as%20aviation%20fuel.&text=PFOA%2Drelated%20compounds%20were%20later,trace%20amounts%20in%20some%20products Accessed 30 November 2021
[106] https://environment.govt.nz/assets/publications/International-action/table-pops-description-use-nz_0.pdf Accessed 30 November 2021

specific emergent PFAS covered in these inventories which were not specifically assessed for this report as the only named PFAS assessed were PFOS and PFOA. No generic PFAS, PFOS or PFOA were listed in the Australian or Canadian databases. Both PFOS and PFOA are listed in the US TRI database, as summarised in Table 24.

Table 24 Discharge of PFOS and PFOA reported by the US Toxics Release Inventory 2020

US Toxics Release Inventory 2020			
Substance	**Primary industry associated with facility[1]**	**TRI Industry sector**	**Surface water discharge (kg)[2]**
PFOS	All other miscellaneous chemical product and preparation manufacturing	Chemicals	0.5
PFOA	All other miscellaneous chemical product and preparation manufacturing	Chemicals	4.1

[1]North American Industry Classification System (NAICS); [2]Converted from pounds.

Preliminary assessment of the removal of PFAS by WWTPs suggests little is removed by conventional treatment processes and more advanced treatments are required (Arvaniti & Stasinakis 2015). Indeed, a New Zealand wastewater sector report indicated that "generally speaking conventional treatment processes have limited success in removing PFAS, thus PFAS can be present in treated discharges and biosolids" (Ho et al 2020). Similarly, a review by the New Zealand Environmental Protection Authority identified that conventional wastewater treatment processes do not efficiently remove PFAS (Dawson 2018).

5.3 DISCHARGE LIMITS AND REGULATION

In their recent Preliminary Effluent Guidelines Program Plan 15, the US EPA indicated there has been little study of PFAS discharge to either surface waters or publicly owned WWTPs, so little is known about the types, concentrations and sources of these chemicals in these discharges (US Environmental Protection Agency 2021). Based on information obtained from a "preliminary multi-industry PFAS study", the US EPA determined that effluent guidelines and standards are warranted for PFAS manufacturers (US Environmental Protection Agency 2021).

The current New Zealand Model General Bylaw for Trade Waste (Standards New Zealand 2004) does not specify limits for PFAS. The New Zealand EPA has recommended that interim trade waste discharge limits be set at 0.1 μg/L for PFOS and PFOA, and 1 μg/L for total PFAS, although it was noted that the limit for total PFAS was "for information as only PFOS and PFOA are restricted compounds under the HSNO Act" (Dawson 2018). The EPA also recommended an interim limit for PFOS in biosolids be set at 0.3 mg/kg dry weight.

6. PHARMACEUTICALS

Given the wide variety of pharmaceutical drugs available in New Zealand, it is not feasible to individually assess the hazard each poses with regards to presence in industrial effluents. As such, this section will provide a general overview of what is known about pharmaceuticals in wastewater and their potential health effects. Wastewater treatment plants have been noted to be "poorly equipped to treat these kinds of compounds efficiently" (Orias & Perrodin 2014) and as such are generally considered the main source of pharmaceuticals to the aquatic environment (Larsson et al 2007, Sengar & Vijayanandan 2022), with pharmaceuticals being found in surface, ground and drinking-water (Figure 3) (ANSES 2013, Khetan & Collins 2007, Sengar & Vijayanandan 2022, WHO 2012).

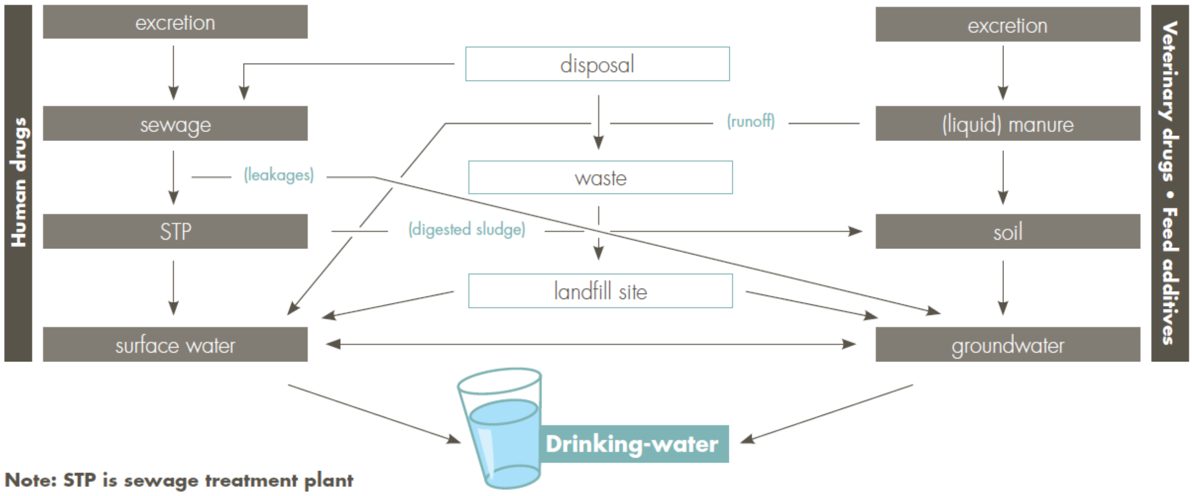

Figure 3 Fate and transport of pharmaceuticals in the environment

Reproduced from WHO (2012).

6.1 HEALTH EFFECTS

Although many studies have assessed the environmental or ecological impacts of pharmaceuticals present in the aquatic environment (reviewed in Khetan and Collins (2007), Orias and Perrodin (2013) and Orias and Perrodin (2014)), the potential human health risks are less well-known (Khetan & Collins 2007). The concentrations of pharmaceuticals typically measured in water are generally much lower than the concentrations used to produce targeted pharmacological/therapeutic effects (Khetan & Collins 2007). However, the health effects of long-term exposure to low levels of either individual or combinations of pharmaceuticals is unclear (Khetan & Collins 2007). Additionally, some pharmaceuticals persist in the environment, or bioaccumulate in the food chain, leading to higher concentrations (Khetan & Collins 2007).

Effluent from wastewater treatment plants is known to be a major contributor to pharmaceuticals present in drinking-water, as shown in Figure 3. In 2012, the WHO released a report on the health risks associated with pharmaceuticals present in drinking-water. This report noted that “trace quantities of pharmaceuticals in drinking-water are very unlikely to pose risks to human health because of the substantial MOE [margin of exposure] or margin of safety between the concentrations detected and the concentrations likely to evoke a pharmacological effect” (WHO 2012). However, they also note that there are knowledge gaps around the risks associated with long-term exposure to low concentrations of pharmaceuticals and possible combined effects of chemical mixtures that include pharmaceuticals (WHO 2012).

Pharmaceuticals present in wastewater may also present a human health hazard due to the role antibiotics play in development of anti-microbial resistance (AMR) (Kumar et al 2019, Larsson et al 2007, Sengar & Vijayanandan 2022). However, this is outside the scope of this review so will not be discussed in further detail.

6.2 INDUSTRIAL EFFLUENT SOURCES

The load of pharmaceuticals reaching municipal WWTPs generally consists of substantial residential and trade waste contributions. Residential contributions reflect not only consumed medicines but also inappropriately discarded medications, such as those flushed down the toilet or sink (WHO 2012). Industries known to produce effluents containing pharmaceuticals include hospitals, pharmaceutical manufacturers and aged residential care facilities.

Hospitals have been noted to be one of the main sources of pharmaceuticals to WWTPs (Orias & Perrodin 2014), and contain a wide variety of pharmaceuticals including antibiotics, hormones, analgesics and β-blockers (Figure 4) (Majumder et al 2021, Orias & Perrodin 2013). Hospitals produce large quantities of wastewater, with an estimated 750 litres per bed per day in Australia (Kumari et al 2020). Many hospitals pre-treat their wastewater prior to discharge to the municipal wastewater network to remove hazardous contaminants, although this is not always the case and even where pre-treatment occurs, not all treatments work efficiently for all pharmaceuticals (Kumari et al 2020, Majumder et al 2021). Hospital effluents often contain much higher concentrations of pharmaceuticals than residential wastewater, particularly analgesics and antibiotics (Majumder et al 2021, Verlicchi et al 2012). In a 2015 US study, acetaminophen (paracetamol) was found to account for up to 45% of the total average pharmaceutical and personal care product (PPCPs) concentration in hospital effluents (Oliveira et al 2015).

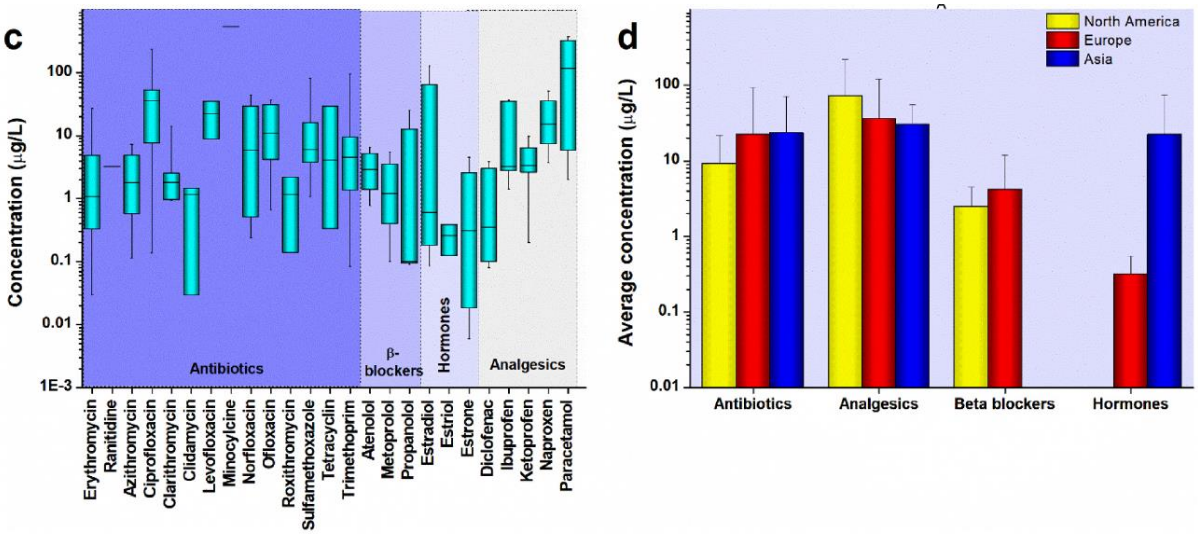

Figure 4 Pharmaceuticals present in hospital wastewater

Reproduced from Majumder et al (2021).

Effluents from the pharmaceutical industry have also been shown to contain substantial levels of pharmaceuticals (reviewed in Cardoso et al (2014)). India and China produce around half of all pharmaceuticals manufactured worldwide (Cardoso et al 2014), and high concentrations of pharmaceuticals have been reported in pharmaceutical industry effluents in these countries (Cardoso et al 2014, Larsson et al 2007). Pharmaceuticals have also been reported in effluents from pharmaceutical manufacturers in Europe and North America (Cardoso et al 2014). A study conducted in New York State concluded that effluents from WWTPs "receiving discharges from pharmaceutical factories contained API [active pharmaceutical ingredient] concentrations 30 to almost 500 times higher than other WWTPs" (Cardoso et al 2014, Phillips et al 2010).

Aged residential care facilities, or senior residences, have been identified as "hot-spots" for discharge of pharmaceuticals to the wastewater network due to the elderly being the "foremost pharmaceutical-consuming age-group" (Lacorte et al 2021). A recent study of wastewater produced by six senior residences in France, Spain and Portugal identified considerable levels of analgesics (eg, paracetamol, ibuprofen), antibiotics (eg, sulfamethoxazole, amoxicillin), diabetic medications (eg, vildagliptin), anticancer drugs and neuropathy treatments (eg, gabapentin) (Lacorte et al 2021). This study identified total pharmaceutical concentrations of 0.4 - 17 g/day being discharged by these facilities, indicating senior residences are a potentially important source of pharmaceuticals into the municipal network (Lacorte et al 2021). This study also noted the need for on-site wastewater treatment procedures at senior residences to reduce discharge of pharmaceuticals to the wastewater network (Lacorte et al 2021).

Preliminary assessment indicates that the efficiency of removal of pharmaceuticals from wastewater is highly variable and they are often poorly removed by WWTPs (Khetan & Collins 2007, OECD 2019, WHO 2012). A recent New Zealand study found that removal efficiency varies substantially depending on the pharmaceutical concerned, with average removal efficiency of ≥ 99% for ibuprofen, acetaminophen and caffeine, ≥ 90% for naproxen, clarithromycin and roxithromycin, 50-70% for fluoxetine, atenolol and sulfamethoxazole and less than 50% for metoprolol and trimethoprim (Kumar et al 2019).

6.3 DISCHARGE LIMITS AND REGULATION

There are few guidelines relating to hospital wastewater management and those that do exist (eg, WHO (2014), US EPA ELGs for Hospitals[107]), do not provide standards for specific pollutants such as pharmaceuticals (Majumder et al 2021). The US EPA has also set ELGs for the pharmaceutical manufacturing industry[108], but this does not provide concentration limits for specific pharmaceuticals. In 2019, the OECD (Organisation for Economic Cooperation and Development) released a report summarising source-directed (Table 25), use-oriented (Table 26) and end-of-pipe (Table 27) policy instruments that can be utilised to reduce/prevent the release of pharmaceuticals into water bodies (OECD 2019). This report notes that in the Netherlands, the issuing of wastewater discharge permits is conditional upon protection of drinking-water sources from pharmaceuticals contamination (OECD 2019).

[107] https://owapps.epa.gov/elg/results Accessed 24 March 2022
[108] https://owapps.epa.gov/elg/results Accessed 24 March 2022

Table 25 Source-directed policy instruments to prevent release of pharmaceuticals to water

Policy instrument type	Policy instrument	Description
Regulatory	Substance bans	Complete prohibition of non-essential use of problematic pharmaceuticals
	Marketing authorisation	Evaluation-dependent authorisation of pharmaceuticals based on their predicted risks to human health and the environment. Such evaluations can also take into account principles of green chemistry such as "rational design" or "benign by design". Incentives can be used for green pharmaceuticals, such as fast-track marketing authorisation, reimbursement for greener APIs or longer exclusivity.
	Environmental quality norms and water quality standards	EQNs and water quality standards for harmful substances in water bodies. Detection above safe levels (or PNEC) can require action upstream to protect water bodies from harmful effects.
	Green public procurement	Clear and shared environmental criteria (and performance indicators) to pre-qualify pharmaceuticals for public procurement. Added advantage of impacting trade of pharmaceutical products across country borders.
	Good manufacturing practices and audits	Mandatory codes of conduct to reduce emissions from pharmaceutical manufacturing plants, as part of good manufacturing practice audits. Alternatively, environmental criteria for green public procurement could incorporate good manufacturing practices.
	Effluent discharge permits	Effluent discharge permits issued to pharmaceutical manufacturing plants with conditions for protection of drinking water sources and freshwater ecosystems. Non-compliance may lead to fines or withdrawal of operation permits.
	Best available techniques	Guidance documents that assist industrial operators with the design, operation, maintenance and decommission of manufacturing plants in compliance with environmental quality standards and discharge permit conditions (i.e. based on the PNEC or safe level of discharge). A BAT-based approach can be used to help set emission limit values as part of discharge permit conditions.
	Drinking water quality standards and water safety planning	Preventive measures to identify and address the source of risks to drinking water.
Economic	Subsidies for "green" action	Financial support from governments in return for environmental commitments by the private sector, such as reduced pollution from pharmaceutical manufacturing facilities.
	Subsidies for green pharmacy innovation	Subsidies or tax incentives for innovations green pharmacy, biological therapies, personalised or precision medicines to improve the business case for industry.
	Pollution charges	Charges to pharmaceutical manufacturing plants for discharging toxic effluent to water bodies.
Voluntary	Information campaigns	Transfer of knowledge or persuasive reasoning to industry on how to avoid water pollution.
	Voluntary agreements between private and public sectors	Non-legally binding agreements negotiated on a case-by-case basis between industry and public authorities fixing environmental targets or specific mitigation measures (e.g. changes in the production chain).

Reproduced from OECD (2019).

Table 26 Use-oriented policy instruments to reduce release of pharmaceuticals to water

Policy instrument type	Policy instrument	Description
Regulatory	Substance bans	Prohibition of non-essential use of pharmaceuticals
	Substance restrictions	Restrictions on the prescription of non-essential use of pharmaceuticals
		Restrictions on over-the-counter sale and purchase of environmentally harmful pharmaceuticals
		Constraints to the placement on the market or the use of a substance at specific points in time (e.g. before rainfall events) or locations (e.g. sensitive areas). This is particularly relevant to farming practices.
	Best environmental practices (BEP) for health care practices	Mandatory codes of conduct for health practitioners to promote sustainable use (e.g. improved diagnostics, rationale use and targeted drug regiments) and responsible disposal of pharmaceuticals
	Best environmental practices (BEP) for veterinary and agriculture practices	Mandatory codes of conduct for veterinarians and farmers to promote improved diagnostics, sustainable use and disposal of pharmaceuticals, and reduce emissions from veterinary and agriculture practices
Economic	Product charges	Tax levied on products high-risk APIs in order to incentivise consumers to reduce or change consumption behaviours. Pharmaceuticals that are of high-risk to the environment and difficult to remove with conventional wastewater treatment could be priced accordingly.
	Substance charges	Tax levied on hazardous compounds in order to incentivise producers to change production processes or substitute chemicals with less hazardous alternatives (e.g. green pharmacy)
	Subsidies for "green" action	Financial support from governments in return for environmental commitments by the private sector
Voluntary	Public environmental health campaigns and disease prevention	Transfer of knowledge or persuasive reasoning on sustainable use, consumption and disposal of pharmaceuticals, and how to prevent illness and the need for pharmaceuticals (e.g. through effective hand washing to prevent spread of infection)
	Eco-labelling of green pharmaceuticals	Products that meet certain environmental standards can be marketed and sold at a premium and/or subsidised (n.b. regulatory changes would be required to set up such schemes)

Reproduced from OECD (2019).

Table 27 End-of-pipe policy instruments to remove pharmaceuticals after their use and release into water bodies

Policy instrument type	Policy instrument	Description
Regulatory	Best available technique (BAT)	Definition of the best technology options for improved wastewater treatment
	Wastewater treatment standards	Definition of performance standards for wastewater treatment (e.g. treatment capacity or effluent load) without requiring a specific technology
	Pharmaceutical disposal requirements	Standards on correct waste disposal, e.g. mandatory consumer-level "take-back" programmes for unused pharmaceuticals
Economic	Effluent/ emission charges	Tax on discharging wastewater to water bodies, in order to incentivise emission reduction
	Wastewater tariffs or taxes for WWTP upgrades	Tariffs or taxes designed to signal the cost of wastewater treatment to remove pharmaceuticals to the public and consumers
	Subsidies for improved wastewater treatment	Financial support from governments to incentivise operators to invest in advanced wastewater treatment; or to promote research on improved wastewater treatment
	Extended producer responsibility (EPR) schemes	Instead of consumers being responsible for the cost of wastewater and waste management, producers, to some extent, become responsible for financing the end-of-life costs (wastewater treatment and solid waste disposal). In principle, companies can internalise these costs and are incentivised to produce pharmaceuticals more cost-efficiently and sustainably
Voluntary	Advisory services	Support from governments in the form of information, advice, and consultancy about improved wastewater treatment or solid waste management
	Voluntary agreements on wastewater treatment	Non-legally binding agreements negotiated on a case-by-case basis between wastewater treatment operators and a public authority to improve wastewater treatment practices
	Waste collection/ take-back schemes	Voluntary schemes designed to collect and appropriately dispose of unused pharmaceuticals, thereby reducing their release to water bodies.

Reproduced from OECD (2019).

7. PESTICIDES

Similar to pharmaceuticals, given the wide variety of pesticides that exist, it is not feasible to individually assess the hazard each poses with regards to presence in industrial effluents. As such, this section will provide an overview of what is currently known about the health hazard posed by pesticides, industrial effluent sources and limitations that exist with regards to the levels of these chemicals in industrial effluents. As the reports on emerging contaminants of potential concern for New Zealand[109] (Stewart et al 2016) specifically identify the insecticides chlorpyrifos, permethrin, bifenthrin and imidacloprid and the herbicide glyphosate, where information is available on these pesticides it will be included in this report.

It is important to note that environmental exposure to pesticides can occur in several ways and wastewater discharge to receiving waters represents only one pathway by which pesticides can enter aquatic environments. For example, Stewart et al (2016) note that pesticides can be "released directly into aquatic environments without any treatment via urban or rural stormwater runoff".

7.1 HEALTH EFFECTS

Although the environmental or ecological impacts of many pesticides are well established, the human health hazards posed by pesticides is often less clear. The three main categories of pesticides are insecticides, fungicides and herbicides. Many of the insecticides act by interfering with the nervous system. The modes of action and potential health effects of fungicides and herbicide are much more diverse. The WHO classifies pesticides into the following categories: Ia, extremely hazardous; Ib, highly hazardous; II, moderately hazardous; III, slightly hazardous; U, unlikely to present acute hazard in normal use (WHO 2020). These classifications are "based primarily on the acute oral and dermal toxicity to the rat since these determinations are standard procedures in toxicology" (WHO 2020), as summarised in Table 28.

Based on the WHO classification system, those pesticides identified in the reports on emerging contaminants of potential concern for New Zealand[110] (Stewart et al 2016) are classified as follows:

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[109] https://www.watercare.co.nz/CMSPages/GetAzureFile.aspx?path=~%5Cwatercarepublicweb%5Cmedia%5Cwatercare-media-library%5Comaha%5Comahawwtpemergingcontaminantspresentation.pdf&hash=9b396b7f4c7cc9bfb4f76701eecee433a81fb84b5a3b8a0d9375f5a182736b5c Accessed 25 March 2022

[110] https://www.watercare.co.nz/CMSPages/GetAzureFile.aspx?path=~%5Cwatercarepublicweb%5Cmedia%5Cwatercare-media-library%5Comaha%5Comahawwtpemergingcontaminantspresentation.pdf&hash=9b396b7f4c7cc9bfb4f76701eecee433a81fb84b5a3b8a0d9375f5a182736b5c Accessed 25 March 2022

- Class II (moderately hazardous): Chlorpyrifos, permethrin, bifenthrin, imidacloprid.
- Class III (slightly hazardous): Glyphosate.

Table 28 Basis of the World Health Organization pesticide classifications

Class		LD_{50} for the rat (mg/kg body weight) Oral	Dermal
Ia	Extremely hazardous	< 5	< 50
Ib	Highly hazardous	5–50	50–200
II	Moderately hazardous	50–2000	200–2000
III	Slightly hazardous	Over 2000	Over 2000
U	Unlikely to present acute hazard	5000 or higher	

Reproduced from WHO (2020).

7.2 INDUSTRIAL EFFLUENT SOURCES

Substantial levels of pesticides have been reported in wastewaters from several pesticides manufacturing facilities around the world. For example, wastewaters from a pesticide formulation and production company in Malaysia were reported to contain substantial amounts (> 100 mg/L) of chlorpyrifos, cypermethrin (class II) and chlorothalonil (class U) (Affam et al 2014). High levels (over 20 mg/L) of tricyclazole (class II) have been reported in effluents from an agrochemical production facility in Vietnam (Pham et al 2021). Additionally, an Italian study identified high levels of several pesticides in wastewater from a herbicide manufacturer, with an average concentration for total pesticides prior to treatment of over 120 mg/L (Mezzanotte et al 2005). Detected pesticides included simazine (class U), prometryn (class III), ametryn (class II), simetryn (class II) and tetraconazole (class II).

Pesticides have also been reported in effluent from the agro-food industry. A recent study in Spain identified a variety of pesticides in wastewater from an industrial plant that processes fruits and vegetables (Campos-Mañas et al 2019). Those pesticides identified at the highest concentrations in this waste stream were the fungicides imazalil (class II), pyrimethanil (class III), thiabendazole (class III) and propiconazole (class II) and the acaricide etoxazole (class III) (Campos-Mañas et al 2019). Pesticides have also been reported in wastewaters from the fruit-packaging industry (Karas et al 2016).

7.3 DISCHARGE LIMITS AND REGULATION

The US EPA has set ELGs for the pesticide chemicals industry. This covers a wide range of pesticides including the emerging contaminants of potential concern chlorpyrifos and permethrin. With regards to organic pesticide chemicals manufacturing, there is a daily maximum of 0.01 kg organic pesticide chemicals per 1000 kg of total organic active ingredients and monthly average amount of 0.0018 kg organic pesticide chemicals per 1000 kg of total organic active ingredients[111].

In Italy, the limit for discharge of total pesticides in industrial wastewaters to surface waters is 50 μg/L (Mezzanotte et al 2005). In Taiwan, discharge limits vary depending on the pesticide, as summarised in Hamilton et al (2003).

In New Zealand, the Model General Bylaw for Trade Waste (Standards New Zealand 2004) sets a maximum concentration of 0.2 g/m^3 (200 μg/L) for total pesticides excluding organophosphate pesticides which have a maximum concentration of 0.1 g/m^3 (100 μg/L).

[111] https://owapps.epa.gov/elg/results/limitations Accessed 25 March 2022

8. MICROPLASTICS

The term microplastics simply refers to any piece of plastic smaller than 5 mm in length (Rochman et al 2019). However, microplastics are a diverse class of contaminant derived from a variety of sources, and as such are comprised of various polymers, with different chemical additives, and can vary in size, colour, and morphology (Rochman et al 2019). Microplastics can be classified as either primary microplastics, where they are specifically manufactured to be less than 5 mm in size (eg, preproduction pellets, microbeads used in personal care products (banned in New Zealand[112])), or secondary microplastics, which are produced due to fragmentation of larger pieces of plastic by physical, biological, or chemical processes (Rochman et al 2019).

Microplastics are ubiquitous in the environment and enter through a variety of residential and industrial sources, and via environmental breakdown of larger plastic pollutants. Microplastics are associated with a range of chemicals that include additives used during the manufacturing process (eg, flame retardants, plasticizers, colourants, stabilisers, fillers) but also other environmental contaminants that have sorbed on to the microplastic such as heavy metals, POPs (Rochman 2015, Rochman et al 2019), bacteria, antibiotics and antibiotic resistance bacteria/genes (Syranidou & Kalogerakis 2021).

8.1 HEALTH EFFECTS

Rahman et al (2021) recently reviewed the current knowledge on human health risks associated with microplastics and noted that there is a major knowledge gap in this area. Microplastics have been proposed to act as vectors for toxic contaminants and may translocate to distant sites within the body via the circulatory system (Rahman et al 2021), and have even been detected in human placentas (Ragusa et al 2021). Further studies are needed to fully evaluate the health effects of microplastics.

8.2 INDUSTRIAL EFFLUENT SOURCES

Given the ubiquitous nature of plastic products in our lives, large volumes of microplastics enter the wastewater network from a variety of residential sources, including substantial amounts of microfibres released during washing of synthetic clothes (reviewed in Prata (2018)). Consequently, WWTPs have been identified as playing an important role in release of microplastics into the environment. Large amounts of microplastics arrive at WWTPs every day, and the majority (up to 99%)

[112] https://environment.govt.nz/acts-and-regulations/regulations/microbeads-regulations/ Accessed 29 November 2021

are removed by treatment processes (Conley et al 2019, Prata 2018, Sun et al 2019). However, although many treatment processes reduce microplastics concentrations to low levels, the sheer volume of effluent released daily means the total amount of microplastics entering the environment is often still considerable (Sun et al 2019), with millions of microplastics potentially discharged daily (Conley et al 2019). Of additional concern is the role WWTPs may play in bringing together microplastics with antibiotics, extracellular antibiotic resistance genes and antibiotic resistant bacteria (Syranidou & Kalogerakis 2021).

In comparison to residential sources of microplastics entering the wastewater network, comparatively little is known about the industrial contribution, and it has been suggested that this may be due to restricted access (Bitter & Lackner 2020). Bitter and Lackner (2020) provided the first quantitative report of microplastics in industrial wastewater, testing effluent from a polymer processing plant. They found that the level of microplastics present in the effluent varied considerably between sampling days and suggested this is likely influenced by the activity of the plant, with cleaning of the facility suggested to contribute the most microplastics to the wastewater stream.

Given the important role residential laundry activities play in release of microplastics into the wastewater network, it is not surprising that the textile manufacturing industry has been identified as another potential source of microplastics pollution. Effluent from textile mills has been shown to contain substantial levels of microfibres (microplastic and natural) (Chan et al 2021, Xu et al 2018, Zhou et al 2020). Microplastics have also been detected in the wastewaters of a marine construction facility that manufactures offshore wind structures and builds and repairs large ships (Franco et al 2020), and wastewaters from machine manufacturing, chemical and electroplating plants in China (Wang et al 2020).

Little additional information is available on microplastics in industrial effluents. However, the German wastewater treatment facility manufacturer EnviroChemie has established the EmiStop joint research project to examine industrial wastewaters for microplastics[113].

8.3 DISCHARGE LIMITS AND REGULATION

Little information could be found on regulation of discharge of microplastics in industrial or municipal wastewaters. However, the EC is currently developing a microplastics initiative which aims to “reduce the unintentional release of microplastics in the environment”[114].

[113] https://www.envirochemie.com/en/innovation/emistop-microplastics-in-industrial-wastewater/ Accessed 29 November 2021
[114] https://ec.europa.eu/environment/topics/plastics/microplastics_en Accessed 29 November 2021

Water Research Australia currently has a project investigating microplastics in wastewater effluent and noted that they are not currently regulated under discharge licenses but that this may change in the future[115]. The Aotearoa Impacts and Mitigation of Microplastics (AIM^2) MBIE (Ministry of Business, Innovation and Employment) Endeavour research programme is also investigating microplastics in wastewater in New Zealand[116].

115 https://www.waterra.com.au/research/open-rffs-and-rfps/2020/microplastics-in-wastewater-effluent/ Accessed 29 November 2021
116 https://www.esr.cri.nz/our-research/research-projects/aotearoa-impacts-and-mitigation-of-microplastics-aim/ Accessed 7 December 2021

9. WASTE OF SPECIFIC CONCERN FOR TIKANGA MĀORI

9.1 THE FUNERAL INDUSTRY

Effluents from facilities associated with the funeral industry (eg, mortuaries, crematoria, funeral homes) are known to contain a wide range of toxic organic contaminants (Gwenzi 2021), many of which have been discussed earlier in this report. This section focuses on contaminants present in these effluents which may not pose a health hazard *per se* but rather are of specific concern for tikanga Māori. Human remains are considered tapu and their disposal to the wastewater network, and ultimate release into receiving waters, breaches tikanga (Rangiwai 2020).

9.1.1 Mortuary/funeral home waste

Wastewater produced during the embalming process contains both blood and embalming fluid (Kleywegt et al 2019). Diluted embalming and body fluids are permitted to be discharged to the wastewater network under the New Zealand Management of Healthcare Waste Standard (NZS 4304:2002) (Standards New Zealand 2002). Blood is considered tapu by Māori, and its disposal to the wastewater network invokes a "serious breach of tikanga" (Rangiwai 2018). Dilution or treatment of the contaminated water does not negate this problem as "tapu is a ritual contamination that is not negated by the mechanical, biological, and chemical filtration processes of wastewater treatment" (Rangiwai 2020). Alternative approaches are needed to address this problem. One such approach, which will be initiated in Gisborne, is to instead transport the mortuary waste for burial at a cemetery[117,118], with disposal of mortuary waste to the sewer network prohibited under the 2021 Gisborne Trade Waste Bylaw (but not yet in force) (Gisborne District Council 2021).

9.1.2 Crematorium waste

Waste from classical cremation is primarily discharged to air rather than water, and as such will not be considered as part of this review. However, in recent years an alternative to classic cremation has emerged. Known as alkaline hydrolysis, resomation, or water cremation, this process involves break down of the body into its chemical components using an alkali solution in combination with pressure and heat (Robinson 2021). The process leaves behind bone fragments (calcium phosphate)

[117] https://www.teaomaori.news/new-trade-bylaw-removes-mortuary-waste-wastewater-system Accessed 29 November 2021
[118] https://www.nzherald.co.nz/kahu/disposing-of-mortuary-waste-in-gisborne-to-be-more-in-line-with-tikanga-maori/6G5LFDXBV5WHH67G37IVDIVRXY/ Accessed 10 December 2021

and liquid waste which contains amino acids, peptides, sugars, and salts (Robinson 2021). The concept of alkaline hydrolysis is not new and has been used for a long time for animal carcasses (Robinson 2021). This process was first used commercially for humans in the USA in 2011, and as at the end of 2020 was legal in 19 states (Robinson 2021).

In 2017, a crematorium in the United Kingdom was granted planning permission to offer the service but their application for a trade effluent permit was refused by the local water utility due to the lack of an industry standard. Water UK also expressed concerns around public perceptions of liquified human remains entering the wastewater system[119] (Robinson 2021). In 2019, Yorkshire Water and Middlesex University conducted analyses on wastewaters produced by five alkaline hydrolysis cremations and concluded they contained no DNA and were suitable for discharge to the sewer network (SAIF 2020). Following this study, Yorkshire Water granted a consent to discharge waste from alkaline hydrolysis cremation to their network (SAIF 2020).

In Australia, alkaline hydrolysis is offered in New South Wales. However, due to Sydney Water not approving disposal to their sewer network the waste is used as fertiliser for plantation forests[120]. Alkaline hydrolysis cremation is not currently performed in New Zealand[121], but was included in a consultation document on the review of the Burial and Cremation Act 1964 (Ministry of Health 2019). The consultation period for this review closed on 31 October 2020[122]. Rangiwai (2020) indicated that disposal of waste from alkaline hydrolysis cremation to the wastewater network would break tikanga, similar to waste from embalming, and a more culturally appropriate solution for the waste fluid is required.

9.2 HOSPITAL WASTE

Bodily waste generated by hospitals poses another challenge with regards to tikanga Māori. Tikanga is considered with respect to the return or disposal of Māori body parts under Hauora o te Tinana me ōna Tikanga: A guide for the removal, retention, return and disposal of Māori body parts and organ donation (Te Puni Kōkiri 1999). However, all body parts are considered tapu (Ataria et al 2016), and as such disposal to the wastewater network poses cultural concerns. Under the New Zealand Management of Healthcare Waste Standard (NZS 4304:2002), diluted or sterilised liquid body parts (eg, blood), and solid body parts which are “only minor, minute and non-recognisable”

[119] https://www.bbc.com/news/uk-england-birmingham-42385567 Accessed 29 November 2021
[120] https://www.abc.net.au/news/science/2019-04-27/green-death-funeral-environment/10994330
[121] https://watercremationaotearoanewzealand.com/ Accessed 29 November 2021
[122] https://www.health.govt.nz/publication/death-funerals-burial-and-cremation-review-burial-and-cremation-act-1964-and-related-legislation Accessed 29 November 2021

may be disposed of to the sewer network (Standards New Zealand 2002). The concern for some hapū around the assurance that “municipal treatment processes can adequately perform a transition from tapu to noa [free from tapu]” for body parts discharged to the wastewater network has been noted (Ataria et al 2016).

10. SUMMARY

Untreated industrial effluents often contain a wide range of contaminants of potential concern for human health. The exact composition of these effluents will vary substantially depending on the industry from which they are derived. Additionally, owing to the variety of different treatment processes which may be employed to treat industrial effluents before they are discharged to the municipal wastewater network or to receiving waters, the composition of treated effluents can also vary substantially.

The aim of this review was to provide an international perspective on those contaminants of most concern for human health reported in industrial effluents based on published and grey literature. Contaminants considered for inclusion in this report were chosen based on a review of international grey and published literature and reports on emerging contaminants of potential concern for New Zealand. Those selected for inclusion were chosen based on a) the potential hazard they may pose to human health and b) presence in industrial effluents. Selected contaminants were grouped into seven classes: EDCs; heavy metals and metalloids; PFAS; pharmaceuticals; pesticides; microplastics; and wastes of specific concern for tikanga Māori. For EDCs and heavy metals, considerable insight was also gained through interrogation of the pollutant release databases of the United States, Canada and Australia.

The EDCs covered in this report were: nonylphenol and its ethoxylates; BPA; the phthalates DEHP, DBP, DiBP and BBP; and dioxins and dioxin-like PCBs. For nonylphenol and its ethoxylates, the textile and paper industries were identified as notable sources of contaminated effluents. Other potential sources identified based on published/grey literature included the leather industry, commercial laundry/dry-cleaning facilities and funeral homes. Data from the pollutant release databases also identified these chemicals in effluents from several industries within the chemicals sector including soap and detergent, paint and coating and plastics material and resin manufacturers. Bisphenol A has been reported in effluents from the paper, textile, metal/wood manufacturing, chemical, plastics and dry-cleaning/cloth washing industries. The phthalates DEHP, DBP and BBP were all reported in effluents from both the paper and leather industries, as well as in varying levels in a range of industrial effluents in France. Although most industrial countries have taken steps to limit release of dioxins and dioxin-like compounds due to their classification as POPs, they have been recently detected in effluents from the funeral and chemical industries, and it has been suggested that effluents from any industrial process that uses chlorine or chlorination should be assessed for dioxins. Discharge limits for nonylphenol and its ethoxylates, and BPA were identified in Canadian regulations. For the phthalates DEHP, BBP and DBP, and dioxins 2,3,7,8-TCDD and 2,3,7,8-TCDF, discharge limits are specified in the US EPA ELGs. Only nonylphenol and its ethoxylates, and the phthalate DEHP are specified in the draft New Zealand Guidelines for Beneficial Use of Organic Materials on Productive Land. Only PCBs are specifically mentioned in the New Zealand Trade Waste Model Standard.

This report covered the heavy metals cadmium, chromium, lead and mercury and the metalloid arsenic. Cadmium was found to be utilised in a variety of industries and according to grey and published literature, has been detected in effluents from the paint, metal processing, battery and brewing industries. Information from the pollutant release databases also highlighted the metal (primary and mining) and paper industries as potentially important sources of cadmium contaminated effluents. Discharge limits for cadmium are specified for several point source categories in the US EPA ELGs. Cadmium is currently covered in the New Zealand Trade Waste Model Standard and the 2003 Biosolids Guidelines.

Chromium has been identified in effluents from a variety of industries, with the textile, leather tanning and electroplating industries noted by the US ATSDR as dischargers of large amounts of chromium to surface waters. In 2017, the energy sector was identified as the major contributor of chromium to water in the EU. The chemical, metal production and processing, mineral and paper and wood production industries have also been identified as sources of chromium to water. Information from the pollutant release databases emphasised the importance of a number of these industries. Discharge limits for chromium vary considerably between countries, industries and oxidation states (chromium VI versus total chromium), and limits for the highly toxic chromium VI are generally substantially lower than those for total chromium. In New Zealand, no distinction is made between chromium VI and total chromium with respect to the discharge limits set in the Trade Waste Model Standard and the 2003 Biosolids Guidelines.

Lead has been identified in effluents from the iron and steel manufacturing, pulp and paper, paint, textile and brewing industries. Information from the pollutant release databases also identified the chemical, electricity generation and petroleum industries as potential sources of lead contaminated effluents. The US EPA has set discharge limits for lead for several point source categories. In New Zealand, limits exist for lead in both the Trade Waste Model Standard and the 2003 Biosolids Guidelines.

Based on available published and grey literature, the main industry associated with mercury contaminated effluents internationally is the dental industry. Data from the pollutant release databases also identified the paper, electric utilities, and metal sectors as potentially important sources of mercury contaminated effluents. Mercury limits are specified for several point source categories in the US EPA Effluents Limitations and Guidelines Standards. Limits exist for mercury in both the New Zealand Trade Waste Model Standard and the 2003 Biosolids Guidelines.

Arsenic is a well-known impurity in metal ores and has been identified as a contaminant in several metal sector industries. Data from the pollutant release databases also identified the paper and fossil fuel electric power generation industries as potentially important sources of arsenic contaminated effluents. Discharge limits for arsenic exist for several point source categories in the US EPA ELGs. In New Zealand, discharge limits exist for arsenic in both the Trade Waste Model Standard and the 2003 Biosolids Guidelines.

Despite manufacture and usage of the most well-known PFAS, PFOS and PFOA being largely phased out due to their classification as POPs, these contaminants have still been reported in industrial effluents due to 'legacy contamination' of machinery and equipment. Additionally, a range of new emerging PFAS whose health risks are not fully characterised have arisen to replace PFOS and PFOA in some industries. The textile industry was identified as the most likely contributor of PFAS contaminated effluents. The metal plating and paper industries were also highlighted as potential sources of PFAS contaminated effluents. Sites where PFOS-based firefighting foams were previously used (eg, airports) were also identified as potential sources of contaminated effluents due to legacy contamination of firefighting equipment. Preliminary assessment of PFAS removal from industrial effluents suggests conventional treatment processes have limited effectiveness. Due to legacy usage of PFOS and PFOA resulting in contamination of effluents with these chemicals despite them no longer being used, it is important that effluents from any facility which historically used these chemicals be assessed for potential PFOS/PFOA contamination. The New Zealand Environmental Protection Authority has recommended interim trade waste discharge limits for both PFOS and PFOA.

Wastewater is noted to be the main source of pharmaceuticals into the aquatic environment, with these chemicals being found in surface, ground and drinking-water. Whilst much is known about the ecological impacts of environmental pharmaceuticals contamination, less is known about the potential human health effects of exposure through environmental contamination. Exposure to trace amounts of pharmaceuticals detected in drinking-water has been noted by the WHO to be unlikely to pose a risk to human health. However, the potential health effects of long-term exposure to individual or combinations of pharmaceuticals is unclear. Hospitals, pharmaceutical manufacturers and senior residences (aged residential care facilities) were identified as key contributors of pharmaceuticals to the wastewater network. Little specific regulation of pharmaceutical levels in industrial effluents was identified. However, the OECD has proposed several policy instruments that could be utilised to prevent/reduce release of pharmaceuticals to receiving waters.

Industrial wastewaters, particularly those from the pesticide manufacturing and agro-food industries, were noted to contain a variety of different pesticides of varying potential concern for human health. Information on regulation of pesticides in industrial effluents in the United States, Italy, Taiwan and New Zealand was also provided.

The potential impact of microplastics on human health is becoming increasingly recognised, particularly due to the potential role they may play as a vector for other harmful chemical and biological contaminants into the body. However, relatively little investigation of microplastics in industrial effluents was identified in international literature, although the potential importance of the textile and manufacturing industries was highlighted. To address this important knowledge gap, the German wastewater treatment facility manufacturer EnviroChemie has established the EmiStop research project, which aims to examine industrial wastewaters for microplastics. Researchers in Australia and New Zealand are also examining microplastics in wastewater. Although many studies suggest the majority of microplastics are removed by wastewater treatment processes, the sheer abundance of these contaminants reaching treatment plants from both residential and industrial sources means that even if a large percentage are removed, the total amount in treated effluents can still be in the range of millions of particles per day. No regulatory limits for discharge of microplastics were identified, however, the EC is currently developing a microplastics initiative that aims to reduce their unintentional release into the environment.

This review also assessed contaminants of specific concern for tikanga Māori which may be present in industrial effluents. Whilst these contaminants may not pose a health hazard, *per se*, their discharge to the wastewater network, and ultimately to receiving waters may breach tikanga due to the tapu nature of the contaminant. Body fluids discharged to the wastewater network by mortuaries and funeral homes was identified as an area of particular concern. An initiative of the Gisborne District Council to bury mortuary waste at a cemetery was identified as a viable alternative approach which addresses the breach of tikanga invoked by discharge of body fluids to the wastewater network. Discharge of blood and body parts by hospitals as permitted under the Healthcare Waste Standard was also identified as an area of potential concern for tikanga. Discharge of wastes generated by a relatively new method of cremation, alkaline hydrolysis, which involves breakdown of a body by alkali, pressure and heat, leaving liquid remains and bone fragments, was also identified as a potential area of concern. This process is not currently performed in New Zealand and has received mixed reception internationally. It was noted that discharge of waste generated by this process to the wastewater network would breach tikanga, and a more culturally appropriate solution for dealing with the wastes is required.

This review has identified the key contaminants of concern for human health present in industrial effluents internationally, and highlighted the main industries associated with discharge of these contaminants. To determine the health risks posed by these contaminants in the Aotearoa New Zealand context, further analysis is required to evaluate the likely prevalence of these contaminants in treated effluents in New Zealand.

This will require comprehensive assessment of:

- What industries associated with discharge of the contaminants internationally are present in New Zealand.
- Whether the contaminants of concern are present in untreated effluents produced by these industries in New Zealand.

- Discharge limits for these contaminants in New Zealand (may vary by region).
- How efficiently these contaminants are removed from wastewater by treatment processes used in New Zealand.
- What monitoring is performed for the priority contaminants in final treated effluents.

GLOSSARY

AICIS	Australian Industrial Chemicals Introduction Scheme
AMR	Antimicrobial resistance
ATSDR	Agency for Toxic Substances and Disease Registry
BBP	Benzyl butyl phthalate
BPA	Bisphenol A
BFRs	Brominated flame retardants
CDC	Centers for Disease Control
COT	United Kingdom Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment
DBP	Di-n-butyl phthalate
DCHP	Dicyclohexyl phthalate
DEHP	Di(2-ethylhexyl) phthalate
DEP	Diethyl phthalate
DiBP	Di-iso butylphthalate
DMP	Dimethyl phthalate
DOP	Di-n-octyl phthalate
DVFA	Danish Veterinary and Food Administration
EC	European Commission
EDCs	Endocrine disrupting compounds
EFSA	European Food Safety Authority
ELGs	Effluent limitations guidelines
EPA	Environmental Protection Agency
EU	European Union
FSANZ	Food Standards Australia New Zealand
HSNO	Hazardous Substances and New Organisms
IPCS	International Programme on Chemical Safety
JECFA	Joint FAO/WHO Expert Committee on Food Additives

kg bw	Kilograms of body weight
LOAEL	Lowest observed adverse effect level
NAICS	North American Industry Classification System
NICNAS	National Industrial Chemicals Notification and Assessment Scheme
OPFRs	Organophosphate flame retardants
OECD	Organisation for Economic Cooperation and Development
PCBs	Polychlorinated biphenyls
PCDDs	Polychlorinated dibenzo-*p*-dioxins
PCDFs	Polychlorinated dibenzofurans
PFAS	Per- and polyfluoroalkyl substances
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonate
POPs	Persistent organic pollutants
POTW	Publicly owned treatment works
PPCPs	Pharmaceutical and personal care products
RfD	Reference dose
RIVM	Dutch National Institute for Public Health and the Environment
SNUR	Significant new use rule
TCDD	2,3,7,8- tetrachlorodibenzo-*p*-dioxin
TDI	Tolerable daily intake
TEF	Toxic equivalency factor
TEQ	Toxic equivalent
TMI	Tolerable monthly intake
TRI	Toxics release inventory
TWI	Tolerable weekly intake
US	United States
WHO	World Health Organization
WWTP	Wastewater treatment plant

APPENDIX

Table 29 Summary of New Zealand pollutant discharge limits

Class	Contaminant	Trade waste model general bylaw maximum concentration[1] (g/m^3)[3]	Draft guidelines for beneficial use of organic materials on productive land concentration limit[2] (mg/kg dry weight)
Endocrine disrupting compounds	Nonylphenol and its ethoxylates	50[4]	50[5]
	Bisphenol A	-	-
	Phthalates	-	DEHP 100
	Dioxins	Polychlorinated biphenyls 0.002	-
Heavy metals and metalloids	Cadmium	0.5	10
	Chromium	5[6]	1500
	Lead	10	300
	Mercury	0.05	7.5
	Arsenic	5	30
Per- and polyfluoroalkyl substances		-	-
Pharmaceuticals		-	-
Pesticides		0.2 in total[7] 0.1 organophosphate pesticides	-
Microplastics		-	-

[1]Standards New Zealand (2004); [2]Water New Zealand (2017), for metals corresponds to 'grade B' biosolids limits specified by NZWWA (2003); [3]Mass limits may also be imposed for any characteristic - any characteristic permitted by mass limit shall also have its maximum concentration limited to the value scheduled unless approved otherwise; [4]Phenolic compounds (as phenols) excluding chlorinated phenols; [5]Sum of technical nonylphenol, NPE10 and NPE20 equivalents; [6]Chromium (VI) is considered more toxic than chromium (III), and for a discharge where chromium (III) makes up a large proportion of the characteristic, higher concentration levels may be acceptable; [7]Pesticides (general) (includes insecticides, herbicides, fungicides and excludes organophosphate, organochlorine and any pesticides not registered for use in New Zealand).

In the following tables, each line represents the discharge from a single facility whose names have been omitted for anonymity. For data from the US TRI[123] and Canadian National Pollutant Release Inventory[124], each facility is listed using the North American Industry Classification System (NAICS). For data from the US TRI, discharge to surface waters refers to “discharges to streams, rivers, lakes, oceans, and other bodies of water. This includes releases from confined sources, such as industrial process outflow pipes or open trenches. Releases due to runoff, including stormwater runoff are also reportable to TRI under this category”[125]. Transfer to POTW refers to “quantities of TRI chemicals that are transferred to publicly-owned treatment works (POTWs) that are disposed of or released to media other than Class I Underground Injection Wells, RCRA C Landfills and/or Other (Non RCRA C) Landfills during the calendar year…This data element shows the quantity of a TRI chemical that has passed through a POTW treatment process, has not been fully destroyed and will be disposed of or released to media other than Class I Underground Injection Wells, RCRA C Landfills and/or Other (Non RCRA C) Landfills…The most common transfers of TRI chemicals to POTWs are conveyances of the toxic chemical in facility wastewater through underground sewage pipes. However, TRI chemicals can also be trucked to a POTW or transferred via other direct methods”[126]. All TRI values were converted from pounds to kilograms.

[123] Releases: Chemical Report | TRI Explorer | US EPA Accessed 4 May 2022
[124] Environment and Climate Change Canada - NPRI Data Search Accessed 4 May 2022
[125] Tri Metadata | TRI Explorer | US EPA Accessed 2 May 2022
[126] Tri Metadata | TRI Explorer | US EPA Accessed 2 May 2022

Table 30 Discharges of nonylphenol and its ethoxylates reported in international pollutant release databases

US Toxics Release Inventory 2020			
Substance	**Primary industry associated with facility**	**TRI Industry sector**	**Discharge to surface waters (kg)**
Nonylphenol	All other basic organic chemical manufacturing	Chemicals	11.8
	All other miscellaneous chemical product and preparation manufacturing	Chemicals	9.1
	Cyclic crude, intermediate, and gum and wood chemical manufacturing	Chemicals	2.7
Nonylphenol ethoxylates	National security	Other	515
	All other basic organic chemical manufacturing All other pipeline transportation	Chemicals	50
	Plastics material and resin manufacturing	Chemicals	28.1
	All other miscellaneous chemical product and preparation manufacturing	Chemicals	2.3
	Petrochemical manufacturing	Chemicals	1.8
Substance	**Primary industry associated with facility**	**TRI Industry sector**	**Transfer to POTW (kg)**
Nonylphenol	Soap and other detergent manufacturing	Chemicals	18.1
	All other miscellaneous chemical product and preparation manufacturing	Chemicals	3.2
	All other basic organic chemical manufacturing	Chemicals	2.3
	Plastics material and resin manufacturing	Chemicals	1.4
Nonylphenol ethoxylates	Toilet preparation manufacturing	Chemicals	9,812
	Soap and other detergent manufacturing	Chemicals	916
	Dry, condensed, and evaporated dairy product manufacturing	Food	618
	All other miscellaneous chemical product and preparation manufacturing	Chemicals	311
	Cheese manufacturing	Food	189

Substance	Primary industry associated with facility	TRI Industry sector	Transfer to POTW (kg)
Nonylphenol ethoxylates	Soap and other detergent manufacturing	Chemicals	157
	Soap and other detergent manufacturing	Chemicals	129
	Soap and other detergent manufacturing	Chemicals	115
	All other misc. chemical product and preparation manufacturing	Chemicals	114
	Dry, condensed, and evaporated dairy product manufacturing	Food	94
	Metal can manufacturing	Fabricated metals	61
	Metal can manufacturing	Fabricated metals	24.5
	Soap and other detergent manufacturing	Chemicals	18.6
	Soap and other detergent manufacturing	Chemicals	16.8
	Paint and coating manufacturing	Chemicals	16.8
	All other basic organic chemical manufacturing	Chemicals	15.9
	Soap and other detergent manufacturing	Chemicals	14.1
	All other miscellaneous chemical product and preparation manufacturing	Chemicals	11.8
	Paint and coating manufacturing	Chemicals	10.9
	Plastics material and resin manufacturing	Chemicals	10.9
	All other miscellaneous chemical product and preparation manufacturing	Chemicals	9.1
	Plastics material and resin manufacturing	Chemicals	8.6
	Surface active agent manufacturing	Chemicals	7.7
	Paint and coating manufacturing	Chemicals	6.8
	All other miscellaneous chemical product and preparation manufacturing	Chemicals	6.4
	Paint and coating manufacturing	Chemicals	5.9
	Soap and other detergent manufacturing	Chemicals	5.9
	Other basic inorganic chemical manufacturing	Chemicals	5.4

Substance	Primary industry associated with facility	TRI Industry sector	Transfer to POTW (kg)
Nonylphenol ethoxylates	Dry, condensed, and evaporated dairy product manufacturing	Food	4.5
	All other miscellaneous chemical product and preparation manufacturing	Chemicals	4.1
	Soap and other detergent manufacturing	Chemicals	4.1
	All other petroleum and coal products manufacturing	Petroleum	3.6
	Artificial and synthetic fibers and filaments manufacturing	Chemicals	2.7
	Polish and other sanitation good manufacturing	Chemicals	2.3
	Plastics material and resin manufacturing	Chemicals	2.3
	Adhesive manufacturing	Chemicals	1.8
	Soap and other detergent manufacturing	Chemicals	1.4
Canadian National Pollutant Release Inventory 2017			
Substance	**Primary industry associated with facility**	**Industry sector**	**On-site release to water (kg)**
Nonylphenol and its ethoxylates	Paint, coating and adhesive manufacturing	Chemicals	1.3

POTW, publicly owned treatment works. Includes all facilities discharging/transferring 1 kg or more per year, apart from WWTPs and hazardous waste treatment facilities.

Table 31 Discharges of cadmium and its compounds reported in international pollutant release databases

US Toxics Release Inventory 2020			
Substance	**Primary industry associated with facility**	**TRI Industry sector**	**Discharge to surface waters (kg)**
Cadmium compounds	Copper, nickel, lead, and zinc mining	Metal mining	254
	Secondary smelting, refining, and alloying of nonferrous metal (except copper and aluminum)	Primary metals	114
	All other basic organic chemical manufacturing	Chemicals	36
	Iron and steel mills and ferroalloy manufacturing	Primary metals	31
	Iron and steel mills and ferroalloy manufacturing	Primary metals	24
	Secondary smelting, refining, and alloying of nonferrous metal (except copper and aluminum)	Primary metals	23
	Secondary smelting, refining, and alloying of nonferrous metal (except copper and aluminum)	Primary metals	10.4
Canadian National Pollutant Release Inventory 2017			
Substance	**Primary industry associated with facility**	**TRI Industry sector**	**On-site release to water (kg)**
Cadmium and its compounds	Non-ferrous metal (except Al) production and processing	Primary metals	211
	Pulp, paper and paperboard mills	Paper	134
	Metal ore mining	Metal mining	77
	Metal ore mining	Metal mining	66
	Foundries	Primary metals	65
	Pulp, paper and paperboard mills	Paper	55
	Pulp, paper and paperboard mills	Paper	53
	Pulp, paper and paperboard mills	Paper	51
	Pulp, paper and paperboard mills	Paper	47
	Pulp, paper and paperboard mills	Paper	46
	Pulp, paper and paperboard mills	Paper	43
	Non-ferrous metal (except Al) production and processing	Primary metals	40

Substance	Primary industry associated with facility	TRI Industry sector	On-site release to water (kg)
Cadmium and its compounds	Pulp, paper and paperboard mills	Paper	38
	Non-ferrous metal (except Al) production and processing	Primary metals	28
	Pulp, paper and paperboard mills	Paper	27
	Pulp, paper and paperboard mills	Paper	25
	Iron and steel mills and ferro-alloy manufacturing	Primary metals	25
	Pulp, paper and paperboard mills	Paper	24
	Pulp, paper and paperboard mills	Paper	21
	Pulp, paper and paperboard mills	Paper	21
	Pulp, paper and paperboard mills	Paper	20
	Pulp, paper and paperboard mills	Paper	19
	Pulp, paper and paperboard mills	Paper	19
	Petroleum and coal product manufacturing	Petroleum	19
	Metal ore mining	Metal mining	18
	Pulp, paper and paperboard mills	Paper	16
	Pulp, paper and paperboard mills	Paper	16
	Coal mining	Coal mining	15
	Coal mining	Coal mining	15
	Pulp, paper and paperboard mills	Paper	14
	Pulp, paper and paperboard mills	Paper	13
	Pulp, paper and paperboard mills	Paper	13
	Pulp, paper and paperboard mills	Paper	12
	Pulp, paper and paperboard mills	Paper	11
	Pulp, paper and paperboard mills	Paper	10
	Pulp, paper and paperboard mills	Paper	10
Australian National Pollutant Inventory 2019-2020			
Substance	**Primary ANZSIC class**	**Primary ANZSIC group**	**Emission to water (kg)**
Cadmium and compounds	Copper, silver, lead and zinc smelting and refining	Basic non-ferrous metal manufacturing	1,400

Substance	Primary ANZSIC class	Primary ANZSIC group	Emission to water (kg)
Cadmium and compounds	Copper, silver, lead and zinc smelting and refining	Basic non-ferrous metal manufacturing	1,100
	Gold ore mining	Metal ore mining	220
	Gold ore mining	Metal ore mining	62
	Gold ore mining	Metal ore mining	56
	Fertiliser manufacturing	Fertiliser and pesticide manufacturing	22
	Other metal ore mining	Metal ore mining	19
	Gold ore mining	Metal ore mining	18
	Alumina production	Basic non-ferrous metal manufacturing	12

POTW, publicly owned treatment works. Includes all facilities discharging/transferring 10 kg or more per year, apart from WWTPs and hazardous waste treatment and disposal facilities.

Table 32 Discharges of chromium and its compounds reported in international pollutant release databases

US Toxics Release Inventory 2020			
Substance	**Primary industry associated with facility**	**TRI Industry sector**	**Discharge to surface waters (kg)**
Chromium	Cement manufacturing	Nonmetallic mineral product	6,569
	Petroleum refineries	Petroleum	318
	Iron and steel mills and ferroalloy manufacturing	Primary metals	173
	Nonferrous forging	Fabricated metals	132
	Farm machinery and equipment manufacturing	Machinery	116
	Copper rolling, drawing, extruding, and alloying	Primary metals	113
	Power boiler and heat exchanger manufacturing	Fabricated metals	113
	Industrial gas manufacturing	Chemicals	85
	Ship building and repairing	Transportation equipment	52
	Turbine and turbine generator set units manufacturing	Machinery	39
	Iron and steel pipe and tube manufacturing from purchased steel	Primary metals	33
	Iron and steel forging	Fabricated metals	28
	Other basic inorganic chemical manufacturing	Chemicals	25
	Secondary smelting and alloying of aluminum	Primary metals	17.7
	Iron and steel mills and ferroalloy manufacturing	Primary metals	15.4
	Iron and steel pipe and tube manufacturing from purchased steel	Primary metals	15.0
	Petroleum refineries	Petroleum	14.5
	Steel foundries (except investment)	Primary metals	14.5
	Ship building and repairing	Transportation equipment	14.1
	Oil and gas field machinery and equipment manufacturing	Machinery	13.6
	Steel wire drawing	Primary metals	13.2

Substance	Primary industry associated with facility	TRI Industry sector	Discharge to surface waters (kg)
Chromium	Aircraft engine and engine parts manufacturing	Transportation Equipment	12.7
	Aircraft manufacturing	Transportation Equipment	12.7
	Cement manufacturing	Nonmetallic mineral product	11.3
	Motor vehicle metal stamping	Transportation Equipment	10.0
Chromium compounds	Fossil fuel electricity generation	Electricity generation	3,629
	Fossil fuel electricity generation	Electricity generation	2,554
	Iron and steel mills and ferroalloy manufacturing	Primary metals	1,077
	Pulp mills	Paper	827
	Fossil fuel electricity generation	Electricity generation	544
	Iron and steel mills and ferroalloy manufacturing	Primary metals	532
	Paperboard mills	Paper	417
	Plastics material and resin manufacturing	Chemicals	401
	Fossil fuel electricity generation	Electricity generation	349
	Iron and steel mills and ferroalloy manufacturing	Primary metals	295
	Nonferrous metal (except aluminum) smelting and refining	Primary metals	227
	Copper, nickel, lead, and zinc mining	Metal mining	227
	Fossil fuel electricity generation	Electricity generation	207
	Fossil fuel electricity generation	Electricity generation	204
	Plastics material and resin manufacturing	Chemicals	188
	Pulp mills	Paper	148
	Petroleum refineries	Petroleum	143
	Iron and steel mills and ferroalloy manufacturing	Primary metals	128
	Fossil fuel electricity generation	Electricity generation	123
	Iron foundries	Primary metals	116
	Paper (except newsprint) mills	Paper	100

Substance	Primary industry associated with facility	TRI Industry sector	Discharge to surface waters (kg)
Chromium compounds	Alumina refining and primary aluminum production	Primary metals	99
	Fossil fuel electricity generation	Electricity generation	96
	Iron and steel mills and ferroalloy manufacturing	Primary metals	92
	Iron and steel mills and ferroalloy manufacturing	Primary metals	87
	Iron and steel mills and ferroalloy manufacturing	Primary metals	83
	Petrochemical manufacturing	Chemicals	82
	Fossil fuel electricity generation	Electricity generation	79
	Iron and steel mills and ferroalloy manufacturing	Primary metals	79
	Iron and steel mills and ferroalloy manufacturing	Primary metals	76
	Iron and steel mills and ferroalloy manufacturing	Primary metals	74
	Paper (except newsprint) mills	Paper	73
	Rolled steel shape manufacturing	Primary metals	73
	Iron and steel mills and ferroalloy manufacturing	Primary metals	68
	Iron and steel mills and ferroalloy manufacturing	Primary metals	68
	Fossil fuel electricity generation	Electricity generation	68
	Fossil fuel electricity generation	Electricity generation	68
	Fossil fuel electricity generation	Electricity generation	67
	Iron and steel forging	Fabricated metals	67
	Petroleum refineries	Petroleum	66
	Fossil fuel electricity generation	Electricity generation	66
	Fossil fuel electricity generation	Electricity generation	66
	Fossil fuel electricity generation	Electricity generation	63
	Pulp mills	Paper	62
	Fossil fuel electricity generation	Electricity generation	54
	Synthetic dye and pigment manufacturing	Chemicals	53
	Plastics material and resin manufacturing	Chemicals	50
	Fossil fuel electricity generation	Electricity generation	48

Substance	Primary industry associated with facility	TRI Industry sector	Discharge to surface waters (kg)
Chromium compounds	Secondary smelting, refining, and alloying of nonferrous metal (except copper and aluminum)	Primary metals	45
	Unlaminated plastics profile shape manufacturing	Plastics and rubber	45
	Fossil fuel electricity generation	Electricity generation	45
	Petrochemical manufacturing	Chemicals	43
	Iron and steel mills and ferroalloy manufacturing	Primary metals	42
	Petroleum refineries	Petroleum	41
	Petroleum refineries	Petroleum	40
	Iron and steel mills and ferroalloy manufacturing	Primary metals	39
	Iron and steel mills and ferroalloy manufacturing	Primary metals	38
	Plastics material and resin manufacturing	Chemicals	37
	Fossil fuel electricity generation	Electricity generation	36
	Fossil fuel electricity generation	Electricity generation	36
	Iron and steel mills and ferroalloy manufacturing	Primary metals	36
	Synthetic dye and pigment manufacturing	Chemicals	32
	Fossil fuel electricity generation	Electricity generation	32
	Iron and steel mills and ferroalloy manufacturing	Primary metals	31
	Petroleum refineries	Petroleum	29
	Iron and steel mills and ferroalloy manufacturing	Primary metals	29
	Fossil fuel electricity generation	Electricity generation	28
	All other basic organic chemical manufacturing	Chemicals	27
	Other motor vehicle parts manufacturing	Transportation equipment	26
	All other miscellaneous chemical product and preparation manufacturing	Chemicals	26
	Fossil fuel electricity generation	Electricity generation	26
	Fossil fuel electricity generation	Electricity generation	25
	Fossil fuel electricity generation	Electricity generation	24
	Secondary smelting, refining, and alloying of nonferrous metal (except copper and aluminum)	Primary metals	24

Substance	Primary industry associated with facility	TRI Industry sector	Discharge to surface waters (kg)
Chromium compounds	Iron and steel mills and ferroalloy manufacturing	Primary metals	23
	Aircraft manufacturing	Transportation equipment	23
	Iron and steel mills and ferroalloy manufacturing	Primary metals	23
	Petroleum refineries	Petroleum	22
	Other basic inorganic chemical manufacturing	Chemicals	21
	Fossil fuel electricity generation	Electricity generation	21
	Iron and steel mills and ferroalloy manufacturing	Primary metals	21
	Iron and steel mills and ferroalloy manufacturing	Primary metals	21
	Iron and steel mills and ferroalloy manufacturing	Primary metals	20
	Petroleum refineries	Petroleum	18.6
	Wood preservation	Wood products	18.1
	Fossil fuel electricity generation	Electricity generation	18.1
	Wood preservation	Wood products	17.2
	Iron and steel mills and ferroalloy manufacturing	Primary metals	15.9
	Iron and steel mills and ferroalloy manufacturing	Primary metals	15.0
	Petroleum refineries	Petroleum	14.5
	Fossil fuel electricity generation	Electricity generation	14.1
	Electroplating, plating, polishing, anodizing, and coloring	Fabricated metals	13.2
	Plastics material and resin manufacturing	Chemicals	13.2
	Fossil fuel electricity generation	Electricity generation	13.2
	Industrial gas manufacturing	Chemicals	12.7
	Sawmills	Wood products	12.7
	Other basic inorganic chemical manufacturing	Chemicals	12.7
	Fossil fuel electricity generation	Electricity generation	12.2
	All other miscellaneous wood product manufacturing	Wood products	12.2
	Fossil fuel electricity generation	Electricity generation	12.2
	Fossil fuel electricity generation	Electricity generation	11.8

Substance	Primary industry associated with facility	TRI Industry sector	Discharge to surface waters (kg)
Chromium compounds	Iron and steel mills and ferroalloy manufacturing	Primary metals	11.8
	Other aluminum rolling, drawing, and extruding	Primary metals	11.3
	Iron and steel mills and ferroalloy manufacturing	Primary metals	11.3
	Other basic inorganic chemical manufacturing	Chemicals	10.9
	Iron and steel mills and ferroalloy manufacturing	Primary metals	10.4
	Iron and steel mills and ferroalloy manufacturing	Primary metals	10.0
	Ship building and repairing	Transportation equipment	10.0
Substance	**Primary industry associated with facility**	**TRI Industry sector**	**Transfer to POTW (kg)**
Chromium	Fabricated pipe and pipe fitting manufacturing	Fabricated metals	2,113
	Nonferrous metal (except copper and aluminum) rolling, drawing, and extruding	Primary metals	222
	Steel investment foundries	Primary metals	172
	Small arms ammunition manufacturing	Fabricated metals	155
	Other industrial machinery manufacturing	Machinery	113
	Animal (except poultry) slaughtering	Food	88
	Metal kitchen cookware, utensil, cutlery, and flatware (except precious) manufacturing	Fabricated metals	70
	Nonferrous forging	Fabricated metals	44
	Other basic inorganic chemical manufacturing	Chemicals	37
	Iron and steel pipe and tube manufacturing from purchased steel	Primary metals	36
	Leather and hide tanning and finishing	Leather	30
	Showcase, partition, shelving, and locker manufacturing	Furniture	29
	Showcase, partition, shelving, and locker manufacturing	Furniture	28
	Surgical and medical instrument manufacturing	Miscellaneous manufacturing	25

Substance	Primary industry associated with facility	TRI Industry sector	Transfer to POTW (kg)
Chromium	Iron and steel pipe and tube manufacturing from purchased steel	Primary metals	23
	Other nonferrous metal foundries (except die-casting)	Primary metals	19.5
	Saw blade and handtool manufacturing	Fabricated metals	18.1
	Other engine equipment manufacturing	Machinery	17.2
	Small arms manufacturing	Fabricated metals	15.9
	Other nonferrous metal foundries (except die-casting)	Primary metals	15.0
	Aircraft manufacturing	Transportation equipment	14.1
	Iron and steel pipe and tube manufacturing from purchased steel	Primary metals	13.2
	Food product machinery manufacturing	Machinery	12.7
	Bolt, nut, screw, rivet, and washer manufacturing	Fabricated metals	11.8
	Mineral wool manufacturing	Nonmetallic Mineral Product	10.9
	Motor vehicle transmission and power train parts manufacturing	Transportation equipment	10.9
	Aircraft manufacturing	Transportation equipment	10.4
	Steel wire drawing	Primary metals	10.4
Chromium compounds	Leather and hide tanning and finishing	Leather	938
	Leather and hide tanning and finishing	Leather	359
	Leather and hide tanning and finishing	Leather	254
	Leather and hide tanning and finishing	Leather	205
	Electroplating, plating, polishing, anodizing, and coloring	Fabricated metals	152
	Turbine and turbine generator set units manufacturing	Machinery	113
	Aircraft manufacturing	Transportation equipment	88
	Plumbing fixture fitting and trim manufacturing	Fabricated metals	80

Substance	Primary industry associated with facility	TRI Industry sector	Transfer to POTW (kg)
Chromium compounds	Electroplating, plating, polishing, anodizing, and coloring	Fabricated metals	70
	Metal coating, engraving (except jewelry and silverware), and allied services to manufacturers	Fabricated metals	64
	Fossil fuel electricity generation	Electricity generation	64
	Electroplating, plating, polishing, anodizing, and coloring	Fabricated metals	54
	Other basic inorganic chemical manufacturing	Chemicals	48
	Leather and hide tanning and finishing	Leather	39
	All Other Plastics Product Manufacturing	Plastics and rubber	39
	Metal coating, engraving (except jewelry and silverware), and allied services to manufacturers	Fabricated metals	36
	Other motor vehicle parts manufacturing	Transportation equipment	36
	Saw blade and handtool manufacturing	Fabricated metals	34
	Electroplating, plating, polishing, anodizing, and coloring	Fabricated metals	32
	Electroplating, plating, polishing, anodizing, and coloring	Fabricated metals	28
	Paint and coating manufacturing	Chemicals	27
	Hardware manufacturing	Fabricated metals	27
	Electroplating, plating, polishing, anodizing, and coloring	Fabricated metals	27
	Electroplating, plating, polishing, anodizing, and coloring	Fabricated metals	23
	Synthetic dye and pigment manufacturing	Chemicals	22
	Paint and coating manufacturing	Chemicals	22
	Electroplating, plating, polishing, anodizing, and coloring	Fabricated metals	20
	Aircraft manufacturing	Transportation equipment	19.5

Substance	Primary industry associated with facility	TRI Industry sector	Transfer to POTW (kg)
Chromium compounds	Electroplating, plating, polishing, anodizing, and coloring	Fabricated metals	19.1
	Electroplating, plating, polishing, anodizing, and coloring	Fabricated metals	17.7
	Other aircraft parts and auxiliary equipment manufacturing	Transportation equipment	17.2
	Motor vehicle gasoline engine and engine parts manufacturing	Transportation equipment	16.3
	Electroplating, plating, polishing, anodizing, and coloring	Fabricated metals	15.9
	Plumbing fixture fitting and trim manufacturing	Fabricated metals	13.6
	Other motor vehicle parts manufacturing	Transportation equipment	13.6
	Plumbing fixture fitting and trim manufacturing	Fabricated metals	13.1
	Electroplating, plating, polishing, anodizing, and coloring	Fabricated metals	12.7
	Metal coating, engraving (except jewelry and silverware), and allied services to manufacturers	Fabricated metals	12.7
	Aircraft engine and engine parts manufacturing	Transportation equipment	11.8
	All other miscellaneous manufacturing	Miscellaneous manufacturing	11.8
	Iron and steel mills and ferroalloy manufacturing	Primary metals	11.3
	Metal coating, engraving (except jewelry and silverware), and allied services to manufacturers	Fabricated metals	11.3
	Electroplating, plating, polishing, anodizing, and coloring	Fabricated metals	10.9
	Other basic inorganic chemical manufacturing	Chemicals	10.9
	All Other Miscellaneous Waste Management Services	Other	10.4
	All other miscellaneous chemical product and preparation manufacturing	Chemicals	10.0

Australian National Pollutant Inventory 2019-2020			
Substance	**Primary ANZSIC class**	**Primary ANZSIC group**	**Emission to water (kg)**
Chromium III compounds	Iron ore mining	Metal ore mining	610
	Other metal ore mining	Metal ore mining	430
	Gold ore mining	Metal ore mining	240
	Gold ore mining	Metal ore mining	190
	Copper, silver, lead and zinc smelting and refining	Basic non-ferrous metal manufacturing	95
	Alumina production	Basic non-ferrous metal manufacturing	56
	Oil and gas extraction	Oil and gas extraction	56
	Pulp, paper and paperboard manufacturing	Pulp, paper and paperboard manufacturing	51
	Gold ore mining	Metal ore mining	48
	Fossil fuel electricity generation	Electricity generation	40
	Iron ore mining	Metal ore mining	38
	Basic inorganic chemical manufacturing	Basic chemical manufacturing	35
	Fertiliser manufacturing	Fertiliser and pesticide manufacturing	26
	Basic inorganic chemical manufacturing	Basic chemical manufacturing	24
	Fertiliser manufacturing	Fertiliser and pesticide manufacturing	22
	Other metal ore mining	Metal ore mining	22
	Iron ore mining	Metal ore mining	21
	Aluminium smelting	Basic non-ferrous metal manufacturing	19
	Fossil fuel electricity generation	Electricity generation	18
	Port and water transport terminal operations	Water transport support services	17

Substance	Primary ANZSIC class	Primary ANZSIC group	Emission to water (kg)
Chromium III compounds	Other non-metallic mineral mining and quarrying	Other non-metallic mineral mining and quarrying	16
	Explosive manufacturing	Other basic chemical product manufacturing	13
	Gold ore mining	Metal ore mining	12
Chromium VI compounds	Iron ore mining	Metal ore mining	26
	Fertiliser manufacturing	Fertiliser and pesticide manufacturing	21
	Oil and gas extraction	Oil and gas extraction	9.7
	Coal mining	Coal mining	7.2
	Petroleum refining and petroleum fuel manufacturing	Petroleum and coal product manufacturing	6.5
	Explosive manufacturing	Other basic chemical product manufacturing	6.0
	Coal mining	Coal mining	5.9
	Basic inorganic chemical manufacturing	Basic chemical manufacturing	3.6
	Oil and gas extraction	Oil and gas extraction	2.2
	Oil and gas extraction	Oil and gas extraction	1.4
	Coal mining	Coal mining	1.0
Substance	**Primary ANZSIC class**	**Primary ANZSIC group**	**Transferred to off-site sewerage (kg)**
Chromium III compounds	Fossil fuel electricity generation	Electricity generation	170
	Port and water transport terminal operations	Water transport support services	55

POTW, publicly owned treatment works. Includes all facilities discharging/transferring 10 kg or more per year, or 1 kg or more per year for chromium VI, apart from WWTPs and hazardous waste treatment and disposal facilities. No releases of 1 kg or more were reported in the Canadian pollutant release database.

Table 33 Discharges of lead and its compounds reported in international pollutant release databases

US Toxics Release Inventory 2020			
Substance	**Primary industry associated with facility**	**TRI Industry sector**	**Discharge to surface waters (kg)**
Lead	Cement manufacturing	Nonmetallic mineral product	4,299
	Other basic inorganic chemical manufacturing	Chemicals	240
	Plastics material and resin manufacturing	Chemicals	124
	Secondary smelting, refining, and alloying of nonferrous metal (except copper and aluminum)	Primary metals	112
	Ship building and repairing	Transportation equipment	103
	Paper (except newsprint) mills	Paper	72
	Breweries	Beverages	71
	All other miscellaneous chemical product and preparation manufacturing	Chemicals	71
	Other basic inorganic chemical manufacturing	Chemicals	61
	Steel wire drawing	Primary metals	43
	All other basic organic chemical manufacturing	Chemicals	42
	Motor Vehicle Metal Stamping	Transportation equipment	36
	Steel wire drawing	Primary metals	25
	Pulp mills	Paper	21
	Ship building and repairing	Transportation equipment	20
	Other basic inorganic chemical manufacturing	Chemicals	20
	Other basic inorganic chemical manufacturing	Chemicals	19.5
	Iron and steel mills and ferroalloy manufacturing	Primary metals	19,5
	Sawmills	Wood products	18.6
	Metal coating, engraving (except jewelry and silverware), and allied services to manufacturers	Fabricated metals	16.3
	Paper (except newsprint) mills	Paper	14.5
	National security	Other	12.7
	Copper rolling, drawing, extruding, and alloying	Primary metals	12.7

Substance	Primary industry associated with facility	TRI Industry sector	Discharge to surface waters (kg)
Lead	Aircraft Manufacturing	Transportation equipment	11.8
	Paperboard mills	Paper	11.8
	Light truck and utility vehicle manufacturing	Transportation equipment	11.8
	Storage Battery Manufacturing	Electrical equipment	10.9
	Secondary smelting and alloying of aluminum	Primary metals	10.4
	Paper (except newsprint) mills	Paper	10.4
Lead compounds	Fossil fuel electric power generation	Electric utilities	1,361
	Alumina refining and primary aluminum production	Primary metals	983
	Paperboard mills	Paper	821
	Paper (except newsprint) mills	Paper	776
	Copper, nickel, lead, and zinc mining	Metal mining	538
	Iron foundries	Primary metals	391
	Paperboard mills	Paper	381
	National security	Other	368
	Paperboard mills	Paper	364
	Pulp mills	Paper	358
	Paperboard mills	Paper	349
	Paperboard mills	Paper	318
	Fossil fuel electric power generation	Electric utilities	304
	Iron foundries	Primary metals	299
	Paper (except newsprint) mills	Paper	299
	Secondary smelting, refining, and alloying of nonferrous metal (except copper and aluminum)	Primary metals	292
	Paperboard mills	Paper	275
	Paper (except newsprint) mills	Paper	268
	Paperboard mills	Paper	264
	Iron and steel mills and ferroalloy manufacturing	Primary metals	218
	Fossil fuel electric power generation	Electric utilities	172
	Small arms ammunition manufacturing	Fabricated metals	160

Substance	Primary industry associated with facility	TRI Industry sector	Discharge to surface waters (kg)
Lead compounds	Paper (except newsprint) mills	Paper	159
	Iron and steel mills and ferroalloy manufacturing	Primary metals	156
	Synthetic dye and pigment manufacturing	Chemicals	153
	Copper, nickel, lead, and zinc mining	Metal mining	146
	Paper (except newsprint) mills	Paper	142
	Fossil fuel electric power generation	Electric utilities	141
	All other basic organic chemical manufacturing	Chemicals	127
	Other chemical and fertilizer mineral mining	Other	127
	Paper (except newsprint) mills	Paper	124
	Copper, nickel, lead, and zinc mining	Metal mining	122
	Ammunition (except small arms) manufacturing	Fabricated metals	120
	Fossil fuel electric power generation	Electric utilities	116
	Paper (except newsprint) mills	Paper	115
	Pulp mills	Paper	108
	Petroleum refineries	Petroleum	108
	Nitrogenous fertilizer manufacturing	Chemicals	102
Substance	**Primary industry associated with facility**	**TRI Industry sector**	**Transfer to POTW (kg)**
Lead	Showcase, partition, shelving, and locker manufacturing	Furniture	113
	Petroleum refineries	Petroleum	94
	Totalizing fluid meter and counting device manufacturing	Computer/electronics products	86
	Showcase, partition, shelving, and locker manufacturing	Furniture	44
	Showcase, partition, shelving, and locker manufacturing	Furniture	39
	Petroleum refineries	Petroleum	31
	Nonferrous metal die-casting foundries	Primary metals	19.1
	National security	Other	16.3

Substance	Primary industry associated with facility	TRI Industry sector	Transfer to POTW (kg)
Lead	Paper (except newsprint) mills	Paper	14.1
	Paperboard mills	Paper	12.2
	Commercial gravure printing	Printing	11.3
	Motor vehicle steering and suspension components (except spring) manufacturing	Transportation equipment	10.9
Lead compounds	Unlaminated plastics profile shape manufacturing	Plastics and rubber	152
	Paperboard mills	Paper	65
	Secondary smelting, refining, and alloying of nonferrous metal (except copper and aluminum)	Primary metals	57
	Secondary smelting, refining, and alloying of nonferrous metal (except copper and aluminum)	Primary metals	51
	Paperboard mills	Paper	47
	Rolled steel shape manufacturing	Primary metals	39
	Paperboard mills	Paper	28
	Small arms ammunition manufacturing	Fabricated metals	26
	Secondary smelting, refining, and alloying of nonferrous metal (except copper and aluminum)	Primary metals	18.6
	Small arms ammunition manufacturing	Fabricated metals	18.1
	Optical instrument and lens manufacturing	Machinery	18.1
	Petroleum refineries	Petroleum	17.7
	Fossil fuel electric power generation; other animal food manufacturing; wet corn milling; soybean and other oilseed processing; all other basic organic chemical manufacturing; medicinal and botanical manufacturing	Electric utilities	16.8
	Secondary smelting, refining, and alloying of nonferrous metal (except copper and aluminum)	Primary metals	15.9
	Fossil fuel electric power generation	Electric utilities	13.2
	Other basic inorganic chemical manufacturing	Chemicals	13.2
	Other basic inorganic chemical manufacturing	Chemicals	13.2

Substance	Primary industry associated with facility	TRI Industry sector	Transfer to POTW (kg)
Lead compounds	Fabricated structural metal manufacturing	Fabricated metals	12.7
	Guided missile and space vehicle manufacturing	Transportation equipment	11.3
	Petroleum refineries	Petroleum	11.3
	Wet corn milling	Food	10.4
	Glass product manufacturing made of purchased glass	Nonmetallic mineral product	10.4
Australian National Pollutant Inventory 2019-2020			
Substance	**Primary ANZSIC class**	**Primary ANZSIC group**	**Emission to water (kg)**
Lead and compounds	Copper, silver, lead and zinc smelting and refining	Basic non-ferrous metal manufacturing	20,000
	Gold ore mining	Metal ore mining	4,000
	Iron ore mining	Metal ore mining	1,700
	Gold ore mining	Metal ore mining	830
	Gold ore mining	Metal ore mining	450
	Gold ore mining	Metal ore mining	240
	Copper, silver, lead and zinc smelting and refining	Basic non-ferrous metal manufacturing	210
	Other metal ore mining	Metal ore mining	120
	Petroleum refining and petroleum fuel manufacturing	Petroleum and coal product manufacturing	110
	Iron smelting and steel manufacturing	Basic ferrous metal manufacturing	95
	Silver-lead-zinc ore mining	Metal ore mining	93
	Nickel ore mining	Metal ore mining	72
	Fossil fuel electricity generation	Electricity generation	59
	Iron ore mining	Metal ore mining	38
	Fertiliser manufacturing	Fertiliser and pesticide manufacturing	37
	Other metal ore mining	Metal ore mining	36

Substance	Primary ANZSIC class	Primary ANZSIC group	Emission to water (kg)
Lead and compounds	Iron smelting and steel manufacturing	Basic ferrous metal manufacturing	32
	Alumina production	Basic non-ferrous metal manufacturing	32
	Iron ore mining	Metal ore mining	29
	Basic inorganic chemical manufacturing	Basic chemical manufacturing	23
	Silver-lead-zinc ore mining	Metal ore mining	19
	Aluminium smelting	Basic non-ferrous metal manufacturing	18
	Other metal ore mining	Metal ore mining	11
	Oil and gas extraction	Oil and gas extraction	10
Substance	**Primary ANZSIC class**	**Primary ANZSIC group**	**Transferred to off-site sewerage (kg)**
Lead and compounds	Iron smelting and steel manufacturing	Basic ferrous metal manufacturing	87
	Port and water transport terminal operations	Water transport support services	30
	Basic inorganic chemical manufacturing	Basic chemical manufacturing	11
Canadian National Pollutant Release Inventory 2017			
Substance	**Primary industry associated with facility**	**Industry sector**	**On-site release to water (kg)**
Lead and its compounds	Non-ferrous metal (except Al) production and processing	Primary metals	1,051
	Iron and steel mills and ferro-alloy manufacturing	Primary metals	329
	Metal ore mining	Metal mining	300
	Metal ore mining	Metal mining	288
	Pulp, paper and paperboard mills	Paper	282
	Iron and steel mills and ferro-alloy manufacturing	Primary metals	160
	Petroleum and coal product manufacturing	Petroleum	158

Substance	Primary industry associated with facility	Industry sector	On-site release to water (kg)
Lead and its compounds	Metal ore mining	Metal mining	139
	Pulp, paper and paperboard mills	Paper	122
	Pulp, paper and paperboard mills	Paper	118
	Metal ore mining	Metal mining	91
	Iron and steel mills and ferro-alloy manufacturing	Primary metals	73
	Petroleum and coal product manufacturing	Petroleum	71
	Iron and steel mills and ferro-alloy manufacturing	Primary metals	66
	Support Activities for Water Transportation	Water transport support services	65
	Pulp, paper and paperboard mills	Paper	61
	Foundries	Primary metals	60
	Pulp, paper and paperboard mills	Paper	56
	Metal ore mining	Metal mining	55
	Pulp, paper and paperboard mills	Paper	53
	Pulp, paper and paperboard mills	Paper	52
	Pulp, paper and paperboard mills	Paper	52
	Pulp, paper and paperboard mills	Paper	46
	Pulp, paper and paperboard mills	Paper	45
	Pulp, paper and paperboard mills	Paper	44
	Pulp, paper and paperboard mills	Paper	42
	Pulp, paper and paperboard mills	Paper	41
	Non-ferrous metal (except aluminum) production and processing	Primary metals	40
	Pulp, paper and paperboard mills	Paper	39
	Pulp, paper and paperboard mills	Paper	34
	Pulp, paper and paperboard mills	Paper	33
	Pulp, paper and paperboard mills	Paper	33
	Pulp, paper and paperboard mills	Paper	32
	Pulp, paper and paperboard mills	Paper	31
	Foundries	Primary metals	31

Substance	Primary industry associated with facility	Industry sector	On-site release to water (kg)
Lead and its compounds	Pulp, paper and paperboard mills	Paper	28
	Pulp, paper and paperboard mills	Paper	28
	Pulp, paper and paperboard mills	Paper	24
	Metal ore mining	Metal mining	24
	Semiconductor and other electronic component manufacturing	Electronics	22
	Metal ore mining	Metal mining	22
	Coal mining	Coal mining	22
	Metal ore mining	Metal mining	21
	Petroleum and coal product manufacturing	Petroleum	19
	Steel product manufacturing from purchased steel	Fabricated metals	18
	Pulp, paper and paperboard mills	Paper	18
	Pulp, paper and paperboard mills	Paper	18
	Metal ore mining	Metal mining	18
	Steel product manufacturing from purchased steel	Fabricated metals	16
	Pulp, paper and paperboard mills	Paper	15
	Pulp, paper and paperboard mills	Paper	14
	Oil and gas extraction	Oil and gas extraction	14
	Pulp, paper and paperboard mills	Paper	13
	Pulp, paper and paperboard mills	Paper	13
	Pulp, paper and paperboard mills	Paper	12
	Pulp, paper and paperboard mills	Paper	12
	Metal ore mining	Metal mining	11
	Iron and steel mills and ferro-alloy manufacturing	Primary metals	10

POTW, publicly owned treatment works. Includes all facilities discharging/transferring 10 kg or more per year, apart from wastewater WWTPs and hazardous waste treatment and disposal facilities. Due to an abundance of records, only facilities releasing 100 kg or more of lead compounds are reported for the US.

Table 34 Discharges of mercury and its compounds reported in international pollutant release databases

US Toxics Release Inventory 2020			
Substance	**Primary industry associated with facility**	**TRI Industry sector**	**Discharge to surface waters (kg)**
Mercury	Cement manufacturing	Non-metallic mineral product	303
	Alumina refining and primary aluminum production	Primary metals	60
	Fossil fuel electric power generation	Electric utilities	14.5
	Fossil fuel electric power generation	Electric utilities	5
	All other miscellaneous fabricated metal product manufacturing	Fabricated metals	3.6
Mercury compounds	Other chemical and fertilizer mineral mining	Other	662
	All Other metal ore mining	Metal mining	300
	Paper (except newsprint) mills	Paper	159
	Petroleum refineries	Petroleum	86
	Iron and steel mills and ferroalloy manufacturing	Primary metals	41
	Fossil fuel electric power generation	Electric utilities	26
	Fossil fuel electric power generation	Electric utilities	9.5
	Petroleum refineries	Petroleum	6.8
	Synthetic dye and pigment manufacturing	Chemicals	6.4
	Synthetic dye and pigment manufacturing	Chemicals	5.9
	Petrochemical manufacturing	Chemicals	5.4
	Iron foundries	Primary metals	4.1
	Pulp mills	Paper	3.6
	Paperboard mills	Paper	3.6
	Plastics material and resin manufacturing	Chemicals	3.6
	Fossil fuel electric power generation	Electric utilities	3.6
	Fossil fuel electric power generation	Electric utilities	3.2
	Other basic inorganic chemical manufacturing	Chemicals	3.2

Substance	Primary industry associated with facility	TRI Industry sector	Discharge to surface waters (kg)
Mercury compounds	Other basic inorganic chemical manufacturing	Chemicals	3.2
	Iron and steel mills and ferroalloy manufacturing	Primary metals	3.2
	Fossil fuel electric power generation	Electric utilities	3.2
	Fossil fuel electric power generation	Electric utilities	2.7
	Petroleum refineries	Petroleum	2.7
	Fossil fuel electric power generation	Electric utilities	2.3
	Fossil fuel electric power generation	Electric utilities	2.3
	Iron and steel mills and ferroalloy manufacturing	Primary metals	1.8
	Fossil fuel electric power generation	Electric utilities	1.8
	Paperboard mills	Paper	1.4
	Paper (except newsprint) mills	Paper	1.4
	Pulp mills	Paper	1.4
	Iron and steel mills and ferroalloy manufacturing	Primary metals	1.4
	Fossil fuel electric power generation	Electric utilities	1.4
	Paperboard mills	Paper	1.4
	Fossil fuel electric power generation	Electric utilities	1.4
	Fossil fuel electric power generation	Electric utilities	1.4
	Fossil fuel electric power generation	Electric utilities	1.4
Substance	**Primary industry associated with facility**	**TRI Industry sector**	**Transfer to POTW (kg)**
Mercury	Iron and steel mills and ferroalloy manufacturing	Primary metals	5.4
	Asphalt shingle and coating materials manufacturing	Petroleum	2.7
Mercury compounds	Petroleum refineries	Petroleum	4.5
	All other miscellaneous waste management services	Other	4.5
	Biological product (except diagnostic) manufacturing	Chemicals	4.5

Australian National Pollutant Inventory 2019-2020			
Substance	**Primary ANZSIC class**	**Primary ANZSIC group**	**Emission to water (kg)**
Mercury and compounds	Copper, silver, lead and zinc smelting and refining	Basic non-ferrous metal manufacturing	24
	Water supply	Water supply, sewerage and drainage services	9
	Oil and gas extraction	Oil and gas extraction	2.7
	Copper, silver, lead and zinc smelting and refining	Basic non-ferrous metal manufacturing	2.0
	Gold ore mining	Metal ore mining	1.9
	Gold ore mining	Metal ore mining	1.8
	Oil and gas extraction	Oil and gas extraction	1.2
Substance	**Primary ANZSIC class**	**Primary ANZSIC group**	**Transferred to off-site sewerage (kg)**
Mercury and compounds	Port and water transport terminal operations	Water transport support services	1.2
Canadian National Pollutant Release Inventory 2017			
Substance	**Primary industry associated with facility**	**Industry sector**	**On-site release to water (kg)**
Mercury and its compounds	Pulp, paper and paperboard mills	Paper	8.1
	Non-ferrous metal (except Al) production and processing	Primary metals	7.8
	Non-ferrous metal (except Al) production and processing	Primary metals	4.2
	Pulp, paper and paperboard mills	Paper	2.6
	Metal ore mining	Metal mining	2.3
	Pulp, paper and paperboard mills	Paper	1.7
	Pulp, paper and paperboard mills	Paper	1.6
	Pulp, paper and paperboard mills	Paper	1.3
	Pulp, paper and paperboard mills	Paper	1.2

Substance	Primary industry associated with facility	Industry sector	On-site release to water (kg)
Mercury and its compounds	Metal ore mining	Metal mining	1.2
	Metal ore mining	Metal mining	1.0

POTW, publicly owned treatment works. Includes all facilities discharging/transferring 1 kg or more per year, apart from WWTPs and hazardous waste treatment and disposal facilities.

Table 35 Discharges of arsenic and its compounds reported in international pollutant release databases

US Toxics Release Inventory 2020			
Substance	**Primary industry associated with facility**	**TRI Industry sector**	**Discharge to surface waters (kg)**
Arsenic	Industrial gas manufacturing	Chemicals	1,789
	Small arms ammunition manufacturing	Fabricated metals	76
	Secondary smelting, refining, and alloying of nonferrous metal (except copper and aluminum)	Primary metals	10
Arsenic compounds	Fossil fuel electric power generation	Electric utilities	1,633
	Fossil fuel electric power generation	Electric utilities	499
	Pesticide and other agricultural chemical manufacturing	Chemicals	308
	Nonferrous metal (except Al) smelting and refining	Primary metals	288
	Fossil fuel electric power generation	Electric utilities	240
	Plastics material and resin manufacturing	Chemicals	188
	Fossil fuel electric power generation	Electric utilities	182
	Fossil fuel electric power generation	Electric utilities	182
	Fossil fuel electric power generation	Electric utilities	159
	All other basic organic chemical manufacturing	Chemicals	142
	Copper, nickel, lead, and zinc mining	Metal mining	96
	Fossil fuel electric power generation	Electric utilities	69
	Fossil fuel electric power generation	Electric utilities	64
	Alumina refining and primary aluminum production	Primary metals	64
	Fossil fuel electric power generation	Electric utilities	59
	Fossil fuel electric power generation	Electric utilities	59
	Fossil fuel electric power generation	Electric utilities	59
	Secondary smelting, refining, and alloying of nonferrous metal (except copper and aluminum)	Primary metals	56

Substance	Primary industry associated with facility	TRI Industry sector	Discharge to surface waters (kg)
Arsenic compounds	Wood preservation	Wood products	49
	Fossil fuel electric power generation	Electric utilities	42
	Fossil fuel electric power generation	Electric utilities	39
	Fossil fuel electric power generation	Electric utilities	38
	Fossil fuel electric power generation	Electric utilities	37
	Fossil fuel electric power generation	Electric utilities	36
	Fossil fuel electric power generation	Electric utilities	36
	Gold ore mining	Metal mining	35
	Fossil fuel electric power generation	Electric utilities	34
	Iron and steel mills and ferroalloy manufacturing	Primary metals	34
	All other miscellaneous wood product manufacturing	Wood products	33
	Sawmills	Wood products	33
	Synthetic dye and pigment manufacturing	Chemicals	30
	Fossil fuel electric power generation	Electric utilities	27
	Fossil fuel electric power generation	Electric utilities	27
	Gold ore mining	Metal mining	25
	Fossil fuel electric power generation	Electric utilities	24
	Fossil fuel electric power generation	Electric utilities	18.6
	Fossil fuel electric power generation	Electric utilities	18.1
	Wood preservation	Wood products	18.1
	Synthetic dye and pigment manufacturing	Chemicals	16.3
	Fossil fuel electric power generation	Electric utilities	14.1
	Wood preservation	Wood products	12.7
	Fossil fuel electric power generation	Electric utilities	11.3
	Wood preservation	Wood products	10.9
	Wood preservation	Wood products	10.4
	Pesticide and other agricultural chemical manufacturing	Chemicals	10.0

Substance	Primary industry associated with facility	TRI Industry sector	Discharge to surface waters (kg)
Arsenic compounds	Fossil fuel electric power generation	Electric utilities	10.0
Substance	**Primary industry associated with facility**	**TRI Industry sector**	**Transfer to POTW (kg)**
Arsenic	Secondary smelting, refining, and alloying of nonferrous metal (except copper and aluminum)	Primary metals	346
	Industrial and commercial fan and blower and air purification equipment manufacturing	Machinery	29
Arsenic compounds	Nonferrous metal (except Al) smelting and refining	Primary metals	113
	Secondary smelting, refining, and alloying of nonferrous metal (except copper and aluminum)	Primary metals	10.4
Australian National Pollutant Inventory 2019-2020			
Substance	**Primary ANZSIC class**	**Primary ANZSIC group**	**Emission to water (kg)**
Arsenic and compounds	Gold ore mining	Metal ore mining	1,900
	Copper, silver, lead and zinc smelting and refining	Basic non-ferrous metal manufacturing	890
	Other metal ore mining	Metal ore mining	540
	Alumina production	Basic non-ferrous metal manufacturing	530
	Iron ore mining	Metal ore mining	340
	Gold ore mining	Metal ore mining	260
	Alumina production	Basic non-ferrous metal manufacturing	250
	Gold ore mining	Metal ore mining	250
	Iron ore mining	Metal ore mining	190
	Gold ore mining	Metal ore mining	190
	Copper, silver, lead and zinc smelting and refining	Basic non-ferrous metal manufacturing	180
	Oil and gas extraction	Oil and gas extraction	94

Substance	Primary ANZSIC class	Primary ANZSIC group	Emission to water (kg)
Arsenic and compounds	Fossil fuel electricity generation	Electricity generation	88
	Fertiliser manufacturing	Fertiliser and pesticide manufacturing	78
	Other non-metallic mineral mining and quarrying	Other non-metallic mineral mining and quarrying	76
	Port and water transport terminal operations	Water transport support services	72
	Fossil fuel electricity generation	Electricity generation	69
	Coal mining	Coal mining	64
	Bauxite mining	Metal ore mining	49
	Gold ore mining	Metal ore mining	48
	Gold ore mining	Metal ore mining	41
	Oil and gas extraction	Oil and gas extraction	38
	Petroleum refining and petroleum fuel manufacturing	Petroleum and coal product manufacturing	32
	Fossil fuel electricity generation	Electricity generation	31
	Aluminium smelting	Basic non-ferrous metal manufacturing	30
	Gold ore mining	Metal ore mining	30
	Copper, silver, lead and zinc smelting and refining	Basic non-ferrous metal manufacturing	28
	Coal mining	Coal mining	28
	Copper ore mining	Metal ore mining	23
	Other metal ore mining	Metal ore mining	21
	Gold ore mining	Metal ore mining	21
	Silver-lead-zinc ore mining	Metal ore mining	20
	Fossil fuel electricity generation	Electricity generation	16
	Oil and gas extraction	Oil and gas extraction	16
	Iron ore mining	Metal ore mining	15
	Fossil fuel electricity generation	Electricity generation	14

Substance	Primary ANZSIC class	Primary ANZSIC group	Emission to water (kg)
Arsenic and compounds	Petroleum refining and petroleum fuel manufacturing	Petroleum and coal product manufacturing	13
	Gold ore mining	Metal ore mining	11
	Explosive manufacturing	Other basic chemical product manufacturing	11
Substance	**Primary ANZSIC class**	**Primary ANZSIC group**	**Transferred to off-site sewerage (kg)**
Arsenic and compounds	Iron smelting and steel manufacturing	Basic ferrous metal manufacturing	170
	Port and water transport terminal operations	Water transport support services	28
Canadian National Pollutant Release Inventory 2017			
Substance	**Primary industry associated with facility**	**Industry sector**	**On-site release to water (kg)**
Arsenic and its compounds	Non-ferrous metal (except Al) production and processing	Primary metals	783
	Non-ferrous metal (except Al) production and processing	Primary metals	586
	Metal ore mining	Metal mining	367
	Metal ore mining	Metal mining	340
	Metal ore mining	Metal mining	309
	Metal ore mining	Metal mining	288
	Pulp, paper and paperboard mills	Paper	246
	Pulp, paper and paperboard mills	Paper	219
	Pulp, paper and paperboard mills	Paper	184
	Pulp, paper and paperboard mills	Paper	168
	Non-ferrous metal (except Al) production and processing	Primary metals	133
	Metal ore mining	Metal mining	131
	Metal ore mining	Metal mining	123
	Pulp, paper and paperboard mills	Paper	119

Substance	Primary industry associated with facility	Industry sector	On-site release to water (kg)
Arsenic and its compounds	Pulp, paper and paperboard mills	Paper	118
	Pulp, paper and paperboard mills	Paper	112
	Pulp, paper and paperboard mills	Paper	111
	Pulp, paper and paperboard mills	Paper	101
	Petroleum and coal product manufacturing	Petroleum	97
	Pulp, paper and paperboard mills	Paper	93
	Pulp, paper and paperboard mills	Paper	90
	Pulp, paper and paperboard mills	Paper	87
	Pulp, paper and paperboard mills	Paper	79
	Foundries	Primary metals	78
	Pulp, paper and paperboard mills	Paper	76
	Metal ore mining	Metal mining	72
	Pulp, paper and paperboard mills	Paper	66
	Pulp, paper and paperboard mills	Paper	64
	Non-ferrous metal (except Al) production and processing	Primary metals	57
	Iron and steel mills and ferro-alloy manufacturing	Primary metals	52
	Pulp, paper and paperboard mills	Paper	46
	Metal ore mining	Metal mining	46
	Pulp, paper and paperboard mills	Paper	41
	Metal ore mining	Metal mining	39
	Pulp, paper and paperboard mills	Paper	34
	Pulp, paper and paperboard mills	Paper	34
	Metal ore mining	Metal mining	32
	Electric power generation, transmission, distribution	Electric utilities	32
	Pulp, paper and paperboard mills	Paper	30
	Non-ferrous metal (except Al) production and processing	Primary metals	30
	Metal ore mining	Metal mining	29

Substance	Primary industry associated with facility	Industry sector	On-site release to water (kg)
Arsenic and its compounds	Pulp, paper and paperboard mills	Paper	26
	Non-metallic mineral mining and quarrying	Mining (other)	24
	Metal ore mining	Metal mining	24
	Pulp, paper and paperboard mills	Paper	23
	Metal ore mining	Metal mining	22
	Metal ore mining	Metal mining	22
	Petroleum and coal product manufacturing	Petroleum	21
	Pulp, paper and paperboard mills	Paper	19
	Metal ore mining	Metal mining	19
	Coal mining	Coal mining	19
	Metal ore mining	Metal mining	17
	Pulp, paper and paperboard mills	Paper	16
	Metal ore mining	Metal mining	16
	Pulp, paper and paperboard mills	Paper	15
	Metal ore mining	Metal mining	15
	Petroleum and coal product manufacturing	Petroleum	13
	Pulp, paper and paperboard mills	Paper	12
	Metal ore mining	Metal mining	12
	Metal ore mining	Metal mining	12
	Iron and steel mills and ferro-alloy manufacturing	Primary metals	12
	Pesticide, fertilizer and other agricultural chemical manufacturing	Chemicals	11
	Electric power generation, transmission, distribution	Electric utilities	10

POTW, publicly owned treatment works. Includes all facilities discharging/transferring 10 kg or more per year, apart from WWTPs and hazardous waste treatment and disposal facilities.

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