

Trade Effluent Hazard Profile: Dental Clinics

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EXECUTIVE SUMMARY

Trade waste describes liquid waste streams and by-products produced by commercial, industrial, institutional or business activities, that are discharged to the municipal wastewater network. The composition of trade wastes may differ from that of domestic wastewater, and they may contain contaminants that pose additional risks to human and/or environmental health or the integrity of network infrastructure if they are not adequately managed. This report provides information on contaminants of potential concern for human health that may be present in trade waste from dental clinics in New Zealand.

Dental clinic wastewater is produced through various clinical activities and practices, and is a heterogenous mixture that may contain water, saliva, blood, coarse and fine tooth and restorative ('filling') material particulates, soft tissues, radiographic solutions, disinfectants and cleaning agents, pharmaceuticals, mouthwashes and gypsum plasters. Amalgam, a restorative compound comprising a mixture of mercury, silver, copper, tin and zinc, has long been of concern because of its high mercury content (~50%); historically, dental clinics have been considered one of the largest contributors of mercury to municipal wastewater treatment plants (WWTPs), and almost all of the literature on contaminants in dental clinic effluents focuses on amalgam and mercury. Silver associated with radiographic fixer solutions, and lead associated with protective aprons and collars, have also been key contaminants of concern. However, the use of amalgam restorations is being phased down, with most direct-replacement restorations now using a resin-based composite; New Zealand's ratification of the Minamata Convention on Mercury would require dental amalgams to be phased out by 2034. The majority of clinics have also transitioned to digital radiography, negating the need for chemical development of films, and reducing the input of radiographic solutions to wastewater streams. Although the presence of other contaminants such as pharmaceuticals, disinfectants and emerging restorative materials in clinic wastewater is often referred to, there is almost no quantitative data on their concentration in the international literature.

There was no publicly available information on the composition or characteristics of dental clinic wastewater in New Zealand. After reviewing the by-laws of various territorial authorities (TAs) around New Zealand and consulting with the Trade Waste and Compliance Officers (TWCO) group, it became apparent that many (though not all) councils require dental clinics to hold a consent to discharge trade waste to the municipal network, and many (though not all) TAs require clinics to install and maintain an ISO-certified amalgam separator capable of removing >95% of amalgam. Dental technicians designing and constructing dental prosthetics (eg crowns, dentures, implants) may be required to install a plaster trap. The consensus among the TWCO group was that dental clinics are considered by TAs to be low risk dischargers, particularly where there is an amalgam trap installed, and sampling of effluents was not prioritised. One TA was able to provide the results of sampling from a dental clinic, which showed mercury and silver concentrations were well below respective discharge limits.

For contaminants that reach the municipal wastewater system, heavy metals will be significantly removed at the WWTP, primarily through their affinity for organic matter and tendency to partition to sludge, although dissolved species may pass through treatment processes and be discharged to the environment. The fate of organic chemical contaminants such as pharmaceutical and disinfectants is highly dependent on their chemical structure and the operational parameters of the WWTP – some will be rapidly degraded and show high rates of removal, while others are persistent and show poor removal. The fate of emerging contaminants, especially micro- and nanoparticles from new restorative materials, is unknown.

Overall, data on the composition of dental clinic wastewater remains a data gap, especially for contaminants other than mercury. However, individual dental clinics tend to produce small volumes of wastewater, likely with small contaminant loads, especially when compared to other healthcare facilities (eg hospitals) or industrial entities. Further, the transition to non-mercury restorative materials and digital radiography, and the requirement of many TAs for clinics to install amalgam separators, will significantly reduce the load of mercury and silver, the two contaminants that have traditionally been of greatest concern for dental clinic wastewater.

1. INTRODUCTION

1.1 BACKGROUND

During the normal course of operation, various commercial, industrial, institutional or business activities may generate a variety of by-products and waste streams that need to be appropriately disposed of. Liquid wastes that are discharged by businesses to the municipal wastewater network are referred to as ‘trade wastes.’^{1,2} The composition of trade wastes can differ significantly from ordinary domestic wastewaters, with the potential to contain elevated levels of fats or oils, suspended solids, nutrients, heavy metals, toxic or corrosive chemicals, microorganisms, extremes of pH or temperature, or other contaminants that may pose risks to the integrity or function of the network infrastructure or treatment plant (eg, through blockages, corrosion, offensive odour, interference with biological treatment) or to environmental and/or public health. A thorough understanding of the nature and characteristics of a trade waste is therefore a key element of effective trade waste management.

A recent report by Eaton (2022) provided a high-level overview of the myriad of contaminants that can be present in different types of trade wastes, and that might be of concern for public health, based on international literature. The review was a useful starting point in understanding the types of hazards that might be present and warrant further consideration regarding their management. However, because the specific composition of trade waste is highly influenced by the nature of the industry from which it originates, and important local considerations such as scale, operational conditions and processes, and regulatory constraints, an industry-specific focus drawing on New Zealand-specific data would provide additional insight into the potential risks these different trade effluents may pose to human health in Aotearoa New Zealand.

1.2 SCOPE AND APPROACH

The objective of this project is to prepare a series of short ‘hazard profile’ reports describing the primary contaminants of human health concern associated with trade wastes from specific industries or sectors. Each ‘industry’ will be prepared as a separate profile. The purpose of these profiles is to help staff from Regional and/or Unitary Councils, Health Protection Officers or others involved in the management of wastewater, to understand whether certain industries

¹ Internationally, the term ‘industrial effluents’ is often used in place of ‘trade waste.’

² In some more remote locations, effluents produced during commercial/industrial/manufacturing or similar processes may be discharged directly to the environment following appropriate on-site treatment, rather than being discharged to the municipal wastewater network. While these effluents are essentially trade waste, they can also be referred to as ‘environmental discharge’ and are managed/regulated in a different way, requiring different, and often more stringent, resource consents or permits for the discharge of effluents to water or land, rather than the wastewater network.

are likely to contribute significant loads of contaminants of concern to municipal wastewater networks, and to gauge the effectiveness of pre-treatment and/or wastewater treatment processes in removing those contaminants. This information may help to identify higher-risk discharges, and where necessary, consider consent conditions options to help protect public health. Each profile will address three main aspects:

- What are the key contaminants of human health concern that are associated with the given industry? What are the potential health impacts of exposure to those contaminants?
- What data exists on the concentrations or loads of these contaminants in effluents or wastewater from the given industry in New Zealand? Are there any regulations or requirements (eg, discharge consent conditions, requirements for pre-treatment) for managing wastewaters with respect to the contaminants identified above?
- Are conventional wastewater treatment plants (WWTPs) likely to remove the main contaminants found in effluents from the given industry?

This current report addresses wastewater effluents discharged from **dental clinics**.

Note that this report focuses only on contaminants that may be of concern for human health; it does not address contaminants that may be present in dental clinic effluents that may be of concern for the ecological health of receiving environments. It is also beyond the scope of this report to provide detailed engineering guidance on the risks of these contaminants to wastewater infrastructure or treatment processes; however, if the integrity of the network or treatment efficacy are likely to be significantly compromised, then by extension, there could be an indirect risk to human health. Finally, this report does not consider hazardous or controlled wastes that may be generated by dental clinics but that are not disposed of via the wastewater system, such as sharps or blood-contaminated dressings, which should be managed in accordance with the New Zealand Standard for the Management of Healthcare Waste (NZS 4304:2002).

2. CONTAMINANTS OF POTENTIAL HUMAN HEALTH CONCERN IN DENTAL CLINIC WASTEWATER

2.1 OVERVIEW OF CONTAMINANTS OF CONCERN IN DENTAL CLINIC WASTEWATER

Dental clinics and surgeries can generate large amounts of medical waste, including solid wastes (gauze, cotton, plastic and latex) that may be contaminated with human bodily fluids, sharps and needles, dental films, disinfectants, waste reconstructive materials, or other types of potentially hazardous waste (Treasure and Treasure 1997; Hiltz 2007; Muhamedagic et al. 2009; Mitsika et al. 2024). In New Zealand, the Healthcare Standard NZS 4304:2002 (Standards New Zealand 2002) describes the ways in which medical waste streams must be handled and disposed of, in order to safely manage the risks associated with the different types of waste. Under the Standard, some categories of (predominantly liquid) waste are permitted to be discharged to the sewer or wastewater system; this can include hazardous or controlled wastes that have been appropriately pre-treated, so that they can be recategorized as a lower risk or non-hazardous waste category (Standards New Zealand 2002). However, before wastes are classified as appropriate for disposal to sewer, they must also meet the requirements of the relevant territorial authority (eg, through Trade Waste Bylaws) (Standards New Zealand 2002; NZDC 2024).

Dental clinic wastewater³ is produced through various clinical activities and practices, including dental procedures (teeth cleaning, ‘fillings’ and restorations, extractions, whitening), development of x-ray films, administration of medications, sterilization and infection control practices, and routine clinic cleaning.⁴ Dental chair units use water to cool and irrigate instruments and tooth surfaces during dental procedures, and provide water for patient oral rinsing and to rinse the chairside spittoon. Liquids draining the spittoon therefore contain a mixture of water, saliva, blood, coarse and fine particulates, and mouthwash or other topical agents applied within the mouth. Liquids coming from the aspiration and vacuum systems similarly include a mixture of water, saliva, blood and fine particulates (Cataldi et al. 2017; Furini et al. 2025). Other contaminants may enter clinic wastewater when substances are disposed of ‘down the drain’ (ie, poured down a sink), or when rinse waters produced through sterilising, washing or cleaning activities are disposed of down a sink or drain (Cataldi et al. 2017; Furini et al. 2025). Dental clinic wastewater is therefore a heterogenous mixture of liquids and particles, including water, saliva, blood, fine tooth particulates, dental amalgam or other restorative materials, soft tissues, disinfectants, cleaning solutions, radiographic solutions,

³ Dental clinics typically produce both ‘domestic’ wastewater from bathrooms and kitchens/tea rooms within the facility, and effluents associated specifically with dentistry; for the purposes of this paper, only the latter are being considered.

⁴ <https://www.des.nh.gov/sites/g/files/ehbemt341/files/documents/dental-practice-ww.pdf>

microorganisms, mouthwash fluids and other topical pharmaceuticals (Binner et al. 2022; Furini et al. 2025). Some of these constituents may pose a risk to human health if they are not managed appropriately. An overview of these contaminants of possible concern, and the potential health effects, follows below.

2.2 MERCURY

The contaminant that has received the most attention (by some margin) is mercury, originating from dental amalgam (Cataldi et al. 2017). Dental amalgam is an alloy of mercury (approximately 50% by weight), silver (35%), tin (9%), copper (6) and zinc (0.5%), and has been used as a key restorative material (ie, in ‘fillings’) for over 150 years (Hylander et al. 2006; Mulligan 2018). Amalgam particles are produced during the placement and finishing of new amalgam restorations and the removal of old restorations, and range in size from large visible particles (>3 mm) to sub-micron colloidal suspensions (<0.01 mm) (Cataldi et al. 2017). Larger particles are typically captured in coarse filters, while smaller particles and dissolved mercury may be carried out to the municipal wastewater network (Stone et al. 2003, 2008; Al Kawas et al. 2008; Muhamedogic et al. 2009). In 2015, the United Nations Environment Programme (UNEP) estimated that dental amalgam accounted for 226-322 tonnes of mercury use annually, or approximately 6% of total global use (UNEP 2017). Various reviews have estimated that dental clinics could contribute between 10 and 70% of the total mercury load to a wastewater treatment plant, depending on other activities within the catchment (Fan et al. 2002; Drummond et al. 2003; Bender 2008). For example, the US Environmental Protection Agency considers dental clinics to be the largest contributor of mercury to municipal WWTPs in the United States⁵ (Bender 2008; US EPA 2016).

In 2013, the UNEP adopted the Minamata Convention on Mercury, an international treaty aimed at protecting human and environmental health from the effects of mercury pollution, and which entered into force in 2017 (UNEP 2024). Initially, the Convention required Parties to take actions towards a phase-down of dental amalgam; however in November 2025, the sixth Conference of Parties (COP 6) agreed to a global phase out of dental amalgam by 2034.⁶ New Zealand signed the Convention in 2013, and intends to ratify it once domestic measures to support implementation have been developed.^{7,8} Nonetheless, a review by Broadbent et al. (2020) highlighted that the use of amalgam in New Zealand is already declining: amalgam accounted for 52% of restorations placed by dentists at the University of Otago Faculty of Dentistry in 1998, but just 7% in 2017. Some clinics have transitioned entirely to alternative restorative materials.⁹ The presence of amalgam-derived mercury (and other amalgam-derived metals) in dental clinic wastewater will likely continue in the short term however, with continued low

⁵ <https://www.epa.gov/eg/dental-effluent-guidelines>

⁶ except where its use is considered necessary by the dental practitioner based on the needs of the patient).

⁷ <https://environment.govt.nz/what-government-is-doing/international-action/minamata-convention-on-mercury/>

⁸ <https://www.treaties.mfat.govt.nz/search/details/p/39/2380>

⁹ <https://lumino.co.nz/treatments/dental-services/tooth-fillings/>

levels of use in some clinics and the removal of existing amalgam fillings from patients (Al Kawas et al. 2008). Further, amalgam has been shown to form sediment within vacuum lines and clinic drains, and the flushing of these lines may release historic amalgam deposits to the wastewater network (NZDA 2001; Fairbanks et al. 2021).

2.2.1 Health effects of mercury

Mercury is highly toxic, and is considered by the World Health Organisation (WHO) to be one of the top ten chemicals of major public health concern (WHO 2021b). The three forms of mercury (elemental, inorganic and organic) have different toxicological profiles and therefore different implications for health, although neurological and renal effects are associated with all three forms (WHO 2021b; ATSDR 2024b). While dental amalgam contains elemental mercury, which could be released as small amounts of vapour, ions or small particles that could be inhaled or ingested, no adverse health effects in patients receiving amalgam fillings have been demonstrated^{10 11} (WHO 2021b). However, once in the environment (or wastewater network), elemental and inorganic mercury can undergo chemical reaction, including biotransformation by microorganisms to organic methylmercury (Mulligan et al. 2018; Fairbanks et al. 2021).

Elemental mercury mainly causes health effects when vapours from liquid mercury are inhaled, as they are readily absorbed across the lungs, while liquid or solid mercury are poorly absorbed (IPCS 1991). Symptoms of exposure include neuromuscular changes (weakness, tremors, impaired motor function and coordination), cognitive impacts (impaired memory and integrative function), headaches, insomnia, sensory and vision disturbance and psychological changes (mood swings, irritability). Higher exposures may also cause kidney toxicity, pneumonitis, respiratory failure and death (IPCS 1991; WHO 2021b; ATSDR 2024b).

Organic mercury (eg methylmercury) is a potent neurotoxin that is highly absorbed across the gastrointestinal tract. Exposure is associated with malaise, impaired cognitive function (memory, learning), decreased fine motor coordination, ataxia, reduced muscle strength, and visual and sensory disturbance (paraesthesia, vision blurring/loss, hearing loss). The developing nervous system is especially sensitive to organic mercury, with potentially severe cognitive, neuromotor and neurosensory deficits associated with prenatal and infant exposure (IPCS 1990; ATSDR 2024b).

Inorganic mercury salts (eg mercuric chloride) are corrosive to the skin, eyes and mucosal membranes, causing rash and blisters, and can cause gastrointestinal damage and kidney toxicity if ingested (WHO 2019). High levels of exposure can cause neurological symptoms including mood swings and memory loss or muscle twitching and weakness. Animal studies also suggest effects on cardiovascular, haematological, immunological and reproductive systems (ATSDR 2024b).

¹⁰ <https://www.medsafe.govt.nz/hot/alerts/amalgam-fillings.asp>

¹¹ https://assets.nzda.org.nz/files/Standards_Guidelines/Position_Statements/Position_Statement_Amalgam.pdf

2.3 SILVER

Silver can enter dental clinic effluents through two main sources: traditional x-ray processing and amalgam waste. Light-sensitive silver-halide crystals present on x-ray film are released as silver thiosulfate during the fixing process, and can be released to wastewater if fixing and developing solutions are not properly contained and disposed of. Used ('spent') fixer can contain up to 8-12 g/L silver (NZDA 2001; Muhamedogic et al. 2009).¹² However, most dental clinics are replacing traditional radiography with digital x-ray imaging, which does not require films or liquid chemicals to develop the images. For example, in a 2016 survey of dental practitioners in New Zealand, 89% of respondents reported using digital radiography (van der Zande et al. 2018) – an increase from 35% in 2007 and 58% in 2012 (Ting et al. 2013); this has likely increased further in recent years. Thus, current levels of silver contamination associated with x-ray film development will be significantly reduced compared to historic data, and may yet decrease further as these technologies continue to be updated.

As silver is a significant component of amalgam, trace amounts of silver may be present in clinic effluents in particles released during placement and polishing or removal of amalgam restorations (Pereira et al. 2010). Silver may also be present in wastewater as a result of applications that take advantage of its antimicrobial properties, including in use of silver diamine fluoride and silver nitrate to treat tooth decay and cavity formation, and more recently, in silver nanoparticles in dental adhesives and sealants (Cuoto Fernandez et al. 2021; NZOHCAN 2025)

2.3.1 Health effects of silver

Metallic silver is generally considered to have a low human toxicity, as it is poorly absorbed by the body and presents a minimal health risk at typical environmental exposure levels (ATSDR 1990; Drake and Hazelwood 2005; WHO 2021c). Soluble silver compounds (eg silver nitrate, silver chloride) and nanosilver are more readily absorbed and can cause more significant health effects (ATSDR 1990; Drake and Hazelwood 2005).

The most well-known health effect associated with chronic exposure to high levels of silver is argyria, a permanent blue grey discoloration of the skin, eyes, hair and other organs, resulting from the deposition of silver in tissues. The condition is thought to be cosmetic and not otherwise harmful to health (ATSDR 1990; WHO 2021c). Exposure to high levels of silver compounds has been associated with breathing difficulties, lung and throat irritation, gastrointestinal irritation and stomach pain, eye irritation, and liver and kidney damage¹³ (ATSDR 1990; Drake and Hazelwood 2005; NIOSH 2021). Dermal contact can cause mild allergic reactions including rash, swelling and inflammation in some people (ATSDR 1990). Animal and cell studies have also suggested that significant exposure to silver nanoparticles may be associated with significant inflammatory response, altered lung function and histopathologic changes in the liver and kidney (NIOSH 2021). There are no studies available

¹² <https://www.hercenter.org/dental/xraywastes.php>

¹³ The extent of irritation or organ dysfunction caused by silver itself is inconclusive, because nitrate and oxide compounds are, by nature, irritants (Drake and Hazelwood 2005).

assessing potential neurological, reproductive, developmental or carcinogenic effects of silver in humans (ATSDR 1999; WHO 2021c).

2.4 LEAD

Lead is also associated with traditional radiography, being used in fine lead foils in x-ray film packets and in lead-lined boxes in which films are stored, as well as protective lead aprons and collars used by patients (Muhamedogic et al. 2009)¹⁴. Lead can enter dental clinic wastewater when protective foils or storage box are improperly disposed of or cleaned (eg, rinsed in sinks), from clinicians washing hands that may have had fine lead residue (eg lead oxide) transfer,¹⁵ or when protective items degrade over time leading to small fragments being dislodged to the waste stream. Although these individual contributions are small, their cumulative load has historically been considerable; however, appropriate handling, collection and recycling of lead items can reduce their impact considerably (Hiltz 2007; Koneru et al. 2014). As is the case for silver, the replacement of traditional radiography by digital technologies should significantly reduce the concentrations of lead in dental clinic effluents (Hiltz 2007; van der Vande et al. 2018).

2.4.1 Health effects of lead

Lead is one of the WHO's top ten chemicals of public health concern.¹⁶ The toxicity of lead has been known for over 2,000 years, and is well described (ATSDR 2020). Absorbed lead accumulates primarily in the bone, as well as the kidney, liver, heart and brain. It is a systemic toxicant, affecting almost every organ system that has been rigorously studied; however the developing nervous system is the most vulnerable to the effects of lead poisoning (Tchounwou et al. 2012; ATSDR 2020; WHO 2022, 2023).

Lead is generally considered a chronic or cumulative toxin, with acute effects usually only observed following exposure to very high doses. Such acute exposure can cause gastrointestinal disturbance (nausea, vomiting, abdominal pain), hepatic and renal damage, hypertension, and neurological effects (malaise, drowsiness, irritability, headaches, encephalopathy) (ATSDR 2020; WHO 2023). In extreme cases, acute exposure may cause convulsions and death (WHO 2023). Chronic exposure to lead can cause reduced neurological and cognitive function, psychiatric symptoms, kidney dysfunction and failure, cardiovascular effects, haematological disturbance (anaemia), immune toxicity, reproductive toxicity and minor birth defects, respiratory sensitivity, bone loss and dental effects, and gastrointestinal symptoms (IPCS 1977; Tchounwou et al. 2012; ATSDR 2020; WHO 2022, 2023). Children and infants are especially vulnerable to adverse effects of lead exposure, and exposure during pregnancy is of significant concern, as even low levels of exposure may cause

¹⁴ <https://jada.ada.org/action/showPdf?pii=S0002-8177%2814%2963381-X>

¹⁵ <https://jada.ada.org/action/showPdf?pii=S0002-8177%2814%2963381-X>

¹⁶ <https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health>

neurodevelopment abnormalities and intellectual disability with life-long implications (Tchounwou et al. 2012; WHO 2022, 2023). There is limited evidence that chronic occupational exposure to lead may contribute to the development of cancer, although results are inconsistent (ATSDR 2020); the IARC has classified inorganic lead compounds as Group 2A carcinogens (probably carcinogenic to humans) (IARC 2006).

No exposure threshold for the adverse effects of lead has been determined and no tolerable exposure limits can be derived. The New Zealand Ministry of Health states that there is no safe level of lead for humans (Ministry of Health 2021).

2.5 OTHER HEAVY METALS

Other heavy metals, including tin, nickel, copper, chromium, cadmium, manganese and zinc, have been reported as being present at trace levels in dental clinic wastewater due to the use of amalgam and radiographic cleaning solutions (NZDA 2001; Shraim et al. 2011; Abdolinasab et al. 2025).

2.5.1 Health effects of other heavy metals

Heavy metals are not biodegradable, meaning they persist in the environment and accumulate with continued input, and may bioaccumulate within the body. Heavy metal toxicity involves numerous mechanistic aspects and cellular targets, with each metal having properties that contributes to its own specific toxicity (Tchounwou et al 2012; Balali-Mood et al 2021). As such, the toxicity of different heavy metals ranges from relatively harmless unless in large doses or certain forms, to highly toxic, and some have been classified as known or possible carcinogens (WHO 1996; Tchounwou et al. 2012).

For example:

- **Cadmium** is highly toxic, even at low levels, and one of the WHO ten chemicals of public health concern.¹⁷ Exposure is associated with kidney toxicity, hepatic, pulmonary and gastrointestinal injury, and disturbance in calcium metabolism leading to kidney stones and bone conditions (ATSDR 2012a; WHO 2019a). Cadmium has been classified as carcinogenic to humans (WHO 2019a).
- **Chromium** exists in different valence states, of which chromium III and chromium VI predominate (WHO 2020a). Chromium III is poorly absorbed and relatively non-toxic, while chromium VI readily penetrates cell membranes and is highly toxic. Depending on the route of exposure, chromium VI may be associated with adverse effects on the liver, kidneys, gastrointestinal tract, spleen, and reproductive and immune systems, and causing skin and respiratory system irritation (IPCS 1988; ATSDR 2012b; WHO 2020a).
- **Copper** is an essential micronutrient, however ingestion of excessive amounts can cause gastrointestinal distress and interfere with zinc absorption, with chronic

¹⁷ <https://www.who.int/news-room/photo-story/detail/10-chemicals-of-public-health-concern>

exposure associated with kidney and liver damage. Inhalation of copper dusts causes respiratory irritation, dizziness and headaches (ATSDR 2024b).

- **Nickel** is most commonly associated with allergic reactions and contact dermatitis, being a potent skin irritant (ATSDR 2005a).
- **Zinc** is an essential micronutrient and relatively harmless unless at very high doses. Chronic exposure may interfere with copper homeostasis, causing anaemia, while acute exposure can cause gastrointestinal distress (ATSDR 2005b).

2.6 PHARMACEUTICALS

Modern dentistry relies heavily on pharmaceuticals for pain management, patient comfort and infection control, allowing clinicians to carry out procedures with minimal discomfort and reduced risk. The main classes of pharmaceuticals used in dentistry are anaesthetics, analgesics and antibiotics, with commonly-used compounds shown in Table 1 (Kaur et al. 2023; Datta et al. 2025; Ross et al. 2025). Pharmaceuticals may enter dental clinic wastewater in several ways, including the disposal of expired or excess medications down the sink, the rinsing/cleaning of instruments used to administer pharmaceuticals, or in topical formats such as mouth rinses, numbing creams, antibiotics and/or anti-inflammatories applied directly to lesions or extraction sites as pastes or in soaked or impregnated gauze or fluoride pastes expelled by the patient to the chairside spittoon¹⁸ (Khetan and Collins 2007; Datta et al. 2025). Whilst a potentially significant portion of the pharmaceuticals administered in-clinic (and certainly all of those prescribed for post-appointment care) will not enter clinic effluents but instead be metabolised and excreted by the patient into the wastewater at a later time, any pharmaceuticals that do enter dental clinic wastewater do so as compounds that are designed to be biologically active and persistent (Khetan and Collins 2007; Reyes et al. 2021).

2.6.1 Health effects of pharmaceuticals

Pharmaceuticals are a large and diverse group of biologically-active compounds intended for the diagnosis, treatment, management and prevention of various health conditions. Depending on the particular compound, they vary enormously with respect to their biological effect; while not feasible to review them all within this report, different pharmaceuticals may affect the cardiorespiratory, nervous, endocrine, digestive, musculoskeletal, haematological, immune or other body systems. Pharmaceuticals are somewhat unique amongst chemical contaminants in that they are intended for deliberate administration to a patient to elicit a therapeutic effect, and are rigorously assessed for their efficacy and safety (Cressey 2018). However, pharmaceuticals do have the potential to cause side effects, especially in sensitive or non-target individuals, or be contraindicated with other medications; purported effects vary from benign symptoms such as headache, nausea or rash to severe allergic reaction, liver or kidney damage or endocrine disruption (Daughton and Ternes 1999; Cressey 2018; Stampfer et al.

¹⁸ <https://www.hercenter.org/dental/pharma.php>

2019; Sengar and Vijayanadan 2022). In all but the most exceptional of cases, however, environmental exposure to pharmaceuticals is likely to be orders of magnitude below those considered a therapeutic dose, meaning that the risk from such exposures, while not zero, is likely to be very low for most individuals (Cressey 2018; Coxon 2024).

Table 1. Examples of commonly used pharmaceuticals in dentistry. Collated from NZDC (2006), Kaur et al. (2023), Datta et al. (2025) and Ross et al. (2025).

Class of pharmaceutical	Commonly-used compounds
Antibiotics	Amoxicillin, amoxicillin-clavulanic acid, metronidazole, clindamycin, erythromycin
Antifungals	Fluconazole
Analgesics*	Ibuprofen, naproxen, acetaminophen (paracetamol), codeine, hydrocodone, fentanyl
Anaesthesia (local, regional)*	Articaine, lidocaine, bupivacaine
Anaesthesia (general)*#	Propofol, ketamine
Sedatives*	Midazolam, lorazepam, diazepam, propofol, ketamine
Other	Hydroxyzine (for anti-anxiety) Chlorhexidine (antiseptic mouthwash) Carbamide peroxide, hydrogen peroxide (whitening agents) Ferric chloride, aluminium chloride, ferrous sulfate (astringents)

* Note this table is indicative only; some medications can be used to provide pain analgesia (pain relief), mild or heavy sedation, and/or general anaesthesia, depending on their dose and combination with other medications.

general anaesthesia is usually performed in specialist surgical facilities or hospital dental department rather than typical dental clinics (Narsinh et al. 2026).

Comment on antimicrobial resistance

While antibiotics in dental clinic wastewater may not present a direct risk to human health as a toxicant, the presence of antibiotics in wastewater is a recognised driver of antimicrobial resistance (AMR), including in dental clinic wastewater (Jiao et al. 2023). Selective pressures imposed on microorganisms by the constant contact with antimicrobial compounds promote the spread of AMR genes in the environment (WHO 2020b; Frascaroli et al. 2021). Antimicrobial resistance undermines the efficacy of antimicrobial therapies, with resistance to drugs previously considered “last-resort” now occurring with increasing frequency, prompting AMR to be described as one of the greatest threats to human health globally (Frascaroli et al. 2021; Ross et al. 2025).

2.7 PATHOGENS

Studies of microbial water quality in dental clinics focus almost exclusively on that of influent water and ensuring suitability for use in healthcare setting (Cataldi et al. 2017). The inner surface of dental unit waterlines (eg, those supplying irrigation water to drills and handpieces) are especially susceptible to biofilm formation, which can be difficult to remove once established (Cataldi et al. 2017). Biofilms may comprise a single bacterial species, or diverse communities that also include fungi, algae and protozoa, and reflect the quality of the influent source water. Most of the microorganisms present in influent water and biofilms are not harmful to human health, but opportunistic pathogens such as *Legionella* sp. and *Pseudomonas aeruginosa* may occasionally be present (Laheij et al. 2012; Cataldi et al. 2017).

The oral cavity is a natural habitat for a large number of microorganisms, with oral biofilms harbouring more than 700 species of bacterial, fungi and viruses; most of these are commensal microflora, however some may cause dental and periodontal infections, including *Streptococcus mutans* and *Porphyromonas gingivalis*¹⁹ (Qiu et al. 2023). It would therefore seem reasonable to expect that these organisms would enter dental clinic wastewater during dental procedures. Other infectious agents may be transmitted through blood or saliva (Laheij et al. 2012) and could potentially be discharged to dental clinic wastewater.

2.7.1 Health effects of pathogens

Two of the most common oral pathogens are *Streptococcus mutans* and *Porphyromonas gingivalis*, responsible for plaque formation and acid production that leads to dental caries (cavities), and periodontal disease characterised by gum disease and tooth loss, respectively (Birch et al. 2025). Other microorganisms are associated with severe infections, including *Streptococcus constellatus*, *Staphylococcus epidermidis*, *Staphylococcus aureus*, *Parvimonas micra*, *Porphyromonas gingivalis*, *Eikenella corrodens*, *Candida albicans*, *Actinomyces odontolyticus* and *Prevotella buccae*. Clinical symptoms include facial swelling, difficulty swallowing, vocal changes, breathing difficulties, and trismus (lockjaw) (Richardson et al. 2024).

The health effects of microbial pathogens not overtly associated with the oral cavity and dentistry, but which may be transmitted through the body fluids of infected individuals are reviewed by Laheij et al. (2012), who concluded their risk of transmission through dentistry was very low.

¹⁹ <https://www.colgate.com/en-us/oral-health/mouth-and-teeth-anatomy/oral-bacteria-what-lives-in-your-mouth>

2.8 STERILANTS AND DISINFECTANTS

Effective sterilisation and disinfection procedures are critical for infection prevention and control in dental practices, reducing the risk of nosocomial infections²⁰ and ensuring staff and patient safety (CDC 2024; NZDC 2024; Patiño-Marín et al. 2025). Sterilisation refers to the complete elimination of all microorganisms (including bacterial spores), with disinfection describing the process of removing many or all microbes but not necessarily bacterial spores, and sanitising reduces the number of microorganisms on a surface to a 'safe level'. General purpose cleaning agents (e.g. detergents) must be used to remove organic matter and debris prior to disinfection or sterilisation. Chemical sterilants and disinfectants are essential tools for controlling microbial contamination, especially for heat-sensitive items and surfaces where heat sterilisation (eg autoclaving or steam sterilising) is not practical or appropriate. Chemical sterilants and disinfectants may enter wastewater streams through the cleaning and sterilisation of instruments, equipment and surfaces, disinfection of waterlines (eg those providing rinsing and cooling water to instruments), hand hygiene, and the disposal of spent solutions down sinks or drains. Among the most commonly-used disinfectants are glutaraldehyde, ortho-phthalaldehyde (OPA), sodium hypochlorite, alcohol-based disinfectants (ethanol or isopropyl at 60-90%), quaternary ammonium compounds, hydrogen peroxide, peracetic acid, and phenolics (CDC 2024; Patiño-Marín et al. 2025).

Because of their inherent nature as biocidal compounds, sterilants and disinfectants may present a risk to the microbial communities within the wastewater network and treatment plant, altering biological processes and removal efficiencies. In addition, some compounds may also be considered hazardous waste on account of their being highly corrosive or reactive, reacting with organic materials within the network and leading to the 'gassing off' of toxic vapours, or damage to the network infrastructure itself.²¹ Although the total volume of disinfectant-derived contaminants from dental clinics is modest relative to hospital or industrial sources, their continuous release and high biological activity underscore the need for controlled disposal practices, neutralization protocols, and adherence to manufacturer-recommended handling guidelines to minimise potential impacts on the wastewater network.

2.8.1 Health effects of sterilants and disinfectants

The most common health effects associated with clinical disinfectants and sterilants, including glutaraldehyde, hydrogen peroxide, peracetic acid, sodium hypochlorite, is that they are corrosive and highly irritating to the skin, eyes and mucosal membranes (ISSA 2014). While the relative strength of each compound differs,²² dermal exposure can cause contact dermatitis, rash, blisters or lesions (ISSA 2014; ATSDR 2017; CDC 2024). Some compounds, notably glutaraldehyde and phenols, are also highly irritating to the respiratory tract when inhaled and

²⁰ Nosocomial infections are those acquired in a hospital or healthcare facility that were not present at the time of admission; often also called hospital-acquired or healthcare-associated infections.

²¹ <https://www.civco.com/in-the-know/how-to-dispose-of-high-level-disinfectants-safely/>

²² Individual compounds differ in their corrosivity or irritability, and further, are typically prepared for use in clinics by diluting a concentrated stock solution to various concentrations depending on the specific application.

can cause throat irritation, bronchial inflammation, nosebleeds and headaches (ATSDR 2017; CDC 2024), while ingestion is associated with vomiting and gastrointestinal damage (ATSDR 2008). Chronic exposure to phenols is associated with central nervous system and cardiovascular system effects (ATSDR 2008; Aranke et al. 2021).

Some disinfectants or sterilant solutions also contain additional substances that act as solubilising agents, surfactants, foam regulators, pH regulators or fragrances, and which may be associated with their own specific hazards (ISSA 2014).

2.9 RESIN-BASED COMPOSITES AND MICROPARTICLES

With the phase-out of amalgam, alternative direct-placement restorative materials such as resin-based composites (RBCs), porcelain, and glass ionomer cement are being increasingly used (Fisher et al. 2018; Mulligan et al. 2018; Binner et al. 2022). Resin-based composites are the most common of these alternatives, consisting of an inorganic filler (eg, glass, silica, quartz or ceramic, often including micro- and nano-sized particles), an organic resin matrix (often methacrylate-based monomers, some of which also contain bisphenol A (BPA)), a bonding/coupling agent (silane), various initiators, activators and inhibitors that control the polymerisation and curing process (eg camphorquinone, hydroquinone) and colour pigments (eg inorganic oxides) (Khan 2020; Binner et al. 2022; Mulligan et al. 2022). During the placement and finishing or the removal of composite restorations, small particulates and microparticles (both unbound filler particles and cured polymer) and unpolymerized resin residues can be released into the wastewater lines (Mulligan et al. 2018, 2022; Khan 2020). Resin-based composites may also be used in a pre-polymerised state for machining in CAD/CAM (computer-aided design and computer-aided manufacturing) applications to produce crowns, veneers, dentures and implants, which creates a microparticle waste powder that can be released to the municipal wastewater network (Mulligan et al. 2018, 2022). Resin-based composite materials can therefore be a wastewater pollutant in terms of both chemicals eluted from resins and the microparticles themselves. However, the environmental fate and impacts of RBCs and other non-amalgam restorative materials remains poorly understood, and risk assessments are not possible due to the lack of data (Mulligan et al. 2018, 2021; Khan 2020).

2.9.1 Health effects of RBCs and microparticles

Micro- and nanoparticles of RBC are distinct from microplastics, in that they are a heterogeneous mixture of polymer and inorganic filler as opposed to being polymer-only (Mulligan et al. 2018); however, they exhibit structural similarities (eg are small, reactive and charged), and may therefore show behaviours that prompt similar health concerns to microplastics (Mulligan et al. 2021, 2022). Microplastics are an emerging pollutant of significant concern because of their ubiquitous environmental presence and recent studies showing their presence in human tissues (Yuan et al. 2022; Roslan et al. 2024). Although there is insufficient

evidence as to the human health effects of exposure to microplastics,²³ concerns include the physical impacts ('particle toxicity') of microplastics themselves, and their potential to leach toxic additives and/or bind other chemicals or pathogens and act as 'vectors' into the body or cells (Yuan et al. 2022). Compounds used in RBCs, such as methacrylates and BPA derivatives, are associated with adverse health effects (Khan 2020; Mulligan et al. 2018). Bisphenol A is a known endocrine disruptor, interacting with estrogen, androgen and thyroid hormone receptors, with potential effects on the reproductive system, nervous system, metabolic function, immune function, and growth and development of offspring, as well as being associated with the development of breast and prostate tumours (Ma et al. 2019; EEA 2023). Studies have shown that while BPA is released from RBCs and dental sealants (Mulligan et al. 2018), RBC restorations contribute an estimated 0.001% to an individual's total BPA exposure, indicating no concern as to potential health risks (Ma et al. 2019). Methacrylates can irritate the skin, eyes, mucous membranes and respiratory system.^{24 25}

2.10 GYPSUM AND PLASTERS

Dental gypsum, usually calcium sulfate hemihydrate, is used to create casts of a patient's teeth and mouth for making prosthetics including dentures and crowns. The presence of these plasters in wastewater is primarily of concern as they form solid, cement-like blockages within the plumbing systems; clinics using these materials should use plaster traps to prevent this waste from entering the wastewater system. The high sulfide content of gypsum means that when mixed with biodegradable waste (eg in the wastewater network), microbial reactions produce hydrogen sulfide – a malodourous gas that in extreme cases can cause adverse health effects.

2.10.1 Health effects of hydrogen sulfide

Exposure to hydrogen sulfide is primarily through inhalation. It is both an irritant and chemical asphyxiant, affecting oxygen utilisation and the central nervous system. Prolonged exposure to concentrations above the odour threshold may cause eye watering or irritation, coughing and respiratory irritation, fatigue, nausea or headache. At extreme levels (typically occupational exposure in confined spaces), it may be associated with drowsiness, vomiting, pulmonary oedema, loss of consciousness or death (OSHA 2005; ATSDR 2016)

²³ <https://www.eea.europa.eu/en/european-zero-pollution-dashboards/indicators/impacts-of-microplastics-on-health-signal>

²⁴ <https://www.chemicalsafetyfacts.org/chemicals/methacrylates/>

²⁵ <https://www.epa.gov/sites/default/files/2016-09/documents/methyl-methacrylate.pdf>

2.11 HUMAN TISSUES

Dental effluents may also contain human body fluids or small particles of tissue, including blood, saliva, soft tissues or tooth materials (as fragments or fine particulates). Larger articles such as extracted teeth should not be disposed of to wastewater (Standards New Zealand 2004; NZDC 2024).

2.11.1 Health effects of human tissues

The risk associated with human tissues or body fluids is due to the potential presence of infectious or pathogenic microorganisms (see Section 2.1.6). However, the presence of human tissues themselves may be associated with cultural concerns or offense; for example, at least once local territorial authority (see Section 4.2) noted that this was concern for iwi/hapū in their area with regard to dental clinic wastewater.

2.12 RADIOISOTOPES

The potential presence of radioisotopes in dental clinic wastewater is mentioned in several reviews (Furini et al. 2025). Radioisotopes (eg technetium-99m, gallium-67) are used in nuclear medicine, a branch of medical imaging that assesses tissue metabolism and molecular processes to provide insights not possible using other imaging technologies (Elsaraj et al. 2025). Radioisotopes are bound to pharmaceuticals that localise within a specific body tissue, and the radiation they emit is detected and imaged using specialised equipment (Bolor et al. 2013; Stefanache et al. 2024). Nuclear medicine is used primarily for advanced diagnostics or specialised research applications rather than routine dental procedures, such as assessing adherence or microleakage of novel restorative materials, assessing various bone conditions, determining the extent of periodontal disease, evaluating implant integrity, and diagnosing tumours of the bone or salivary glands²⁶ (Bolor et al. 2013; Stefanache et al. 2024). As these activities occur in specialised radiologic clinics, radioisotopes are not expected to be detected in wastewater from dental clinics in New Zealand.

²⁶ <https://pocketdentistry.com/18-alternative-and-specialized-imaging-modalities/>

3. CONCENTRATIONS OF CONTAMINANTS IN DENTAL CLINIC WASTEWATER

3.1 CONCENTRATIONS OF CONTAMINANTS OF CONCERN IN DENTAL CLINIC EFFLUENTS IN NEW ZEALAND

Despite an extensive online search, no publicly available data was identified that provided information as to the presence or concentration of the abovementioned contaminants in dental clinic effluents in New Zealand. Indeed, no publicly-available data of any kind regarding the sampling or composition of dental clinic effluents in New Zealand was identified.

Subsequently, an informal request for information was sent to Territorial Authorities via email and a presentation to the Trade Waste and Compliance Officers group,²⁷ to enquire about their classification of dental clinic effluents under their respective Trade Waste Bylaws, requirements for pre-treatment or similar (see Section 4.2), and any sampling data that they may hold which was not discoverable in the public realm. Following those communications, it became evident that dental clinic effluents are not currently sampled by TAs in New Zealand, and that they did not hold any data on the composition of this type of trade waste. The general feedback was that because of their low total volume, effluents from dental clinics were largely considered to be low risk compared to other types of trade wastes a TA might be managing within their jurisdiction. Further, the requirement for an amalgam trap was expected to manage any risk that did exist with respect to mercury. One TA was, however, able to provide the results of sampling effluents from a dental facility over a five year period. The data shows that the effluents were tested for mercury and silver, and that both metals were well below their respective limits under the Bylaw of 0.05 g/m³ and 2.0 g/m³ by more than an order of magnitude (Table 2).

Thus, the presence or load of contaminants of human health concern in New Zealand dental clinic effluents remains a substantial knowledge gap.

²⁷ The Trade Waste and Compliance Officers group is a special interest group of the New Zealand Trade and Industrial Waters Forum, comprising Trade Waste Officers or equivalent roles from territorial authorities to network and collaborate on challenges or topics relating to trade waste and bylaw management. <https://nztiwf.org.nz/groups/trade-waste-compliance-officers/>

Table 2. Mercury and silver concentrations in wastewaters from a dental facility, as provided by an undisclosed TA.

Date	Concentration (g m ⁻³)	
	Mercury	Silver
18/11/21	0.001	0.001
01/03/22	0.001	0.001
01/09/22	0.001	0.001
02/05/23	0.001	0.001
03/10/23	0.0005	0.001
04/09/24	0.001	0.001
17/03/25	0.001	0.001
11/09/25	0.002	0.009
Limit under the TA's Trade Waste Bylaw	0.05	2.0

Note: the report provided by the TA included figures showing the sample result and the limit of detection (LOD), however only the sample result was quantified. The apparent overlap of the sample result and LOD in the figures, together with the consistency of values in the tabulated results, suggests that these values likely represent the LOD, with the actual mercury and silver concentrations being below this, with the exception of the slightly elevated levels on 11/09/25.

3.2 CONCENTRATIONS OF CONTAMINANTS OF CONCERN IN DENTAL CLINIC EFFLUENTS INTERNATIONALLY

In the near-complete absence of any New Zealand-specific data regarding the composition of dental clinic wastewater, some international data is described below to provide some insights into the potential contaminant loads that may be present in New Zealand. However, noting the potential for differences in clinical practice or levels of care, available technologies, and regulation of effluents in different countries, and that some of the studies pre-date the Minamata Convention and other formal policies for mercury phase-down, no assertion is made that the data below reflect the contaminant loads in New Zealand dental clinic effluents.

Overall, there is relatively little data available, with the vast majority of studies focusing on the presence of mercury from amalgam; data are reported inconsistently, for example, as concentrations in dental clinic wastewater, or as estimates of mercury release per dental chair per day, per dentist per day, per clinic per day, or per clinic per year (Tables 3 and 4). The concentrations of mercury are highly variable between studies, ranging from tens of µg/L to tens (and in some extreme cases, hundreds) of mg/L (Table 3). Most studies only report the 'total recoverable mercury,' which does not differentiate between solid amalgam particles and dissolved mercuric ion, although the fates and impacts of the two phases are different (Fan et al. 1997). The solubility of metals in amalgam is low (Arenholt-Bindslev and Larsen 1996), and if the elemental mercury in amalgam is not released to the environment but remains

amalgamated, risk estimates may be overstated (Fan et al. 1997). However, dental amalgams are not inert, and some soluble and colloidal mercury may be mobilised to enter wastewater and subsequently the environment (Hylander et al. 2006). For example, Stone (2004) reported dental wastewater contained total mercury content of 21.44 mg/L, comprising amalgam particles (21.36g mg/L), dissolved elemental mercury (24.1 µg/L), inorganic mercury (54 µg/L) and methylmercury (278 ng/L). Another study reported the presence of dissolved mercury in clinic wastewater reached 0.37 mg/L, with total mercury averaging 3.9 mg/L (Stone 2004). Stone et al. (2003) and Rani et al. (2015) also reported ng/L to µg/L concentrations of organic methylmercury in samples collected chairside and holding tanks. An estimated 97% of the mercury load is present in amalgam particulates (Stone 2004).

Several studies also report the presence of other heavy metals (including copper, zinc, nickel, tin and cadmium), sometimes at high levels, although these are often in developing countries (Shraim et al. 2011; Benaïssa et al. 2020; Abdolinasab et al. 2025) (Table 5).

Aside from heavy metals, quantitative data on the presence of other contaminants are seldom reported. A small number of studies have characterised the presence of RBC and amalgam-alternative restorative materials, although they focus on describing size distribution rather than total load. Binner et al. (2002) reported that inorganic particulates in effluents collected from clinics using predominantly amalgam-free materials were dominated by the 1.2-5 µm³ size range (accounting for 52-65% of particles from different effluents), with 1-6% being larger than 50 µm; the morphology of the particles was highly suggestive of raw filler materials. Mulligan et al. (2021) similarly reported that microparticles generated from simulated clinical use of RBC materials ranged in size from 0.5 µm to 1 mm, with the median size for different samples between 6 and 10 µm. Nanoscale filler particles (5-100 µm) exhibited a degree of aggregation and were observed at the microscale. With regards to microorganisms, Birch et al. (2025) used a wastewater-based epidemiology approach to determine the presence of dental pathogens *S. mutans* and *P. gingivalis* in wastewater from a mid-sized city in the United States. However, there is no attribution of these pathogens specifically to dental clinics; rather, as samples were collected at the wastewater treatment plant, these microbes are likely introduced to wastewaters during normal daily hygiene routines (eg brushing teeth) of the wider community.

Table 3. Overview of mercury and methylmercury concentrations in dental clinic effluents from selected international studies.

Metal	Concentration (mg/L)		Country	Treatment/comment	Reference
	Average (Median)	Range			
Mercury	15.8 (4.8)	1 – 74	Sweden	12 clinics; pre-remediation of amalgam separators	Hylander et al. (2006)
	1.7 0.82	0.23 – 6.6	Sweden	12 clinics; post-remediation of amalgam separators	Hylander et al. (2006)
	85		Sweden	1 clinic, without amalgam separator	Hylander et al. (2006)
	31.3	13.3 – 43.0	Canada	Chairside filter 1.34 mm + vacuum pump screen 0.75 mm, no amalgam separator	Adegbembo et al. (2002)
	0.18	0.05 – 0.34	Canda	Chairside filter 1.34 mm + vacuum pump screen 0.75 mm, amalgam separator	Adegbembo et al. (2002)
	(0.012)	<MDL – 0.124	United Arab Emirates	No treatment	Al Kawas et al. (2008)
	0.010 (0.0065)	0 – 0.040	Iran	11 clinics; 2 with poorly maintained amalgam separators	Abdolinassab et al. (2025)
	5.3	0.009 – 59.3	Saudi Arabia	No treatment	Shraim et al. (2011)
		12 – 480	USA	No treatment	Welland (1991)
	45.182	1.780 – 173	USA	No treatment	Stone et al. (2003)
	13.439	2.395 – 35.600	USA	Sedimentation tank	Stone et al. (2003)
	5.351	2.360 – 12.636	USA	Sedimentation tank	Stone et al. (2003)
	21.44		USA	No treatment	Stone (2004)
	0.220		USA		Rani et al. (2015)
Methyl-mercury	0.0009	<0.001-0.003	USA	No treatment	Stone et al. (2003)
	0.0268	0.002-0.099	USA	Sedimentation tank	Stone et al. (2003)
	0.0083	<0.001-0.020	USA	Sedimentation tank	Stone et al. (2003)
	0.198		USA		Rani et al. (2015)

For reference, the limits for mercury in trade waste under different New Zealand Trade Waste Bylaws range from 0.005 to 0.055 mg/L. Refer to Table 6 for more information.

Table 4. Overview of estimated heavy metal loading from dental clinics from selected international studies.

Metal	Estimated outputs		Country	Treatment/comment	Reference
Mercury	Individual dental clinic	100 – 200 g/year	Denmark		Arenholt-Bindslev (1992)
		25 – 146 µg/day	United Arab Emirates	No treatment	Al Kawas et al. (2008)
		200 – 340 mg/day	Algeria		Benaïssa et al. (2020)
	Individual chair	0.32 – 84 g/year	Sweden	12 clinics, pre-remediation of amalgam separators	Hylander et al. (2006)
		0.07 - 5.9 g/year	Sweden	12 clinics, post-remediation of amalgam separators	Hylander et al. (2006)
		73 g/year	Sweden	No amalgam separator	Hylander et al. 92006)
		32 mg/day	USA	No treatment, just chairside trap	Drummond et al. (2003)
		1,087 mg/day	USA	No filters	Stone et al. (2008)
		79 mg/day	USA	50 µm filter	Stone et al. (2008)
		4.3 mg/day	USA	0.5 µm filter	Stone et al. (2008)
	Individual dentist	270 mg/day 65-842 mg/day	Denmark	Without amalgam separator	Areholt-Bindslev and Larsen (1996)
		35 mg/day 12-199mg /day	Denmark	With amalgam separator	Areholt-Bindslev and Larsen (1996)
Silver	Individual chair	19 mg/day	USA	No treatment, just chairside trap	Drummond et al. (2003)

Table 5. Overview of other heavy metal concentrations in dental clinic effluents from selected international studies.

Metal	Concentration (mg/L)		Country	Treatment/comment	Reference
	Average (Median)	Range			
Cadmium	0.020	0.002 – 0.151	Saudi Arabia	No treatment	Shraim et al. (2011)
Chromium	0.337	0.004 – 5.113	Saudi Arabia	No treatment	Shraim et al. (2011)
Copper	5.2 (4.1)	<MLD – 13.03	Iran	11 clinics; 2 with poorly maintained amalgam separators	Abdolinassab et al. (2025)
Copper	10.0	0.086 – 69.6	Saudi Arabia	No treatment	Shraim et al. (2011)
Copper	23.89		USA		Rani et al. (2015)
Nickel	0.331	0.005 – 4.087	Saudi Arabia	No treatment	Shraim et al. 2011
Silver	0.005 (0)	<MLD – 0.015	Iran	11 clinics; 2 with poorly maintained amalgam separators	Abdolinassab et al. (2025)
Silver	0.485	0.003 – 4.52	Saudi Arabia	No treatment	Shraim et al. (2011)
Silver	2.27		USA		Rani et al. (2015)
Tin	3.0	0.003 – 77.7	Saudi Arabia	No treatment	Shraim et al. (2011)
Zinc	76.7	4.5 – 431	Saudi Arabia	No treatment	Shraim et al. (2011)
Zinc	11.11		USA		Rani et al. (2015)

<MDL – below minimum detection limit

For reference, the limits for different metals in trade wastes under different New Zealand Trade Waste Bylaws are as follows: chromium 5-25mg/L (depending on whether Cr(III), Cr(VI) or total Cr is assessed); copper 5-10 mg/L; nickel 5-10 mg/L; silver 2-5 mg/L; tin 5-20 mg/L, zinc 5-15 mg/L. Refer to Table 6 for more information.

4. REGULATION OF DENTAL CLINIC EFFLUENTS IN NEW ZEALAND

4.1 CLASSIFICATION AND CONSENTING OF DENTAL CLINIC EFFLUENTS UNDER TRADE WASTE BYLAWS

In New Zealand, the regulation of trade waste discharges to municipal wastewater networks is regulated by the relevant territorial authority (TA)²⁸ through trade waste bylaws. The bylaws set out specific requirements for entities producing trade wastes, including the need for approval or consent to discharge trade waste, acceptance criteria, prohibited or restricted characteristics or substances, discharge limits for key contaminants, requirements for the installation of maintenance of pre-treatment systems where required, and conditions for monitoring and reporting. Local bylaws are based on the Model Trade Waste Bylaw NZS9201:Part 23:2024 (Standards New Zealand 2004), which is intended to provide a nationally consistent framework and set of principles to the management of trade waste across regions or jurisdictions, and then adapted to the needs of individual territorial authorities, reflecting local network capacity, treatment plant performance, environmental sensitivities and council capability and capacity.

The Model Trade Waste Bylaw introduces three categories of trade waste:

- **Permitted:** a discharge that has been approved by or is acceptable to the wastewater authority, as long it meets the physical and chemical characteristics defined in Schedule 1A of the Model Trade Waste Bylaw. Acceptance is normally automatic, although a consent to discharge trade waste to sewer may be required by the wastewater authority (ie, typically the territorial authority)
- **Conditional:** a trade waste that has a risk of being unacceptable, in that is that has, or is likely to have, a characteristic that exceeds the limits specified in Schedule 1A of the Model Trade Waste Bylaw. A consent to discharge is required, which will outline conditions placed on the discharge, for example requirements for certain pre-treatment or waste, implementation of waste minimisation practices, submission of a waste management plan.
- **Prohibited:** A waste that has one or more prohibited characteristic as defined in Schedule 1B of the Bylaw and/or exceeds the limits specified in Schedule 1A, and is therefore not acceptable for discharge to the wastewater network. A prohibited discharge may be pre-treated in an appropriate manner to become a conditional discharge, on approval from the wastewater authority.

²⁸ Territorial authorities are the second tier of local government, comprising city councils (for urban centres) and district councils (for mixed urban and rural areas), and being responsible for local services including water and wastewater services.

In reviewing the Trade Waste Bylaws of multiple territorial authorities, and in discussions and follow-up email correspondence with members of the Trade Waste and Compliance Officers group (see Section 3.1), it is apparent that the specific adaptations and implementation of trade waste bylaws differ slightly across the country. For example, most TAs require a discharge consent be obtained for all trade wastes being discharged to the wastewater network (ie, including permitted wastes); however, other TAs consider permitted discharges to be low risk and therefore do not require a consent, although some may still require the discharge to be registered. The specifications for acceptable and prohibited characteristics (ie, Schedules 1A and 1B in the Model Trade Waste Bylaw) appear relatively consistent across each of the various TA Bylaws, but there is some variation in the limits for certain parameters (eg, see Section 4.2 below).

With regards to wastewater or effluent produced specifically by dental clinics, the Model Trade Waste Bylaw and its appended Guidelines identify dentists as an example of a business that may discharge a conditional trade waste (Table G2, Standards New Zealand 2004). Many individual TA bylaws also identify dentists as a business producing conditional trade waste; these councils therefore require dental clinics obtain a consent to discharge their effluents to the wastewater network. However, some TAs advised that they considered dentists to be low-risk permitted activities that did not require consenting or registration. Further, there may be variation not only between jurisdictions but within them: a staff member from one TA noted that while dental clinics in their region generally did not require a discharge consent, certain dental clinics did if they were located within a catchment where the wastewater treatment plant had a tendency towards high mercury loading. This was not to say that dentists were responsible for the mercury loading, but that the council was taking additional steps to manage all potential sources of the mercury being discharged to those particular networks.

As discussed in Chapter 3, TAs indicated that there was no routine or active sampling of dental clinic effluents occurring in New Zealand at the time of writing this report.

4.2 CONTAMINANT LIMITS UNDER TRADE WASTE BYLAWS

One of the functions of Trade Waste bylaws is to specify limits for certain contaminants or characteristics that define permitted or prohibited wastes. In reviewing a large number of Trade Waste Bylaws for this report, small differences in the parameters covered and the limits for those parameters were apparent. A summary of the limits for the contaminants of potential concern in dental clinic effluents, as identified in previous sections of this report, is shown in Table 6.

Some bylaws also include statements that prohibit the discharge of effluents containing healthcare waste that is prohibited from sewer disposal under the Healthcare Waste Standard, the discharge of pathological or histological wastes, and/or any pharmaceuticals. Other bylaws may permit the discharge of pharmaceuticals, subject to compliance with the limits in Table 6.

Table 6. Summary of limits for selected contaminants in trade waste effluent, as specified in Trade Waste Bylaws for territorial authorities across New Zealand. Note that where variation is observed in limits between jurisdictions, the different limits are shown separated by commas.

Contaminant	Limit (mg/L or g/m³)*	
Metals		
Chromium (III and VI)	5	
Chromium (total)	25	
Copper	5, 10	
Lead	2, 5, 10	
Mercury	0.005, 0.03, 0.05	
Nickel	5, 10	
Silver	2, 5	
Tin	5, 10, 20	
Zinc	5, 10, 15	
Organics		
Formaldehyde	30, 50	
Glutaraldehyde	30	
Radioactive substances		
Radioactive substances	Must be below limits specified in Office of Radiation Safety <i>Code of Practice CSP1 for the Use of Unsealed Radioactive Material</i>	
Pharmaceuticals		
Volume of pharmaceutical waste must not exceed the following volumes, based on the concentration of active ingredients:	Active ingredients	Volume
	125 mg/5 ml	10L
	250 mg/5 ml	5L
	>250 mg/5 ml	3L

Note that this table is a summary of a large number of Trade Waste Bylaws from around New Zealand, but is not a comprehensive review of all 67 territorial authorities.

* Some TAs report limits in mg/L and some TAs report limits in g/m³; the units are equivalent.

4.3 REQUIREMENTS FOR PRE-TREATMENT OF DENTAL CLINIC EFFLUENTS

Strategies to reduce the contaminant loads in dental clinic wastewater include regulations, industry best management practices for handling and disposal of hazardous substances (eg NZS 4304; NZDA 2001, NZDC 2024) and source elimination and reduction (eg transition to non-amalgam restorative materials or digital radiography) (Hiltz 2007). Guidance should be sought from the local TA if there is uncertainty as to requirements for disposal of potentially hazardous wastes and whether disposal to the wastewater network is appropriate (NZDC 2024).

Most dental clinics have chairside traps, filters or screens to filter out larger particulate wastes produced during clinical procedures, as well as finer, secondary filters to protect vacuum pumps (Adegbembo et al. 2002; Hiltz 2007). Depending on the pore size of the filters,²⁹ they are estimated to remove as much as 40-80% of amalgam particulates (Adegbembo et al. 2002; Drummond et al. 2003; Vandeven and McGinnis 2005; Fairbanks et al. 2021; Binner et al. 2022). In New Zealand, the majority, though not all, TAs require dental clinics to install and maintain an amalgam separator certified to ISO11143 (Dental Equipment – Amalgam Separators) to pre-treat wastewater before discharge to the municipal network. These separators capture scrap amalgam which is too fine to be removed using a trap or screen, using principles of sedimentation, filtration, centrifugation and/or ion exchange to remove amalgam from wastewater (NZDA 2001; Hiltz 2007; Cataldi et al. 2017). A variety of systems are available that cover a wide range of complexity and cost (Stone et al. 2008). To achieve ISO certification, separators must achieve a removal efficiency of ≥95% of amalgam particles in standardised tests (Stone et al. 2008). Efficiency testing shows that systems are often capable of removal efficiencies of 96 to >99% (Adegbembo et al. 2002; Fan et al. 2002; Stone 2004; Batchu et al. 2006; Muhamedagic et al. 2009; Mulligan et al. 2018); however, this can vary significantly, with removal rates as low as 26-50% reported in some systems, especially those lacking adequate maintenance (Hylander et al. 2006). Furthermore, as the certification protocol is based on a sample with a known particle distribution ranging between <100 µm and 3.15 mm, stated removal efficiencies do not include very small particulates or dissolved mercury species (Stone 2004; Hylander et al. 2006; Stone et al. 2008). For example, Letzel et al. (1999) estimated that 4-15% of amalgam particles are smaller than 10 µm, and 15-30% were <50 µm. Notably, these fractions may be more reactive to methylation and other chemical processes occurring in wastewater and receiving environments. Nonetheless, properly installed and maintained amalgam separators are considered one of the best means of reducing the amount of amalgam entering wastewater networks (Fan et al. 2002). Advanced mercury removal systems (AMRS) are commercially available, but can be expensive to purchase and maintain and labour intensive to operate (Stone et al. 2008). Additional amalgam removal techniques can include holding tanks for sedimentation tanks, or electrical or chemical separation for removal of colloidal or dissolved mercury (Fan et al. 1997; NZDA 2001).

In some jurisdictions, trade waste bylaws also require that dental technicians³⁰ must have plaster traps installed, maintained and serviced to remove plaster particulates from clinic wastewater before discharging to the municipal network.

Although not mandated, dental clinics can install silver recovery units to salvage silver from waste fixer and developer solutions for recycling.³¹ However, these are unlikely to be cost-effective for practices using small amounts of fixer, and collection of spent fixer by an approved waste handling service for off-site recovery is likely the most appropriate option (Hiltz 2007;

²⁹ Common chairside traps have pore sizes of 0.7 mm, with vacuum pump filters generally having a pore size of 0.4 mm (Fairbanks et al. 2021).

³⁰ A dental technician is a distinct role from a dentist. They design, construct and/or repair dental prosthetics, such as dentures, crowns, veneers, and implants. They work in a laboratory rather than a dental clinic or surgery, however some dental clinics provide both clinical care and in-house dental laboratories within the same facility.

³¹ <https://www.des.nh.gov/sites/g/files/ehbemt341/files/documents/2020-01/silver-recycling-disposal-dental.pdf>

Korneu et al. 2014). Unused dental film contains unreacted silver and should be returned to a supplier or approved waste carrier for recycling, as should the lead film packets they are stored in (Hiltz 2007).

5. REMOVAL OF CONTAMINANTS BY MUNICIPAL WASTEWATER TREATMENT

5.1 MUNICIPAL WASTEWATER TREATMENT PROCESSES USED IN NEW ZEALAND

A recent review of the Wastewater Sector determined that there were 318 active municipal wastewater treatment plants in Aotearoa New Zealand, with an estimated combined output of 1.5 million m³ per day (Beca et al. 2020). These plants vary significantly in terms of their size and complexity: the majority of WWTPs serve small populations (<5,000 people), with 78% of individual WWTPs serving just 6% of the connected population,³² while a small number of very large plants serve the majority of New Zealand's connected population. A variety of wastewater treatment technologies are used, ranging from aerated lagoons and facultative waste stabilisation ponds to activated sludge systems with extensive tertiary treatment processes. More than half (~64%) of New Zealand's WWTPs are simple waste-stabilisation pond systems (although an increasing number are being retrofitted with upgrades to improve nutrient removal), with approximately three quarters of the population served by a WWTP using an activated sludge-based system (Beca et al. 2020).

5.2 REMOVAL OF HEAVY METALS FROM WASTEWATER

Heavy metals are non-biodegradable, meaning that they persist within the environment; they must therefore be physically removed from the wastewater, rather than being degraded or transformed as per other types of contaminants (Cantinho et al. 2008; Du et al. 2020). Although not specifically designed for metal removal, both waste stabilisation ponds (WSPs) and activated sludge (AS) systems can achieve significant attenuation of heavy metals (Agoro et al. 2020).

Metals may enter the municipal network in different forms (dissolved, organically-complexed, precipitated, or sorbed to organic matter), which may change during treatment (Cantinho et al. 2008). In waste stabilisation and facultative ponds, heavy metal removal occurs primarily via physical sedimentation and biological adsorption. Heavy metals are often adsorbed onto organic matter and suspended sediments, and are therefore removed as sediments settle out to form sludge. Biological adsorption and accumulation within algal biomass is also an important mechanism of removing metals from wastewater; for systems with macrophytes (eg larger plants), metals may also be removed by phytofiltration. Chemical precipitation can also

³² 'Connected population' describes the New Zealand population that is connected to a reticulated wastewater network and treatment system. It does not include the ~21% of the population that is connected to an onsite wastewater management system (Beca et al. 2020).

be induced in the anaerobic zone of the pond, as metals react with sulfide to produce insoluble metal sulfide precipitates, while the high rates of photosynthesis at the surface of the ponds produces a high pH that promotes the formation of metal hydroxide precipitates, which also partition to the sludge layer. Similarly, within activated sludge systems, a portion of particulate-bound metals will be removed during primary treatment and clarification stages, with additional load removed by biosorption to microbial flocs, with subsequent removal with waste activated sludge. While it is generally accepted that most of the metals entering the WWTP will partition to sludge with only a small amount released in final effluents, relevant data as to their fate and removal efficiencies within treatment systems remains contradictory at times (Cantinho et al. 2008; Du et al. 2020) (Table 7). The removal rates vary slightly for different metals due to different affinities for particulates, and with different operational parameters (eg, hydrodynamics, solids retention, redox stratification, algal mass, number and sequence of ponds).

As the removal of heavy metals from wastewater using conventional treatment processes can be variable, and their partitioning to sludge has implications for the reuse or disposal of biosolids, a variety of advanced treatment processes are being developed for improved removal. These processes can be expensive and technically complex to implement, and are not routinely used in municipal wastewater treatment, although they may be used in specific applications where there is an explicit need to manage given contaminants (eg, in pre-treating certain industrial effluents). A brief overview of processes, specifically focused on heavy metals, is provided by Eaton (2025). Eaton (2022) also reported that where data was publicly available, heavy metal concentrations in municipal wastewater in New Zealand were all below those required by the respective discharge consents. Overall, combined removal of mercury through both amalgam separators and WWTP processes is estimated to remove >99% of the total mercury in dental clinic wastewater prior to eventual release to the environment (Mulligan et al. 2018).

Table 7. Removal efficiencies reported for heavy metals in municipal wastewaters.

Metal	Removal efficiency (%)	Reference
Hg	33-90	Carletti et al. (2008)
	57-92	Carletti et al. (2008)
Cu	73-99	Carletti et al. (2008)
	54-82	Carletti et al. (2008)
	58	Karvelas et al. (2003)
	>70	Choubert et al. (2011)
Pb	53-78	Carletti et al. (2008)
	95	Carletti et al. (2008)
	31	Karvelas et al. (2003)
	>70	Choubert et al. (2011)
Ni	72-91	Carletti et al. (2008)
	43-95	Carletti et al. (2008)
	44	Karvelas et al. (2003)
	30-70	Choubert et al. (2011)
Zn	28-93	Carletti et al. (2008)
	87-88	Carletti et al. (2008)
	43	Karvelas et al. (2003)
	30-70	Choubert et al. (2011)
Cd	25-74	Carletti et al. (2008)
	55	Karvelas et al. (2003)
	30-40	Choubert et al. (2011)
Cr	57-72	Carletti et al. (2008)
	68-85	Carletti et al. (2008)
	50	Karvelas et al. (2003)
	>70	Choubert et al. (2011)

5.3 REMOVAL OF PHARMACEUTICALS FROM WASTEWATER

Conventional wastewater treatment plants are not specifically designed to remove pharmaceuticals, thus a substantial amount of some compounds may pass through to receiving environments (Verlicchi et al. 2012; Margot et al. 2015; Peake et al. 2016; Adeleye et al. 2022). For example, a review of WWTPs in the UK found that 13% of all WWTPs had pharmaceuticals in their effluents at sufficiently high concentrations to have the potential for adverse environmental impacts (Comber et al. 2018). Sewage sludge and biosolids are also well-documented to contain a diverse array of pharmaceutical residues (Chen et al. 2013; Tran et al. 2018; Kinney and Vanden Huelvel 2020). Only two studies have assessed the removal of a limited number of pharmaceuticals from New Zealand wastewater (Gielen 2007, Kumar et al. 2019).

The fate of different pharmaceuticals through a WWTP is highly dependent on the physicochemical properties of the individual compound (eg hydrophobicity, sorption affinity, biodegradability), and the treatment processes and operational parameters within the WWTP

(eg levels and configurations of secondary or tertiary treatment, retention times) (Verlicchi et al. 2012; Luo et al. 2014; Margot et al. 2015; Vinayagam et al. 2022). The two main mechanisms of removal of pharmaceuticals in conventional wastewater treatment plants are sorption to particulate matter (ie sludge) and biological transformation. Compounds that are lipophilic, hydrophobic or positively charged tend to show higher rates of partitioning to sludge and/or floc during primary and secondary treatment (Radjenovic et al. 2009; Margot et al. 2015). However, many pharmaceuticals have a high solubility and tend to be present in the dissolved phase, requiring removal by biological transformation or degradation. Some compounds are readily degraded, while others are not; many antibiotics tend to show low rates of biodegradation due to their inherent antimicrobial properties (Loos et al. 2013). Removal efficiencies can therefore vary significantly for different pharmaceutical compounds, as well as for the same compound under different treatment conditions, with removal efficiencies spanning the full range from 0 to 100% reported. Instances of so-called 'negative removal' are reported for some compounds³³ (Wang and Wang 2016; Reyes et al. 2021; Adeleye et al. 2022). Examples of published removal rates for selected compounds reported as used in dental practice (eg, as identified in Table 1) shown in Table 8.

Waste stabilisation ponds and conventional activated sludge appear to have mixed removal efficacy, with good removal of some pharmaceutical contaminants (eg, acetaminophen, ibuprofen) and poor to negligible removal for others (eg, carbamazepine, clofibric acid). Overall, many contaminants appear to be removed by less than 50% (Margot et al. 2015). More advanced tertiary treatment such as ultrafiltration, activated carbon adsorption or advanced oxidation appear capable of removing a greater proportion of pharmaceuticals and producing a higher quality effluent compared with conventional treatments (Castiglioni et al. 2006; Gracia Lor et al. 2012; Luo et al. 2014; Oluwole et al. 2020; Vinayagam et al. 2022). However, many of these processes are not routinely used unless expressly required (eg, for certain reuse applications or protection of sensitive receiving environments) due to the establishment and/or operational costs or the potential to produce undesirable byproducts (Luo et al. 2014; Vinayagam et al. 2022; Saeed et al. 2025).

³³ Negative removal may happen when conjugated pharmaceutical metabolites present in influent wastewater are deconjugated by microorganisms during biological treatment processes, leading to a higher relative concentration of the parent compound in treated effluents (Kumar et al. 2019).

Table 8. Removal rates for select pharmaceuticals (reported as being used in dental practice) from municipal wastewater treatment plants.

Compound		Removal %	WWTP process	Reference
Analgesics/ Anti-inflammatories	Acetaminophen	86-100	CAS	Verlicchi et al. (2012)
		100	5-stage Bardenpho	Kumar et al. (2019)
	Codeine	82	CAS	Verlicchi et al. (2012)
	Diclofenac	7-65	CAS	Verlicchi et al. (2012)
		28	5-stage Bardenpho	Kumar et al. (2019)
	Ibuprofen	82-99*	CAS	Verlicchi et al. (2012)
		100	5-stage Bardenpho	Kumar et al. (2019)
		85	AS	Gielen (2007)
Antibiotics	Amoxicillin	96	CAS	Verlicchi et al. (2012)
	Azithromycin	39-74	CAS	Verlicchi et al. (2012)
	Clarithromycin	5-83	CAS	Verlicchi et al. (2012)
		90	5-stage Bardenpho	Kumar et al. (2019)
	Clindamycin	-150	CAS	Verlicchi et al. (2012)
	Erythromycin	3-35*	CAS	Verlicchi et al. (2012)
	Metronidazole	38	CAS	Verlicchi et al. (2012)
	Ofloxacin	13-84	CAS	Verlicchi et al. (2012)
	Penicillin V	60	CAS	Verlicchi et al. (2012)
Sedatives	Oxytetracycline	4	CAS	Verlicchi et al. (2012)
	Diazepam	8	CAS	Verlicchi et al. (2012)

*occasional negative removal rates were reported. CAS – conventional activated sludge.

5.4 REMOVAL DISINFECTANTS AND STERILANTS FROM WASTEWATER

Many disinfectants are disposed of through the sewer system and diluted by flushing extensively with cold water, although some first require neutralisation by mixing with another compound to ‘deactivate’ the disinfectant and render it non-hazardous.^{34, 35, 36} The fate of disinfectants and sterilants in the wastewater network will depend on their chemical structure. Oxidising compounds such as sodium hypochlorite or hydrogen peroxide will rapidly react with various organic and inorganic substances within the wastewater, decaying into stable components such as oxygen, water, acetic acid and/or chloride ions, although sodium hypochlorite may also release a small fraction of chloride to form chlorinated organic byproducts (SDA 1997; US EPA 2007). Typically, these rapid reactions mean that quantities discarded down the drain will have completely reacted prior to reaching the WWTP, although

³⁴ <https://www.civco.com/in-the-know/how-to-dispose-of-high-level-disinfectants-safely/>

³⁵ <https://www.health.vic.gov.au/infectious-diseases/cleaning-and-waste-disposal-procedures-infection-control>

³⁶ <https://www.phoenix.gov/content/dam/phoenix/waterservicessite/documents/092015.pdf>

exposure of microbial floc to very high levels can reduce biological treatment efficacy (SDA 1997; Bodik et al. 2008; Chen et al. 2021).

For other disinfectants, glutaraldehyde degrades readily in water under both aerobic and anaerobic conditions so that significant degradation is expected during passage through the wastewater network and treatment system, while reaction with proteins present in wastewater will further remove significant amounts of glutaraldehyde from the waste stream. Any residual glutaraldehyde present will have been significantly diluted by the wider municipal network, and may undergo further biodegradation at the WWTP (Leung 2001; OECD 2001). Studies suggest that the broad-spectrum antiseptic triclosan is routinely detected in municipal wastewater (reflecting its broad use as an antiseptic in many consumer products) but tends to be highly removed by wastewater treatment (ie, >95%) (Thompson et al. 2005; Heidler et al. 2006; Lozano et al. 2013). However, the inherent biocidal activity of disinfectants and sterilants means they may be toxic to the microorganisms in secondary treatment and activated sludge processes, reducing the ability of organisms to biodegrade these compounds (OSHA 2006); for example, studies suggest that sewage microorganisms may become inhibited at glutaraldehyde concentrations 25-80 mg/L, but are otherwise capable of degrading glutaraldehyde from wastewater (OECD 2001; Laopaiboon et al. 2003).

5.5 REMOVAL OF PATHOGENS FROM WASTEWATER

Although the main role of the primary and secondary treatment components at the WWTP is to reduce solids and organic material from influent wastewater, these processes also facilitate the removal of a significant portion of the microbiological load (Loughran et al. 2010).

Conventional wastewater treatment often reduces enteric microbial load by 90-99.9% (Gerardi and Zimmerman 2005; Flapper et al. 2012; Liu et al. 2015). There are several possible fates for microbial pathogens that enter the wastewater treatment system: they may be removed (eg, by sorption to particulates and settling to sludge), inactivated (eg, weakened and rendered non-infectious by conditions within the treatment system), destroyed (ie, killed by conditions in the treatment system, such as oxidative or thermal stress), consumed by other microorganisms within the treatment system (eg by algae or protozoa), or they may persist and leave the treatment plant in final effluents (Gerardi and Zimmerman 2005). Pathogen removal in municipal wastewater treatment systems is therefore achieved through a combination of physical separation, biological interactions, and environmental inactivation processes.³⁷ Pathogens that leave the WWTP in a viable or inactivated state may be of concern, since there is potential for subsequent public exposure in the receiving environment (Gerardi and Zimmerman 2005).

Considering the very low loading of dental pathogens that are likely to be introduced into the wastewater system and the degree of dilution occurring at the WWTPs, removal of pathogens at this efficiency is likely to render their concentrations well below levels of concern – particularly

³⁷ https://water360.com.au/wp-content/uploads/2022/10/72m---7104-quantification-of-pathogen-removal-in-activated-sludge-plant_final_report_.pdf

in the context of the wide variety and high concentrations of other opportunistic and pathogenic microorganisms that are known to be present in sewage and wastewater (WHO 2021a).

6. CONCLUSIONS

Dental clinic wastewater is a heterogenous mixture that may contain water, saliva, blood, coarse and fine tooth and restorative ('filling') material particulates, soft tissues, radiographic solutions, disinfectants and cleaning agents, pharmaceuticals, mouthwashes and gypsum plasters. In particular, mercury associated with amalgam has been the primary contaminants of concern in dental clinic wastewaters; historically, dental clinics have been considered one of the largest contributors of mercury to municipal WWTPs. International data shows that mercury concentrations in dental clinic wastewater are hugely variable, ranging from tens of µg/L to tens or even hundreds of mg/L, especially in settings without amalgam separators. Silver associated with amalgam and radiographic fixer and developer solutions, and lead associated with protective aprons and collars during x-ray, have also been key contaminants of concern. However, with the use of amalgam restorations being phased out in line with the Minamata Convention and related initiatives to reduce mercury use globally, mercury (and other amalgam-associated heavy metals) in dental clinic wastewater is expected to decline, although inputs may continue in the near-term as existing amalgam restorations are removed, and amalgam sediments are displaced from vacuum lines, pipes and sedimentation tanks. Furthermore, with the transition of the majority of New Zealand dental clinics to digital radiographic technologies which negate the need for film, chemical developers or lead protective equipment, the presence of silver and lead in clinic wastewaters are expected to decline too.

Although the presence of other contaminants such as pharmaceuticals, disinfectants and emerging restorative materials in clinic wastewater is often referred to, there is almost no quantitative data on their concentration in the international literature. The presence of resin-based composite nano- and microparticles is highlighted in several papers as an area requiring further research to better understand the presence, fate and impacts of these emerging contaminants.

There was no publicly available information on the composition or characteristics of dental clinic wastewater in New Zealand. After reviewing the by-laws of numerous TAs around New Zealand, and in consulting with the TWCO group, it is apparent that many councils require dental clinics to hold a consent to discharge to the municipal network, and many TAs require clinics to install and maintain an ISO-certified amalgam separator capable of removing >95% of amalgam; however, these were not universal requirements. In some parts of New Zealand, dental technicians may be required to install a plaster trap. The majority of trade waste officers spoken to considered dental clinics to be low risk dischargers because of their low discharge volumes, particularly where there is an amalgam trap installed, and sampling of effluents was not prioritised against larger and/or higher risk trade waste dischargers. One TA was able to provide the results of sampling from a dental clinic, which showed mercury and silver concentrations were well below respective discharge limits of 0.05 and 2.0 g/m³ (or mg/L), respectively.

For contaminants that reach the municipal wastewater system, heavy metals will be largely removed at the WWTP, primarily through their affinity for organic matter and tendency to partition to sludge, although dissolved species may pass through treatment processes and be discharged to the environment. The fate of organic chemical contaminants such as pharmaceutical and disinfectants is highly dependent on their chemical structure and the operational parameters of the WWTP – some will be rapidly degraded and show high rates of removal, while others are persistent and show poor removal. The fate of emerging contaminants, especially micro- and nanoparticles from new restorative materials, is unknown.

Overall, data on the composition of dental clinic wastewater remains a data gap, especially for contaminants other than mercury. However, individual dental clinics tend to produce small volumes of wastewater, likely with small contaminant loads, especially when compared to other healthcare facilities (eg hospitals) or industrial entities (Muhamedagic et al. 2009; Koneru et al. 2014). Moreover, the transition to non-mercury restorative materials and digital radiography, and the requirement of many TAs for clinics to install amalgam separators, will significantly reduce the load of mercury and silver, the two contaminants that have traditionally been of greatest concern in dental clinic effluents.

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