

Trade Effluent Hazard Profile: Veterinary 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 may contain contaminants that pose additional risks to human and/or environmental health or to 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 veterinary clinics.

Veterinary clinic and veterinary hospital wastewater is produced through various clinical and surgical procedures, and routine clinic activities such as cleaning and infection prevention protocols. Clinic wastewater is a heterogeneous mixture that, depending on the size of the clinic and the specific services offered, could potentially contain water, animal body fluids or tissues, urine and faecal material, hair/fur, microorganisms, pharmaceuticals, disinfectants and cleaning agents, radiographic solutions, histology stains, laboratory chemicals or radioisotopes. However, quantitative data on the concentrations of these contaminants in wastewater from companion and non-production animal veterinary clinics is extremely limited; the literature concerning veterinary wastewater or effluents focuses almost exclusively on the use of pharmaceuticals (especially antibiotics) or presence of antimicrobial resistance (AMR) genes in agricultural contexts, in intensive agriculture settings. Nonetheless, a small number of studies have reported the detection of antibiotics and antimicrobial resistance genes in veterinary hospital and small animal clinic effluents in Europe and Asia. The potential presence of zoonotic pathogens in wastewater can be implied by their detection in surface samples from veterinary rehabilitation clinics and in animal clinical samples, and established transmission from pets. The majority, if not all, of the disinfectant load present in trade waste is expected to be completely consumed (ie, have reacted with organic material in the wastewater) or degraded prior to reaching the wastewater treatment plant (WWTP). Recent transitions to digital technologies (eg, for radiography, thermometers) should reduce the potential for contaminants such as heavy metals and radiographic solutions to enter wastewater streams. Effective observation of best practice and/or regulation regarding radioisotopes should prevent their entry into wastewater, however the specific isotopes used in veterinary medicine should rapidly decay and are unlikely to present a human health issue if they were to enter the municipal network. Specialist services such as radiation oncology or advanced histology or pathology are often outsourced to specialist facilities (which may include human health facilities).

No publicly available information on the composition or characteristics of veterinary clinic wastewater in New Zealand was identified. After reviewing the trade waste bylaws of multiple territorial authorities (TAs) around New Zealand and consulting with the Trade Waste and Compliance Officers (TWCO) group, it appears that a large proportion of TAs require veterinary clinics to hold a consent to discharge clinic wastewater to the municipal network. Many of the compliance officers indicated that veterinary clinics in their jurisdiction are required to install screens or traps on sinks and floor drains to prevent hair, fur and other solid materials entering

the wastewater system, since these may cause blockages or damage network infrastructure such as pumps. No other pre-treatment is required. Few of the specific contaminant groups identified in this report are regulated: some TA bylaws stipulate limits for pharmaceutical compounds or outright prohibit their discharge to wastewater, while others do not regulate them. Cytotoxic pharmaceuticals and their associated wastes are regulated under the Healthcare Waste Standard (NZS 4304:2002) as requiring segregation and disposal by incineration unless expressly permitted for discharge to wastewater by the relevant TA; however no examples of such permission were identified. The overall consensus among the TWCO group was that veterinary clinics are considered to be low risk dischargers, and no TA reported undertaking sampling of veterinary clinic effluents.

For contaminants that reach the municipal wastewater system, pathogens should be largely removed at the wastewater treatment plant, through a combination of physical removal, inactivation and destruction. Waste stabilisation ponds and conventional activated sludge processes are reported to remove 90 to 99.99% of microorganisms entering the treatment plant, with tertiary treatment such as UV disinfection included in many activated sludge-based WWTPs for additional pathogen removal. Pharmaceuticals, chemical sterilants, disinfectants and other organic micropollutants exhibit a wide range of fates within the WWTP, being highly influenced by both their individual chemical structure and the operational parameters of the WWTP; some are rapidly degraded and show high rates of removal, while others are highly persistent and poorly removed. While the heavy metal load of veterinary clinic wastewater is expected to be low, these tend to show significant removal at the WWTP, primarily through affinity for organic matter and partitioning to sludge.

Overall, data on the composition of veterinary clinic wastewater remains a data gap. However, individual clinics tend to produce relatively small volumes of wastewater, likely with small contaminant loads, especially when compared to other healthcare facilities (eg, human hospitals) or industrial entities. Clinic wastewater is then significantly diluted upon entering the municipal wastewater network, with some contaminants such as pathogens and heavy metals showing relatively high rates of removal at the WWTP. Whilst the use of pharmaceuticals in companion and non-production animal healthcare is relatively low and many of those prescribed are used outside of the clinic (eg, at home), pharmaceutical stewardship – especially for antibiotics – is an important focal point for the profession in helping to manage the development and spread of antimicrobial resistance, since wastewater is a known hotspot for AMR development.

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 disposed of appropriately. 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 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/District/Unitary Councils, Health Protection Officers or others involved in the management of wastewater, to understand whether certain industries are likely to contribute significant loads of contaminants of concern to municipal

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.

wastewater networks, and to gauge the effectiveness of pre-treatment and/or wastewater treatment processes in removing those contaminants. This information will help to identify higher-risk dischargers, and where necessary, possible consent conditions (or similar) that could 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 for managing wastewaters with respect to the contaminants identified above (eg, discharge consent conditions, requirements for pre-treatment)?
- 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 **veterinary clinics**. For the purposes of this report, this includes clinics treating domestic companion animals, but does not include agricultural or animal production settings.

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 veterinary 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 in detail hazardous or controlled wastes that may be generated by veterinary clinics but that are not disposed of via the wastewater system, such as sharps or blood-contaminated dressings.

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

2.1 OVERVIEW OF CONTAMINANTS OF CONCERN IN VETERINARY CLINIC WASTEWATER

Veterinary clinics and hospitals can generate large amounts of medical waste, including solid wastes (gauze, dressings, latex, plastic tubing) potentially contaminated with biological fluids, sharps and needles, anatomical waste, chemical waste, pharmaceutical or cytotoxic wastes, and other types of potentially hazardous waste^{3,4} (Stull et al. 2018). In New Zealand, the Healthcare Standard NZS 4304:2002 (Standards New Zealand 2002) describes the ways in which human and animal 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 system; this can include hazardous or controlled wastes that have been appropriately pre-treated and thus recategorized as a lower risk or non-hazardous waste category. However, before wastes are classified as appropriate for disposal to sewer, they must also meet the requirements of the relevant territorial authority (eg, as specified in their Trade Waste Bylaw) (Standards New Zealand 2002).

Veterinary clinics provide a wide range of medical care for animals, including preventative care and general health consultations, emergency medicine, surgical procedures (including under sedation or general anaesthesia), dental care, radiography and imaging, desexing (spay/neuter), vaccinations, microchipping, and palliative or end-of-life care. Smaller clinics may offer a more limited range of services, with larger clinics and veterinary hospitals providing a wider range of advanced treatments, often with specialist facilities, in-house laboratories and in-patient care or boarding. Urban veterinary clinics typically provide care for a range of domestic companion animals, while rural centres often offer care for equine and farm animals as well.

Veterinary clinic wastewater may be produced through various clinical activities and practices, including sterilization and infection prevention, routine and post-procedural cleaning activities, wash-down of cages/kennels, and disposal of liquid wastes down sinks and drains. Liquids being discharged to the municipal wastewater network may therefore contain a heterogeneous mixture of liquids and solids, including water, biological fluids and animal waste (blood, saliva, urine, faeces), pharmaceuticals (including antimicrobial, cytotoxic and radioactive compounds), disinfectants and cleaning agents, microorganisms, soft tissues from surgery or necropsy, tooth or bone fragments, radiographic solutions (x-ray developers and fixers) or

³ <https://www.stericycle.co.uk/en-gb/resource-centre/blog/what-is-veterinary-waste>

⁴ <https://nzva.org.nz/home/news/waste-not/>

tissue fixatives and cytology stains.⁵ Some rural clinics may discharge wastewater to an onsite wastewater management system, rather than the municipal wastewater network.

2.2 ZOONOTIC PATHOGENS

Animals can be carriers of a diverse array of microorganisms, including bacteria, viruses, protozoa and fungi, and larger internal and external parasites such as fleas or worms. These organisms include commensal microorganisms that co-exist with the animal without causing harm, and pathogens that cause illness or disease. Depending on the organism, it may be present in or on various body surfaces, tissues, body fluids and wastes; as a result, organisms may be readily transferred to wastewater during the direct disposal of body fluids, irrigation solutions, urine, faeces or vomit to the wastewater network; the wash-down of examination and surgical tables, cages/kennels, food bowls, litter trays or other surfaces contaminated by animal waste or body fluids; the laundering of contaminated bedding or staff personal protective equipment (eg, scrubs or gowns); or staff handwashing following contact with an animal or contaminated material (Stull et al. 2018). Although data on the presence of pathogens in veterinary clinic wastewater is limited, studies showing the contamination of surfaces within veterinary rehabilitation facilities (Spratt et al. 2024), documenting the presence of hospital-acquired infections in both animal patients and veterinary clinic staff (Epp and Waldner 2012; Traverse and Aceto 2014) or describing the culture and identification of pathogens from animal clinical samples (Chen et al. 2025; Berry et al. 2026) highlight the presence of these organisms within the veterinary clinic, and thus their potential to enter wastewater.

Notably, not all organisms that cause infections and/or illness in animals present a risk to people (ie, some are non-zoonotic). Nonetheless, a number of zoonotic pathogens have the potential to spread from companion or other non-production animals to humans through contact with infected animals or their medical waste (Epp and Waldner et al. 2012; Sykes and Weese 2013; Traverse and Aceto 2014; Caddey et al. 2025). The potential presence of these pathogens in wastewater will depend on their presence in the animals being attended to in the clinic (ie, an infected animal being present), and the likelihood of the relevant body tissue/fluid entering wastewater. In addition, the route or mode of disease transmission is an important consideration as to the potential risk that the presence of the pathogen in wastewater may pose. For example, zoonotic pathogens that are transmitted via direct contact between broken skin or mucous membranes and contaminated body tissues or fluids (eg, rabies virus, *Bartonella henselae* that causes cat scratch disease), transmitted through a vector (eg, *Borrelia* spp. that causes Lyme disease), transmitted via inhalation (eg, *Coxiella burnetii* that causes Q fever, *Chlamydophila psittaci* that causes psittacosis⁶) or that are unlikely to survive in the wastewater system (eg, fleas or lice) are likely to present little risk to people via wastewater. In contrast, enteric pathogens transmitted via the faecal-oral route (eg, *Campylobacter*, *Giardia*),

⁵ <https://skagitcounty.net/HealthEnvironmental/Documents/envirostars/Veterinary%20Clinics-%20Hazardous%20Waste.pdf>

⁶ <https://www.healthnz.govt.nz/health-topics/conditions-treatments/infectious-diseases/psittacosis>

which are shed in high loads in faeces and may exhibit greater survival in wastewater, have the potential to cause human infection if released to the environment in a way where subsequent ingestion occurs (eg, through ingestion of contaminated food/water, or contact recreation in contaminated waterways).

Examples of animal pathogens associated with veterinary clinics (including companion and small animal clinics but excluding agricultural and animal production settings) that are known to cause zoonotic infection, and that may have potential to be transmitted via wastewater are shown in Table 1. Pathogens that are of concern internationally but that are not present in New Zealand⁷ (eg, hookworms,⁸ *Borrelia* spp,⁹ *Brucella* spp.,¹⁰ rabies virus,¹¹ *C. burnetii*,¹² *Francisella tularensis*,¹³ *Sporothrix schenckii*¹⁴) have been excluded.

2.2.1 Health risks from pathogens

Different pathogens can cause different symptoms and syndromes. A summary of the human health effects caused by the pathogens identified above as being capable of zoonotic infection is provided in Table 1. Notably, municipal wastewater is itself a significant source of microorganisms, a number of which are associated with mild to severe human illness¹⁵ (WHO 2022, 2025). The human health risk posed by pathogens from veterinary clinic wastewater relative to the overall risk from pathogens in the municipal wastewater system is therefore likely to be very low.

⁷ Cases may be reported in travellers having acquired infection overseas.

⁸ <https://healthify.nz/health-a-z/w/worms-in-humans>

⁹ <https://www.healthnz.govt.nz/health-topics/keeping-healthy/healthy-homes-environments/insect-bites-and-pest-control/tick-bites-in-nz>

¹⁰ <https://intel.cph.co.nz/media/47264/brucellosis-protocol.pdf>

¹¹ <https://www.healthnz.govt.nz/health-professionals/guidance-standards/topic/conditions/communicable-disease-control-manual/rabies-and-other-lyssaviruses>

¹² <https://www.healthnz.govt.nz/health-professionals/guidance-standards/topic/conditions/communicable-disease-control-manual/q-fever>

¹³ <https://www.mpi.govt.nz/dmsdocument/40064-surveillance-magazine-vol-47-no-1-march-2020>

¹⁴ <https://www.mpi.govt.nz/dmsdocument/10832/direct>

¹⁵ <https://www.who.int/teams/environment-climate-change-and-health/water-sanitation-and-health/burden-of-disease/water-sanitation-hygiene-microbial-pathogens>

Table 1. Summary of the human health effects caused by different zoonotic pathogens that may be present in veterinary clinic wastewater. Compiled from Epp and Walder 2012; Sykes and Wilkes, 2013; WHO 2018, 2022.

Pathogen	Syndrome/symptoms of human infection
Bacteria	
<i>Campylobacter jejuni</i>	Campylobacteriosis – diarrhoea, abdominal pain, fever, muscle pain.
<i>Clostridium difficile</i>	‘C. diff’ infection – diarrhoea, abdominal pain, colitis.
<i>Leptospira</i> spp.	Leptospirosis – fever, body aches, headache, vomiting or nausea, diarrhoea.
<i>Listeria monocytogenes</i>	Listeriosis – diarrhoea, nausea, vomiting, muscle aches, in severe cases neurological symptoms, sepsis. Can cause severe complications in pregnant women or immunocompromised individuals.
<i>Mycobacterium bovis</i> , <i>Mycobacterium tuberculosis</i>	Tuberculosis – fever, chills, cough, fatigue, weight loss.
<i>Pasteurella multocida</i>	Pasteurellosis - wound infection, lymphangitis, fever, vomiting. Rarely sepsis, pneumonia, meningitis.
<i>Salmonella</i> spp.	Salmonellosis – diarrhoea (sometimes bloody), fever, abdominal cramps, nausea.
<i>Staphylococcus aureus</i> , <i>Staphylococcus pseudintermedius</i>	Skin infection, abscess, pyoderma. MRSA and MRSP can cause infections that are hard to treat and can become life-threatening.
Parasites	
<i>Cryptosporidium</i> spp.	Cryptosporidiosis – diarrhoea, abdominal pain.
<i>Giardia</i> spp.	Giardiasis – diarrhoea, bloating, abdominal cramps, fatigue
<i>Toxoplasma gondii</i>	Toxoplasmosis – flu-like symptoms or asymptomatic, however, can cause serious complications in pregnant women or immunocompromised individuals
<i>Toxocara canis</i> , <i>Toxocara cati</i>	Toxocariasis. Mostly asymptomatic, but can cause visceral larval migrans (non-specific symptoms including fever, myalgia, weight loss).
Fungi	
<i>Microsporium</i> spp	Dermatophytosis (skin, nail infection), ringworm
<i>Trichophyton</i> spp.	Dermatophytosis (skin, nail infection), ringworm

MRSA – methicillin-resistant *Staphylococcus aureus*; MRSP – methicillin-resistant *Staphylococcus pseudintermedius*

2.3 PHARMACEUTICALS

Similarly to human healthcare, veterinary practice relies heavily on a diverse array of pharmaceutical compounds to prevent, diagnose, treat or manage disease or adverse health outcomes (Saeed et al. 2024). In particular, the increasing demand for animal food products and the search for efficiencies in livestock production and animal welfare have led to significant increases in the use of pharmaceuticals in veterinary care, especially of antibiotics (Delgado et al. 2023; Albarano et al. 2024). Much of the literature on veterinary pharmaceuticals focuses on this agricultural and food production context, which accounts for the vast majority of pharmaceutical use (Prescott 2017; Ministry for Primary Industries 2025). For example, companion and non-production animals account for just 3-5% of total antibiotic use in animals in New Zealand (Pattis et al. 2022; Ministry for Primary Industries 2025). Nonetheless, scientific advancement and shifting economic conditions and social norms increasingly see households spend money on healthcare for their domestic and companion animals, including pharmaceuticals (Vatovec et al. 2021). Most of the available data on the use of pharmaceuticals in companion and non-production animals also focuses on antimicrobials. Within this group, patterns of use tend to mirror those in human medicine (Prescott 2017), with the most commonly used compounds including amoxicillin-clavulanic acid, cephalexin and enrofloxacin, although their overall usage is very low compared with human consumption (Pleydell et al. 2012; Pattis et al. 2022; Caddey et al. 2025). In addition to antibiotics, an incredibly broad range of other pharmaceutical compounds, addressing a wide variety of health concerns, are used in veterinary care; over 5,000 prescription and over-the-counter medications or vaccines are approved for veterinary use (Lust et al. 2011). Examples of some of the different types of compounds used are listed in Table 2.

Studies have shown that the administered pharmaceutical dose is seldom entirely metabolised within the body, and that animals may excrete as much as 90% of the initial dose in their urine and faeces, depending on the compound¹⁶ (Delgado et al. 2023). These unmetabolised fractions – together with their metabolites, which may also be bioactive – may therefore be released to veterinary clinic wastewaters when hosing out the kennels or cages of animals admitted for inpatient care, washing down tables or surfaces where animals have soiled, or otherwise disposing of bodily wastes.¹⁷ Pharmaceuticals may also enter veterinary clinic wastewater during the disposal of excess, expired or unwanted medications down the sink, the rinsing/cleaning of instruments used to administer pharmaceuticals, or as wash-off of topical formats such as local numbing agents or medicated shampoos and bathing solutions (Lam et al. 2018). For example, the parasitocides fipronil and imidacloprid which are used in topical tick and flea treatments, have been shown to enter household wastewater through post-treatment handwashing and animal bathing (Teerlink et al 2017; Perkins et al. 2024), suggesting that veterinary clinics may also be a source of these widely-used pharmaceuticals.

¹⁶ <https://www.msddvetmanual.com/pharmacology/pharmacology-introduction/disposition-and-fate-of-drugs>

¹⁷ A significant proportion of pharmaceuticals prescribed in veterinary care will be administered by the pet-owner at home, and therefore not enter clinic wastewater.

Table 2. Examples of different pharmaceuticals used in veterinary medicine. Compiled from the World Small Animal Veterinary Association (WSAVA) Therapeutics Guidelines Group list of essential medicines for cats and dogs (Steagall et al. 2020).

Pharmaceutical class/ Target body system	Example pharmaceuticals
Anaesthetics, analgesics, sedatives	Xylazine, medetomidine or dexmedetomidine, lignocaine, midazolam, diazepam, propofol, ketamine, isoflurane, sevoflurane, paracetamol
Other emergency drugs	Adrenaline/epinephrine, atropine, mannitol, dextrose, heparin, vitamin K1, antihistamines, crystalloid solutions and fluids
Antimicrobials (antibacterials, antivirals, antifungals, antiparasitic)	Amoxicillin, amoxicillin-clavulanic acid, cephalexin, cefadroxil, clindamycin, cefazolin,, ampicillin, doxycycline, sulfadiazine, trimethoprim, erythromycin, metronidazole, enrofloxacin, alfoxolaner, fluralaner, imidacloprid, nitenpyram, dinofuran, fipronil, pyrethrum, permethrin, deltamethrin, ivermectin, selamectin, praziquantel, febantel, fenbendazole, flubendazole, mebendazole, oxibendazole, pyrimidine nucleotides, famciclovir, zidovudine, fusidic acid, florfenicol, gentamicin, neomycin, enrofloxacin, marbofloxacin, polymyxin B, chlorhexidine, povidone-iodine, miconazole, econazole, clotrimazole, terbinafine
Cardiorespiratory and renal systems	Furosemide, torsemide, pimobendane, amlodipine, enalapril, benazepril, catoprilil, spironolactone, propranolol, atenolol, salbutamol, fluticasone
Endocrinology	Insulin, prednisolone, deoxycorticosterone pivalate, methimazole, levothyroxine, desmopressin acetate
Euthanasia	Thiopental, pentobarbital, potassium chloride
Gastrointestinal system	Ranitidine, sucralfate, omeprazole, apomorphine, xylazine, metoclopramide, ondansetron, maropitant, activated charcoal
Immunomodulatory	Prednisone, prednisolone, azathioprine, cyclosporine/cyclosporin, tacrolimus, oclacitinib
Neurology	Dexamethasone, prednisolone, phenobarbital/phenobarbitone, thiamine, mannitol, dextrose, imepitoin, potassium bromide, levetiracetam, gabapentin
Oncology	Cyclophosphamide, chlorambucil, lomustine, melphalan, doxorubicin, vincristine, vinblastine, carboplatin, prednisolone, toceranib, masitinib, imatinib,
Ophthalmology	Dexamethasone phosphate, prednisolone acetate, flurbiprofen, diclofenac, ketorolac, cyclosporine, tacrolimus, tropicamide, atropine, proparacaine, tetracaine, latanoprost, dorzolamide
Reproductive systems	Deslorelin, aglepristone, cabergoline, oxytocin, osaterone acetate, delmadinone acetate

Table 2 continued.

Pharmaceutical class/ Target body system	Example pharmaceuticals
Vaccines	Vaccinations for: canine distemper virus (CDV), canine adenovirus (CAV), canine parvovirus-2 (CPV), feline parvovirus (FPV), feline herpesvirus-1 (FHV), feline calicivirus (FCV), Feline immunodeficiency virus (FIV), feline leukaemia virus.

Note: This table is not intended to be a comprehensive list of all pharmaceuticals which may be administered by a veterinarian or to reflect commonly used compounds. It may not reflect prescribing patterns in New Zealand, and focuses on cats and dogs, meaning that medications indicated for the treatment of other small or companion animals (especially vaccines) may not be included. Pharmaceutical class/target body systems are indicative only; numerous pharmaceuticals can be used in different ways across different body systems, depending on the clinical presentation and requirement of the patient.

2.3.1 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 environmental 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). Nonetheless, pharmaceuticals do have the potential to cause side effects or adverse health outcomes, 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. 2019; Sengar and Vijayanadan 2022). Further, despite the cross-over with many pharmaceuticals being used in both human and veterinary medicine^{18,19} (Promariya et al. 2025), some veterinary pharmaceuticals may not be intended for human consumption, and may pose mild to serious risks to human health upon exposure by ingestion or injection (Lust et al. 2018). In addition, specific classes of pharmaceuticals, such as cytotoxic drugs used in chemotherapy, are inherently highly toxic (see below). As environmental pharmaceutical concentrations are typically orders of magnitude below those considered a therapeutic dose, the risk from environmental exposure to pharmaceuticals, while not zero, is likely to be very low for most individuals (Cressey 2018; Coxon 2024).

¹⁸ <https://hub.vetcouncil.org.nz/non-consented-human-medicines-used-by-veterinarians>

¹⁹ <https://www.mpi.govt.nz/dmsdocument/22117-ACVM-News-and-views-Feb-2014>

Comment on antimicrobial resistance

Perhaps the most significant human health concern regarding pharmaceuticals in veterinary clinic wastewaters is related to the spread of antimicrobial resistance (AMR), rather than direct pharmaceutical toxicity (Kumar et al. 2010; WHO et al. 2020; Frascaroli et al. 2021; Sengar and Vijayanandan 2022). Antimicrobial resistance occurs when bacteria, viruses, fungi and parasites evolve so that they are no longer inhibited or killed by antimicrobial medications. The misuse and overuse of antimicrobials in humans, animals and plants are primary drivers of the development of AMR; selective pressures imposed on microorganisms in environments where there is constant contact between microorganisms and antimicrobial compounds (including in wastewater) promote the development and spread of AMR genes.^{20,21} The World Health Organization (WHO) considers AMR to be one of the top global public health threats²² as it undermines the efficacy of antimicrobial medications, making infections more difficult or impossible to treat, and increasing the risks of disease spread, severe illness, disability and mortality (Frascaroli et al. 2021).

The development of AMR in companion and non-production animal veterinary settings presents a risk to animal welfare through the potential for hospital-acquired infections that are difficult to manage or treat. It also presents a risk to human health both through the direct transmission of resistant organisms to humans (ie, as zoonoses) or through indirect transmission of resistance genes between bacterial species, so that human pathogens acquire resistance (ie, through horizontal gene transfer).²³ Antimicrobial-resistant bacteria and antimicrobial resistance genes (ARG) are increasingly being recognised as emerging contaminants in veterinary medicine and have been detected in veterinary hospital wastewater. This includes methicillin-resistant *Staphylococcus aureus* (MRSA), extended spectrum β -lactamase-producing *Escherichia coli*, and multi-drug resistant *Salmonella* spp., *Acinetobacter* spp., *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Enterobacter* spp. and enterococci (Stull et al. 2018; Spratt et al. 2024; Nadas et al. 2025; Berry et al. 2026), as well as the ARGs *ermB* (resistance to macrolides), *tetW* (resistance to tetracyclines), *blaTEM* (resistance to β -lactams), *sulI* (resistance to sulfonamides) and *qnrS* (reduced susceptibility to fluoroquinolones) (Lucas et al. 2016). Many guidelines and stewardship programmes are being initiated to respond to the threat of AMR, including the New Zealand Antimicrobial Resistance Action Plan,²⁴ New Zealand Veterinary Council Antimicrobial Stewardship Strategy²⁵ and New Zealand Veterinary Association guidelines for animal-specific antimicrobial prescribing.^{26 27 28}

²⁰ <https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance>

²¹ <https://www.mpi.govt.nz/dmsdocument/60892-Antimicrobial-resistance-AMR-Information-for-veterinarians>

²² <https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance>

²³ <https://www.mpi.govt.nz/dmsdocument/60892-Antimicrobial-resistance-AMR-Information-for-veterinarians>

²⁴ <https://www.health.govt.nz/system/files/2017-08/new-zealand-antimicrobial-resistance-action-plan.pdf>

²⁵ <https://vetcouncil.org.nz/Web/Web/3.About/Current%20Projects/AMR-Strategy.aspx>

²⁶ https://www.amrvetcollective.com/assets/guidelines/guide_comp.pdf

²⁷ https://www.amrvetcollective.com/assets/guidelines/AMR_Guide_Pigs.pdf

²⁸ <https://www.amrvetcollective.com/home/guidelines/>

Comment on cytotoxic pharmaceuticals

Cytotoxic pharmaceuticals (also known as chemotherapy drugs) are used in the treatment of cancer, and their use in veterinary practice is increasing (AVA 2021; Northover et al. 2025). The nature of these drugs – in that they are highly toxic, and intended to target and destroy cancerous cells – means they also affect healthy cells, and therefore present a significant health risk to people who may be exposed to them²⁹ (Smith et al. 2018; VCI 2025). They are carcinogenic, mutagenic, teratogenic and abortifacient, and clinical outcomes can include low cell counts, contact dermatitis, liver damage, infertility, miscarriage and congenital malformation³⁰ (Smith et al. 2018). Medications that are frequently used in veterinary oncology include doxorubicin, chlorambucil, vincristine and cyclophosphamide, and may be administered through intravenous injection or orally in pills (Biller et al. 2016; Northover et al. 2025; VCI 2025). Treatment is usually performed either as a day-clinic or outpatient procedure.

Cytotoxic residues may be present in animal faeces, urine and other bodily fluids for a number of days following administration, and may enter veterinary clinic wastewater if these are disposed of down drains or toilets when animals are admitted for in-patient care or present at the clinic for treatment of reactions or adverse events (Smith et al. 2018; VCI 2025). Cleaning of drug preparation or administration facilities or laundering bedding may also present minor sources.³¹ Clinics can order pre-filled syringes of chemotherapeutics for specific patients, reducing the risk of spills associated with storage or titration (Northover et al. 2025). Under the New Zealand Healthcare Standard, all materials contaminated with cytotoxic waste must be segregated and disposed of by incineration; liquid cytotoxic waste (eg, excess or unwanted medication) must not be disposed of to sewer unless expressly permitted by the local territorial authority. A recent survey of 164 New Zealand veterinarians reported that while 55% of the clinics at which they worked had administered chemotherapy in the past 12 months, only 5% had done so in the past week, and a further 5% in the past month. This suggests that the majority of veterinary clinics administer chemotherapy sporadically, and that only a small number are administering chemotherapy on a regular basis (Northover et al. 2025). The load of cytotoxic pharmaceuticals entering municipal wastewater via veterinary clinic effluents is therefore likely to be very low.

2.4 STERILANTS AND DISINFECTANTS

Animals treated within veterinary clinics may carry infectious (or opportunistic) pathogens that can easily spread to other animals or to people; effective cleaning, disinfection and sterilisation procedures are therefore essential elements of infection prevention and control within the clinic (Sykes and Weese 2013; Anderson et al. 2020). 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

²⁹ <https://www.cdc.gov/niosh/healthcare/hazardous-drugs/antineoplastic-agents.html>

³⁰ <https://www.ava.com.au/policy/guidelines-cytotoxic-drug-safety>

³¹ <https://www.ava.com.au/policy/guidelines-cytotoxic-drug-safety>

reduces the number microorganisms on a surface to a 'safe level'. General purpose cleaning agents (eg, detergents) must be used to remove organic matter and debris prior to disinfection or sterilisation (Sykes and Weese 2013; Anderson et al. 2020). Chemical sterilants and disinfectants are essential tools for controlling microbial contamination, especially for heat-sensitive items and surfaces where heat (eg, autoclaving/steam sterilising) or ethylene oxide gas sterilisation is not practical or appropriate (Sykes and Weese 2013). A variety of factors influence the selection of disinfectants and sterilants, including the item or surface type and the required level of disinfection or sterilisation; for example, surgical equipment requires much higher levels of disinfection or sterility than is required for examination tables, kennels/cages or food and water bowls, although these still require regular disinfection (Anderson et al. 2020). Chemical sterilants, disinfectants and cleaning solutions may enter wastewater streams through the cleaning and sterilisation of instruments, equipment and surfaces, hand hygiene, and the disposal of spent solutions down sinks or drains.

Among the most commonly-used chemical sterilants and disinfectants³² are glutaraldehyde, ortho-phthalaldehyde (OPA), potassium peroxymonosulfate, sodium hypochlorite, quaternary ammonium compounds, hydrogen peroxide, peracetic acid and phenolics (eg, ortho-phenylphenol) (Sykes and Weese 2013; Anderson et al. 2020; CDC 2024). Alcohol-based disinfectants (ethanol or isopropyl at 60-90%), iodophors and chlorhexidine are commonly used as antiseptics (Sykes and Weese 2013).

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.³³ Although the total volume of disinfectant-derived contaminants from veterinary 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.

2.4.1 Health effects of chemical sterilants and disinfectants

The most common health effects associated with clinical disinfectants and sterilants, including glutaraldehyde, hydrogen peroxide, peracetic acid and sodium hypochlorite, is that they are corrosive and highly irritating to the skin, eyes and mucosal membranes^{34,35} (ISSA 2014). While

³² Some disinfectants can be used as sterilants when used at high enough concentrations and for sufficiently long contact times, including glutaraldehyde, OPA, hydrogen peroxide and peracetic acid; often they may be used in combination. Items must be repeatedly rinsed with sterile water once sterilisation is complete.

³³ <https://www.civco.com/in-the-know/how-to-dispose-of-high-level-disinfectants-safely/>

³⁴ https://www.nj.gov/health/workplacehealthandsafety/occupational-health-surveillance/Veterinary_HealthSafety_Toolkit.pdf

³⁵ <https://archive.cdc.gov/#/details?url=https://www.cdc.gov/niosh/topics/disinfectant/default.html>

the relative strength of each compound differs,³⁶ 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 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).

2.5 RADIOISOTOPES

Veterinary nuclear medicine involves the use of radioactive materials that are administered to animals for diagnosis or treatment, with particular application in endocrinology, medical imaging and oncology (Krzeminski et al. 2004). One of the most common procedures involves the use of radioiodine (iodine-131, or ¹³¹I) for the treatment of hyperthyroidism in cats (IAEA 2021). Radioiodine is administered at licenced clinics as a one-off sub-cutaneous injection, which is absorbed into the bloodstream and localises in the thyroid, destroying overactive tissue.³⁷ Following administration, the cat is typically admitted for 7-10 days of isolation boarding, during which time the majority of excess radioactive material is excreted in the urine and faeces (Peterson 2006).

Radioisotopes are also used in diagnostic nuclear imaging techniques including scintigraphy and positron emission tomography (PET).³⁸ Trace amounts of radioisotopes are bound to a pharmaceutical with an affinity for the particular tissue or organ of interest; the distribution of these compounds within the body can then be imaged using different modalities, allowing for functional imaging that provides information on metabolic or physiological processes that cannot be obtained through other imaging techniques.³⁹ In New Zealand, scintigraphy is often associated with equine medicine, especially bone scans and soft tissue injury assessment. It uses technetium-99m (^{99m}Tc), a short-lived isotope with a half-life of 6 hours and which is excreted in urine and faeces^{40,41}. PET produces 3-dimensional imaging using positron-emitting

³⁶ 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.

³⁷ <https://www.mcmasterheap.co.nz/wp-content/uploads/2026/03/Radioactive-Iodine-Client-INFO-.pdf>

³⁸ <https://www.msdevetmanual.com/clinical-pathology-and-procedures/diagnostic-imaging/nuclear-medicine-imaging-in-animals>

³⁹ ³⁹ <https://www.msdevetmanual.com/clinical-pathology-and-procedures/diagnostic-imaging/nuclear-medicine-imaging-in-animals>

⁴⁰ <https://ceh.vetmed.ucdavis.edu/imaging>

⁴¹ <https://www.epa.gov/radiation/radionuclide-basics-technetium-99>

isotopes of lighter elements including oxygen, carbon and fluorine (eg, in ^{18}F -sodium fluoride to detect bone lesions and ^{18}F -fluorodeoxyglucose to stage cancers).⁴²

For veterinary oncology, iodine-131 is used to treat thyroid carcinoma in dogs,⁴³ and isotopes including samarium-153 (^{153}Sm) have been used in the treatment of bone cancers (IAEA 2021). Increasingly, external beam radiotherapy techniques (eg, stereotactic radiotherapy) are being used in veterinary care (Marza et al. 2026); access appears limited in New Zealand at the time of writing, although a small number of practices offer this service⁴⁴ or have partnerships with human radiology facilities to provide treatment.⁴⁵ External beam therapies use an external radiation source and do not present a risk of associated contaminants to wastewater.⁴⁶ Veterinary brachytherapy (where a radiation source such as radioactive strontium-9, iridium-192 or iodine-125 beads are placed inside the body to provide radiotherapy) is a highly specialised cancer treatment⁴⁷ (Marza et al. 2026) that does not appear to be available in New Zealand.

Most radioactive waste from veterinary nuclear medicine contains short-lived nucleotides, making it feasible to manage as conventional waste following an appropriate period that allows for decay⁴⁸ (IAEA 2021). Animal excreta or biological waste contaminated with radionucleotides could be released to wastewater if they are not contained appropriately. Animals must therefore be housed in appropriate facilities with urine, faeces and vomit collected and stored to allow the decay of nucleotides (eg, in storage bins, or by designing drains that terminate in a delay/holding tank)⁴⁹ (Peterson 2006; IAEA 2021; Ministry of Health 2023, 2026). In New Zealand, radioactive pharmaceuticals are usually ordered in pre-dispensed syringes, packaged with appropriate shielding and ready for administration to each animal; they are not dispensed from stock solution in-clinic, reducing the potential for spills or improper disposal down drains (Ministry of Health 2023). Following appropriate segregation and interim storage to allow for decay, and subject to mechanisms that demonstrate compliance with regulatory clearance requirements, wastes can subsequently be managed as non-radioactive waste, with minimal environmental impact of subsequent discharge or release⁵⁰ (IAEA 2021).

⁴² <https://www.msdevetmanual.com/clinical-pathology-and-procedures/diagnostic-imaging/nuclear-medicine-imaging-in-animals>

⁴³ https://www.msdevetmanual.com/therapeutics/radiation-therapy/radiation-therapy-in-animals#Brachytherapy_v45376222

⁴⁴ <https://www.vsaahospital.co.nz/services/vsa-specialist-cancer-care-for-your-pets/>

⁴⁵ <https://arcvets.co.nz/our-services/oncology/>

⁴⁶ <https://www.msdevetmanual.com/therapeutics/radiation-therapy/radiation-therapy-in-animals>

⁴⁷ <https://www.vetoncologyconsults.com/types-of-radiation-therapy/>

⁴⁸ The duration of this period will depend on the half-life of the specific isotope and its initial activity level. The half lives of commonly-used isotopes are as follows: ^{131}I – 8 days; $^{99\text{m}}\text{Tc}$ – 6 hours; ^{18}F – 110 minutes; ^{153}Sm – 46 hours.

⁴⁹ Wastes excreted within 3 days of ^{131}I administration must be stored for 6 weeks, with wastes excreted after 3 days of treatment stored for 3 weeks (Ministry of Health 2020).

⁵⁰ Assuming the waste does not also require management as another type of hazardous waste (eg, sharps, cytotoxic).

2.5.1 Health effects of radioisotopes

Radioisotopes present a risk to human health because they emit ionising radiation, which has sufficient energy to interact with the atoms in living tissue, causing DNA and cellular damage.⁵¹

⁵² The potential health effects of exposure to ionising radiation depend on the type and dose of radiation received or absorbed, which are determined by the specific radioisotope. Radioactive particles (alpha and beta particles) can be especially harmful if inhaled, ingested or absorbed, depending on the route of exposure (ie, internal or external) and the behaviour of the specific nucleotide within the body (eg, tendency to localise in certain tissues).⁵³ For example, the major health risks associated with exposure to ¹³¹I are linked to thyroid function (Ministry of Health 2023). Acute, high-dose exposure to radioisotopes is rare, but can cause radiation sickness (nausea, vomiting, diarrhoea), skin burns and redness, immune system impairment, and may be fatal. These symptoms are only seen after extremely high radiation exposures, such as a nuclear explosion or the rupture of a highly radioactive source.⁵⁴ Chronic, low dose exposure does not tend to cause immediate health effects but can increase the risk of longer-term effects such as cancer, cataracts or cardiovascular disease, developing years to decades later.⁵⁵ ⁵⁶ Children and adolescents are much more vulnerable to radiation exposure than adults.⁵⁷

Because of the short half-lives of the radioisotopes used in veterinary medicine and the extremely low levels that are likely to enter clinic wastewater, it is not expected that these will present a human health risk.

2.6 HEAVY METALS

Despite a lack of published literature, it seems reasonable to expect that veterinary clinic effluent may contain trace amounts of heavy metals, including lead, zinc, copper, silver and mercury, originating from various pharmaceuticals, chemical disinfectants or laboratory reagents, x-ray development solutions or broken equipment. For example, in conventional film-based radiography, light-sensitive silver halide crystals present on x-ray films are released as silver thiosulfate during the fixing process,⁵⁸ and can be released to wastewater if fixing and developing solutions are not properly contained and disposed of appropriately (commonly collection by an approved waste handler for recovery and recycling). While no specific data on the silver content of radiographic solutions from veterinary clinics was identified in the literature, data from dental clinics show used radiographic fixer can contain up to 8-12 g of silver (NZDA 2021; Muhamedogic et al. 2009). In addition, lead has been associated with film

⁵¹ <https://www.who.int/news-room/fact-sheets/detail/ionizing-radiation-and-health-effects>

⁵² <https://world-nuclear.org/information-library/safety-and-security/radiation-and-health/radiation-and-health-effects>

⁵³ <https://www.epa.gov/radiation/radiation-health-effects>

⁵⁴ <https://www.epa.gov/radiation/radiation-health-effects>

⁵⁵ <https://www.epa.gov/radiation/radiation-health-effects>

⁵⁶ <https://www.epa.gov/radiation/radiation-health-effects>

⁵⁷ <https://www.who.int/news-room/fact-sheets/detail/ionizing-radiation-and-health-effects>

⁵⁸ <https://www.researchbank.ac.nz/server/api/core/bitstreams/8dd03a10-5b52-4619-8d96-e0d99a282371/content>

radiography, being used in fine lead foils in x-ray film packets and in protective lead aprons and gloves worn by staff taking x-rays.⁵⁹ Lead could enter wastewater when protective foils or storage boxes 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,⁶⁰ or when protective items degrade over time leading to small fragments being dislodged to the waste stream. However, film radiography is increasingly being replaced by digital technologies in small animal clinics and hospitals (Niemieć 2014; Booth et al. 2018), which negate the need for chemical film development. Although there is scant information about the relative use of film and digital technologies, a survey of New Zealand veterinary clinics regarding the use of dental radiography equipment reported that all clinics providing dental radiography services were using digital systems.⁶¹ Furthermore, a search of websites for New Zealand veterinary clinics providing radiography services found clinics typically promoted their use of new digital technologies⁶². Thus, the presence of silver and lead in clinic wastewater due to x-ray generation and development is likely to be significantly reduced compared with historic loads, and to further decrease as these technologies continue to be updated.

Old medical devices such as thermometers or sphygmomanometers contain elemental liquid mercury, which could be released to wastewater if equipment is damaged. However, these items have been all but phased out in veterinary care and replaced with mercury-free (often digital) alternatives.

2.6.1 Health effects of heavy metals

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) are more readily absorbed and can cause more obvious health effects (ATSDR 1990; Drake and Hazelwood 2005). The most well-known health effect of 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 damage⁶³ (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).

⁵⁹ <https://www.researchbank.ac.nz/server/api/core/bitstreams/8dd03a10-5b52-4619-8d96-e0d99a282371/content>

⁶⁰ <https://jada.ada.org/action/showPdf?pii=S0002-8177%2814%2963381-X>

⁶¹ <https://www.researchbank.ac.nz/server/api/core/bitstreams/8dd03a10-5b52-4619-8d96-e0d99a282371/content>

⁶² Noting the potential for bias, in that clinics that have not adopted digital x-ray technologies may also be less likely to have invested in website development.

⁶³ 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).

Lead is one of the WHO's top ten chemicals of public health concern.⁶⁴ 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). It is generally considered a chronic or cumulative toxin, causing 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 (Tchounwou et al. 2012; ATSDR 2020; WHO 2022, 2023). Acute effects are usually only observed following exposure to very high doses causing gastrointestinal distress (nausea, vomiting, abdominal pain), hepatic and renal damage, hypertension, and neurological effects (headaches, drowsiness, malaise) (ATSDR 2020; WHO 2023).

Mercury is highly toxic, and is also considered by the WHO 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. 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).

2.7 CYTOLOGY STAINS AND FIXATIVES

Most veterinary clinics offer a degree of in-house laboratory testing, including blood and urine testing using basic instrumentation like refractometers or glucose meters, chromatographic strips or basic cytology.^{65,66,67} Some larger veterinary clinics offer more extensive laboratory facilities, including more advanced analytical machinery or histology, which may require more extensive sample preparation. Cytology involves the analysis of individual cells taken from the animal in a scraping or fluid sample and smeared on a microscope slide. Cells may be stained to allow aspects of their structure or the presence of microorganisms to be more clearly visualised. Histology is a more detailed examination of tissues that have been collected by biopsy, then preserved, sectioned (thinly sliced), mounted onto a microscope slide and stained

⁶⁴ <https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health>

⁶⁵ <https://www.vetnursing.ie/>

⁶⁶ https://www.merckvetmanual.com/clinical-pathology-and-procedures/diagnostic-procedures-for-the-private-practice-laboratory/clinical-biochemistry#Point-of-Care-Tests:_v3297932

⁶⁷ <https://www.vetsouth.co.nz/blog/post/160151/why-an-in-house-laboratory-matters/>

for analysis. While many of the different stains⁶⁸ are not especially hazardous, there are several stains that can present serious health risks. Further, some of the associated chemicals used to process, fix and mount tissues can also be toxic, such as formalin and formaldehyde used to preserve tissues, and xylene used for clearing tissues. Often, complex analyses are referred to a specialist diagnostic laboratory for analysis following preservation of the sample in formalin.

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Many laboratory chemicals, stains and fixatives are categorised as hazardous substances due to their flammability and/or ecotoxic effects, as well as potential human health effects, and therefore require strict management within the laboratory.⁷² Typically, used stains and fixatives should be disposed of and collected as hazardous waste and not be disposed of via sewer (some substances may be disposed to sewer if appropriate inactivation or neutralisation has occurred).⁷³ However, trace amounts may enter the wastewater following slide preparation (eg, rinsing trays or forceps used to prepare slides), but should be flushed with copious amounts of water to ensure appropriate dilution.⁷⁴

2.7.1 Health effects of stains and fixatives

Many stains, fixatives and other laboratory chemicals can be irritants, given sufficient exposure to tissue.^{75,76} However, some stains are notable for their toxicity and potential carcinogenicity, including Basic Fuchsin (mutagenic, carcinogenic),⁷⁷ Crystal Violet (highly toxic, teratogenic, possibly carcinogenic),⁷⁸ Congo Red (highly toxic, potentially carcinogenic),⁷⁹ and Giesma (toxic)⁸⁰ stains. Formaldehyde is irritating to the lungs and mucous membranes (eyes, nose, mouth), and repeated skin exposure can cause allergic dermatitis in some individuals (ATSDR 1999; University of Auckland 2024). The International Agency for Research on Cancer (IARC) have classified formaldehyde as a Group 1 carcinogen (carcinogenic to humans) (WHO 2022). Formalin is an aqueous solution of formaldehyde, typically used as a 3-10% formalin solution to fix tissues (University of Auckland 2024).

⁶⁸ Different stains are used to visualise different cellular elements, for example lipids, particular proteins etc. <https://www.vettimes.co.uk/app/uploads/wp-post-to-pdf-enhanced-cache/1/understanding-special-stains.pdf>

⁶⁹ <https://www.awanuijets.co.nz/>

⁷⁰ <https://skagitcounty.net/HealthEnvironmental/Documents/envirostars/Veterinary%20Clinics-%20Hazardous%20Waste.pdf>

⁷¹ https://www.msdevetmanual.com/clinical-pathology-and-procedures/diagnostic-procedures-for-the-private-practice-laboratory/cytology#Cytology-of-Specific-Sites:_v4500833

⁷² <https://skagitcounty.net/HealthEnvironmental/Documents/envirostars/Veterinary%20Clinics-%20Hazardous%20Waste.pdf>

⁷³ https://www.otago.ac.nz/_data/assets/pdf_file/0035/318995/download-the-chemical-disposal-waste-guidelines-080557.pdf

⁷⁴ https://www.auckland.ac.nz/assets/health-safety-wellbeing/health-safety-topics/safety-in-labs/SMOU_formaldehyde_v1.0.pdf

⁷⁵ <https://www.leicabiosystems.com/knowledge-pathway/safety-with-special-stains/>

⁷⁶ <https://pmc.ncbi.nlm.nih.gov/articles/PMC3927343/pdf/JOMFP-17-402.pdf>

⁷⁷ <https://www.hopenn.com/sds/Basic-Fuchsin.pdf>

⁷⁸ <https://www.carolina.com/teacher-resources/Document/msds-crystal-violet/tr-msds-crystal-violet.tr>

⁷⁹ <https://www.chemsupply.com.au/uploads/sds/STLZV2TV.pdf>

⁸⁰ https://www.ethosbiosciences.com/wp-content/uploads/SDS_5545.pdf

3. CONCENTRATIONS OF CONTAMINANTS IN VETERINARY CLINIC WASTEWATER

3.1 CONCENTRATIONS OF CONTAMINANTS OF CONCERN IN VETERINARY 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 veterinary clinic effluents in New Zealand. Indeed, no publicly-available data of any kind regarding the sampling or composition of veterinary clinic effluents in New Zealand was identified.

Subsequently, an informal request for information was sent to Territorial Authorities (TA) via email following a presentation to the Trade Waste and Compliance Officers group,⁸¹ to enquire about their classification of veterinary clinic effluents under their respective Trade Waste Bylaws, any requirements for pre-treatment or similar (see Section 4.2), and any sampling data that they may hold but which was not discoverable in the public realm. Based on these communications, it appears that veterinary clinic effluents are not currently sampled by TAs in New Zealand, and that TAs do not hold any data on the composition of this type of trade waste. The general feedback was that because of their low total volume, and likely low loads of any hazardous contaminants, effluents from veterinary clinics were considered to be low risk compared to other types of trade wastes a TA might be managing within their jurisdiction. Thus, the presence or load of contaminants of human health concern in New Zealand veterinary clinic effluents remains a substantial knowledge gap.

3.2 CONCENTRATIONS OF CONTAMINANTS OF CONCERN IN VETERINARY CLINIC EFFLUENTS INTERNATIONALLY

In the absence of any New Zealand-specific data regarding the composition of veterinary clinic wastewater, it was intended that international data would be described below to provide some insights into the potential contaminant loads that may be present in New Zealand. A comprehensive search of online databases including Web of Science, Science Direct, PubMed and ProQuest was undertaken using the search terms ‘veterinary’ or ‘vet’ and ‘wastewater,’ ‘effluent’ or ‘trade waste,’ with and without reference to specific contaminant groups

⁸¹ 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/>

(pathogens, radioisotopes, pharmaceuticals, antibiotics, radiographic, sterilants, and chemical contaminants). However, very few papers of relevance to this review were identified, as almost all of the returned items discussed wastewaters from agricultural animal production or abattoirs⁸² – a substantively different enterprise to veterinary clinics providing medical care and treatment of companion animals.

3.2.1 Antibiotics in veterinary clinic wastewater

Lucas et al. (2016) analysed the presence of antibiotics in wastewater from a large veterinary hospital and teaching facility in Spain (Table 3). They detected a large variety of compounds, with quinolones being the most prevalent group (>15,000 ng/L as the sum of 10 compounds), followed by β -lactams (10,253 ng/L), tetracyclines (4,807 ng/L), metronidazoles (4,774 ng/L), macrolides (309 ng/L), trimethoprim (52 ng/L), and sulfonamides (31 ng/L).

3.2.2 Antimicrobial resistance genes in veterinary clinic wastewater

Lucas et al. (2016) reported the detection of several antimicrobial resistance genes in wastewater from a large veterinary hospital in Spain, including *emB*, *tetW*, *bla_{SHV}*, *sull* and *qnrS*, at concentrations of 10²-10⁵ gene copies per ml. Promariya et al. (2025) detected the genes *aph*, *oqxB*, *blaOXA* and *mph* in veterinary hospital wastewater from a hospital in Thailand.

3.2.3 Pathogens in veterinary clinic wastewater

Rosales et al. (2024) analysed wastewater from a large municipal animal shelter in the United States, and routinely detected canine parvovirus (CPV), with occasional detection of *Streptococcus zooepidemicus* and canine distemper virus (CDV). While CPV and CDV are highly contagious in dogs, they do not infect people.^{83 84} *S. zooepidemicus* infection is a rare infection in humans and is often linked to contact with horses or consumption of unpasteurised milk by individuals with underlying disease (Priestnall and Erles 2010; Shah et al. 2024).

⁸² <https://www.sciencedirect.com/science/article/pii/S004896972103494X>

⁸³ <https://www.purina.co.uk/articles/dogs/health/symptoms/canine-parvovirus>

⁸⁴ <https://www.bluecross.org.uk/advice/dog/health-and-injuries/canine-distemper>

Table 3. Concentrations of antibiotics in wastewater from a large veterinary hospital in Spain. Adapted from Lucas et al. (2016).

Compound	Concentration ng/L
Ciprofloxacin	13881 ± 2410
Enrofloxacin	982 ± 224
Ofloxacin	220 ± 29
Marbofloxacin	191 ± 24
Enoxacin	190 ± 42
Norfloxacin	91 ± 10
Pipemidic Acid	88 ± 24
Danofloxacin	23 ± 2
Nalidixic Acid	16 ± 3
Cinofloxacin	5 ± 1
Cefazolin	4810 ± 152
Ampicillin	2138 ± 100
Ampicillin B	1965 ± 61
Cefalexin	1178 ± 70
Cefuroxime	162 ± 46
Doxycycline	4697 ± 752
Tetracycline	63 ± 10
Oxytetracycline	38 ± 6
Chlortetracycline	8 ± 1
Metronidazole	4588 ± 880
Metronidazole OH	186 ± 49
Erythromycin	201 ± 54
Tilmicosin	57 ± 18
Azithromycin	23 ± 6
Tylosin	14 ± 5
Clarithromycin	13 ± 4
Spyramycin	9 ± 3
Trimethoprim	52 ± 11
Sulfamethoxazole	16 ± 4
Sulfadimethoxine	15 ± 5

Amoxicillin, cloxacillin, clindamycin, lincomycin, oxacillin, penicillin G, penicillin V, sulfadiazine, N-acetilsulfadiazine, sulfamerazine, N-acetilsulfamerazine, sulfamthazine, sulfamethizole, sulfamethoxipiridazine, sulfisoxazole and sulfapyridine were analyzed but not detected.

Pharmaceutical limits for wastewater New Zealand Bylaws (where they feature) as based on the total concentration of active pharmaceutical ingredients, as described in Section 4.2.

4. REGULATION OF VETERINARY CLINIC EFFLUENTS IN NEW ZEALAND

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

In New Zealand, the discharge of trade waste to a municipal wastewater network is regulated by the relevant territorial authority (TA)⁸⁵ through trade waste bylaws. The bylaws set out specific requirements for entities producing trade wastes, which may include 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 and maintenance of pre-treatment systems, 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 provides a nationally consistent framework and set of principles to the management of trade waste across regions or jurisdictions, and is then adapted to the needs of individual TAs to reflect 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 it 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 any conditions placed on the discharge, such as requirements for certain pre-treatment of waste, implementation of waste minimisation practices, or submission of a waste management plan.
- **Prohibited:** A waste that has one or more prohibited characteristics, 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.

⁸⁵ 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.

After reviewing the Trade Waste Bylaws of multiple territorial authorities,⁸⁶ and following discussions and email correspondence with members of the Trade Waste and Compliance Officers group (see Section 3.1), it appears that the specific adaptations to, and implementation of, trade waste bylaws differ slightly across the country. For example, some 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 not require a consent, although some may still require the discharge to be registered. The specifications for acceptable and prohibited characteristics (based on Schedules 1A and 1B in the Model Trade Waste Bylaw) appear relatively consistent across each of the various TA bylaws, although 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 veterinary clinics, the Model Trade Waste Bylaw and its appended Guidelines identify veterinary surgeries as an example of a business that produces “permitted trade waste, but which may require a consent as a conditional trade waste” (Table G2, Standards New Zealand 2004). Few TA bylaws specifically identify or classify veterinary clinics (ie, to identify them as either a permitted or conditional activity). At least one TA was found to require a specific application form for discharge consent for conditional trade waste from veterinary clinics. Many Trade Waste Officers advised that they did require veterinary clinics to hold a discharge consent, although they were largely considered to be low-risk dischargers. Several TAs commented that they did not require consent as they assumed that hazardous waste was managed separately (eg, incineration of biohazard, segregation and collection of sharps or hazardous chemicals), significantly reducing the risk associated with veterinary trade waste.

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

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. Within the subset of Trade Waste Bylaws reviewed 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 concern that were identified in previous sections of this report is shown in Table 4. 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

⁸⁶ Due to time constraints, it was not possible to review the trade waste bylaws for each of the 67 Territorial Authorities in New Zealand. Instead, the trade waste bylaws from 20 different TAs, ranging in both size (small districts to large cities) and location (spread across New Zealand) were reviewed as a representative sample of these documents in New Zealand. In addition, staff from TAs that were not captured in the bylaw review were present in the TWCO meeting. Thus, whilst not exhaustive, this section should provide an accurate summary of how veterinary clinic wastewaters are categorised and regulated around New Zealand.

anatomical or histological wastes, and/or any pharmaceuticals (although some TAs others allow pharmaceuticals to the limits in Table 4).

Table 4. 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/m ³)*	
Metals		
Lead	2, 5, 10	
Mercury	0.005, 0.03, 0.05	
Silver	2, 5	
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> ⁸⁷	
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

⁸⁷ The Code of Safe Practice for the Use of Unsealed Radioactive Material (CSP1) has been superseded by Code of Practice for Unsealed Radioactive Material: ORS C11 (2020). The updated documents states that radioactive material may be discharged to the sewerage system without an approved waste management plan if it consists of aqueous materials, meets specified activity limits according to the particular isotope, and is recorded in an appropriate register. <https://www.health.govt.nz/system/files/2020-07/code-of-practice-unsealed-radioactive-material-ors-c11-1july2020.pdf>

4.3 REQUIREMENTS FOR PRE-TREATMENT OF VETERINARY CLINIC EFFLUENTS

Strategies to reduce the contaminant loads in veterinary clinic wastewater include regulations and best management practices for handling and disposal of hazardous substances (eg, NZS 4304), source reduction and stewardship (especially for antibiotics and other pharmaceuticals), and pet health maintenance and preventative care.⁸⁸ Compliance with regulations and best practice will significantly reduce the release of most types of contaminants identified in this report to municipal wastewater.

Most TAs advised that they require veterinary clinics and/or veterinary hospitals to install screens and filters over sinks and operating table and floor drains to trap hair and other solid materials to prevent them from entering the wastewater system, as these are associated with blockages and damage to valves or pumps. There are no additional requirements for the pre-treatment of wastewater or effluent prior to discharge to the municipal network.

⁸⁸ <https://nzva.org.nz/home/news/animal-health-key-to-addressing-bacterial-resistance/>

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,⁸⁹ 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 connected population served by a WWTP using an activated sludge-based system (Beca et al. 2020).

5.2 REMOVAL OF PATHOGENS FROM WASTEWATER

Although the main role of the primary and secondary treatment components of the WWTP is to reduce solids and organic material from influent wastewater, these processes can also facilitate the removal of a substantial 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). However, given the high concentrations of microorganisms that can be present in influent wastewater (eg, up to 10⁶-10⁸ *E. coli* per 100 ml; Beca et al. 2020), removal rates of >90% may still equate to significant microbial loads in effluent wastewater, requiring additional treatment to meet regulatory targets for pathogen reduction in many cases. There are several possible fates for microbial pathogens and helminths (worms) that enter the wastewater treatment system: they may be removed, inactivated, destroyed, consumed by other microorganisms in the treatment system, or they may persist and leave the treatment plant in final effluents (Gerardi and Zimmerman 2005). Pathogen removal in municipal wastewater treatment systems is achieved through a combination of physical separation, biological interactions, and environmental inactivation

⁸⁹ '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).

processes.⁹⁰ 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).

In activated sludge-based systems, pathogens may be removed from the wastewater by their adsorption to biological and/or inert solids. Some removal of pathogens adsorbed to particulates occurs during primary treatment as these materials settle out; however, in conventional activated sludge systems, the majority of pathogen removal occurs in the activated sludge reactor basins and secondary clarifiers, where microorganisms that provide secondary treatment aggregate into flocs, promoting the adsorption of bacteria, viruses, and protozoa through electrostatic interactions and adsorption bridging, with subsequent settling in the clarifiers. This physical removal mechanism is complemented by biological mechanisms including predation by protozoa and metazoa, enzymatic degradation and competitive exclusion by the microbial community within the treatment plant, and chemical mechanisms, notably oxidative stress induced by aeration processes which increases pathogen inactivation (Flapper et al. 2012). Since conventional activated sludge systems are not optimised for pathogen removal, they are typically followed by a dedicated pathogen removal step (ie, tertiary treatment) before final effluents are discharged to the environment. Tertiary treatments can include various physical and chemical processes, notably UV irradiation, chlorination, ozonation, membrane filtration or a combination thereof. In New Zealand, the majority of plants use artificial UV light to inactivate microorganisms⁹¹ through DNA damage (eg, Mangere,⁹² Porirua⁹³). UV treatment is effective and efficient, requiring a much shorter contact time (<1 minute) compared with chemical disinfection and avoiding the production of hazardous by-products. However, it does require sufficient removal of suspended solids in earlier stages of treatment, as high turbidity, suspended solids or organic matter can absorb the UV light or shield microbes from it, reducing treatment efficiency. Chlorination or ozonation are rarely used to disinfect wastewaters in New Zealand (if at all), due to concerns about hazardous byproducts or residuals entering receiving environments; dechlorination is possible, but adds cost and complexity (Beca et al. 2020). Finally, membrane filtration (eg ultrafiltration) technologies achieve disinfection through physical size exclusion - final effluent is able to pass through while pathogens and other physical contaminants (residual fine particulates, sludge floc) are retained. They are becoming more common in New Zealand treatment plants, largely in higher-specification WWTP where the discharge consent limits are especially stringent; internationally they are also used for situations of water reuse. While membrane filtration can achieve more consistent performance than UV irradiation, it is associated with much higher capital costs, higher energy demand, and requires ongoing maintenance to prevent fouling and damage of the membranes (Beca et al. 2020).

In waste stabilisation ponds, pathogen removal occurs through natural environmental processes over prolonged retention times. These systems utilise solar radiation, temperature and ecological interactions within microbial communities to reduce pathogen loads (Kamel et

⁹⁰ https://water360.com.au/wp-content/uploads/2022/10/72m---7104-quantification-of-pathogen-removal-in-activated-sludge-plant_final_report_.pdf

⁹¹ Inactivating microbes does not necessarily kill them, but renders them harmless as they can no longer replicate or cause infection. Occasionally however, if the UV dose is too low, microbes enter a dormant state but are able to repair the DNA damage to replicate later (a process known as photoreactivation).

⁹² <https://www.engineeringnz.org/programmes/heritage/engineering-heritage-records/water-infrastructure/mangere-wastewater-treatment-plant/>

⁹³ <https://www.gw.govt.nz/assets/Documents/2022/03/Appendix-N-Virus-reduction-performance.pdf>.

al. 2026). Ultraviolet radiation is a key mechanism for inactivation and death of microorganisms, causing direct DNA damage and contributing to oxidative stress through the generation of reactive chemical species. Photosynthesis by algae in the ponds increases dissolved oxygen and can increase pH, creating conditions that enhance pathogen inactivation. Sedimentation of particle-associated microbes removes a significant fraction of influent microorganisms to the sludge layer of the pond, while predation by protozoa and zooplankton further reduce bacterial and viral concentrations in the water column. UV disinfection can also be used improve the microbial quality of the final effluents from waste stabilisation ponds (eg, Featherston⁹⁴), however, disinfection efficacy can be impacted by the presence of algae in the wastewater (Beca et al. 2020).

Data shows that removal of microorganisms is influenced by the type of pathogen and the operational conditions of the WWTP. For example, viruses tend to show lower and more inconsistent removal than bacteria, due to their greater persistence (ie, ability to withstand inactivation) and weaker association with particulates and bacterial flocs (Loughran et al. 2010; Kamel et al. 2026). Protozoa tend to be effectively removed due to their large size and strong particle association, however, cysts that are not removed through these processes can be incredibly resistant to inactivation or destruction. Whilst the long retention periods used within ponds systems tend to result in higher overall pathogen reduction compared with conventional activated sludge systems (except where tertiary treatment is used), pond systems can be more variable in their performance than the more controlled activated sludge systems and are highly influenced by environmental conditions, with systems in cooler climates (or seasons) or cloudier regions achieving lower removal efficiencies (Liu et al. 2015; Kamel et al. 2026). Examples of removal rates reported in studies of waste stabilisation ponds and WWTPs with activated sludge processes are shown in Table 5 below.

Considering the relatively low loads of pathogens that are likely to be present in veterinary clinic wastewater, the degree of dilution that occurs as clinic wastewater enters the main municipal wastewater stream (itself a significant source of pathogenic microorganisms, including many of those mentioned in Table 1; WHO 2020), and the overall efficacy of pathogen removal at the WWTP, it is highly likely that pathogens originating from the veterinary clinic and being discharged in final effluents are well below levels of concern.

⁹⁴ <https://www.gw.govt.nz/assets/Documents/2022/04/Appendix-2-Part-1-Consideration-of-Alternative-Treatment-and-Disposal-Options-merged-merged.pdf>

Table 5. Reported removal rates for microbial pathogens and indicators from conventional activated sludge and waste stabilisation ponds.

Compound	Log reduction value^	WWTP process	Country	Reference
Bacteria				
Faecal coliforms*	4-5	WSP	New Zealand	Loughran et al. (2020)
	0.6-3.2	AS (12 WWTPs)	Australia	Flapper et al. (2012)
	~6	AS	Egypt	Kamel et al. (2026)
	~5	WSP	Egypt	Kamel et al. (2026)
<i>E. coli</i> *	0.8-3.3	AS (12 WWTPs)	Australia	Flapper et al. (2012)
	~6	AS	Egypt	Kamel et al. (2026)
	~5	WSP	Egypt	Kamel et al. (2026)
Enterococci*	4	WSP	New Zealand	Loughran et al. (2020)
	0.63-3.1	AS (12 WWTPs)	Australia	Flapper et al. (2012)
	~5.3	AS	Egypt	Kamel et al. (2026)
	~5.5	WSP	Egypt	Kamel et al. (2026)
<i>Pseudomonas aeruginosa</i>	~3.7	AS	Egypt	Kamel et al. (2026)
	~2.5	WSP	Egypt	Kamel et al. (2026)
<i>Listeria</i> spp.	~3	AS	Egypt	Kamel et al. (2026)
	~2.2	WSP	Egypt	Kamel et al. (2026)
<i>Staphylococcus aureus</i>	~3.3	AS	Egypt	Kamel et al. (2026)
	~2.5	WSP	Egypt	Kamel et al. (2026)
<i>Salmonella</i> spp.	~3.3	AS	Egypt	Kamel et al. (2026)
	~3.3	WSP	Egypt	Kamel et al. (2026)
<i>Clostridium perfringens</i> *	0.4-1.7	AS (12 WWTPs)	Australia	Flapper et al. (2012)
Viruses				
Norovirus GI	>1.6	WSP	New Zealand	Norquay et al. (2025)
	0.8	AS	United States	Wang et al. (2025)
	<0.5	WSP	United States	Wang et al. (2025)
	1.4	AS	Sweden	Nordgren et al 2008.
Norovirus GII	>2.8	WSP	New Zealand	Norquay et al. (2025)
	1.1	AS	United States	Wang et al. (2025)
	<1	WSP	United States	Wang et al. (2025)
	1.2	AS	Sweden	Nordgren et al 2008.
Human adenovirus	2.7-3.1	AS (3 WWTPs)	Australia	Sidhu et al. (2018)
	1.8	AS	United States	Wang et al. (2025)
	0.6	WSP	United States	Wang et al. (2025)
	3.23	AS	New Zealand	McBride (2017)
Human polyomavirus	3.5-4.0	AS (3 WWTPs)	Australia	Sidhu et al. (2018)
Human enteroviruses	3.66	AS	New Zealand	McBride (2017)
Human torque teno virus*	2.7-3.0	AS (3 WWTPs)	Australia	Sidhu et al. (2018)
F-RNA coliphage*	0.8-2.1	AS (12 WWTPs)	Australia	Flapper et al. (2012)
Somatic coliphage*	3.2-4.2	AS (3 WWTPs)	Australia	Sidhu et al. (2018)
Protozoa				
<i>Cryptosporidium</i>	0.4-2.1	AS (12 WWTPs)	Australia	Flapper et al. (2012)
<i>Giardia</i>	1.2-2.4	AS (12 WWTPs)	Australia	Flapper et al. (2012)

Table footnotes over page.

AS – activated sludge, WSP – waste stabilisation pond, UV – ultraviolet disinfection

* Used as a microbial indicator, typically not pathogenic.

^ A log value reduction is a measure of the extent to which microorganisms have been inactivated or removed (depending on the analytical method use). For each increment of 1, the pathogen concentration is reduced by a factor of 10. Therefore, a 0 log reduction is no removal, 1 log reduction is 10-fold or 90%, 2 log reduction is 100-fold or 99%, 3 log reduction is 1,000-fold or 99.9% and so on.

5.3 REMOVAL OF PHARMACEUTICALS FROM WASTEWATER

Conventional wastewater treatment plants are not specifically designed to remove chemical micropollutants such as pharmaceuticals, thus the removal of many of these compounds from these plants can be poor, allowing them to pass through to receiving environments (Verlicchi et al. 2012; Margot et al. 2015; Peake et al. 2016; Sabri et al. 2020; Adeleye et al. 2022). For example, a review of WWTPs in the UK found that 13% of all WWTPs had human 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 or disinfectants 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, configuration and specific technologies used in treatment, amount and type of biomass, 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 WWTPs are sorption to particulate matter and biological degradation or transformation. Sorption may occur by means of absorption due to hydrophobic interactions or adsorption due to electrostatic interactions between compounds and/or microorganisms, with compounds that are lipophilic, hydrophobic or positively charged typically showing higher rates of partitioning to sludge and/or floc during primary and secondary treatment (Radjenovic et al. 2009; Verlicchi et al. 2012; Margot et al. 2015). However, many pharmaceuticals have a high solubility and tend to be present in the dissolved phase, requiring removal through transformation or degradation by microorganisms (Verlicchi et al. 2012). While some compounds are readily degraded, others are not; in particular, many antibiotics tend to show low rates of biodegradation due to their inherent antimicrobial properties (Loos et al. 2013; Lucas et al. 2016). 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% being reported. Further, instances of so-called ‘negative removal’ are

reported for some compounds (Lucas et al. 2016; Wang and Wang 2016; Sabri et al. 2020; Adeleye et al. 2022). Negative removal may happen when conjugated pharmaceutical metabolites present in influent wastewater are deconjugated by microorganisms during biological treatment processes, or when compounds that are sorbed to particulate matter (eg, antibiotics, which are predominantly shed in faeces) are released during treatment, leading to a higher relative concentration of the parent compound in treated effluents (Verlicchi et al. 2012; Kumar et al. 2019).

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). Most of the literature centres on human pharmaceuticals, since human consumption, metabolism and excretion are the primary source of pharmaceuticals to the environment (Khetan and Collins 2007). Examples of published removal rates for compounds reported as used in veterinary practice or detected in veterinary clinic wastewater are shown in Table 6. More advanced tertiary treatment such as ultrafiltration, activated carbon adsorption, advanced oxidation and bioremediation 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; Sabri et al. 2020; Oluwole et al. 2020; Vinayagam et al. 2022; Saeed et al. 2025). However, many of these processes are not routinely used unless expressly required for certain reuse applications or the protection of sensitive receiving environments, due to the high operational costs or potential to produce undesirable byproducts (Luo et al. 2014; Vinayagam et al. 2022; Saeed et al. 2025).

Table 6. Removal rates for select pharmaceuticals (reported as being used in veterinary 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)
	Cefaclor	98	CAS	Verlicchi et al. (2012)
	Cefalexin	53-100	CAS	Verlicchi et al. (2012)
	Chlortetracycline	82-85	CAS	Verlicchi et al. (2012)
	Ciprofloxacin	18-96	CAS	Verlicchi et al. (2012)
	Clarithromycin	5-83	CAS	Verlicchi et al. (2012)
		90	5-stage Bardenpho	Kumar et al. (2019)
	Doxycycline	14-100	CAS	Verlicchi et al. (2012)
	Enrofloxacin	38-70	CAS	Verlicchi et al. (2012)
	Erythromycin	3-35	CAS	Verlicchi et al. (2012)
	Lincomycin	17-57	CAS	Verlicchi et al. (2012)
	Norfloxacin	18-96*	CAS	Verlicchi et al. (2012)
	Ofloxacin	13-84	CAS	Verlicchi et al. (2012)
	Penicillin V	60	CAS	Verlicchi et al. (2012)
	Oxytetracycline	4	CAS	Verlicchi et al. (2012)
	Sulfamethazine	16-100	CAS	Verlicchi et al. (2012)
	Sulfamethoxazole	5-100	CAS	Verlicchi et al. (2012)
		62	5-stage Bardenpho	Kumar et al. (2019)
	Sulfapyradine	20-89	CAS	Verlicchi et al. (2012)
	Sulfathiazole	65-100	CAS	Verlicchi et al. (2012)
	Tetracycline	-88-72	CAS	Verlicchi et al. (2012)
	Trimethoprim	-88-85	CAS	Verlicchi et al. (2012)
		35	5-stage Bardenpho	Kumar et al. (2019)
Barbiturates	Phenobarbital	99.5	CAS	Verlicchi et al. (2012)
Beta-agonists	Salbutamol	95	CAS	Verlicchi et al. (2012)
Antiseptics	Triclosan	69	CAS	Verlicchi et al. (2012)

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

5.4 REMOVAL OF ANTIMICROBIAL RESISTANCE GENES FROM WASTEWATER

Conventional wastewater treatment systems are not designed to remove ARGs (Kalli et al. 2025). Available data show that effluents from WWTPs can still contain high levels of ARGs, potentially contributing to the spread of antimicrobial resistance (Rizzo et al. 2013; Sun et al. 2019; Sabri et al. 2020; Kalli et al. 2025). For example, Munir et al. (2011) assessed the removal of ARGs from several WWTPs in Michigan, USA using different treatment technologies, and reported two activated sludge-based systems attained log removal rates of ~2.5-4.5 log for tetracycline- and sulfonamide-resistance genes (*tetO*, *tetW*, and *sul1*). Sabri et al. (2020) assessed the removal of ARGs from three WWTPs in the Netherlands using conventional activated sludge treatment (one with additional activated carbon filtration) or aerobic granular sludge, with removal rates between 1.3 log and 2.3 log observed for the four genes assessed (*ermB*, *sul1*, *sul2* and *tetW*). In Athens, Kalli et al. (2025) reported 1.9-3.2 log removal of the genes *blaTEM*, *tetA*, *qnrS*, *ermB*, *sul1*, *sul2*. Pallares-Vega et al. (2019) measured ARG removal in 62 WWTP in Netherlands using activated sludge processes, and found that on average, removal rates were highest for *qnrS*, *ermB* and *tetM* genes (2.65 ± 0.68 , 2.65 ± 0.74 and 2.5 ± 0.68 log removal respectively), with 2.4 ± 0.56 log for *bla_{ctxM}*, and 2.00 ± 0.48 for *sul1*.

Notably, several authors have reported that ARG loads within sewage sludge suggest this is an important reservoir and potential source of environmental release of ARGs if subsequently reused (Munir et al. 2011; Sabri et al. 2020). The use of advanced tertiary treatment technologies such as ultrafiltration, membrane biological reactors and activated carbon may show further removal of ARGs from wastewater in the order of 1-3 log removal (Munir et al. 2011; Sun et al. 2019), however disinfection treatment such as chlorination or UV treatment are relatively ineffective at improving ARG removal (Kallis et al. 2025).

5.5 REMOVAL OF DISINFECTANTS AND CHEMICAL 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.^{95, 96, 97} The fate of disinfectants and sterilants in the wastewater network also depends on their chemical structure. Oxidising compounds such as sodium hypochlorite, peracetic acid and hydrogen peroxide will rapidly react with various organic and inorganic substances within the municipal wastewater stream and/or decompose naturally due to their chemical instability, decaying into stable components such as water, oxygen, acetic acid and/or chloride ions (SDA 1997; US EPA 2007). Sodium hypochlorite may also release a small fraction of chloride to form chlorinated organic byproducts. Typically, these rapid reactions mean that quantities discarded down the

⁹⁵ <https://www.civco.com/in-the-know/how-to-dispose-of-high-level-disinfectants-safely/>

⁹⁶ <https://www.health.vic.gov.au/infectious-diseases/cleaning-and-waste-disposal-procedures-infection-control>

⁹⁷ <https://www.phoenix.gov/content/dam/phoenix/waterservicessite/documents/092015.pdf>

drain will have completely reacted prior to reaching the WWTP, although exposure of microbial floc to very high levels⁹⁸ can reduce biological treatment efficacy (SDA 1997; Bodik et al. 2008; Chen et al. 2021).

Other disinfectants such as glutaraldehyde may reach the WWTP significantly diluted by the wider municipal network; they are typically present in the dissolved phase, meaning their removal through primary treatment and sedimentation is typically poor (ATSDR, 2017). Glutaraldehyde degrades readily in water under both aerobic and anaerobic conditions, and 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 remaining compound that may enter receiving environments is likely to be rapidly diluted and undergo further biodegradation (Leung 2001; OECD 2001). However, the inherent biocidal activity of disinfectants and sterilants means they may be toxic to the microorganisms in activated sludge processes if present at sufficiently high concentrations, reducing the ability of microorganisms to biodegrade these compounds (OSHA 2006); studies suggest that sewage microorganisms may become inhibited at concentrations above 25-80 mg/L, but are otherwise capable of degrading glutaraldehyde from wastewater (OECD 2001; Laopaiboon et al. 2003).

5.6 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 and activated sludge-based 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, large aquatic plants), metals may also be removed by phytofiltration. Chemical precipitation can also be induced within 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 and subsequent removal with waste activated sludge. While it is generally accepted that most of

⁹⁸ For example, direct exposure of floc in pilot-scale systems.

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). Thus, removal rates can be variable 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.

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

Metal	Removal efficiency (%)	Reference
Cadmium	25-74	Carletti et al. (2008)
	55	Karvelas et al. (2003)
	30-40	Choubert et al. (2011)
Chromium	57-72	Carletti et al. (2008)
	68-85	Carletti et al. (2008)
	50	Karvelas et al. (2003)
	>70	Choubert et al. (2011)
Copper	73-99	Carletti et al. (2008)
	54-82	Carletti et al. (2008)
	58	Karvelas et al. (2003)
	>70	Choubert et al. (2011)
Lead	53-78	Carletti et al. (2008)
	95	Carletti et al. (2008)
	31	Karvelas et al. (2003)
	>70	Choubert et al. (2011)
Mercury	33-90	Carletti et al. (2008)
	57-92	Carletti et al. (2008)
Nickel	72-91	Carletti et al. (2008)
	43-95	Carletti et al. (2008)
	44	Karvelas et al. (2003)
	30-70	Choubert et al. (2011)
Zinc	28-93	Carletti et al. (2008)
	87-88	Carletti et al. (2008)
	43	Karvelas et al. (2003)
	30-70	Choubert et al. (2011)

CONCLUSIONS

Veterinary clinic wastewater is a heterogenous mixture that could potentially contain water, animal blood or body tissues, urine or faecal materials, hair/fur, microorganisms, pharmaceuticals, disinfectants and cleaning agents, radiographic solutions, histology stains, laboratory chemicals or radioisotopes. However, there is little data available quantifying the presence of contaminants of potential concern in the wastewater from companion animal veterinary clinics or hospitals; the available literature is skewed almost exclusively towards the presence of pharmaceuticals, especially antibiotics, in effluents associated with animal husbandry and animal production contexts. No publicly available data on the composition of or contaminants in veterinary clinic wastewater from New Zealand was identified.

Following a review of Trade Waste Bylaws from numerous Territorial Authorities around New Zealand, and consultation with the Trade Waste Compliance Officers group, it is apparent that while some councils require veterinary clinics to hold a discharge consent to release wastewater to the municipal network, others do not. Further, a large number of TAs (though not all) require clinics to install screens or traps on sinks and floor drains to prevent hair, fur or other solid materials entering the wastewater system, as these may cause blockages or related damage to network infrastructure (eg, pumps). Some TAs stipulate limits for pharmaceutical compounds (as a group, rather than specific compounds) while some prohibit their discharge to wastewater. Cytotoxic pharmaceuticals (and associated wastes) are regulated under the Healthcare Waste Standard as requiring segregation and disposal.

It is likely that veterinary clinic wastewater could contain microbial pathogens, since a number of these are shed in faeces or in body fluids that may be disposed directly to wastewater during cleaning of cages/kennels or examination or surgical tables. However, not all of these pathogens are capable of zoonotic infection, and some require route of transmission that is unlikely to occur through wastewater. The small number of the pathogens that may be present within the clinic and that could cause concern include *Salmonella*, *Campylobacter*, *Leptospira*, *Cryptosporidium* and *Giardia*. Notably, these pathogens are routinely detected in municipal wastewater independently of veterinary inputs. Further, the extent of dilution of veterinary effluents within the municipal network, and the high rates of removal of many pathogens at the treatment plant (especially those using tertiary disinfection) suggest that the overall risk from microbial pathogens through veterinary clinic effluents is very low.

For organic micropollutants that reach the municipal wastewater system and treatment plant, including pharmaceuticals and antibiotics, disinfectants and laboratory chemicals, their fate will be highly dependent on both their individual 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. Contaminants of concern should be assessed on a case-by-case basis to assess likely removal given the specific compound and local treatment conditions. However, it should be noted that the loading of these compounds will likely be significantly lower than those contributed to the wastewater system by other sources, such as human hospitals, and in the case of pharmaceuticals, the loads contributed through the excretion of parent compounds and metabolites by the general population.

The potential heavy metal burden in effluents from veterinary clinics or hospitals is unclear, however, traditional sources of heavy metals such as film-based radiography and the use of equipment containing liquid mercury have been all but phased out. Heavy metals that may be present 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.

Radioisotopes are not expected to be present if appropriate control measures are observed; the short-lived nature of the isotopes used in veterinary care means that any breach resulting in their entry into the wastewater system is unlikely to present a human health risk.

Overall, data on the composition of veterinary clinic or veterinary hospital wastewater remains a data gap, both internationally and in New Zealand. However, it is likely that individual clinics tend to produce small volumes of wastewater with low contaminant loads, especially when compared to other healthcare facilities (eg, human hospitals) or industrial entities, and which are highly diluted upon reaching the municipal network. Although companion and non-production animal healthcare in New Zealand is a relatively low user of antibiotics and other pharmaceuticals compared with agriculture or human healthcare, pharmaceutical stewardship – especially for antibiotics – will remain an important focal point for the profession in helping to manage the development and spread of AMR.

REFERENCES

- Adeleye AS, Xue J, Zhao Y, et al. 2022. Abundance, date and effects of pharmaceuticals and personal care products in aquatic environments. *Journal of Hazardous Materials* 424: 127284. 32p.
- Albarano L, Suarez EGP, Maggio C, et al. 2024. Assessment of ecological risks posed by veterinary antibiotics in European aquatic environments: a comprehensive review and analysis. *Science of the Total Environment* 954: 176280.
- Anderson MEC, Wimmers M, Wesse JS. 2020. *Infection Prevention and Control Best Practices for Small Animal Veterinary Clinics*. 2nd ed. Guelph, Ontario, Canada: Ontario Animal Health Network and Centre for Public Health and Zoonoses. 103p.
- Arenke M, Moheimani R, Phuphanich M, et al. 2021. Disinfectants in interventional practices. *Current Pain and Headache Reports* 25: 21. 10p.
- ATSDR. 1990. *Toxicological Profile for Silver*. Atlanta, Georgia, USA: Agency for Toxic Substances and Disease Registry (ATSDR), Department of Health and Human Services. 145p.
- ATSDR. 1999. *Toxicological Profile for Formaldehyde*. Atlanta, Georgia, USA: Agency for Toxic Substances and Disease Registry (ATSDR), US Department of Health and Human Health Services. 468p.
- ATSDR. 2017. *Toxicological Profile for Glutaraldehyde*. Atlanta, Georgia, USA: Agency for Toxic Substances and Disease Registry (ATSDR), US Department of Health and Human Services.
- ATSDR. 2020. *Toxicological Profile for Lead*. Atlanta, Georgia, USA: Agency for Toxic Substances and Disease Registry (ATSDR), US Department of Health and Human Health Services. 530p.
- ATSDR. 2024. *Toxicological Profile for Mercury*. Atlanta, Georgia, USA: Agency for Toxic Substances and Disease Registry (ATSDR), US Department of Health and Human Services. 712
- Beca, GHD, Boffa Miskell. 2020. *The New Zealand Wastewater Sector*. Prepared from the Ministry for the Environment. Christchurch, New Zealand: GHD Limited. 262p.
- Berry A, Cowan ML, Lam A, et al. 2026. Common bacterial pathogens and antimicrobial resistance trends cultured from respiratory, ear, dental and nasolacrimal duct infections in rabbits (2018-2024): 74 isolates. *Australian Veterinary Journal* 104 (5): 281-286.
- Biller B, Berg J, Garrett L, et al. 2016. AAHA Oncology Guidelines for Dogs and Cats. Veterinary Practice Guidelines. *Journal of the American Animal Hospital Association* 52 (4): 181-204. https://www.aaha.org/wp-content/uploads/globalassets/02-guidelines/oncology/2016_aaha_oncology_guidelines_for_dogs_and_cats.pdf
- Bodik I, Gasparikova E, Dancova L, et al. 2008. Influence of disinfectants on domestic wastewater treatment plant performance. *Bioresource Technology* 99: 532-539.
- Booth NJ, Morley SJ, Ewers RS. 2018. Use of radiography in small animal practice in the UK and Republic of Ireland in 2013. *Veterinary Record* 182 (8): 225.

- Caddey B, Fisher S, Barkema HW, et al. 2025. Companions in antimicrobial resistance: examining transmission of common antimicrobial-resistant organisms between people and their cats, dogs and horses. *Clinical Microbiology Reviews* 38 (1): e00146-22.
- Cantinho P, Matos M, Trancoso MA, et al. 2015. Behaviour and fate of metals in urban wastewater treatment plants: a review. *International Journal of Environmental Science and Technology*
- Carletti G, Fatone F, Bolzonella D, et al. 2008. Occurrence and fate of heavy metals in large wastewater treatment plants treating municipal and industrial wastewaters. *Water Science and Technology* 57 (9): 1329-1336
- Castiglioni S, Bagnati R, Fanelli R, et al. 2006. Removal of pharmaceuticals in sewage treatment plants in Italy. *Environmental Science and Technology* 40: 357-363.
- CDC. 2024. *Guideline for Disinfection and Sterilisation in Healthcare Facilities*. 2008. Updated June 2024. Atlanta, Georgia, USA: US Centres for Disease Control and Prevention (CDC). 163p.
- Chen Y, Yu G, Cao Q, et al. 2013. Occurrence and environmental implications of pharmaceuticals in Chinese municipal sewage sludge. *Chemosphere* 93: 1765-1772.
- Chen J, Liu X, Pavlostathis SG. 2021. Long-term evaluation of the effect of peracetic acid on a mixed aerobic culture: organic matter degradation, nitrification and microbial community structure. *Water Research* 190: 116694. 10p.
- Chen Y, Slocombe R, Cauci C, et al. 2025. Severe *Strongyloides stercoralis* infection in a puppy from a metropolitan area of Melbourne, Australia: a need for heightened awareness of this zoonotic pathogen. *Australian Veterinary Journal* 104 (4): 206-209.
- Comber S, Gardner M, Sörme P, et al. 2018. Active pharmaceutical ingredients entering the aquatic environment from wastewater treatment works: a cause for concern? *Science of the Total Environment*: 613-614: 538-547.
- Coxon S. 2024. *Assessment of the presence of pharmaceuticals in, and removal from, municipal wastewater in Aotearoa New Zealand*. ESR Client Report No. FW24028. Prepared for the Ministry of Health. Christchurch, New Zealand: Institute for Environmental Science and Research (ESR). 92p.
- Cressey P. 2018. *Risks to Public Health from Emerging Organic Contaminants in the New Zealand Aquatic Environment*. Report No. FW18010. Prepared for the Ministry of Health. Christchurch: Institute of Environmental Science and Research. 77p
- Daughton CG, Ternes TA. 1999. Pharmaceuticals and personal care products in the environment: agents of subtle change. *Environmental Health Perspectives* 107: 907-938.
- Delgado N, Orozco J, Zambrano S, et al. 2023. Veterinary pharmaceuticals as emerging contaminants in wastewater and surface water: an overview. *Journal of Hazardous Materials* 460: 132431. 11p.
- Drake PL, Hazelwood KJ. 2005. Exposure-related health effects of silver and silver compounds: a review. *Annals of Work Exposures and Health* 49 (7): 575-585.
- Du P, Zhang L, Ma Y, et al. 2020. Occurrence and fate of heavy metals in municipal wastewater in Heilongjiang Province, China: A Monthly Reconnaissance from 2015 to 2017. *Water* 12 (#): 728.

- Eaton C. 2022. *Review of potential health hazards associated with industrial effluents*. ESR Client Report No. FW23016. Prepared for the Ministry of Health. Christchurch, New Zealand: Institute for Environmental Science and Research (ESR). 133p.
- Eaton C. 2025. *Assessment of the presence of heavy metals in municipal wastewater in Aotearoa New Zealand*. ESR Client Report No. FW25020. Prepared for Health New Zealand Te Whatu Ora. Christchurch, New Zealand: Institute for Environmental Science and Research (ESR). 83p.
- Epp T, Waldner C. 2012. Occupational health hazards in veterinary medicine: zoonoses and other biological hazards. *Canadian Veterinary Journal* 53: 144-150.
- Flapper T, Campbell B, O'Connor N, et al. 2012. *Quantification of pathogen removal in Australian activated sludge plants (Phase 1 and 2). Projects 512-001 and 72M-7104. Final Report*. Australia: Smart Water Fund. 114p.
- Frascaroli G, Reid D, Hunter C, et al. 2021. Pharmaceuticals in wastewater treatment plants: a systematic review on the substances of greatest concern responsible for the development of antimicrobial resistance. *Applied Sciences* 11: 6670. 26p.
- Gracia-Lor E, Sancho JV, Serrano R, et al. 2012. Occurrence and removal of pharmaceuticals in wastewater treatment plants at the Spanish Mediterranean area of Valencia. *Chemosphere* 87: 453-462.
- Gielen GJHP. 2007. *The Fate and Effects of Sewage-Derived Pharmaceuticals in Soil*. PhD Thesis, University of Canterbury, Christchurch, New Zealand. 173p
- IAEA. 2021. *Radiation Protection and Safety in Veterinary Medicine. Safety Reports Series No. 104*. Vienna, Austria: International Atomic Energy Agency (IAEA). 181p.
- IPCS. 1991. *Environmental Health Criteria 118: Inorganic Mercury*. International Programme on Chemical Safety (IPCS). Geneva, Switzerland: World Health Organisation (WHO). <https://incchem.org/documents/ehc/ehc/ehc118.html>
- ISSA. 2014. *Use of disinfectants in the health care sector: chemical hazards and preventative measures. Fact sheet 3L Hazards of chemical disinfectants*. Hamburg, Germany: International Social Security Administration Association (ISSA), International Section on Prevention of Occupational Risks in Health Services. 25p.
- Kamel MA, Rizk NM, Gad M, et al. 2016. Comparative performance of activated sludge and waste stabilisation ponds for the removal of pollutants and pathogens in full-scale wastewater treatment plants in Egypt. *Scientific Reports* 16: 5266. 13p.
- Karvelas M, Katsoyiannis A, Samara C. 2003. Occurrence and fate of heavy metals in the wastewater treatment process. *Chemosphere* 53: 1201-1210.
- Khan NA, Ahmed S, Farooqi IH, et al. 2020. Occurrence, sources and conventional treatment techniques for various antibiotics present in hospital wastewaters: a critical review. *Trends in Analytical Chemistry* 129: 115921. 15p.
- Khetan SK, Collins TJ. 2007. Human pharmaceuticals in the aquatic environment: a challenge to green chemistry. *Chemistry Reviews* 107 (6): 2319-2364.
- Kinney CA, Vanden Heuvel B, 2020. Translocation of pharmaceuticals and personal care products after land application of biosolids. *Current Opinion in Environmental Science and Health* 14: 23-30.

- Krzeminski M, Lass P, Teodorczyk J, et al. 2004. Veterinary nuclear medicine. *Nuclear Medicine Review Central and Eastern Europe* 7 (2): 177-182.
- Lam J, Chan SS, Conway FDL, et al. 2018. Environmental stewardship practices of veterinary professionals and educators related to use and disposal of pharmaceuticals and personal care products. *Journal of the American Veterinary Medical Association* 252 (5): 596-604.
- Laopaiboon L, Hall SJ, Smith RN. 2003. The effect of an aldehyde biocide on the performance and characteristics of laboratory-scale rotating biological reactors. *Journal of Biotechnology* 102 (1): 73-82.
- Leung HW. 2001. Ecotoxicology of glutaraldehyde: review of environmental fate and effects studies. *Ecotoxicology and Environmental Safety* 49: 26-39.
- Liu L, Hall G, Champagne P. 2015. Effects of environmental factors on the disinfection performance of a wastewater stabilisation pond operated in a temperate climate. *Water* 8 (1): 5. 11p.
- Lodder WJ, van den Berg HHJL, Rutjes SA, et al. 2010. Presence of enteric viruses in source waters for drinking water production in the Netherlands. *Applied and Environmental Microbiology* 76 (17): 5965-5971
- Loughran P, Jenner G, Haverland. 2020. *Porirua Wastewater Treatment Plant – Virus Reduction and Disinfection Performance*. Resource Consent Application to Discharge Treated Wastewater to the CMA from the Porirua Wastewater, Appendix N. 17p.
- Loos R, Carvalho R, Antonio DC, et al. 2013. EU-wide monitoring survey on emerging polar organic contaminants in wastewater treatment plant effluents. *Water Research* 47: 6475-6487
- Lucas D, Badia-Fabregat M, Vicent T, et al. 2016. Fungal treatment for the removal of antibiotics and antibiotic resistance genes in veterinary hospital wastewater. *Chemosphere* 152: 301-308.
- Luo Y, Guo W, Ngo HH, et al. 2014. A review of the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment. *Science of the Total Environment* 473-474: 619-641.
- Lust E, Barthold C, Malesker MA, et al. 2011. Human health hazards of veterinary medications: information for emergency departments. *The Journal of Emergency Medicine* 40 (2): 198-207.
- Margot J, Rossi L, Barry DA, et al. 2015. A review of the fate of micropollutants in wastewater treatment plants. *WIREs Water* 2 (5): 457-487.
- Marza SM, Munteanu C, Lacatus R, et al. 2026. Radiation in veterinary practice: paradigm shift towards precision and curative approaches. *Life (Basel)* 16 (4): 626. 28p.
- McBride G. 2017. *Bell Island Wastewater Treatment Plant, Quantitative Microbial Risk Assessment*
- Ministry for Primary Industries. 2025. *2024 Antibiotic Agricultural Compound Sales Analysis*. Wellington, New Zealand: Ministry for Primary Industries (MPI). 76p.
- Ministry of Health 2020. *Code of Practice for Veterinary Radiation: ORS C9*. Wellington, New Zealand: Ministry of Health. 26p.
- Ministry of Health. 2023. *Compliance Guide for Veterinary Radiation; OS G9*. Wellington, New Zealand: Ministry of Health. 73p.

- Nadas GC, Manchon AM, Mouari CM, et al. 2025. Veterinary clinics as reservoirs for *Pseudomonas aeruginosa*: a neglected pathway in One Health surveillance. *Antibiotics (Basel)* 14 (7): 720. 21p.
- Niemiec BA. 2014. Feline dental radiography and radiology. *Journal of Feline Medicine and Surgery* 16 (11): 887-899.
- NIOSH. 2021. *Current Intelligence Bulletin 70: Health Effects of Occupational Exposure to Silver Nanomaterials*. Kuempel E, Roberts JR, Roth G, Dunn KL, Zumwalde R, Drew N, Hubbs A, Trout D, and Holdsworth G. Publication No. 2021-112. Cincinnati, Ohio, USA: US Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health (NIOSH). 332p.
- Nordgren J, Matussek A, Mattson A, et al. 2009. Prevalence of norovirus and factors influencing virus concentrations during one year in a full scale wastewater treatment plant. *Water Research* 43: 1117-1125.
- Norquay K. 2025. *Norovirus monitoring deepens understanding of wastewater public health risks*. 10th IWA-Aspire Conference and Water New Zealand Conference and Expo. Christchurch, New Zealand. September-October 2025.
- Northover S, Hill, K, Cogger N, et al. 2025. Surveying cytotoxic chemotherapy use in small animal cancer treatment: insights into use and influencing factors in New Zealand. *New Zealand Veterinary Journal* 73 (6): 414-423.
- NZDA. 2001. *Controlling dental amalgam waste and wastewater discharges*. NZDA Practice Guideline, February 2001. Auckland, New Zealand: New Zealand Dental Association (NZDA). 5p.
- Munir M, Wong K, Xagorakai I. 2011. Release of antibiotic resistant bacteria and genes in the effluent and biosolids of five wastewater utilities in Michigan. *Water Research* 45: 681-693.
- Muhamedagic B, Muhamedagic L, Masic I. 2009. Dental Office Waste – Public Health and Ecological Risk. *Materia Socio Medica* 21 (9): 35-38.
- OECD. 2001. *Screening Information Data Set (SIDS) Initial Assessment for Glutaraldehyde*. Paris, France: Organisation for Economic Co-operation and Development (OECD). 83p. <https://hvpchemicals.oecd.org/UI/handler.axd?id=da11e1ee-332f-4be5-96ef-d1d4f81d3d57>
- Oluwole AO, Omotola EO, Olatunji OS. 2020. Pharmaceuticals and personal care products in water and wastewater: a review of treatment processes and use of photocatalyst immobilised on functionalised carbon in AOP degradation. *BMC Chemistry* 14: 62. 29p.
- Pallares-Vega R, Blaak H, van der Plaats R, et al. 2019. Determinants of presence and removal of antibiotic resistance genes using WWTP treatment: a cross-sectional study. *Water Research* 161: 319-328.
- Pattis I, Weaver L, Burgess S, et al. 2022. Antimicrobial resistance in New Zealand – a One Health perspective. *Antibiotics* 11: 778. 26p.
- Peake BM, Braund R, Tong AYC, et al. 2016. *The Life-Cycle of Pharmaceuticals in the Environment*. Woodhead Publishing Series in Biomedicine: Number 51. Cambridge, UK: Elsevier. 258p.

- Perkins R, Barron L, Glauser G, et al. 2024. Down-the-drain pathways for fipronil and imidacloprid applied as spot-on parasiticides to dogs: estimating aquatic pollution. *Science of the Total Environment* 917: 170175.
- Peterson ME. 2006. Radioiodine treatment of hyperthyroidism. *Clinical Techniques in Small Animal Practice* 21 (1): 34-39.
- Pleydell EJ, Souphavanh K, Hill KE, et al. 2012. Descriptive epidemiological study of the use of antimicrobial drugs by companion animal veterinarians in New Zealand. *New Zealand Veterinary Journal* 60 (2): 115-122.
- Prescott F. 2017. History and current use of antimicrobial drugs in veterinary medicine. *Clinical Microbiology* 5 (6): 10.1128. 15p.
- Priestnall S, Erles K. 2010. *Streptococcus zooepidemicus*: an emerging canine pathogen. *Veterinary Journal* 188 (2): 142-148.
- Promariya A, Treenarat S, Akrimajirachote N, et al. 2025. Cultivation of *Arthospira platensis* in veterinary hospital wastewater enhances pigment production and reduces antibiotic resistance genes. *Biology* 14 (10): 1396. 16p.
- Radjenovic J, Petrovic M, Barcelo D. 2009. Fate and distribution of pharmaceuticals in wastewater and sewage sludge of the conventional activated sludge and advanced membrane bioreactor (MBR) treatment. *Water Research* 43: 831-841.
- Rizzo L, Manaia C, Merlin C, et al. 2013. Urban wastewater treatment plants as hotspots for antibiotic resistant bacteria and genes spread into the environment: a review. *Science of the Total Environment* 447: 345-360.
- Rosales A, Bradley N, Kreisler RE, et al. 2024. Animal shelter wastewater sampling for pathogens with epidemic potential. *Journal of Shelter Medicine and Community Animal Health* 3 (S1).
- Sabri NA, van Holst S, Schmitt H, et al. 2020. Fate of antibiotics and antibiotic resistance genes during conventional and additional treatment technologies in wastewater treatment plants. *Science of the Total Environment* 741: 140199. 12p.
- Saeed H, Padmesh S, Singh A, et al. 2024. Impact of veterinary pharmaceuticals on environment and their mitigation through microbial bioremediation. *Frontiers in Microbiology* 15: 1396116. 15p.
- SDA. 1997. *Sodium Hypochlorite*. Soap and Detergent Association (SDA). Washington, DC, USA: Soap and Detergent Association (SDA). 10p.
https://www.cleaninginstitute.org/sites/default/files/research-pdfs/Sodium_Hypochlorite.pdf
- Sengar A, Vijayanandan A. 2022. Human health risk assessment of 98 pharmaceuticals and personal care products (PPCPs) detected in Indian surface waters. *Science of the Total Environment* 807: 150677. 18p.
- Shah N, Al Janabi T, Lien E, et al. 2024. A rare case of *Streptococcus equi* subspecies *zooepidemicus* bacteremia. *Cureus* 16 (5): e59911.
- Sidhu J.P.S, Sena K, Hodgers L, et al. 2018. Comparative enteric viruses and coliphage removal during wastewater treatment processes in a sub-tropical environment. *Science of the Total Environment* 616–617. 669–677.

- Smith AN, Klahn S, Phillips B, et al. 2018. ACVIM small animal consensus on safe use of cytotoxic chemotherapeutics in veterinary practice. *Journal of Veterinary Internal Medicine* 32: 904-913.
- Spratt HG, Millis N, Levine D, et al. 2024. Bacterial contamination of environmental surfaces of veterinary rehabilitation clinics. *Animals* 14: 1896. 12p.
- Stampfer HG, Gabb GM, Dimmitt SB. 2019. Why maximum tolerated dose? *British Journal of Pharmacology* 85 (10): 2213-2217.
- Standards New Zealand. 2002. *Management of Healthcare Waste*. NZS 4304:2002. Wellington, New Zealand: Standards New Zealand. 54p.
- Standards New Zealand. 2004. *New Zealand Model General Bylaws. Part 23: Trade Waste*. NZS 9201: Part 23: 2004. Wellington, New Zealand: Standards New Zealand. 86p.
- Steagall PV, Pelligand L, Page SW, et al. *The World Small Animal Veterinary Association (WSAVA) List of Essential Medicines for Cats and Dogs. Version 1*. Toronto, Canada: World Small Animal Veterinary Association (WSAVA). 26p. https://wsava.org/wp-content/uploads/2020/03/WSAVA_List_of_Essential_Medicines_for_Cats_and_Dogs_final.pdf
- Stull JW, Bjorvik E, Bub J, et al. 2018. AAHA Infection Control, Prevention and Biosecurity Guidelines. Veterinary Practice Guidelines. *Journal of the American Animal Hospital Association* 54 (6): 1-30
- Sun L, Shi P, He N, et al. 2019. Antibiotic resistance genes removal and membrane fouling in secondary effluents by combined processes of PAC/BPAC/UF. *Journal of Water and Health* 17 (6):910-920.
- Sykes JE, Weese JS. 2013. Infection Control Programmes for Dogs and Cats. *Canine and Feline Infectious Diseases*. pp. 105-118.
<https://pmc.ncbi.nlm.nih.gov/articles/PMC7152206/pdf/main.pdf>
- Tchounwou PB, Yedjou CG, Patlolla AK, et al. 2012. Heavy metals toxicity and the environment. *EXS* 101: 133-16
- Teerlink J, Hernandez J, Buff R. 2017. Fipronil washoff to municipal wastewater from dogs treated with spot-on products. *Science of the Total Environment* 599-600: 960-966.
- Traverse M, Aceto H. 2014. Environmental cleaning and disinfection. *Veterinary Clinic North America Small Animal Practice* 45 (2): 299-330.
- Tran NH, Reinhard M, Gin KYH. 2018. Occurrence and fate of emerging organic contaminants in municipal wastewater treatment plants from different geographical regions – a review. *Water Research* 133: 182-207.
- Tse A, Chee W, Boyd CJ, et al. 2026. Paracetamol prescribing to small animals by veterinarians in Australia and New Zealand. *Australian Veterinary Journal* 104 (6): 327-333.
- University of Auckland. 2024. *Chemical Risk Management Protocol. Safe Methods of Use: Formaldehyde*. Auckland, New Zealand: University of Auckland. 6p.
- US EPA. 2007. *Memorandum: Peroxy Compounds: Hydrogen Peroxide and Peroxyacetic Acid. Environmental Fate Science Chapter*.
https://www3.epa.gov/pesticides/chem_search/cleared_reviews/csr_PC-000595_12-Jul-07_a.pdf

- Vatovec C, Kolodinsky J, Callas P, et al. 2021. Pharmaceutical pollution sources and solutions: survey of human veterinary medication purchasing, use and disposal. *Journal of Environmental Management* 285: 112106. 7p.
- VCI. 2025. *Safe Use of Cytotoxic Drugs. Guidance Document on the Safe Use of Cytotoxic Drugs in Veterinary Practice*. Dublin, Ireland: Veterinary Council of Ireland (VCI). 6p. <https://cms.vci.ie/wp-content/uploads/2025/12/Safe-Use-of-Cytotoxic-Drugs-Guidance-Document-1.pdf>
- Verlicchi P, Al Aukidy M, Zambello E. 2012. Occurrence of pharmaceutical compounds in urban wastewater. Removal, mass load and environmental risk after secondary treatment: a review. *Science of the Total Environment* 429: 123-155.
- Vinayagam V, Murugan S, Kumaresan R, et al. 2022. Sustainable adsorbents for the removal of pharmaceuticals from wastewater: a review. *Chemosphere* 300: 134597. 25p.
- Wang J, Wang S. 2016. Removal of pharmaceuticals and personal care products (PCPPs) from wastewater: a review. *Journal of Environmental Management* 182: 620-640.
- Wang P, Hill T, Morrison C, et al. 2025. Virus log reduction and dominant mechanisms in full scale secondary biological wastewater treatment systems. *Water Environment Research* 97 (9): e70180.
- WHO. 2018. *Guidelines on Sanitation and Health*. Geneva, Switzerland: World Health Organization (WHO). 198p
- WHO. 2020. *Technical brief on water sanitation, hygiene and wastewater management to prevent infections and reduce the spread of antimicrobial resistance*. Geneva, Switzerland: World Health Organization (WHO). 25p
- WHO. 2021a. *Preventing Disease Through Healthy Environments. Exposure to Mercury: A Major Public Health Concern. 2nd Edition*. Geneva, Switzerland: World Health Organisation (WHO). 6p.
- WHO. 2021b. *Silver in Drinking-water. Background document for development of WHO Guidelines for Drinking-water Quality*. WHO/HEP/ECH/WSH/2021.7. Geneva, Switzerland: World Health Organization (WHO). 22p
- WHO. 2022. *Guidelines for Drinking-water Quality. Fourth Edition Incorporating the First and Second Addenda*. Geneva, Switzerland: World Health Organisation (WHO). 541p.
- WHO. 2023. *Preventing Disease Through Healthy Environments. Exposure to Lead: A Major Public Health Concern. 3rd ed*. Geneva, Switzerland: World Health Organisation (WHO). 6p.
- WHO. 2025. *Top 10 Drinking-water and Sanitation Related Pathogens*. Geneva, Switzerland: World Health Organisation (WHO). 6p. https://cdn.who.int/media/docs/default-source/wash-documents/burden-of-disease/top-10-drinking-water-and-sanitation-pathogens_final.pdf



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