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Freeman Environmental

Literature review of the risks and adverse effects from discharges of stormwater, wastewater, industrial and trade waste, and other hazardous substances in Otago

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1. Introduction

1.1 Purpose of this document

Plan Change 6A (Water Quality) to the Regional Plan: Water for Otago, which was made operative in May 2014, focused on managing contaminant losses from rural properties. Amongst other provisions, it set permitted activity discharge thresholds on nitrate and nitrite-nitrogen (NNN), ammoniacal-nitrogen (NH_4-N), dissolved reactive phosphorus (DRP), *Escherichia coli*, and turbidity.[1]

ORC now wishes to review how the discharges which have not been addressed in Plan Change 6A are managed. Those include discharges from stormwater, wastewater (human), industrial and trade waste, and other potentially hazardous activities (such as agricultural practices, landfill and contaminated sites). As a first step to this review, the ORC has commissioned a review of the latest scientific knowledge on the risks and adverse effects from the relevant discharges on the values receiving environments support, taking into account the sensitivity of those receiving environments across Otago. This will inform a) the assessment of ORC's discharge management policies, b) the identification of the key contaminants and indicators that ORC should target with regard to the discharges and c) the development of a water quality risk assessment methodology, which will spatially identify and quantify water quality issues and risks in the Otago Region.

ORC commissioned Streamlined Environmental Ltd (SEL) working with Freeman Environmental Ltd (FEL) to undertake this literature review. The scope for these services is included in Appendix A.

2. Setting the scene

2.1 The Otago Region

The Otago region is made up of five districts: Dunedin City, Clutha, Queenstown Lakes, Central Otago and part of Waitaki (Figure 1).[2] Otago's fresh waters arise in the Southern Alps with Mt Aspiring/Tititea the highest point in Otago. The three iconic lakes: Wakatipu, Wanaka, and Hawea form the sources of the Clutha River/Mata-Au that flows through Otago before discharging to the coast near Balclutha. Otago's coastal marine area, extends from the line of mean high water springs, to the limits of the territorial sea at 12 nautical miles (22.2 kilometres), from the Waitaki River in the north to Wallace Beach in the south. There is a wide range of rivers, lakes, groundwater, wetlands and coastal marine waters in Otago. The climate, soils and land use also varies considerably across Otago, from the frosty winters and hot dry summers of Central Otago to the more temperate coastal climate, and from the arid soils (e.g., mottled argillic semiarid soils) of Central Otago to the heavy loams near Dunedin (e.g., acidic orthic gley soils).

The predominant land use in Otago is pastoral agriculture (sheep, beef, dairying and deer) with a significant amount of horticulture (grapes and stone fruit) in Central Otago. Otago also has a very wide range of industries throughout the region, from gold mining in East Otago to making chocolate in Dunedin.

[1] http://www.orc.govt.nz/Publications-and-Reports/Regional-Policies-and-Plans/Regional-Plan-Water/Water-Quality-Rules-Plan-Change-6A/

[2] http://www.orc.govt.nz/About-us-and-the-Region/About-the-Region/Map-of-Otago/

Figure 1. Map of Otago[3]

2.2 Receiving environments of the Otago Region

Water and water resources have played a critical role in the development of Otago. As such, there is a history of long-standing or traditional use of water including Kai Tahu customary uses and, following European settlement, mining, irrigation, recreation, fishing, hydro-electric power generation and waste disposal. A brief description of the freshwater and coastal receiving environments of the Otago Region is presented below based primarily on information from Regional Plans (Otago Regional Council, 2015a, 2012).

[3] http://www.orc.govt.nz/About-us-and-the-Region/About-the-Region/Map-of-Otago/

2.2.1 Freshwater environments

Otago's distinctive character is often derived from its lakes, rivers and wetlands. For centuries, Otago's people and communities have used water to provide for their social, economic and cultural well being. This is evidenced in the wide range of heritage values associated with lakes and rivers: from the use of rivers as transport routes by Polynesian settlers, through to their importance in gold mining, some early remnants of which are still visible. The character of the region's water bodies is diverse, reflecting the variation in environmental conditions throughout.

Lakes – Otago contains many lakes of varying size. Approximately 23 percent of New Zealand's lake surface area occurs in Otago. The largest and iconic lakes - Wakatipu, Wanaka, and Hawea - are found in the aptly named Queenstown Lakes District. Lake Wakatipu (Queenstown) drains to the Kawarau River, Lake Wanaka drains to the Clutha River, and Lake Hawea drains to the Hawea River. The artificial Lake Dunstan (near Cromwell) was formed on the Clutha River as a result of the construction of the Clyde Dam. Smaller lakes in the South-West Otago region include Waihola, Mahinerangi and Onslow.

Rivers and streams – The Clutha River/Mata-Au drains much of the Otago region and is the largest river in New Zealand in terms of the quantity of water carried each year. Seventy five percent of the total flow of the Clutha River/Mata-Au at Balclutha results from the catchments of Lakes Hawea, Wanaka and Wakatipu. Important rivers feeding into the Clutha catchment include the Cardrona, Lindis, Shotover, Nevis, Fraser, Manuherikia and Teviot. The Clutha and its principal tributary, the Kawarau River, pass through gorges, two of which are dammed for hydro-electricity generation. One of the larger tributaries of the Clutha in its lower reaches is the Pomahaka River.

The second largest catchment in Otago is that of the Taieri River. Rising in the uplands of Central Otago, it passes through a gorge and crosses the Taieri Plain. There it joins the waters of the Lake Waipori and Waihola catchments and becomes tidal before making its way through another gorge to the sea at Taieri Mouth.

Other significant Otago rivers drain the coastal hills in catchments of varying character. In the north, the Kakanui, Waianakarua, Shag and Waikouaiti Rivers rise in high country and pass through predominantly dry lowlands. The Tokomairiro River drains rolling country between the Taieri and Clutha catchments. Rivers to the south of Otago, particularly the Catlins area, emerge from wetter, often forested hills.

Wetlands are an important component of Otago's water resource, providing a diverse set of landscape elements, including high altitude blanket bogs and string bogs, saline areas, swamp forest remnants, shallow lake complexes, estuarine saltmarshes and valley floor swamps. They are of particular significance due to their scarcity and ecological and cultural values. High altitude wetlands are often considered important for supporting summer stream flows, as well as being near-pristine ecosystems. Wetlands in more developed landscapes are also valuable sanctuaries for wildlife and mahinga kai for Kai Tahu.

Aquifers (Groundwater) – groundwater occurs in many parts of the region and many of Otago's people and communities have come to rely upon this water to provide for their social, economic and cultural well-being. The Otago region has few large regional aquifers; most aquifers generally lie within a number of disconnected basins. These basins are usually associated with glacial outwash or moraine deposits in river valleys. The basins may contain multiple aquifers, depending on the environment in which they were formed (Heller, 2001). There are a number of localities in Otago where groundwater is of particular significance due to existing use or potential demand in the drought prone areas of the region. At present all of Otago's many aquifers have water of useable quality.

2.2.2 Marine environments

Otago's 480 km coastline is diverse. In the north, the cobble beaches of the Waitaki Fan reach as far south as Cape Wanbrow. The rest of the coastline is made up of alternating cliff headlands and sand beaches, interrupted by the ancient Dunedin Volcano, now Otago Harbour.

Harbours and bays – Otago Harbour is the natural harbour of Dunedin, consisting of a long, much-indented stretch of generally navigable water separating the Otago Peninsula from the mainland. They join at its southwest end, 21 km from the harbour mouth. It is home to Dunedin's deep water port facilities on its western shores in the suburb of Port Chalmers. The harbour water is known for various rare wildlife. The area is the home of many species of wading birds. Other bird species which visit the harbour include two species of penguins. Taiaroa Head, at the tip of the Otago Peninsula, is home to a colony of northern royal albatrosses, the only such albatross close to a city in the world. It is also an important area for a number of marine mammals. There are numerous settlements located within the bays of Otago Harbour.

Estuaries – Many of the river mouths form estuarine wetlands of significant importance to both marine and freshwater wildlife. All estuarine areas along Otago's coast are particularly valuable in terms of biological productivity. This productivity results from the continuous flow of nutrients down rivers, the relative shelter compared to the open coast, and the relatively high (in coastal terms) amount of light available. Estuaries provide a benign environment for flora and fauna and are believed to act as both nursery areas and nutrient suppliers for the open coast and deeper ocean waters.

Near-shore coastal environments – Is all of the Otago coastline that is not a harbour, bay or estuary. This environment is characterised by high energy environments (such as currents and waves) with significant associated values (including recreation, ecosystem, cultural).

2.3 Values of receiving environments

The Regional Plan for Otago: Water, and the Regional Plan for Otago: Coastal, identify a range of values for aquatic receiving environments in the Otago region (Otago Regional Council, 2015a). Table 1 summarises our assessment of the potential values as they apply to the various receiving environments. A brief description of each value is presented below.

Table 1. Summary of potential values for each type of receiving environment in Otago

Value	Lake	River	Wetland	Aquifer	Bay	Harbour	Estuary	Near-shore
Aesthetic	√	√	√	X	√	√	√	√
Cultural	√	√	√	√	√	√	√	√
Ecosystem Health	√	√	√	√	√	√	√	√
Groundwater quality	√	√	√	√	√	√	√	√
Irrigation	√	√	X	√	X	X	X	X
Mahinga kai (kai for human consumption)	√	√	√	X	√	√	√	√

Value	Lake	River	Wetland	Aquifer	Bay	Harbour	Estuary	Near-shore
Primary contact recreation	√	√	X	X	√	√	√	√
Recreational	√	√	√	X	√	√	√	√
Drinking (potable) water	√	√	√	√	√	√	√	√
Stock	√	√	X	√	X	X	X	X

2.3.1 Aesthetic values

Individual and community experiences of water can be influenced by how it looks and smells. One of the major aesthetic concerns is around obvious visual signs of pollution of the water body as a consequence of materials on the river, wetland, lake bed or coastal environment, in or on the water, or deposited in the riparian margins or foreshore environments. Such signs include discolouration of water, presence of scums or grease or oil slicks, presence of litter, as well as odour. Impacts on aesthetic values may impact on individual and community social well-being, and may also have flow-on effects, including impact on residential property values and tourism opportunities.

2.3.2 Cultural values

Water has an important place in ceremonial occasions and is particularly recognised where the cultural components of tapu and noa are at work. Water symbolises the spiritual link between the present and the past, the never-ending source of life, for generations that have gone before and those to follow.

Kai Tahu's priority is to maintain the properties of water that are necessary to ensure the sustainability of customary uses. Customary uses range from the use of water for ceremonial purposes to the maintenance of the quality and quantity of water to sustain mahinga kai populations and habitats (Chapter 4, Otago Regional Council, 2015a).

2.3.3 Ecosystem health

An ecosystem is a biological community of interacting organisms and their physical environment. Ecosystem health is a metaphor used to describe the condition of an ecosystem. Ecosystem condition can vary as a result of fire, flooding, drought, extinctions, invasive species, climate change, mining, overexploitation in fishing, farming or logging, chemical spills, and a host of other reasons. There is no universally accepted benchmark for a healthy ecosystem, and the term ecosystem health has been employed to embrace some suite of environmental goals deemed desirable.

Discharges of contaminants to freshwater and marine environments can severely impact ecosystem health values through acute (short-term) effects and chronic (long-term) effects. The cumulative effects of multiple contaminants being discharged to an aquatic environment may also be highly significant; some contaminants discharged in isolation may have little influence on ecosystem health but when discharge alongside other contaminants, can have serious consequences.

2.3.4 Groundwater quality

Parts of Otago are very dry, with high pressure on a number of rivers and groundwater to provide for local water requirements. Small farming communities depend on limited water supplies for their livelihood.

Groundwater is the component of water that underlies the Earth's surface and occurs almost everywhere, beneath hills, mountains, plains, and deserts. Groundwater may occur close to the land surface, as in a marsh, or it may lie many hundreds of feet below the surface, as in arid areas. Water at very shallow depths might be just a few hours old; at moderate depth, it may be 100 years old; and at great depth or after having flowed long distances from places of entry, water may be several thousands of years old.

Groundwater is stored in, and moves slowly through, moderately to highly permeable rocks called aquifers. Aquifers literally carry water underground. In terms of storage at any one instant in time, ground water is the largest single supply of fresh water available for use by humans.

Groundwater can contain elevated concentrations of disease-causing microorganisms (pathogens) and chemical contaminants. The groundwater resource can then become an increased risk of illness to humans (if used as drinking (potable) water) or stock. If groundwater is used for irrigation, some toxic chemical contaminants present may bioaccumulate in stock causing a potential human health consumption risk.

2.3.5 Irrigation

Irrigation is an important feature of many areas of Otago, and often is critical to the continued well-being of the people and communities who rely on the primary production that it supports. Irrigation water can be sourced from lakes, ponds, rivers and aquifers and as such may contain pathogens and chemical contaminants. Some toxic chemical contaminants are of greatest concern for irrigation as they have the potential to bioaccumulate through the food chain and adversely affect public health.

2.3.6 Mahinga kai

The mahinga kai custom of producing or procuring food resources from a range of resources on a seasonal basis is a fundamental basis of the traditional economy. Maintenance of the custom and knowledge associated with the natural resource is governed by lore. Transfer from one generation to the next of the cumulative knowledge is tied to practical use and management of the mahinga kai resource. Water resources provide mahinga kai directly, provide ecosystem support for mahinga kai species, and support other significant mahinga kai environments, for example forest and coastal areas.

Contaminants in water can affect mahinga kai values directly through lethal and sub-lethal effects (e.g. reduction of species condition) on the resource.

Furthermore, consumption of chemical and biological contaminants present in mahinga kai species can be a significant short term and long term risk to public health. Immediate effects may be due to pathogenic bacteria, viruses or biotoxins. Long term effects may be attributed to chemical contaminants such as heavy metals and organochlorines (see Section 2.5.1). Public health is protected through warnings to avoid harvesting at particular times (acute effects) or through development of food safety standards for chronic effects (e.g. FSANZ, 2016).

2.3.7 Primary contact recreation

Primary contact is when users are in direct contact with water, and can fully immerse their body and swallow water. This includes activities such as surfing, water skiing, diving, swimming, or white water sports. The major public health risk from primary contact with water arises from ingesting pathogens through the mouth, nasal passages and ears. Pathogens might be bacterial or viral, and include such things as campylobacter, cryptosporidium, giardia, hepatitis A viruses, and salmonella.

2.3.8 Drinking (potable) water

Potable water, also known as drinking water, is water that is safe to drink or to use for food preparation, without risk of health problems. Drinking water contaminated with pollutants can cause short-term illness or (in extreme cases) even death, the severity of which is dependent on a variety of factors including contaminant concentration, volume ingested, age and well-being of the person. Effects can range from an short term (acute) stomach upset (due to microbial pathogens), to long term (chronic) mass poisoning (for example elevated arsenic concentrations in groundwater wells in Bangladesh[4]).

2.3.9 Recreational

The recreational opportunities provided by Otago's lakes and rivers and their margins can include angling for sports fish, hunting game birds and a range of other active and passive recreation. Recreation is one of the important values associated with the coastal marine area. Parts of Otago's coast have features which make them desirable for recreational activities. Examples of recreational use of natural features are sailing within Otago Harbour and some of the larger estuaries, swimming at patrolled beaches, surfing at the beaches which have a suitable wave environment, or the less active pursuit of walking along the many accessible beaches.

2.3.10 Stock

Good water quality is essential for successful livestock production. Poor quality water may reduce animal production and impair fertility. In extreme cases, stock may die.

2.4 Sensitivities of receiving environments

Depending on the contaminant of concern, different receiving environments will have differing sensitivities, which may mitigate or accentuate the potential adverse effects of the contaminant (these are addressed within individual sections).

2.5 Activities, discharges and contaminants that affect receiving environments

A summary of the types of activities, their discharges and the key contaminants[5] associated with those discharges considered in this report is presented in Table 2. Although the activities/discharges contain a much more extensive list of pollutants, only the key contaminants - identified as those that are most frequently cited in the literature on each discharge type - are included in Table 2. There is considerable overlap of

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[4] http://www.who.int/bulletin/volumes/90/11/11-101253/en/

[5] Contaminants are also called pollutants/toxicants

contaminants from each of the discharges - for instance heavy metals are present in all discharges, however individual metals may vary. A broad lay person summary of contaminants follows Table 2.

Table 2. Summary of activities, associated discharges and key contaminants

Activities	Discharges	Key Contaminants[1]
Urbanisation	Stormwater	Metals (copper, lead and zinc), hydrocarbons (including PAHs), EOCs, gross pollutants (rubbish etc.), faecal coliforms, sediment
Wastewater treatment	Human wastewater	E. coli, faecal coliforms, viruses, BOD[2], nutrients, EOCs, metals (cadmium, chromium, copper, lead, nickel, zinc)
Industrial and trade	Industrial and trade waste	Metals, POPs, EOCs, BOD, hydrocarbons, cleaning products
Agricultural and horticultural practices	Agricultural runoff	Pesticides, fungicides, cadmium (in fertiliser)
Landfills	Landfill leachate	Dissolved organic matter, ammonia, metals (cadmium, chromium, copper, lead, nickel, zinc), POPs, EOCs
Contaminated sites	Soil leaching	Metals, POPs, EOCs
Mining	Acid mine drainage	pH, metals, sulphides
Aquaculture	Fish/shellfish excreta and leaching/spills of chemicals used in aquaculture facility	BOD, Metal/metalloids (copper, chromium, arsenic), EOCs

[1] Selected as those most frequently cited in literature on each discharge type. PAHs (Polycyclic Aromatic Hydrocarbons); EOCs (Emerging Organic Contaminants); POPs (Persistent Organic Pollutants); BOD (Biochemical Oxygen Demand)
[2] BOD is a measure of biodegradable organic material present in a discharge and is not a specific contaminant

2.5.1 Toxicants

Toxicants are chemicals or a mixture of chemicals that present a risk of death, disease, injury or birth defects in exposed organisms at certain doses. They can be natural (e.g. metals such as zinc and copper which are essential for life but become toxic at high concentrations) or unnatural (i.e. man-made substances such as pesticides). Common toxicants in waterways include oil, herbicides, pesticides, heavy metals, industrial chemicals and plastics. These toxicants range widely in their sources and effects.

Heavy metals

Heavy metals, metalloids and organometallics are used in many common items and may enter waterways through point-source discharges (e.g. industrial or sewage discharges) or through diffuse run-off (Figure 2). Concentrations in diffuse run-off are usually higher in run-off originating from urban areas; for example, copper is used in car brake linings and is therefore higher in areas with high road density; zinc concentrations in run-off may be related to roof density. In New Zealand, metals also occur at naturally elevated concentrations in some environments, for example geothermal regions, due to the natural geology. Metals are the basis for much of the mining undertaken in the Otago region.

Some metals such as cobalt, copper, chromium, iron, magnesium, manganese, molybdenum, nickel, selenium and zinc are essential nutrients that are required for various biochemical and physiological functions. Inadequate supply of these micro-nutrients results in a variety of deficiency diseases or syndromes. However, in high enough concentrations these metals can exhibit toxic effects. Other metals (including but not limited to) aluminium, arsenic, cadmium, lead, mercury, nickel, and silver have no established biological functions and are considered as non-essential metals.

Metal toxicity depends on several factors including the dose, route of exposure, and chemical speciation (chemical form), as well as the age, gender, genetics, and nutritional status of exposed individuals. Because of their high degree of toxicity, arsenic, cadmium, chromium, lead, and mercury rank among the priority metals that are of public health significance. These metallic elements are considered systemic toxicants that are known to induce multiple organ damage, even at lower levels of exposure (Tchounwou, et al., 2012). They are also classified as known or probable human carcinogens.[6]

Metals may partition preferentially to sediment or water (the amount of which is dependent on the metal, pH, temperature, and amount of oxygen in the surrounding water). Metals are readily taken up by low trophic level species (those at the bottom of the food chain). Some, such as mercury, transfer (bioaccumulate) up the food chain (in species such as fish and marine mammals) and have been reported at sufficiently high concentrations in some species to pose a potential human health risk (Phillips, et al., 2014).

Pesticides

Pesticides (which includes herbicides, insecticides, and fungicides) are used in both rural and urban areas to control pest plants, insects and other animals. The term pesticide can be used as a general term to encompass any chemical product used to kill a pest, whether the pest is animal or plant. In rural areas, pesticides are generally used to control weeds and insect pests on crops. In urban areas, uses can include pest control in residences, weed control in private and public areas and mosquito control. Pesticides are of concern as they commonly have some effect on non-target organisms, particularly in aquatic systems.

Pesticides can enter waterways via a number of pathways, including leaching through groundwater, surface run-off, soil erosion, aerial drift or spills. Pesticides vary in the time they take to break down (their half-life), the toxicity of breakdown products, their tendency to adsorb to sediment or be taken up by organisms, and their toxicity to non-target organisms, and may present problems even after their use has been discontinued.

Pesticide residues have been found to be present in many aquatic systems in New Zealand, although concentrations are generally very low and below maximum acceptable values (Humphries and Close, 2014).

[6] https://www.epa.gov/iris

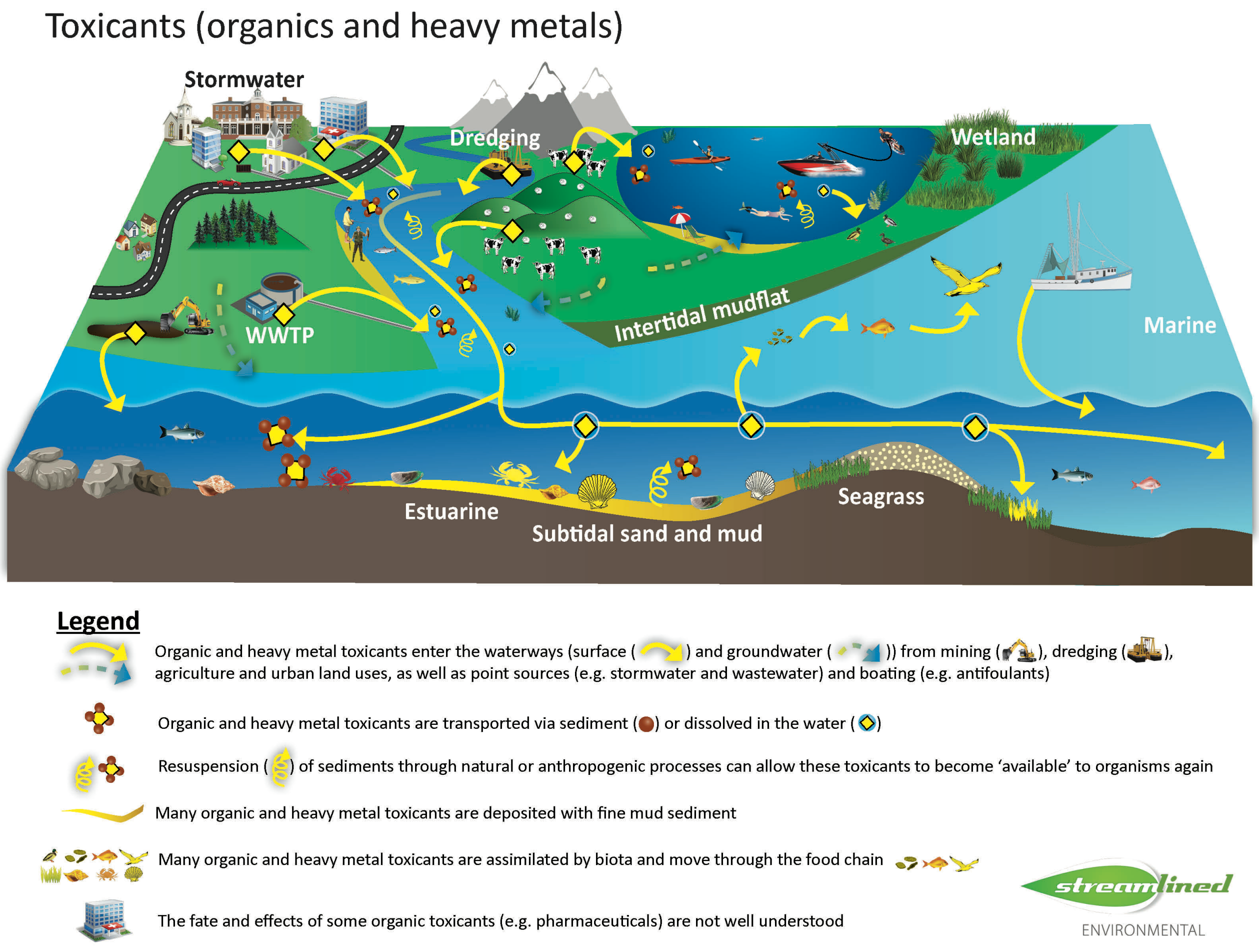

Figure 2. Conceptual model of the potential sources and fate of organic and heavy metal toxicants

Legacy Organic Contaminants

Legacy organic contaminants are chemicals, often used or produced by industry, which remain in the environment long after they been banned. Due to their persistence they are also called persistent organic pollutants (POPs). POPs generally have low solubility in water and associate strongly with particulate matter (suspended solids). As such, they may be transported great distances and settle in low energy environments (such lake beds, slow moving sections of rivers, estuaries). POPs may exhibit acute and chronic toxic effects and generally bioaccumulate through the food chain. Bioaccumulation processes follow the 'you are what you eat' principle and concentrations of POPs generally increase up the food chain (trophic level), increasing the risk of consumption of higher trophic species. The amount of bioaccumulation of POPs is dependent on lipid (fat) content and the amount of depuration (removal).

Primary indicators of POP contamination are through ANZECC sediment quality guidelines. Secondary indicators of POP contamination and potential consumption risks are through comparison of POP levels in selected species with food safety guidelines (FSANZ). Shellfish are good indicators of POP contamination in the marine environment as they are sessile (fixed in one place) filter feeding organisms with high lipid (fat) content that is linked to POP accumulation. Similarly, in the freshwater environment, eels are good indicators of POP contamination as they are long-lived apex predators with high levels of lipid.

The most common classes of POPs include organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), and dioxins.

OCPs are insecticides used historically in significant quantities in New Zealand, and include dichlorodiphenyltrichloroethane (DDT), dieldrin, and chlordane. OCPs have been banned for a considerable time (circa. 1989), however due to their persistence and stability in soil and sediment (and long-lived biota, such as eels) they are still present in the environment.

Exposure to OCPs occurs mostly from eating foods containing low concentrations of these compounds, particularly meat, fish and poultry. OCPs have various human health effects and the three mentioned above have all been classed as probable human carcinogens.[7] OCPs are highly toxic to most aquatic species (ANZECC & ARMCANZ, 2000).

Polychlorinated biphenyls (PCBs) are mixtures of up to 209 individual chlorinated compounds, referred to as congeners. PCBs have been used as coolants and lubricants in transformers, capacitors, and other electrical equipment because they have low flammability and are good electrical insulators.[8] Ingestion of PCBs is largely via contaminated food (fish, meat and dairy) and drinking contaminated water, while inhalation exposure can occur by breathing air near hazardous waste sites.[8] Health effects that have been associated with exposure to PCBs include acne-like skin conditions in adults and neurobehavioral and immunological changes in children.[8] The US EPA classifies PCBs as a probable human carcinogen.[7] PCBs cause a variety of acute and chronic toxicity effects on aquatic biota (ANZECC & ARMCANZ, 2000).

Dioxins[9] are mainly by-products of industrial processes but can also result from natural processes, such as volcanic eruptions and forest fires. Dioxins are unwanted by-products of a wide range of manufacturing processes including smelting, chlorine bleaching of paper pulp and the manufacturing of some herbicides and pesticides. In terms of dioxin release into the environment, uncontrolled waste incinerators (solid waste and hospital waste) are often the worst culprits, due to incomplete burning. The highest levels of dioxins are found in some soils, sediments and food, especially dairy products, meat, fish and shellfish. Very low levels are found in plants, water and air. Dioxins are highly toxic to humans and aquatic organisms.

Emerging Organic Contaminants (EOCs)

Many chemicals present in the environment may be classed as emerging organic contaminants (EOCs), which are a subset of emerging contaminants (ECs). ECs can be defined as:

- "any synthetic or naturally occurring chemical or any microorganism that is not commonly monitored in the environment but has the potential to enter the environment and cause known or suspected adverse ecological and (or) human health effects".[10]

[7] https://www.epa.gov/iris
[8] http://www.atsdr.cdc.gov/substances/index.asp
[9] http://www.who.int/mediacentre/factsheets/fs225/en/
[10] http://toxics.usgs.gov/regional/emc/

EOCs encompass a large variety of chemicals. These include human and animal medicines (pharmaceuticals), antimicrobial disinfectants in soaps/shampoos, UV-filters in sunscreens, fragrances, pesticides, and those associated with industry (plasticisers, corrosion inhibitors, surfactants, flame retardants). There is considerable overlap of similar types of EOCs found in wastewater, stormwater, and landfill leachate, whereas those derived from agriculture, horticulture and aquaculture are more specialised to these industries (Table 3).

There is global concern that the presence of EOCs in the environment may lead to adverse effects on human and ecological health. Some EOCs (endocrine disrupting chemicals or EDCs) are implicated in affecting male and female reproduction, juvenile development and certain cancers by disrupting endocrine (hormonal) systems in many species (WHO/UNEP, 2012).

Antimicrobial resistance - resistance of a microorganism to an antimicrobial drug that was originally effective for treatment of infections caused by it - is an increasing threat to global public health. The use and misuse of antimicrobial drugs accelerates the emergence of drug-resistant strains (WHO, 2015). Furthermore, accumulation of antimicrobial chemicals in sediments may have an impact on resident microbial communities, important in such processes as nitrogen cycling (for example, nitrifying and denitrifying bacteria).

In certain jurisdictions some EOCs have recently undergone restrictions or bans, or their safety is currently being assessed (see Section 6.10.1).

Indicators are generally lacking for many EOCs. There are ANZECC guidelines for 11 EOCs in water (including surfactants, plasticisers, pesticides and a herbicide) but no ANZECC sediment quality guidelines. Biosolids guidelines for some EOCs are currently being developed (see Section 4.7.2).

Table 3. Classes of EOCs by major sources (modified from Stewart et al., 2016b)

EOC Class	Sewage	Stormwater	Landfill leachate	Agriculture /Horticulture	Aquaculture	Recreation
Pharmaceuticals	√	√	√			√
Plasticisers	√	√	√			
Antimicrobials	√	√	√			
Corrosion inhibitors	√	√				
Flame retardants	√	√	√			
Surfactants	√	√	√	√		
UV-filters	√	√	√	√		√
Steroid hormones				√		
Musk fragrances	√	√	√			
Veterinary medicines				√	√	
Pesticides				√		
Antifouling co-biocides					√	

Petroleum-based organic contaminants

Contaminants contained in petroleum industry include hydrocarbons, simple aromatics and fused aromatics. Hydrocarbons are, by definition, made up of carbon and hydrogen. Some chemicals that may be found in petroleum are jet fuels, mineral oils, BTEX (benzene, toluene, xylenes), and polycyclic aromatic hydrocarbons (PAHs, e.g. naphthalene, and fluorine).

Often, BTEX and PAHs are measured as specific components as they have a range of toxic effects. Many PAHs have chronic and/or acute toxicity to a range of aquatic organisms. Their toxicity can be magnified significantly by photo activation with UV light (ANZECC, 2000). PAHs are known to bioaccumulate in some species lower in the food chain (shellfish especially) as they don't have the ability to metabolise and remove them.

PAHs are known to be carcinogenic in humans and other animals and can also induce narcosis, photoactivated toxicity and disrupt endocrine processes. The toxicity of PAHs in specific discharges would be governed by the bioavailability of the contaminants, which is largely a function of their concentrations in the dissolved phase.

Oil contamination of the aquatic environments is most commonly sourced from urban run-off or boats (Figure 3). The component of petroleum that does not have a high toxicity can cause taste problems in seafood in locations in the vicinity of consistent discharges. This is now a rare occurrence. The incidence of unsightly slicks and the effects on aesthetic values are seen as the main issue with this stressor. Large oil spills from tankers or the like are specific cases and are also considered here.

PAHs are formed by the incomplete combustion of organic material. Natural background levels of PAH are found in the environment from events such as forest fires and volcanic activities. However, the most significant sources are from human activities such as motor vehicle emissions, roading materials such as coal tar, and wood and coal burning fires (Kelly, 2007).

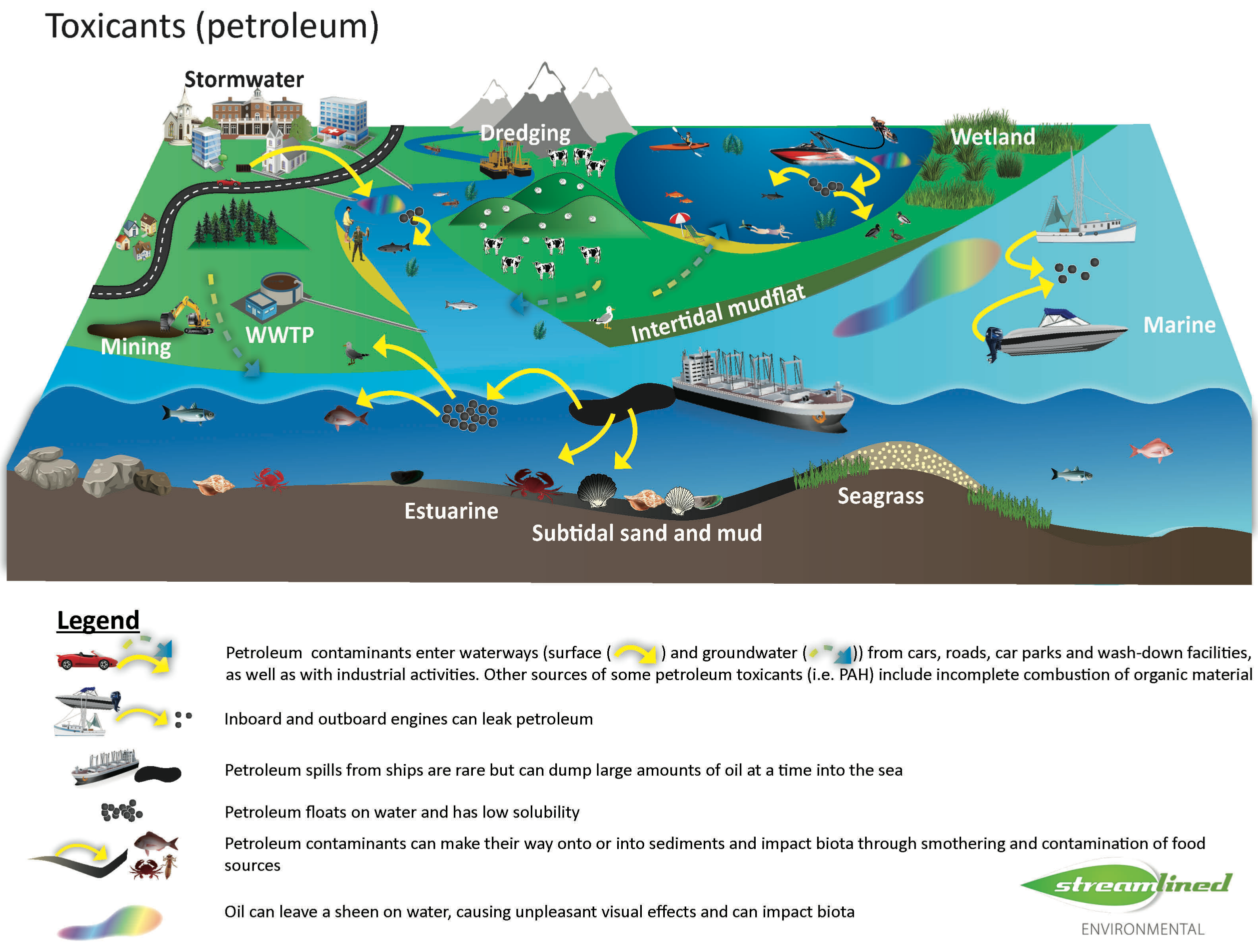

Figure 3. Conceptual model of potential sources and fate of petroleum based toxicants

<u>Miscellaneous toxicants</u>

Some chemical toxicants are only relevant to specific industrial and tradewaste discharges (see Section 5.4). These are outside general metal, POP, or EOC classifications and include solvents and radionuclides.

2.5.2 Nutrients

Nitrogen (N) and phosphorus (P) are nutrients that are natural parts of aquatic ecosystems. N and P support the growth of algae and aquatic plants, which provide food and habitat for fish, shellfish and smaller organisms that live in water.

However, too much N and P in water bodies (see Figure 4) can cause aquatic plants and algae to grow faster than ecosystems can handle. Significant increases in algae harm water quality, food resources and habitats, and decrease the oxygen that fish and other aquatic life need to survive. Large growths of algae are called “algal blooms” and can severely reduce or eliminate oxygen in the water, leading to illnesses or mortality of fish. Some algal blooms are harmful to humans because they produce elevated toxins and bacterial growth that can make people sick if they come into contact with polluted water, consume contaminated fish or shellfish, or drink contaminated water. For example, cyanobacteria (blue-green algae) can produce neurotoxins that, when ingested, can cause nausea, paralysis and even death in humans and livestock. Once the algal bloom dies off and the algae breaks down, the nutrients contained within the algae that caused the initial growth can then be released back into the water, initiating another cycle of weed and algal growth and decay. This is known as 'nutrient spiralling'.

Nitrate and ammonia show potential for toxic effects in freshwater. ANZECC provide trigger values for different levels of species protection (80-99%) to protect ecosystem health from nitrate and ammonia (ANZECC & ARMCANZ, 2000). Furthermore, NPS-FM attribute states (levels) have been set to protect ecosystem health in rivers (for nitrate) and rivers and lakes (for ammonia) (Ministry for the Environment, 2014). Drinking water guidelines (maximum acceptable values: MAVs) have been set for nitrate (and nitrite: NO_2) by Ministry of Health (2008). They stated that short-term exposure MAVs for nitrate and nitrite have been established to protect against most vulnerable populations, i.e. methaemoglobinaemia (blue baby syndrome) in bottle-fed infants.

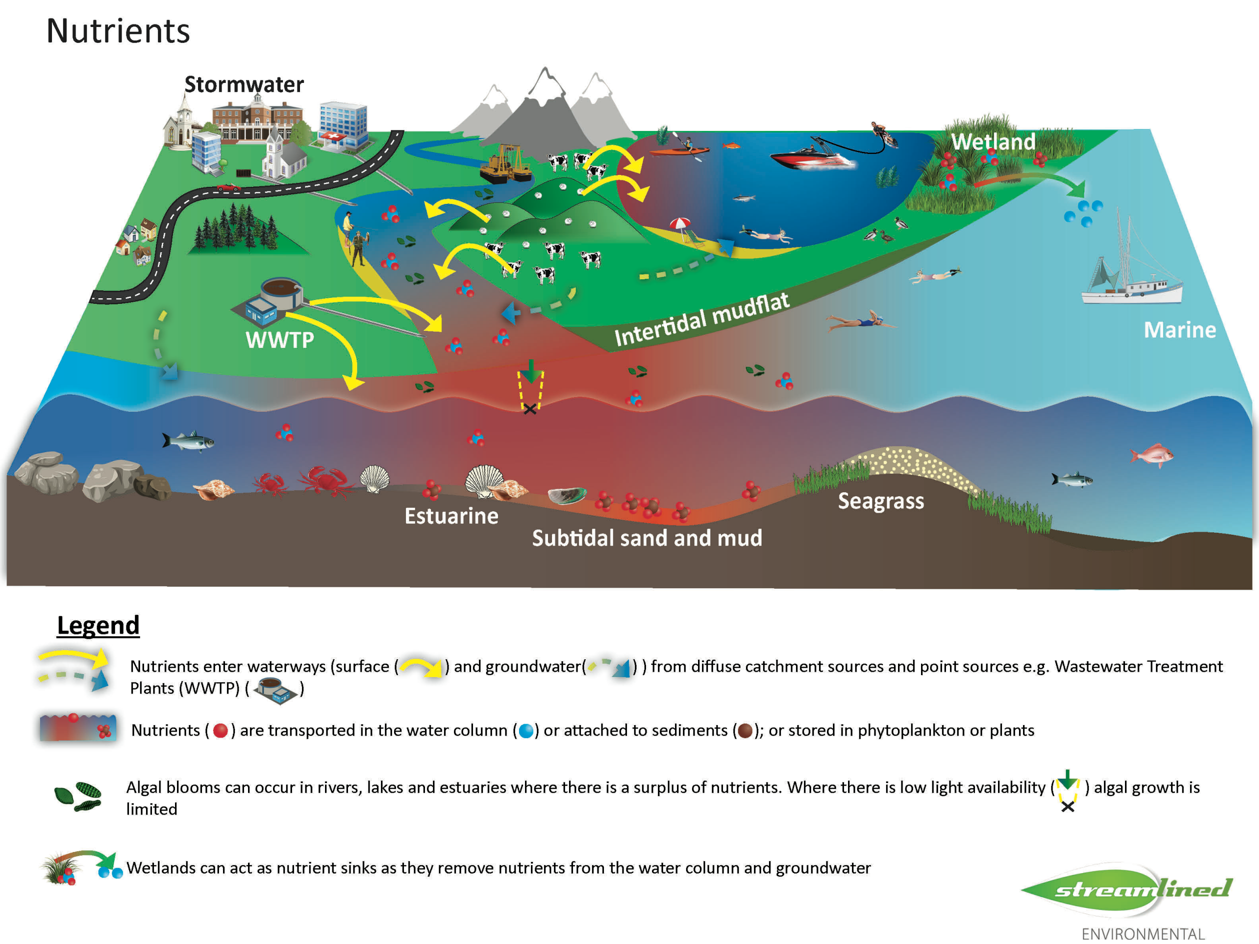

Figure 4. Conceptual model of potential sources and fate of nutrients

2.5.3 Sediment

Sediment is possibly the most common contaminant of streams, rivers, and estuaries throughout NZ, and is caused principally by a combination of inappropriate landuse activities and intensive rainfall. Consequently sediment has the potential to affect the biota in those environments (see Figure 5).

Water bodies with high turbidity can affect ecosystem health either directly or indirectly. Suspended solids directly affect the ecosystem by settling on top of algae and organic matter which smothers a critical food source. Suspended solids can also smother benthic organisms, invertebrate and fish eggs, and is also capable of blocking fish and invertebrate gills. If waterways contain very high amounts of suspended solids, it can result in deterioration of the habitat within streams, for example by infilling and reducing water depths, and subsequently impacting fish migration or reducing available habitat for macroinvertebrates. Indirect effects include reduced light penetration which decreases primary production and reducing visibility for predators, resulting in alterations to predator-prey relationships. Elevated suspended sediments can also impact aesthetic and cultural values through reduction in visual clarity.

In riverine environments, Rowe et al., (2002) demonstrated lethal effects for sensitive fish species at turbidity levels larger than 1000 NTU. However, NTU values above 20,000 were necessary for lethal effects on mayflies, caddisflies and koura. Infilling of estuaries and associated expansion of mangroves (not an issue in Otago) are the principal effects of sediment in nearshore marine environments, however large pulses of sediment also have the potential to smother fauna resulting in large decreases in abundance and slow recovery times (Kelly, 2010a). Suspended sediment also affects photosynthesis and primary production by reducing water clarity, which can affect the survival, recruitment and occurrence of seagrass (Kelly, 2010a).

Sediment can also be a vector for long-range transport of toxicants, nutrients and pathogens through the aquatic environment. In low energy environments settlement may occur with the potential for the associated contaminants to be released into the water column.

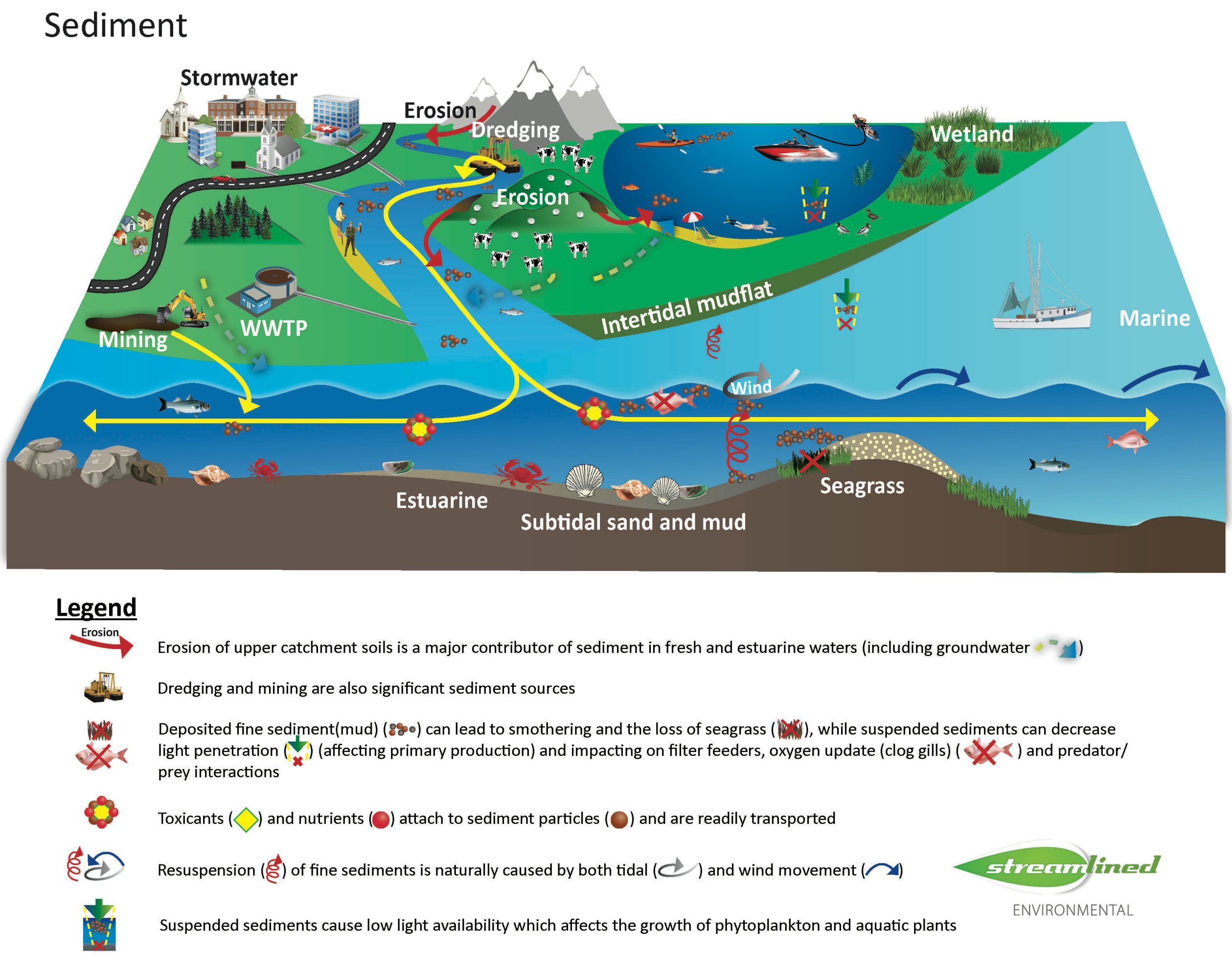

Figure 5. Conceptual model of potential sources and fate of sediment

2.5.4 Pathogens

Pathogens include bacteria, viruses, protozoans and fungi, and are causative agents of disease. Unsafe concentrations of pathogens in fresh and coastal waters can lead to restrictions on drinking water supplies, shellfish harvesting, fish kills and if ignored or unnoticed, to health problems in humans and other organisms (see Figure 6).

Some pathogens occur naturally, while others are carried into waterways after defecation/urination/shedding from human or animal hosts. Human derived sources include sewage effluent, stormwater run-off, sewage from ships, recreational population using the water, and industrial processes. Animal derived sources include agriculture (effluent discharge and disposal; stock access to waterways) and wildlife. Rivers discharging into coastal areas may carry abundant micro-organisms from these diverse sources. High concentrations of pathogens usually occur after storms due to surface run-off, sediment re-suspension and because rainwater gets into sewerage pipes through faults and illegal connections and causes sewage to overflow. Contamination from human sources (e.g. faecal pollution) presents a greater risk to humans than contamination from animal sources because many animal pathogens are not infectious to humans. Risks to humans from pathogenic organisms are higher in areas with large population densities or with significant tourism, and are perhaps best assessed by the volume of stormwater and coastal discharges indicators.

Different pathogen-indicator organism relationships may exist between saline and fresh waters, so the same level of faecal indicator bacteria in freshwater and marine environments does not mean the health risk is the same.

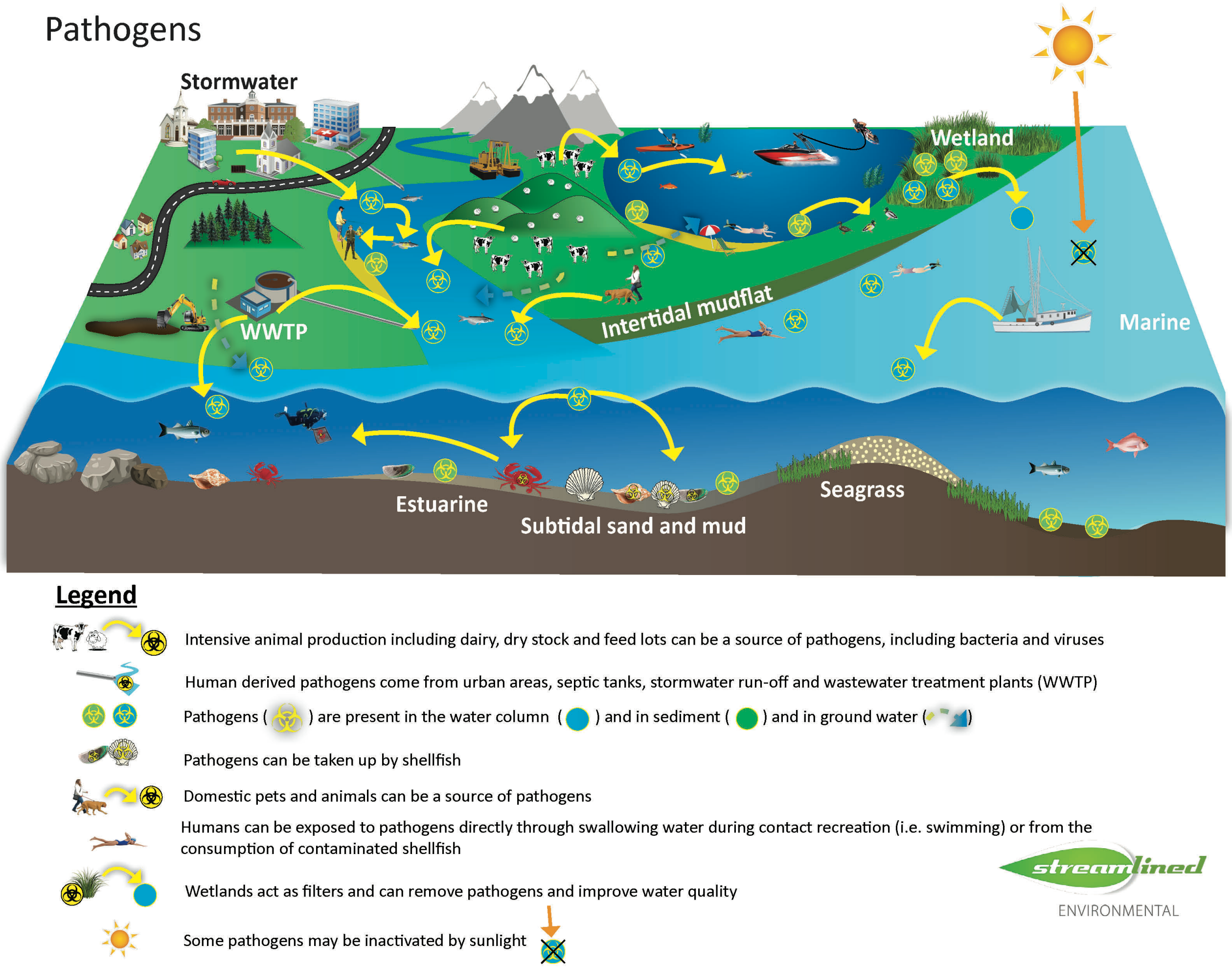

Figure 6. Conceptual model of potential sources and fate of pathogens

2.5.5 Gross pollutants

In context of this report, gross pollutants are associate exclusively with stormwater discharges.

Based on international standards, gross pollutants are generally defined as material that would be retained by a five millimetre mesh screen (Fitzgerald and Bird, 2010). Gross pollutants include vegetation, personal and commercial plastics, personal paper and metals. Coarse sediment (>5mm) also fits into this category. The largest proportion of gross pollutant load (by mass) carried by urban stormwater is from leaves, twigs and grass clippings, while the greatest proportion of litter – by mass and frequency – comprised paper and plastics, which enter the drainage network as street litter from mainly commercial areas (Allison, et al, 1997).

Gross pollutants primarily cause degradation of aesthetic values, however they may contribute to other effects. For example, plastics can result in death of marine life through entanglement and ingestion, as well as causing more chronic effects by providing vectors for dispersal of POPs and invasive marine pests. Furthermore, where plastics are degraded into smaller sizes (microplastics) they may be ingested by aquatic organisms, providing an avenue for uptake of toxicants associated with that plastic.

2.5.6 Temperature

Water temperature directly affects the solubility of dissolved oxygen, and the rates of physico-chemical (example toxicant solubility) and biochemical (example enzyme rate) processes. Temperature profoundly affects aquatic ecosystems because the growth of most organisms (that have little or no ability to thermo-regulate) is a strong function of temperature. Each species has an optimum temperature of maximum growth rate. Either side of this optimum temperature, stresses occur on aquatic organisms with their ability to tolerate these changes varied and dependent on the species (Davies-Colley et al., 2013).

2.5.7 Inorganic macrocomponents

In the context of this report, inorganic macrocomponents are associate exclusively with landfill leachate (see Section 6.4.2), as these discharges may contain inorganic macrocomponents at potentially toxic levels. Inorganic macrocomponents include calcium, magnesium, sodium, potassium, ammonium, iron, manganese, chloride, sulphate and bicarbonate. With the exception of ammonia, inorganic macrocomponents generally require concentrations many orders of magnitude higher than toxicants (covered in previous sections) to elicit toxic effects. For example, the ANZECC 99% freshwater trigger value for manganese is 1200 µg/L, whereas copper and lead are 1.0 µg/L, and zinc is 2.4 µg/L (ANZECC & ARMCANZ, 2000).

2.6 Synergistic effects

Discharges contain a variety of contaminants, and synergistic effects can occur between contaminants. Two common examples are described below.

2.6.1 Ammonia and pH/temperature

Ammonia exists in water in two forms, as ammonia (NH_3) and ammonium (NH_4^+). There exists an equilibrium between the two forms, the proportion of which is dependent on pH and temperature. The reduction in *both* pH (i.e. more acidic water) and temperature favours the ammonium form. High levels of ammonia (NH_3) can be toxic to aquatic life. Acutely toxic concentrations of ammonia may cause loss of equilibrium, hyper-excitability, increased breathing, cardiac output and oxygen uptake; and in extreme circumstances, convulsions, coma and death in fish (ANZECC & ARMCANZ, 2000). Sub-lethal concentrations of ammonia may reduce hatching success, growth rate and morphological development, and result in pathological changes in tissues of gills, liver and kidneys (ANZECC & ARMCANZ, 2000). Therefore, higher temperature and pH water is likely to produce a synergistic effect which makes ammonia present more toxic to aquatic species.

2.6.2 Water hardness and nitrate/metal toxicity

Water hardness is the concentration of calcium and magnesium ions in solution. Water hardness has an effect on toxicity of six heavy metals; cadmium, chromium (III)[11], copper, lead, nickel and zinc, where the bioavailability of these 6 metals (and hence toxicity) reduces with increasing water hardness. As such ANZECC recommend correcting for water hardness when deriving water quality trigger value guidelines for these 6 metals (ANZECC & ARMCANZ, 2000). Maximum acceptable values of these 6 metals in drinking water are not corrected for water hardness (Ministry of Health, 2008).

Water hardness also has an effect on nitrate toxicity. A number of studies have identified water hardness as a factor affecting both acute and chronic nitrate toxicity in some species. The mechanism for this effect is presently unknown, but it is likely that chloride ion (Cl^-) - which is known to modify nitrite (NO_2) toxicity – and not calcium/magnesium (as for metals) is the most likely factor in nitrate toxicity (Hickey, 2013).

2.7 Indicators of adverse effects

An indicator can be defined as:

> "An environmental indicator is a parameter, or a value derived from parameters, that points to, provides information about and/or describes the state of the environment, and has a significance extending beyond that directly associated with any given parametric value. The term may encompass indicators of environmental pressures, conditions and responses"[12].

There are a huge range of indicators that can potentially be used to detect and measure the effects of discharges and associated contaminants on the values of aquatic environments. These indicators, methods used to assess them, and relevant guidelines or publications are summarised in Table 4, with more detailed information included in Appendix B.

Table 4. Major applicable indicators/methods used to assess adverse effects on specific values. Acronyms are defined in preceding text.

Value	Indicator	Method/Parameters	Relevant guideline(s)/reference
Aesthetic	Water clarity	Secchi depth, Black disk clarity	ANZECC WQG
	Nuisance plant growth	Periphyton cover	NOF NPS-FM
	Greasy films	Total Petroleum Hydrocarbons (TPH)	Sediment only: ANZECC-ISQG (under revision (Simpson et al., 2013))
	Litter	Presence/extent of litter	None
Cultural	Range of physical and biological indicators	Cultural Health Index; Marine Cultural Health Index; State of the Takiwa	None
Ecosystem Health	Macroinvertebrate community condition	MCI/QMCI %EPT # EPT taxa	Stark and Maxted (2007)

[11] Only chromium (III), not chromium (VI)
[12] https://stats.oecd.org/glossary/detail.asp?ID=830

Value	Indicator	Method/Parameters	Relevant guideline(s)/reference
		Abundance	
	Fish community composition	Fish Index of Biotic Integrity (IBI)	Joy (2013)
	Fish health	Fish condition	Richardson (1998)
	Aquatic macrophyte condition	LakeSPI	Burton and Clayton (2014)
	Fish deaths	Number of mass mortality events	None
	Benthic health	Benthic Health Model (BHM)	Anderson et al. (2006)
	Trophic condition	Estuarine Trophic Index (ETI)	Under development. See Robertson et al., (2016a, 2016b)
Drinking (potable) water	Water quality	Water quality analysis (e.g. nitrate, E. coli, arsenic, dieldrin)	MOH drinking water standard (2005, Revised 2008)
Irrigation	Water quality	Water quality analysis (e.g. nitrate, E. coli, arsenic, dieldrin) Salinity and sodicity	ANZECC WQG
Human consumption of aquatic organisms (mahinga kai)	Microbiological contamination	E. coli Faecal coliforms	ANZECC guidelines QMRA (McBride, 2014)
	Organic and metal contaminants	Contaminant concentrations	FSANZ
Primary contact recreation	Skin irritation Greasy films	Cyanobacterial counts Total Petroleum Hydrocarbons (TPH)	NOF NPS-FM Sediment only: ANZECC-ISQG (under revision (Simpson et al., 2013))
	Microbiological contamination	# of E. coli (freshwater) # of Enterococci (saltwater)	QMRA (McBride, 2014) MfE Microbial Water Quality Guidelines
Public Health	Water quality	Water quality analysis (e.g. nitrate, E. coli, arsenic, dieldrin)	MOH drinking water standard
Recreational	Secondary contact	E. coli Planktonic cyanobacteria	ANZECC WQG for recreational purposes; NOF NPS-FM; Sediment
Stock	Reduction of animal production, fertility Stock deaths	Biological parameters Salinity and sodicity Nutrients Organic and metal contaminants	ANZECC livestock drinking water

2.8 Making connections

An understanding of how the values of receiving environments are affected by discharges is essential for making informed decisions on how to prioritise management efforts. Figure 7 provides a simplistic overview of these connections. Subsequent chapters describe these connections for each of the major discharge types.

Essentially, adverse effects on the values of receiving environments may result from contaminants in discharges. The relative sensitivity of the receiving environment may lessen or worsen the adverse effects. Indicators provide a means of measuring the contaminants and values, as well as changes in either of these as the result of management actions.

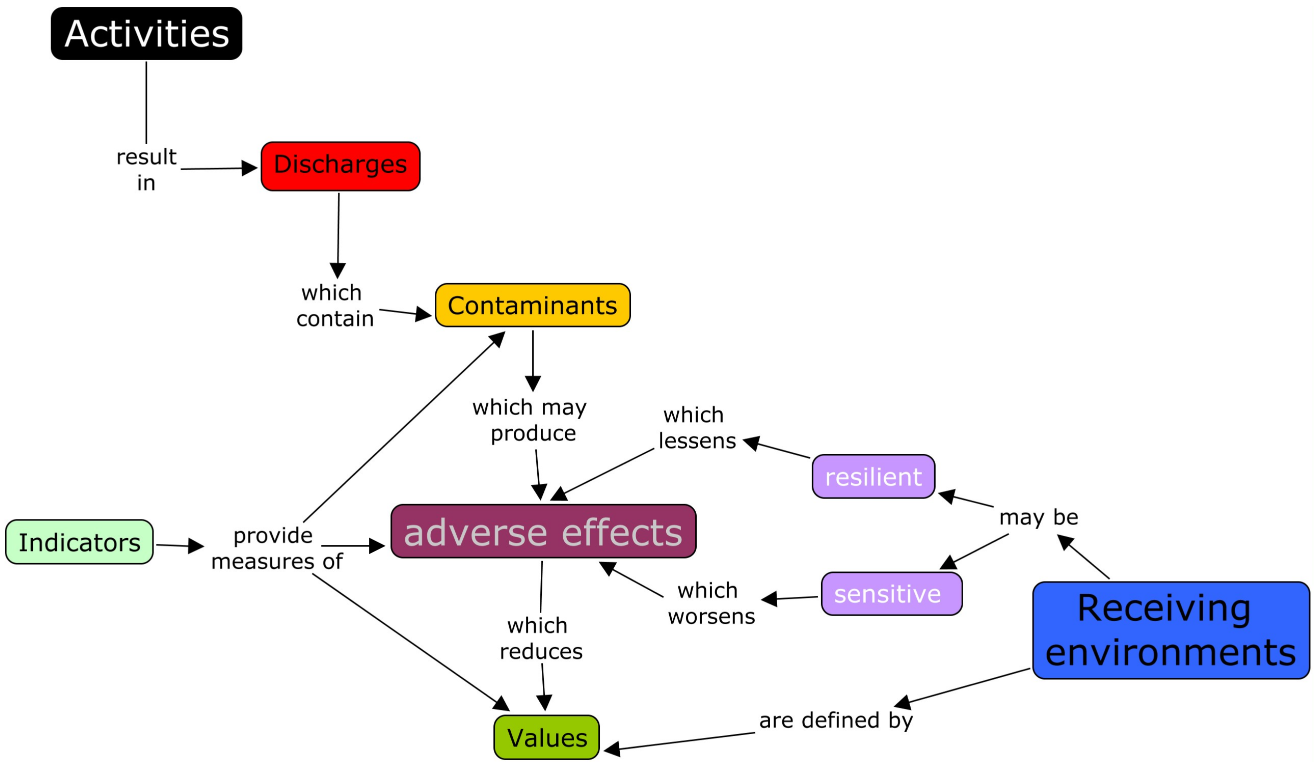

Figure 7. Graphical representation of the relationship between activities and receiving environments

3. Stormwater

3.1 Key points for Stormwater

- **Adverse effects –** Adverse effects in the Upper Otago Harbour have been associated with specific stormwater outfalls and legacy effects. Recent monitoring of Upper Harbour waters found general exceedance of ANZECC guidelines, though this is not generally reflected in biotic measures. High faecal indicator concentrations (exceeding recreational guidelines) have been found in stormwater outfalls, especially under wet weather flows but also under base flow conditions. Streams forming the headwaters of Dunedin's stormwater system are generally degraded but, in common with international studies, there is no evidence that stormwater contaminants are the principal cause.
- **Key contaminants –** Key stormwater contaminants typically include heavy metals, PAHs, EOCs, pathogenic bacteria and viruses and gross pollutants (especially plastics). In lake catchments, nutrients and suspended sediment may also be important contaminants. There are two broad sources of contaminants – those associated with dry deposition and subsequent wash off, and those associated with sewage cross-contamination. International studies have shown that human sewage contamination of stormwater systems is near universal.
- **Key knowledge gaps/risks –** While results of consent monitoring indicate ecological effects are relatively low, the monitoring design that these conclusions are based upon doesn't lend itself to robust scientific conclusions. New chemical and microbiological techniques for detecting sewage ingress should be trialed. There is no regional information on effects of stormwater on inland waters, particularly around Queenstown and Wanaka. While risks are low, it is an information gap that should be filled.
- **Current management/mitigation –** Auckland is the leading region in New Zealand on management/mitigation of stormwater effects, though other regions are making a push in this area. Internationally, many countries have specific expertise, though in our region Australia is a key player, particularly for freshwaters and urban stream restoration. Stormwater detention ponds are still the major mitigation method for new developments, together with water-sensitive urban design features such as grassy swales, pervious pavers, and stormwater reuse. For older cities, a range of chemical adsorbents have been trialed. Major issues with operational costs and the need for relatively frequent replacement of adsorbent beds have been identified. Low cost methods of mitigation from dry deposition of contaminants include increasing the frequency of street cleaning.

3.2 Introduction

3.2.1 What is stormwater?

Water run-off from roads, roofs, car parks, gardens and fields often goes straight to the nearest waterway (e.g. stream, lake, beach, harbour or wetland). Stormwater results from human environments where natural vegetation has been cleared and replaced by hard, impermeable surfaces. These prevent rainwater from soaking into the ground and cause water to run off the ground more quickly. This run-off can be erosive, fast moving and can contain many contaminants (also called pollutants).

3.2.2 Why is stormwater an issue?

In the past, stormwater run-off was only considered to be a concern because it could cause flooding and erosion. Nowadays, stormwater is acknowledged as a major source of pollution in the world's waterways. Our modern lifestyle contributes to stormwater pollution, often unwittingly.

Stormwater may be contaminated by:

- Construction sites;
- Motor vehicles, through oil and metals such as lead, copper, zinc washing off roadways;
- Soil, which makes waterways cloudy and can silt them up. Silt can suffocate fish by clogging their gills;
- Rubbish, such as plastic bags, bottles and other street litter;
- Herbicides, garden fertilisers, rotting garden clippings;
- Detergent from car washing;
- Domestic animal faeces;
- Illegal and accidental spills or dumping into stormwater drains;
- Air pollution, particularly dust-borne contaminants.

3.3 Types of stormwater discharges considered

Discharges from stormwater considered in this report are those from publicly owned (municipal) stormwater systems, roads, and industrial sites. Runoff from roads normally enters the stormwater network in urban areas but in rural areas, particularly state highways, road runoff may enter watercourses directly. Because of relatively low traffic density in rural Otago, these areas are not expected to be as large an issue for the more urban focussed contaminants discussed in Section 3.4. However, an exception may be runoff from de-icing agents used on highways during winter (salt, and calcium magnesium acetate (CMA) being the two most common chemicals used for that purpose), and sediment run-off from gravel roads. A single study on the environmental effects of CMA in Otago is discussed in Appendix C. Stormwater from industrial sites also usually enters the municipal stormwater network, but for ‘high risk’ industries, some Councils impose on-site treatment requirements. The contaminant runoff from such sites are likely to be a subset of the contaminants discussed in Section 3.4.

Contaminants in stormwater and their effects on receiving environments have been extensively studied internationally, and much of this chapter focusses on advances in that arena and the implications of these findings to Otago.

Not surprisingly, most of the work on contaminants in Otago stormwater and the effect on receiving environments is centred on Dunedin. There appear to be no reports on stormwater quality in Otago outside the Dunedin metropolitan area.

Most of this monitoring effort has focussed on the upper Otago Harbour, which receives stormwater from multiple outlets draining the Dunedin CBD and inner suburbs. These reports are reviewed in Appendix C. In summary, the consent monitoring reports conclude that:

1. Concentrations of stormwater contaminants were generally within the range found for other NZ urban centres;

2. An exception was polycyclic aromatic hydrocarbons (PAHs) and total petroleum hydrocarbon (TPH) loadings in the Portobello road catchment, which were at the high end of ranges reported in NZ and internationally (due to legacy effects from an old gas works);
3. Isolated stormwater related 'hotspots' were adjacent to stormwater outlets outside the upper Harbour (e.g. Carey's Bay), however the contaminants associated with these hotspots were readily traceable to specific activities (e.g. high copper with boat building/repairs);
4. Tracing studies for the presence of sewage in stormwater have been ambiguous, and;
5. Stormwater systems at new developments are not giving rise to contaminants at concentrations where they would be of concern, although high indicator bacteria concentrations at one such development (Sunninghurst) may be indicative of sewage inputs.

3.4 Typical contaminants

Urban stormwater arises principally from the entrainment of contaminants deposited on streets, buildings, and other urban infrastructure, and leached from parks and gardens. It is thus largely an episodic discharge associated with a rainfall event. Stormwater is also commonly contaminated by sewage, which can occur from overflowing sewers, which are common in older cities, (Gasperi et al., 2012), or accidental or illegal cross-connections. As will be discussed later in this section, some degree of sewage contamination is near common in urban stormwater systems worldwide. Thus stormwater can be expected to contain litter, sediment, nutrients, metals, fuels, oils, polycyclic aromatic hydrocarbons (PAHs), legacy pesticides (such as DDT, lindane, dieldrin and chlordane), legacy synthetic compounds (such as PCBs), newer emerging organic contaminants (EOCs), and pathogens.

The contaminants most frequently cited as causing adverse effects from urban stormwater in receiving environments are: metals, PAH and total petroleum hydrocarbons, pathogens, and, as more is known about their effects, EOCs. With the possible exception of pathogens and some EOCs (e.g. some pharmaceuticals and pesticides), these contaminant groups are important because they adsorb to sediments and settle in lentic (still-water) environments (such as lakes or estuaries). Litter, sediments, and nutrients are still important, but usually only result in significant effects from stormwater in more extreme cases. A summary of these contaminant classes, the values they potentially compromise, and the receiving water types potentially the most sensitive to these contaminants is given in Table 5. A discussion of the likely effects of stormwater on different receiving environments in Otago is given in Section 3.5.

Table 5. Typical constituents present in stormwater discharges with associated values affected and most sensitive receiving environments

Type	Example	Effect	Values Affected	Most sensitive receiving environments
Litter	Plastic bags and containers	Mortality to marine life, transport of other chemicals and organisms, visual	Aesthetic, Ecosystem Health	Marine (bay; harbour; estuary; nearshore)
Sediment	Total suspended solids	Visual (fish), mortality to marine life (burial), reduction in photosynthesis and primary production	Aesthetic, Ecosystem Health, Cultural (Mahinga Kai)	Freshwater (lakes; river) Enclosed marine environments (harbour; estuary)
Nutrients	Nitrogen, phosphorus, nitrate	Algal blooms, oxygen depletion, toxic effect	Aesthetic, Cultural, Ecosystem Heath, Human Heath (Nitrate), Recreation	Freshwater (Lake; river; aquifer Enclosed marine environments (harbour; estuary)
Microbial contaminants	Pathogenic bacteria, viruses	Risk to human health when drinking freshwater; bathing and eating shellfish	Public Health; Cultural; Groundwater Quality; Primary Contact Recreation; Mahinga Kai; Recreational	Freshwater (lake; river; aquifer) Marine (bay; harbour; estuary; near-shore)
Biodegradable organic materials	Oxygen depletion in rivers, lakes and coastal environments, grease	Fish death, odours	Ecosystem Health; Cultural; Aesthetic	Freshwater (Lake; river; aquifer; wetland) Enclosed marine environments (harbour; estuary)
Trace organic materials	Fuels and oils, PCBs, PAH, solvents, detergents, other EOCs	Toxic effect Aesthetic inconveniences Bio-accumulation in the food chain	Aesthetic; Cultural; Ecosystem Health; Groundwater Quality; Irrigation; Mahinga Kai Consumption; Primary Contact Recreation; Public Health; Recreational; Stock	Freshwater (lake; river; aquifer) Enclosed marine environments (harbour; estuary)
Metals	Hg, Pb, Cd, Cr, Cu, Ni	Toxic effect, bioaccumulation	Aesthetic; Cultural; Ecosystem Health; Groundwater Quality; Irrigation; Public Health; Recreational; Stock	Freshwater (lake; river; aquifer; wetland) Marine (bay; harbour; estuary; near-shore)

Litter, particularly plastics are prevalent in urban stormwater. Plastics are estimated to comprise 60-80% of all marine litter and their volume and persistence in the marine environment makes them particularly problematic. While plastics can cause issues in either freshwater or marine environments, it is their common presence in the marine environment that causes most concern, with small plastic fragments found in even remote locations.

While plastic fragments are found on most NZ beaches, they are most abundant near urban centres (Gregory, 2009) and at least some of this litter would have originated from stormwater. However, while it is an issue, and has been included here for the sake of completeness, it is relatively easily mitigated through use of screens and litter traps.

Sediment is possibly the most common contaminant of streams, rivers, and estuaries throughout NZ, and is caused principally by a combination of inappropriate landuse activities and intensive rainfall. Many toxicants (organic pollutants, metals and pathogens) may be transported by sediment. While suspended sediment effects on seagrass is a significant issue for activities such as dredging in estuarine or near-shore coastal environments for example, the suspended sediment load from urban stormwater is unlikely to be sufficiently high or persistent to be an issue. A similar conclusion can be drawn for the effects of stormwater from stable urban catchments in freshwater environments. However, for developing urban catchments (i.e. 'greenfield' sites) the combination of high intensity rainfall and exposed soils can cause significant ecological damage in both freshwater and marine environments (Timperley and Reed, 2008). Sediment loads from developing urban catchments have been a major issue in the Auckland region and have led to stringent consent conditions requiring advanced treatment including flocculation on 'at risk' sites.

Nutrients (nitrogen and phosphorus) in urban stormwater are usually associated with ingress of untreated sewage into the stormwater system, rather than stormwater *per se* (Kelly, 2010a). A revision of the NZ urban stormwater handbook (in prep) recommends using median concentrations 0.3 g/m^3 and 1.98 g/m^3 for phosphorus and nitrogen, respectively (R.B Williamson, pers. comm.). While these are considerably higher than median concentrations in runoff from forested areas, they are comparable to those from pastoral runoff. High nutrient loads from urban stormwater can result in nuisance algal blooms in lakes, rivers and estuaries. However, this does not appear to be an issue in urban Auckland (Kelly, 2010a) where there is a very high proportion of urban landuse. We therefore, would not expect it to be a significant issue in Otago either. Similarly, biodegradable organic substances are generally only an issue for stormwater where there is significant ingress of untreated sewage wastewaters.

While the contaminants of concern in stormwater have been known for decades (see the review by Kelly, 2010a), studies since 2010 have aimed to put more certainty on the sources of contaminants, and identified key emerging organic contaminants (EOCs) that have some specificity to stormwater. There have been two themes to this work: (a) Identifying chemical contaminants applicable to urban stormwater and their source (particularly EOCs), and (b) identifying microbial contaminants (pathogens) and particularly the influence of sewage (overflows and cross connections) on microbial contamination from stormwater systems. Large differences in the contaminant profiles have been reported in urban stormwater studies around the world (Ingvertsen et al., 2011). These differences relate to variation in factors influencing contaminant build-up e.g., land use, traffic intensity, antecedent dry period between storm events, diffuse atmospheric contribution, abrasive variation among materials, adjacent soil types, and wind and turbulence. The degree of sewage contamination is also a major factor determining the variation in contaminant profile.

Heavy metal contamination of sediments has long been associated with stormwater and indeed it was the focus of significant research undertaken for Auckland Regional Council in the 1990s and 2000s (Kelly, 2010a). The principal metals of concern were copper (Cu), zinc (Zn) and lead (Pb). These 3 heavy metals are synonymous with studies on stormwater effects on aquatic environments worldwide. Copper is widely used in the manufacture of alloys with zinc, nickel and tin, in metal plating and in the production of copper wire and piping. In the context of stormwater it is often associated with automobile debris, particularly from brake pads (though this is being phased out). It is also used as a fungicide, wood preservative and as a decorative cladding material. The largest uses of zinc are for galvanised iron (roofs) and as as an alloy (Li et al., 2012). Historically, the most significant source of lead in the urban environment was as an antiknock additive in petrol. This has been phased out in the developed world (including New Zealand in 1996) and many international studies have reported declining lead concentrations in stormwater and sediments (Callender et al., 2000). We do note, however, that stormwater monitoring in Dunedin is still reporting lead levels in excess of guideline values (Appendix C).

Apart from biodegradable organic substances, which in stormwater are usually associated with sewage contamination, there are large numbers of other organic substances, many of which occur at trace concentrations. One class of contaminants in particular; polycyclic aromatic hydrocarbons (PAHs) are a key contaminant in urban stormwater. In urban environments, PAHs accumulate in road dust through car exhausts, tyre wear, and oil leaks, and through wear of coal tar binders and asphalt on the road itself (Ahrens and Depree, 2010). PAHs are consequently washed off road surfaces during storm events and enter the stormwater system. PAHs have a low solubility in water and preferentially concentrate on organic and sediment particles or accumulate in the lipid-rich tissues of organisms.

The analysis and understanding of the effects PAHs have in the environment is a rapidly evolving science, and because of their health significance, there has been a lot of recent research targeting specific PAH compounds in stormwater, and their origins. Ingvertsen et al. (2011) proposed a consistent 'minimum' dataset - which included three PAHs; phenanthrene, fluoranthene, and benzo(b,k)fluoranthene - designed to evaluate the effectiveness of stormwater treatment facilities.

Prompted by the European Water Framework Directive, which established a list of "priority hazardous substances", whose emissions, discharges and losses are scheduled to be phased out or completely removed, Zgheib et al. (2012) and Gasperi et al. (2012) published companion papers that provided an inventory of contaminants in stormwater unimpacted and impacted, respectively, by combined sewer outfalls (CSO). The study by Zgheib et al. (2012), which took place in Paris, showed that even with separate stormwater systems a large number of priority pollutants were measured, including PAHs. Gasperi et al. (2012) reported higher concentrations of PAHs in combined sewer outfalls (and some particulate-bound metals) than either stormwater or wastewater alone, which they attributed to the contribution of in-sewer erosion deposits. All the 16 USEPA priority PAHs were measured in CSOs with 75% consisting of the high molecular weight PAHs. This together with high contributions of fluoranthene and pyrene (approx. 15% each) led Gasperi et al (2012) to conclude that most PAHs in CSOs were of pyrolytic (combustion in the absence of oxygen) origin from diesel and gasoline powered vehicles.

Similar findings have been found in other jurisdictions. In Beijing, Zheng et al. (2014) used a dynamic modelling approach for assessing the PAH pollution and its associated environmental risk. A variable time-step model was developed to simulate the continuous cycles of pollutant build-up and wash-off. They showed that Beijing's PAH pollution of road runoff is relatively severe, and the associated risk exhibits seasonal variation. The practice of road sweepings is effective in mitigating the pollution, but the effectiveness is both weather-dependent and chemical-dependent.

PAHs were first reported in Dunedin stormwater in the PhD studies of Brown (2002a). Brown's studies, and later monitoring studies (see Appendix C) found high concentrations of PAHs associated with the Portobello Road catchment, and was thought to be mainly a legacy contaminant associated with a disused gas works.

As well as PAHs, a number of other trace organic chemicals that have a potential ecotoxic effect have been identified in stormwater. The Paris studies of Gasperi et al. (2012) and Zgheib et al. (2012) found a large number of trace organics. For example, polychlorinated biphenyls (PCBs), which have not been used in France since 1987, were regularly detected at environmentally significant concentrations. Pesticides commonly detected included aldrin, dieldrin, atrazine, desethylatrazine (all POPs) whereas other pesticides (diuron, isoproturon, aminotriazole, and glyphosate) as well as phthalates are EOCs. All are termed 'Priority Pollutants' by the European Community as presenting a significant risk to the aquatic environment. Other POPs shown to be environmentally significant in urban stormwater include the perfluoroalkyl acids (PFAAs) (Xiao et al., 2012), which have been produced for both industrial and commercial applications including firefighting foam, insecticides and as polymers to repel water and stains.

Microbial contaminants in stormwater are important because of the association with human health (as opposed to ecological health). In contrast to the other 'typical contaminants' discussed above, receiving waters (as opposed to sediments) is the main exposure risk and human health, rather than ecosystem health the main concern. Because 'pure' stormwater is episodic and therefore related to storm events, it may be argued that it is of little consequence because people are unlikely to be swimming during a storm event. While this may be the case, there are two main reasons why stormwater could still be an issue. Firstly, some people are likely to engage in aquatic recreational activities immediately after a storm event, and pathogens in receiving waters may still be viable. Secondly, it is likely that the stormwater system may be contaminated with sewage, in which case pathogens may enter receiving waters even during baseflow. This may be the case in the Upper Otago Harbour (receiving Dunedin CBD stormwater) as high indicator bacteria have been reported in monitoring, even under baseflow conditions (Appendix C). Thus one of the principal objectives of studies on microbial contaminants in stormwater is to track microbes to their source, known as microbial source tracking.

There have been a number of recent studies internationally that highlight the common nature of sewage contamination of stormwater systems. While such issues are a recognised problem in 'old' cities such as Paris (Gasperi et al., 2012; Zgheib et al., 2012), studies in newer cities such as Brisbane (Chong et al., 2013; Sidhu et al., 2013), Milwaukee (new area) (Sauer et al., 2011) and a rural town in Nova Scotia (Stea et al., 2015) have shown even in situations that have separate stormwater and sewage systems, human sewage contamination of stormwater systems occurs, and is a major reason for the long-term persistence of low quality surface waters around major cities.

Because Australia is a water-short continent, a lot of effort has gone into water reuse, and stormwater is a prime candidate for this. A human health-risk assessment by Chong et al. (2013) found that the concentration of chemical contaminants and associated toxicity were relatively low when benchmarked against alternative water sources such as recycled wastewater, however high numbers of faecal indicator bacteria and detection of human-related pathogens is a major impediment to stormwater reuse (Sidhu et al., 2013). Pathogens reported in this Australian study included human adenovirus (associated with respiratory infections), and human polyomavirus (associated with diseases in immunocompromised individuals).

Traditionally, culture methods for *E. coli* and enterococci have been used for water quality monitoring due to low cost and ease of use. However, these standard indicators are found in both animal and human sources and vary greatly in their potential to carry human pathogens, consequently measuring their levels contributes little to our knowledge of the source of contamination. Recent advances in microbial source tracking techniques based on genetic methods have enabled much more specific information to be obtained on sources of microbial contamination in urban stormwater (Sauer et al., 2011). These authors collected samples from five stormwater outfalls (from a separated stormwater system) over a four-year period and assessed their microbial contamination using traditional indicators as well as genetic methods. All outfalls had the HF183 (human) Bacteroides genetic marker detected in at least one sample, suggesting sewage contamination is nearly commonplace in the urban environment. Based on the ratios of human Bacteroides to total Bacteroides spp., the major source of faecal pollution at four of five river sites that received stormwater discharge appeared to be from human sewage sources rather than non-human sources.

3.5 Adverse effects and indicators

Contaminants enter urban stormwater systems as 'washoff' from streets, roofs, parks, gardens and other municipal areas. They can also enter stormwater systems as overflow from combined sewer systems, or from accidental/illegal sewer connections. In older cities, such as Dunedin, the majority of the stormwater system is piped. In towns, and new suburban developments where concepts of water-sensitive urban design have been taken up, the existing stream network may be retained albeit with some modifications. Urban stormwater is episodic and may be discharged into lakes, streams, and the nearshore environment.

3.5.1 Indicators

Monitoring stormwater effects can be an expensive business and regulators and scientists alike are interested in methods that provide useful indicators of the presence of stormwater in receiving environments, the sources of various contaminants, and whether some threshold of effects has been breached. Traditionally, chemical indicators have been confined to heavy metals, particularly copper and zinc, and indeed this is still a focus (see Section 4.3). However, there has been a lot of emphasis recently on emerging organic contaminants (EOCs) and public health effects. General indicators of contaminants irrespective of the source in relation to effects thresholds are discussed in Section 2.7. Here we discuss some recent efforts to either provide surrogates for stormwater contamination, or to track the source of specific stormwater contaminants.

Beck and Birch (2012) reported significant relationships between TSS and Cu, Pb and Zn for stable urban catchments flowing into a Sydney estuary. They suggested that TSS may be used as a surrogate (indicator) for estimating metal loading in real time for urban catchments, once relationships between metals and TSS were established for individual catchments and for base and high flow conditions. However, (in their case) meaningful relationships were not apparent at base flows.

In another Australian study, Tang et al. (2013) assessed stormwater samples from across Australia using six biological endpoints, as indicators of chemicals with modes of toxic action of particular relevance for human and environmental health. They concluded it was necessary to use a battery of bioassays, as their variable modes of action gives valuable information of the composition of the sample. These included: phytotoxicity (indicator of herbicides), dioxin-like activity (indicator of road runoff), and estrogenicity (indicator of sewage contamination).

Studies based on molecular markers (e.g. polymerase chain reaction, PCR) show the feasibility and benefits of these microbial source tracking tools as specific indicators of human faecal pollution (sewage inputs) to stormwater systems. Urbanised coastal areas, such as Dunedin, are amongst our oldest cities and are often challenged with maintaining aging infrastructure. Identifying and mitigating sources of sewage contamination within the stormwater system should therefore be a high priority, particularly if stormwater discharges compromise contact recreation in the receiving environment. To date, attempts to identify sources of sewage contamination appear to have led to ambiguous results (Appendix C). PCR and qPCR (quantitative PCR) methods have been used internationally to track sources of contamination systematically through the stormwater systems and there may be a case for using it in Otago also.

A range of chemical source trackers have also been used as indicators of sewage input to urban stormwater. Fluorescent whitening agent (used in washing powders) has been used for this purpose historically and has been used to provide an indicator of sewage ingress in Dunedin's outfall monitoring with variable success (see Appendix C). More recently, a range of anthropogenic (human derived) organic chemicals with low detection limits have successfully been used as sewage tracers in stormwater studies. These include caffeine, acetaminophen (paracetamol), salicylic acid and acesulfame-K (Potera, 2012; Sidhu et al., 2013). The latter authors noted a very good consensus (>91%) between the concurrence of acesulfame-K and caffeine and specific genetic markers of human sewage contamination.

Other studies have targeted indicators of stormwater pond quality. Tixier et al. (2012, 2011) added an oligochaete (worm) assessment component to the Sediment Quality Triad (SQT) assessment tool widely used in North America. The oligochaete assessment is based primarily on their potential to mineralise organic matter but also on their potential categorization according to known sensitivity to pollution. Other 'indicators' of stormwater treatment include a hierarchical 'minimum dataset' (Ingvertsen et al., 2011) based on selected contaminants being 'representative' of broad contaminant groups (e.g. copper and zinc for all heavy metals) and 'mode of action' within stormwater treatment devices. While the concept of the minimum dataset is sound from the viewpoint of testing the efficacy of stormwater treatment facilities, we suspect it will not gain traction for environmental monitoring, which is more specific to the values of the ecosystem into which the stormwater discharges.

3.5.2 Specific stormwater discharges in Otago

Discharge to harbour environments

The effects of stormwater discharges on receiving environments in Otago has been largely assessed by inference from monitoring studies in the Upper Otago Harbour. These studies had their origin from an Otago University PhD study by Brown (2002) who studied both PAH and heavy metals in stormwater draining the Portobello Road and Waters of Leith catchments. He found much higher concentrations and loads of metals and particularly PAHs from the Portobello Road catchment, which he attributed to legacy effects from the disused gas works. He used chemical partitioning to reason that although ∑16PAH (16 USEPA priority PAHs) was high, the toxicity of the discharges would be governed by the bioavailability of the contaminants, which is largely a function of their concentrations in the dissolved phase. The contaminant levels in the truly dissolved phase were such that they were unlikely, in his view, to exhibit acute toxic effects. However, Brown (2002) concluded that the PAHs and zinc could lead to impaired functioning for some aquatic organisms in the Upper Otago Harbour environment.

Following Brown's studies, Stewart (2005c) surveyed the spatial distribution of contaminants with reference to the Portobello Road stormwater outfall. The results suggested that this outfall was indeed the source of contaminants in the south-eastern corner of the Upper Harbour Basin. For metals and metalloids, only chromium did not exceed the ANZECC trigger values at any point. Levels of metal contaminants were particularly high along the Andersons Bay Inlet causeway. PAH contamination was widespread and at reasonably high levels. The most severe contamination was within 100m of the outfall.

In his evidence to the 2013 hearing for renewal of stormwater consents, Stewart (2013) summarised the effects information gleaned from monitoring up to that date. He noted (paragraph 61 of his evidence) that samples collected each year in the Upper Harbour sediments have shown a trend towards smaller cockles as one nears the Portobello Road outfall. He opined that this could be a result of the legacy PAH contamination, which is extremely high beneath the surface at this site, but a number of other factors, not least of which are freshwater exposure and exposure at low tide, need to be considered. He noted that the diversity of infauna around the Portobello Road stormwater outfall was the lowest of any site sampled in the Upper Harbour. With the exception of the Portobello Road outfall, Stewart (2013) was unable to attribute ecological effects in the vicinity of other stormwater outfalls in the Upper harbour to any particular contaminant source.

In the latest Dunedin stormwater monitoring report, Stewart (2015) assessed the potential effects of stormwater on the receiving environment by comparison with ANZECC (2000) guidelines. Under wet weather flow conditions, samples from all 10 key stormwater outfalls exceeded the guideline value for copper and lead, and all but 1 exceeded the guideline value for zinc.

Similarly, water samples collected at 5 sites in the Upper Harbour (Figure 8) were above ANZECC trigger values for protection of 95% of species for copper, lead and zinc under both dry and wet weather sampling conditions. Enterococci contamination also exceeded guidelines for marine waters (i.e. >140 MPN/100ml = amber alert; >280 MPN/100ml = red alert, especially on the flood tide during a rain event). Stewart (2015) was of the view that this may have been due to discharge of wastewater from known overflow outlets during major events. However, there was also evidence of bacterial contamination during dry spells, notably off Portsmouth drive in the substation area, and in the vicinity of the Wickliffe Street and Mason Street outfalls. Harbour water quality was not specifically targeted in annual stormwater sampling rounds prior to 2014, and while there is limited historic date available (Stewart and Ryder, 2005), the 2015 copper, lead and zinc, and enterococci results fall outside this historical range.

Accumulation of contaminants in sediment could have adverse effects on benthic biota, and, potentially on higher organisms feeding on infauna. However, the 2015 sediment sampling found no evidence for accumulation of contaminants above guideline values. The only exception was zinc levels at the Kitchener Street site (H2: Figure 8) which were above guideline values (1990 mg/kg in text, 419 mg/kg in table). Stewart (2015) notes however, that the 2015 contaminant levels were generally much lower than those found historically at other sites in the Upper Harbour (Table 6). However, he also noted that sediments were sampled much closer to the outfalls prior to 2014. There was no explanation as to why sampling locations were changed, but presumably sampling locations were specified in the 2013 consent.

Table 6. Maximum contaminant concentrations (mg/kg) in sediments sampled in 2015 and historically (from Stewart, (2015): Table 3.3.2)

	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn	PAH
2015 maximum	8.17	0.194	28	16.5	43.4	0.142	29.2	419	22.53
Historic maximum	46	6.2	98	433	800	0.17	44	4450	651

Figure 8. Upper Harbour Basin seawater and sediment sampling sites. Red squares are harbour water quality sites; yellow circles are sediment sites (from Fig. 2.1 in Stewart (2015)

Stewart (2015) also presented analysis of biota sampling at the Orari Street, Kitchener Street and Portobello Rd outfalls together with two reference sites. Metrics analysed included macroalgal cover, epifauna abundance, faunal diversity, cockle size and abundance, and contaminants in cockle flesh. All the biotic indices were typical of those in the Upper Otago Harbour and not associated with any one outfall. The communities are numerically dominated by polychaete worms and amphipods and are very similar to those found in other moderately impacted Otago inlets. The heavy metal concentrations in cockle flesh remain at least an order of magnitude below accepted Food Safety Australia New Zealand (FSANZ) maximum levels. PAH levels in cockles remain high adjacent to the Portobello Road outfall for reasons discussed earlier. There are no specific maximum limits for PAHs in any foodstuffs (including shellfish) in NZ (FSANZ, 2016).

Discharge to open coastal environments

The only study of stormwater discharges to the open coast we are aware of is that carried out by Stewart and Ryder (2005) on St Clair and Second Beach. This study only considered microbial contaminants (faecal coliforms and enterococci) though the authors did comment on heavy metal levels off Second Beach, which was done for another purpose. Stewart and Ryder (2005) reported that although the concentrations of faecal coliforms and entercocci in these outfalls were high (of the order 10^5/100 mL at St Clair), the concentrations in the receiving water were generally less than 50/100 mL. This they attributed to the high levels of dilution in this high energy coast. We note, however, that high concentrations of indicator bacteria at St Clair Beach, even when no rainfall had occurred for 5 days, may be indicative of sewage ingress.

Similar conclusions for open coastal sites in Auckland were reported by Kelly (2010a).

Discharge to estuaries

Although stormwater enters the Kaikorai Stream (which flows into the Kaikorai Estuary) there have not been any specific studies of stormwater effects on estuarine environments in Otago. Stewart (2009) undertook habitat mapping of the Kaikorai estuary, which included an assessment of its uses and values. This included stormwater, but Stewart (2009) noted that the potential pressures on the Estuary from this source were low. Stewart (2007) similarly concluded that the pressure of stormwater discharges from Karitane township on the Waikouaiti Estuary was low. We note that these conclusions were based on the relative size of the stormwater discharges to the volume of the estuary.

Discharge to streams and rivers

While a number of Otago towns (e.g. Balclutha and Alexandra) have stormwater outlets to large rivers, the only study on stormwater effects on rivers and streams in Otago appear to be that of Ludgate & Bywater (2010) for 'streams' in Dunedin's stormwater catchments. They surveyed the middle to upper reaches of nine Dunedin catchments impacted by stormwater, which were natural channels upstream of the stormwater pipe network. The catchments included those covered by Stewart (2015) for their impacts on the marine environment. Ludgate & Bywater (2010) compared the quality of different habitat features (riparian vegetation, bank stability, flow variability, bed substrate, instream cover, water quality, invertebrates and fish) and ascribed a rating of 'poor', 'good' and 'excellent' relative to each of the sites. Of the eight criteria assessed, the streams assessed received 'poor' classifications most commonly for invertebrates and fish. There is no overall conclusion as to why this is the case, but water quality seems to be 'poor' in no more instances than other criteria. We conclude that as has been found in other international studies (see Section

3.7), stormwater contaminants are but one of many pressures on urban streams. This is discussed further in Sections 3.7.2 and 3.8.1.

Discharge to lakes

There have not, to our knowledge, been any studies on the effects of stormwater on Otago Lakes. This includes all lake types from the large deep microtrophic lakes such as Wakatipu and Wanaka (which receive stormwater inputs from Queenstown and Wanaka, respectively) to medium sized lakes such as Lake Hayes, to shallow lakes such as Lake Waihola.

As with enclosed coastal waters we would expect there to be ecological issues associated with benthic organisms close to outfalls, and, potentially, public health issues for contact recreation. Whether these effects are more than minor is a matter that only monitoring can determine, though the volumes of the lake in question relative to the volume of stormwater would give an indication as to whether monitoring was justified. The next phase of this project should address the risks from urban stormwater to Lakes Wakatipu and Wanaka in particular, given their importance to tourism. While nutrients (nitrogen and phosphorus) are not as important as other contaminants in stream, or coastal environments, they may be in lakes, particularly oligotrophic lakes that are found in Otago. New developments around lakes may provide a source of soil-associated nutrients during the development phase (Cooke et al., 2015a) and stringent conditions around stormwater treatment may be required where there is a risk of the nutrient stimulating algal blooms.

Discharge to wetlands

There are no stormwater discharges we are aware of to natural wetlands in Otago.

Discharge to aquifers

There are no stormwater discharges in Otago we are aware of that have the potential to cause effect to aquifers. New developments with water-sensitive urban design features are more likely to incorporate ground soakage, which consequently has the potential to impact aquifers, but these are generally designed to avoid such consequences.

3.5.3 Other jurisdictions

The monitoring studies that have been undertaken in Otago have focussed on contaminants. There have been few "effects" based studies of stormwater contaminants other than those associated with known sources, such as those associated with the disused gas works and apparent sewage contamination. Other researchers, both nationally and internationally, have reported effects and we briefly review them in this section to contribute to our summary of potential adverse effects in Otago receiving waters, which appears in the next section. This section also includes literature on stormwater effects in other receiving environments (aquifers and wetlands) which has not been covered previously in this report.

The NZ leader in the assessment of effects of urban stormwater on receiving waters has been the Auckland Council and, particularly, its predecessor the Auckland Regional Council. Kelly (2010a) reviewed this work and a summary of his review provides some useful insights (see Table 7). Kelly (2010a) effectively captured all significant literature on effects published up until 2010. There have been relatively few publications since that time that have focussed on effects, and fewer still that have added to the key information summarized by Kelly.

In the coastal environment Burton et al. (2005) and Cederkvist et al. (2013) reported on advances in chemical partitioning to give a more complete description of the environmental effects of urban stormwater in estuaries. However, this does not change any of the fundamental conclusions summarised in Table 7.

In freshwater environments two apparently contradictory studies illustrate the difficulty of determining the effects of contaminants from stormwater on stream biota in isolation from other stressors. Johnson et al. (2011) used an experimental method whereby varying proportions of stormwater collected from urban roads was added to mesocosms containing combinations of algae, fish and snails. They concluded that stormwater quality does not necessarily have negative impacts on stream biota. However, we note the artificial nature of their study, which had coarse treatment thresholds, restricted biota, and did not factor in first flush effects or other stressors. In contrast, King et al. (2011) applied a new analytical method, threshold indicator taxa analysis (TITAN), to a stream biomonitoring data set from Maryland (USA) to explicitly evaluate linear community response models to urbanization that implicitly assume individual taxa decline or increase at incrementally different levels of urbanization. They reported sharp, synchronous declines of numerous taxa and established a consistent threshold response at exceptionally low levels of catchment urbanization. They also noted that higher-gradient, smaller catchments required less impervious cover than lower gradient, larger catchments to elicit community response thresholds. King et al. (2011) did not attempt to isolate particular stressors but rather used large datasets and several corroborating lines of evidence to produce a very useful method for predicting effects of urbanization on streams. While TITAN appears a useful technique, Kelly (2010a) summarised very similar conclusions (Table 7), with respect to imperviousness and disentangling the chemical, physical and biotic stressors caused by urbanisation.

Table 7. Key learnings from the Auckland experience on effects of urban stormwater on coastal waters and streams (Kelly, 2010a)

Coastal waters	Streams
Relatively small receiving environments with poor flushing characteristics, tend to accumulate stormwater contaminants	During urbanisation a lot of exposed soil which gets mobilised during storm events. This can result in accelerated stream bank erosion
The ecology of natural marine systems is closely linked to geophysical and associated chemical characteristics	The soil eroded off site decreases as an urban catchment matures. This offset is replaced by greater accumulation and transport of urban contaminants that are toxic to biota
Stormwater commonly carries contaminants which alter the physical and chemical characteristics of marine habitats, which impact on the ecology	There is a general reduction in ecological condition with increasing imperviousness.
Sediment is a major marine contaminant that degrades coastal habitats and is harmful to many marine organisms	There is a consequent decrease in community metrics such as EPT and increase in pollution tolerant macroinvertebrates
Sedimentation rates in Auckland's estuaries are up to an order of magnitude higher than when the surrounding catchments had their original forest cover	Disentangling individual stressor effects to the overall ecological impacts of urban streams is difficult (physical, chemical biotic) as they all occur.
Benthic organisms have a preference for particular sediment textures, so a shift toward finer sediments leads communities adapted to living in those sediments	All aquatic invertebrates accumulate trace metals in their tissues, but the body concentrations of metals vary enormously depending on the metal and taxa
Several factors make Auckland's urban harbours and estuaries particularly prone to contaminant accumulation including: 1.urbanisation has occurred along the coast, so there is little opportunity for contaminant attenuation between source and sea, 2. the coastline contains many sheltered inlets, which trap sediments and associated contaminants; and 3. no provision was made for treating stormwater in many older, fully developed catchments	Once absorbed, the fate of trace metals depends on the physiology of the invertebrate. It may be used for essential metabolic purposes, excreted, stored in the body in a detoxified state, or it may exert a toxic effect.
The ecological significance of contaminant accumulation cannot be determined by simply measuring contaminant concentrations in the environment	ANZECC (2000) water quality guidelines provide high reliability freshwater trigger values for Pb, Zn, and Cu
The use of multivariate statistics has been particularly useful for examining links between stormwater contaminants and benthic community structure in the Auckland Region	PAH's are commonly elevated in Auckland stormwater sediments. 50% exceeded low ANZECC Tolerance Values (TV) of 4000 ng/g
Urban wastewater systems are inherently prone to seepage, exfiltration and overflows. As a consequence, nutrients, microbiological contaminants and other wastewater constituents frequently enter the urban stormwater system and groundwater, and are discharged to the coast.	Fine sediment in urban streams detrimental to freshwater fish. Variable sensitivity to sediment. Banded Kokopo most sensitive and even >25NTU reduce feeding rates, upstream migration rates and increase avoidance.
High nutrient loads can also induce nuisance algae blooms, although this does not appear to be an issue in urban Auckland	Urban wastewater systems are inherently leaky due to overflows and seepage, and as a consequence, nutrients, wastewater solids, and other contaminants frequently enter the urban stormwater system and groundwater.
Health risks vary among locations, but highest concentrations of indicator bacteria (enterococci) (and therefore greatest health risk) usually occur after rainfall events which cause wastewater overflows	However, few problems of this kind have been reported in New Zealand urban streams. Usually, problems caused by high nutrient or organic loadings, are due to the large and direct inputs of untreated wastewater, rather than stormwater

3.5.4 Other adverse effects

Other adverse effects of stormwater which are not related to contaminants are related to flood hydrology. Traditionally stormwater systems have been designed to mitigate flooding from urban areas, i.e. to remove potential flood hazards away from homes and public spaces as quickly as possible. With high intensity rainfall events, however, the increased flood velocities generated in stormwater systems can have unintended consequences including:

- 'Downstream' damage to infrastructure (e.g. culverts and bridges) and property;
- Eroded streambanks and sediment-clogged waterways;
- Widened stream channels, with consequent loss of property;
- Threats to public safety – increased exposure to drowning in high velocity flood waters;
- Impaired recreational use of urban streams (through use of pipes to transmit flood waters);
- Economic and recreational impacts through closure of shellfish gathering after storm events.

Therefore, in addition to recognising the need to treat contaminated stormwater to prevent impairment of the receiving waters into which they discharge, there is increasing recognition of the need for a hydrologically less-intrusive approach to stormwater management, in order to prevent the unintended adverse affects listed above. Such approaches, as well as efforts to 'restore' urban streams affected by poor stormwater management are discussed in Sections 3.7.2 and 3.8.1. Internationally, there is also a push to put more effort into stopping contaminants at source, rather than 'treating' them once they are in the environment. Prevention/reduction at source is a more efficient way of consistently achieving significant load reductions across the country and a good example is the removal of lead from petrol.

3.5.5 Summary of adverse effects

An assessment of the potential stormwater discharges to result in effects in each receiving environment discussed above is given in Table 8, together with our assessment of likely effects given current knowledge of Otago stormwater discharges.

Table 8. Summary of values affected and severity of effects from stormwater discharges

Activity	Values affected	Effects	Potential Severity of effects	General Trend
Near-shore ocean discharge	Ecosystem health	Reduction in sensitive benthic species; loss of biodiveristy	Low due to dilution effects; contaminant accumulation unlikely in high energy environment	Low potential for adverse effects based on known discharges to near-shore ocean environment
	Primary contact recreation	Illness to those in contact	Risk is low due to dilution and timing of discharge compared with time of activity but consequences if infected medium – high for the individual	
	Mahinga kai consumption	Contaminated shellfish (contaminants, microbes)	Low risk due to dilution and high energy environment which makes it unlikely contaminants will be taken up by shellfish and therefore effect consumers	
	Aesthetic	Discolouration of	Low as unlikely to be observed	

Activity	Values affected	Effects	Potential Severity of effects	General Trend
		water	under storm conditions	
Inner harbour discharge	Ecosystem health	Reduction in sensitive benthic species; loss of biodiversity	Medium to high close to outfalls where particulate-associated contaminants (metals, PAHs) etc settle. Low with increasing distance away from outfall.	Increased adverse effects in Upper Otago Harbour in vicinity of stormwater drains
	Primary contact recreation Secondary contact recreation	Illness for those in contact	Low if sewage ingress minimal. Medium otherwise especially close of outfalls.	
	Mahinga kai consumption	Contaminated shellfish (contaminants, microbes)	Medium if significant shellfish gathered and consumed in this environment. Risk depends on quantity and frequency of consumption	
	Aesthetic	Discolouration of water	Medium because stormwater discharge continues sometime after storm due to hydrological lag effects. Likely to be relatively high number of observers in urban area.	
Estuary discharge	Ecosystem health	Reduction in sensitive benthic species; loss of biodiveristy	Medium to high close to outfalls where particulate-associated contaminants (metals, PAHs) etc settle. Low with increasing distance away from outfall.	Low potential for adverse effects expected based on known stormwater discharges to estuaries in Otago, but no rigorous assessment has been undertaken
	Primary contact recreation Secondary contact recreation	Illness for those in contact	Low if sewage ingress minimal. Medium otherwise especially close to outfalls.	
	Mahinga kai consumption	Contaminated shellfish (contaminants, microbes)	Medium if significant shellfish gathered and consumed in this environment. Risk depends on quantity and frequency of consumption	
	Aesthetic	Discolouration of water. Algal blooms	Medium because stormwater discharge continues sometime after storm due to hydrological lag effects. Likely to be relatively high number of observers in urban area. Low-medium risk of contributing to localised algal blooms (cumulative effects)	
River discharge	Ecosystem health	Reduction in sensitive benthic	Low in large and medium sized rivers due to dilution and lack	Severity of effects potentially higher in

Activity	Values affected	Effects	Potential Severity of effects	General Trend
		species; loss of biodiveristy	of settling in riverine environments. Medium to high in small streams but a number of physical, chemical, and biotic factors responsible for effects (not just contaminants) i.e. 'cumulative' effects	urban Dunedin streams that are part of stormwater network but decrease as river size increases and more removed from urban influence (e.g. Kaikorai Stream (small stream close to urban area – high potential severity) Pomahaka (medium sized river), Clutha (large river))
	Primary contact recreation	Illness through exposure to pathogens	Large-medium sized rivers only where swimming possible. Low risk due to episodic nature of stormwater discharge and dilution	
	Secondary contact recreation	Illness through exposure to pathogens	Small sized rivers- streams. Low if stormwater system not impacted by sewage but medium to high if significant sewage ingress. Risk highest for children playing in small urban streams	
	Public health (drinking water)	Illness through exposure to pathogens	Low to dilution in large to medium sized rivers. High from streams with sewage ingress, but very unlikely to be a source of drinking water	
	Aesthetic	Reduced water clarity due to elevated suspended particulates	Low-medium Near-field effects likely to be greatest and worst under low flow conditions.	
	Aesthetic	Increased periphyton growth due to nutrient enrichment	Low for large rivers – increasing risk of effect for small streams, especially with sewage contamination and especially at low flows	
	Cultural	Loss of kaitiakitanga from mixing of waters. Contaminants an affront, especailly if known to contain sewage	Low-medium compared with other wastewaters, especially sewage	
	Mahinga kai consumption	Contaminated fish/eels (contaminants, microbes)	Low as contaminants from stormwater in water column as transitory and subject to dilution. Particulate associated contaminants will not settle in riverine environment.	
	Irrigation	Contaminants accumulate in irrigated soils and crops	Low for large – medium rivers which are likely source of irrigation water.	
Lake discharge	Ecosystem health	Reduction in sensitive benthic species; loss of biodiveristy	Low due to episodic nature of stormwater discharges and dilution. Could be some effects close to outfall point	Low in deep oligotrophic lakes such as Wakatipu and Wanaka, but worth monitoring to ensure that

Activity	Values affected	Effects	Potential Severity of effects	General Trend
	Ecosystem health	Algal blooms due to excessive nutrients may lead to deoxygenation and loss of biodiversity	Low due to episodic nature of stormwater discharges and dilution. Could contribute to cumulative effects in lakes also receiving agricultural runoff	no localised effects arise. Low – medium contributor to cumulative effects elsewhere
	Primary contact recreation	Illness through exposure to pathogens	Low due to episodic nature of discharge and dilution. Increasing risk with decreasing volume of lake and sewage contamination of stormwater	
	Secondary contact recreation	Illness through exposure to pathogens	Low due to episodic nature of discharge and dilution	
	Public health (drinking water)	Illness through exposure to pathogens	Low due to episodic nature of discharge and dilution. Increasing risk with decreasing volume of lake and sewage contamination of stormwater. Unlikely to be a source of drnking water without treatment except for sole supplies which would be some distance from a stormwater outfall.	
	Aesthetic	Reduced water clarity due to elevated suspended particulates	Medium to high in low flow environment which is possible due to hydrological lag effects for discharges to deep oligotrophic lakes	
	Aesthetic	Algal blooms due to nutrient enrichment	Low due to episodic nature of stormwater discharges and dilution. Could contribute to cumulative effects in lakes also receiving agricultural runoff	
	Cultural	Potential damage to kaitiakitanga from mixing of waters. Contaminants an affront, especailly if known to contain sewage	Low-medium compared with other wastewaters, especially sewage	
	Mahinga kai consumption	Contaminated fish/eels (contaminants, microbes)	Low as contaminants from stormwater in water column as transitory and subject to dilution.	
	Irrigation	Contaminants accumulate in irrigated soils and crops	Low for large – medium lakes. Higher risk for small shallow lakes as cumulative effect but risks still low.	
Aquifers (discharge to land)	Public health	Elevated nitrogen and pathogens	Depending if water is extracted for human consumption. Highly linked to concentration/load of contaminants in stormwater	Severity of effects potentially low

Activity	Values affected	Effects	Potential Severity of effects	General Trend
			and aquifer properties (material types, groundwater depth, recharge processes)	
	Stock water	Stock become ill drinking contaminated water	Medium where soils highly permeable and aquifer water extracted for stock watering Highly specific to concentration/load of contaminants in irrigated stormwater	
Wetland discharge	Ecosystem health	Reduction in sensitive plant and benthic species; loss of biodiversity	Low due to episodic nature of stormwater discharges into saturated environment. May be very localised effects	Severity of effects potentially low – no known instances of stormwater discharges to natural wetlands in Otago
	Secondary contact recreation	Illness through exposure to pathogens (e.g. duck hunters)	Low due to episodic nature of discharge and dilution	

3.6 Knowledge gaps and risks

From the review of Otago-specific stormwater studies and other NZ and international studies we conclude:

- The focus on Otago Harbour and specifically the Upper Harbour is justified as it is the receiving water for the highest density of stormwater outlets in Otago, and its geomorphology is conducive to sedimentation and the settling of contaminants. In addition, parts of the Dunedin stormwater network are aged, and contain residual effects of former polluting industries. Therefore, if there were to be stormwater-based effects on the Otago coastal environment, they should be manifest first in the Upper Otago Harbour.
- Table 7 provides a check list from which to compare findings in Auckland estuaries with monitoring results from the Upper Otago Harbour. We recommend this should be carried out in the next phase of the project, where a spatially-based risk assessment is carried out.
- While the conclusions from the consent monitoring programmes to date indicate that ecological effects are relatively minor, the monitoring design they are based upon does not lend itself to scientifically-robust conclusions. Partly this is because sampling sites (for sediments anyway) appear to have changed from the 2007 to the 2013 consents, and partly because consent monitoring is generally not designed to test hypotheses. There may be some advantage to both ORC and Dunedin City Council (DCC) joining in a collaborative approach with some clear hypotheses and a well-designed statistical design. Such an approach was used for Auckland's benthic health model (reviewed in Kelly (2010a)), which showed a clear pollution gradient due to stormwater. A successful outcome from such a study could provide justification for a consent review, which could potentially save the consent holder money in the long term. A clear analysis of the values that are deemed important by stakeholders to the Upper Harbour would be a useful starting point for the formulation of hypotheses and subsequent commissioning of studies (if any).
- The studies on human sewage ingress into the Dunedin's stormwater system appear ambiguous. This may be due in part to a reliance on fluorescent whitening agent as a chemical indicator on human

sewage. The literature review shows that there are much more sensitive chemical indicators now available, as well as microbial source tracking techniques, which have been shown to provide definitive results. The review of international literature shows that human sewage ingress into stormwater systems is near common, and the biggest improvements to stormwater quality are those gained by isolating sewage leakages and cross-connections.

- While PAHs have been monitored since the studies by Brown (2002) on the Portobello Road area, our review has shown that other contaminants (EOCs especially) are associated with stormwater. However, as there is significant cross-over of EOCs between stormwater and human sewage, this gap can best be filled in the short-term by identifying the EOCs in the influent and discharge of sewage treatment plants.
- The absence of information of stormwater effects on inland waterways is a clear information gap. This is something that could be addressed in the next phase of the project, where a risk assessment of contaminant sources is carried out. However, irrespective of risk, it would appear that at least some information of stormwater composition and potential effects at Queenstown and Wanaka is justified, given its burgeoning population and importance to tourism.

3.7 Management and mitigation practices

3.7.1 Leading regions and countries

Historically Auckland was the leading region in New Zealand for the characterisation and assessment of stormwater effects on receiving waters (Kelly, 2010a), particularly the marine environment. However, since the merging of Auckland Regional Council into Auckland Council it would appear that the emphasis on receiving water effects has diminished, whereas other regions are instigating studies. Greater Wellington Regional Council in particular is putting a lot of emphasis on Integrated Catchment Management Planning which includes stormwater, as are Territorial Local Authorities (TLAs) in the Waikato region. It is likely that the NPS Freshwater Management (2014) has prompted many regions to review all sources of contaminants, including stormwater.

Internationally there are pockets of discrete expertise in Europe, China, North America and Australia. From the literature it appears that regionally, Australia has a lot of expertise in stormwater management. Specific expertise includes hydrological processes (Section 3.8.1), water-sensitive urban design, chemical and microbial source tracking, and effects on freshwater ecosystems. Australia appears to be at the forefront of integrating social sciences into decision making on stormwater renovation (Farrelly and Brown, 2011).

3.7.2 Advances in stormwater mitigation and urban stream restoration

The chief method of mitigating the hydrological effects of stormwater has been the stormwater detention pond. While historically these have been designed to ‘capture’ the large volumes of stormwater associated with impervious surfaces (see Section 3.8) researchers have highlighted their potential for also reducing the concentration of contaminants and as a potential as a community resource (Walsh et al., 2015). Hogan and Walbridge (2007) showed that stormwater detention ponds designed using basin topography and wetland vegetation, provided superior water quality improvement (nutrient and sediment removal) compared with those designed solely for hydrograph retention. They recommended that design for water quality improvement would foster more responsible urban development and be an appropriate mitigation action for receiving aquatic ecosystems, without compromising their ability to mitigate flooding.

Stormwater ponds are not practical, particularly in old urban areas where there are land constraints. Because of this there have been a variety of contaminant adsorbents proposed. While many of these appeared promising after pilot trials, they have ultimately been discounted because of cost and/or maintenance issues. Crushed greenlipped mussel shells (<500 µm) have been shown to be a particularly effective adsorbent for Cu and Zn at the concentrations normally found in urban stormwater (Craggs et al., 2010). This is an exciting development as it has been trialled in New Zealand and is a potentially sustainable mitigation practice in areas close to mussel farms, which produce a large quantity of waste shell material.

Other more generic treatment devices perhaps better suited to new urban developments, include aluminium oxide-coated sand (Johannsen et al., 2016) to adsorb contaminants and reduce their transport to a receiving environment and permeable pavers (Drake et al., 2014). These latter authors showed that an interlocking permeable paver system provided excellent stormwater treatment for petroleum hydrocarbons, total suspended solids, metals (copper, iron, manganese and zinc) and nutrients (total-nitrogen and total-phosphorus) by reducing event mean concentrations (EMC) as well as total pollutant loadings. There was however, no analysis that demonstrated the longevity of the permeable pavers, which will be an important factor for the uptake of the technology because of their significant cost compared to conventional pavers.

Not all treatment technologies need to be high cost, however, or even involve treatment devices. Because most urban pollutants have a 'deposition' phase before they are washed off during storm events, increasing the frequency of street cleaning can have a dramatic effect on reducing pollutants in runoff (Zgheib et al., 2011; Zheng et al., 2014).

Over the last decade there has been a 'movement' from pragmatic engineering-based stormwater solutions, to more holistic water-sensitive urban design. The permeable pavers described above are part of this movement, as are rain-gardens and a number of other devices and technologies mainly suited to greenfields urban developments. However, there have also been developments to 'restore' urban streams in mature catchments. The majority of such restoration techniques have been at a reach scale and focussed on mitigating the factors causing physical and biological degradation (e.g. riparian planting, channel deepening). However, two studies evaluating the effectiveness of such reach-scale restoration (Sudduth et al., 2011; Violin et al., 2011) failed to find evidence that such restoration had been successful. Walsh et al. (2015) maintained that for urban stream restoration to be successful, researchers need to 'embrace the community'. However, they presented no evidence for successful urban stream restoration, once this social alliance has been achieved. As noted by Ludgate & Bywater (2010) in the Dunedin situation, in older areas much of the stream network is 'in pipes' making stream restoration an even more challenging issue.

3.8 Specific matters

3.8.1 Hydrology

The effects of hydrology on the export of contaminants in stormwater has been understood for many decades and there have been a myriad of papers documenting the 'first-flush effect'. These 'me too' studies continue to be published, for example Li et al. (2012) reported that the concentration of contaminants in first flush of stormwater in Beijing exceeded China's environmental standards, but that it quickly declined with more runoff. The first-flush effect is due to the build-up of contaminants from air-borne deposition. Experimental studies on different paving types exposed for varying lengths of time before a runoff event occurred have found that contaminant build up occurs asymptotically. A NZ study carried out in Christchurch (Wicke et al., 2012) reported that accumulation of Pb, Cu, Zn and TSS increased over the first week and levelled off thereafter. Almost identical results were reported in Brisbane (Egodawatta et al., 2013).

Going beyond simple relationships with impervious surfaces and first-flush effects requires a more fundamental understanding of hydrological effects. Walsh et al. (2005) were the first to coin the phrase 'urban stream syndrome' which describes the consistently observed ecological degradation of streams draining urban land. The causes are complex and additive, but mainly flow related. Fletcher et al. (2014) provided a broad overview of hydrological effects of stormwater in urban areas, including new urban developments to assess the costs and benefits of management options. They noted that prior to 1990 there were many attempts to mitigate hydrological impacts of urbanization, which were characterized by a focus on peak flows. In the 1990s and early 2000s, environmental concerns drove major innovation in stormwater control measures, leading to techniques with a primary focus on pollutant load and peak reduction. While this represented a significant step forward, they stated the approach missed an explicit link to the needs of receiving waters. Fletcher et al. (2014) advocate an ecohydrological approach as key to understanding and reversing the urban stream syndrome (and to incorporate the needs of receiving waters). The term ecohydrology in this sense describes the 'understanding of relationships between hydrological and biological processes at the catchment scale to achieve water quality improvement, biodiversity enhancement and sustainable development'. Urban streams, for example, are typically much more sensitive to variations in pollutant concentrations than long-term pollutant loads, meaning that they may not be effectively managed simply by setting load reduction targets, just as attenuation of peak flows only is unlikely to be sufficient to avoid loss of biodiversity. The paper by Fletcher et al. (2014) provides useful theory that can be applied to stormwater management, but it provides no evidence that approaches such as incorporating flow-regime management into every set of stormwater performance objectives have resulted in improved urban streams.

Liu et al. (2012) recognised that modelling based on urban land use and the fraction of impervious areas was not adequate for modelling load and concentrations from different urban landuses. However, their solution to addressing this deficiency (that of incorporating urban form, which is the spatial representation of road layout urban areas and urban design features) is a long way from the ecohydrological approach recommended by Fletcher et al. (2014). It may, however, be a pragmatic improvement which could result in improved predictions in the short-term. Such a pragmatic approach was recently used by Cooke et al. (2015a) to model the effects of an urban development from a greenfields state through to a mature catchment. The study was used to define the potential contaminants limiting urban development around a hypertrophic lake, together with stormwater treatment objectives to enable the development to proceed without significant effects on receiving waters.

Costs of an ecohydrological approach to stormwater management

The ecohydrological approach to stormwater management has its critics, with traditional stormwater engineers in particular arguing that water-sensitive urban design (WSUD) is too costly compared with stormwater networks designed to alleviate flooding. While flood prevention is important, proponents of WSUD argue that in many cases 'overdesign' has led to more costly outcomes, that are largely ineffective at mitigating contaminant export to receiving water. Understanding the cost-effectiveness of stormwater treatment devices is certainly one of the keys of gaining community acceptance of WSUD (Farrelly and Brown, 2011). Fletcher et al. (2014b) note that an ecohydrological approach requires allowing streams more 'room to move' such that floods move out into floodplains without causing major cost or inconvenience to the community. Intuitively this is a difficult concept to achieve, particularly in a built-up environment where land is short. Nevertheless, there are WSUD features that can be incorporated into existing stormwater networks that can have a significant effect on contaminant loads. For example, Hogan and Walbridge (2007) noted large reductions in sediment-related contaminants by retrofitting a weir to a stormwater detention basin resulting in increased flood retention time, and establishment of 'volunteer' wetland plants. Walsh et al. (2015) trialled a number of WSUD retrofits (rainwater tanks, rain gardens, infiltration systems, passive irrigation to gardens, baseflow trickle to stormwater systems, and low-flow water quality filtration systems) in an existing catchment in an attempt to reduce the volume and intensity of runoff into stormwater systems. They reported that such retrofits were a cost effective way of reducing contaminant loads, but noted that their effectiveness at improving the ecosystem heath of urban streams would take many years to evaluate.

For new urban developments there are more options. As a general rule of thumb, WSUD will have lower capital costs than conventional stormwater treatment, but have higher ongoing management costs (Liu, 2011). Liu (2011) also noted that in urban settings rainfall events with less than a 1 year return period contribute the majority of the contaminant load, stormwater treatment designs based on small/frequent rainfall events are better in terms of treatment performance, and more cost-effective. This reinforces the point of overdesign of centralised stormwater treatment leading to high capital costs and poor contaminant removal. Hogan and Walbridge (2007) also reported that the use of decentralized planted infiltration troughs instead of centralized stormwater treatment enhanced ground water recharge, flood protection, and suspended and soluble pollutant removal with lower overall costs.

4. Human wastewater

4.1 Key points for human wastewater

- **Adverse effects –** Wastewater discharges can have adverse effects on a variety of values. The effects are varied and depend on the level of wastewater treatment, the volume of the discharge and location and the sensitivity of the receiving environment. Generally, severity of effects follows a pattern of: near-shore ocean discharge < land < wetland < large river, small river < large lakes < small lakes. On-site wastewater system leachate fields are likely to be significant contaminant source to groundwater, via land discharge.
- **Key contaminants –** Wastewater typically contains a myriad of contaminants. Key contaminants include nutrients (N and P); suspended solids; metals/metalloids; microorganisms (bacteria, viruses); biodegradable organic material (BOD); specific organic chemicals (e.g. EOCs); acids/bases; thermal effects; and odour.
- **Key knowledge gaps/risks –** Viruses and EOCs present significant knowledge gaps in wastewater. The risks of these contaminants are unknown, which is *potentially* exacerbated where there is a lack of advanced treatment necessary to reduce the concentrations of these contaminants in wastewater discharge. The lack of knowledge about numbers of failing on-site treatment systems in the region presents another significant knowledge gap.
- **Current management/mitigation –** Management and mitigation of effects from wastewater includes best practice mitigation (appropriate level of treatment for a discharge location) and management (infrastructure maintenance) procedures.

4.2 Introduction

4.2.1 What is human wastewater?

Humans create large volumes of wastewater during their daily lives. This may include flushing the toilet, pulling the plug from a sink, having a shower, or doing the washing. This human wastewater, also known as 'sewage', is greater than 95 percent water and includes organic matter such as human waste and food scraps, fats, oil and grease, and debris such as sand, grit, and plastic. Human wastewater can also include household and industrial chemicals (e.g. detergents, insecticides, flame retardants, and pharmaceuticals).

4.2.2 Why is human wastewater an issue?

Many of the contaminants contained in wastewater streams (see Section 4.4) are at concentrations and/or loads that may cause adverse effects on the receiving environment if discharged untreated. Therefore, it is necessary to treat the wastewater stream (to remove contaminants or reduce them to an acceptable level) prior to discharge into a receiving environment.

Human wastewater can be treated either off-site or on-site.

For properties (households or business premises) that are connected to a municipal wastewater network (generally in towns and cities), human wastewater is transported via a network of sewer systems to municipal wastewater treatment plants (WWTPs). Other waste streams (i.e. industrial and/or stormwater discharges) may also be incorporated into the WWTPs. The entire waste stream is then treated before being discharged into a receiving environment such as near-shore ocean, river, or land.

For properties (households or business premises) that are *not* connect to a municipal wastewater network, treatment is via on-site treatment systems, where discharge is via a leachate field in the vicinity of the treatment system.

Wastewater treatment systems will remove some but not all of the chemicals from human wastewater and at least some will find their way to aquatic receiving environments. Problems arise when the wastewater discharge contains contaminants in concentrations above thresholds that elicit an adverse effect on the receiving environment. Thresholds for these effects are dependent on the sensitivity of each receiving environment.

Wastewater quantity can also be a potential issue and needs to be managed effectively, especially in areas of large urban development. Increased volumes on infrastructure currently at (or near) capacity can lead to discharge of inadequately treated wastewater.

4.2.3 Treatment

There are different levels of wastewater treatment employed at each WWTP and individual on-site systems.

<u>WWTPs</u>

The quality of wastewater discharge (i.e. the propensity of that discharge to adversely affect the receiving environment) is dependent on the level of treatment employed at the treatment plant. There are generally three levels of wastewater treatment, as summarised in Figure 9.

Preliminary screening uses coarse filters to remove large debris, which are disposed to landfill. Material passing through preliminary screening undergoes primary treatment, which involves gravity sedimentation. Solids rich in nutrients and organic matter undergo a separate biosolids process which may be applied to land or incinerated. Soluble material may undergo secondary treatment, involving biological (microbial) removal (ca. 90%) of organic and nutrient loads. Where high quality discharge is required tertiary treatment is employed, including disinfection (chlorine, ozone, UV), high nutrient removal (for example, Biological Nutrient Removal (BNR) or flocculation/precipitation for high P removal), and micro-pollutant removal (for example, oxidation, membrane filtration or activated carbon). Tertiary treatment incurs a significant economic cost in terms of construction and maintenance of the infrastructure.

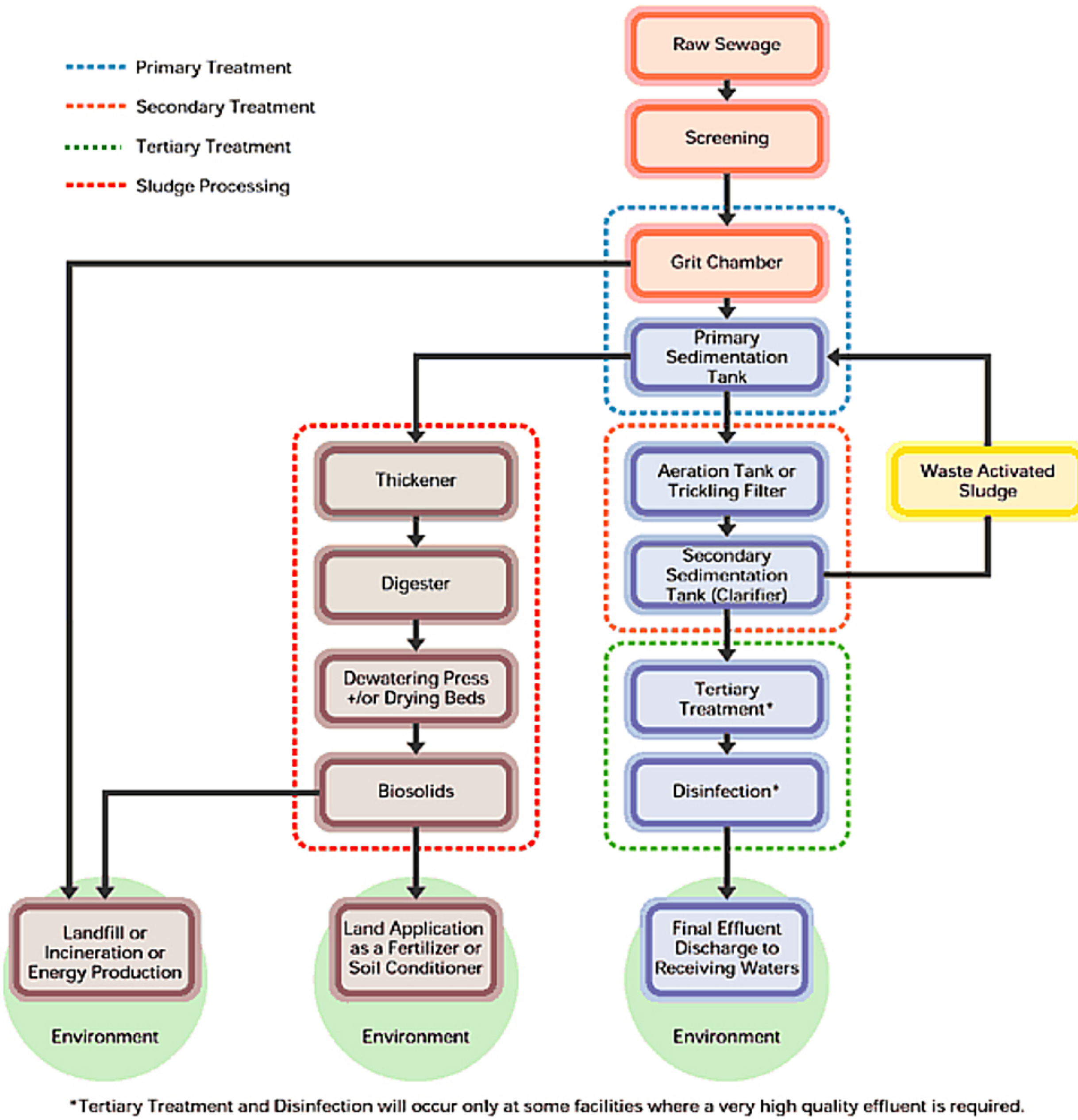

Figure 9. Wastewater treatment process[13]

[13] http://www.unep.or.jp/ietc/publications/freshwater/fms1/2.asp

Nutrient removal is highly dependent on the level of treatment, with very low concentrations attainable with advanced treatment processes (Table 9). Note, the low concentration of nitrate in untreated wastewater is a function of the anaerobic conditions not suitable for nitrification processes.

Table 9. Typical nutrient concentration ranges in untreated wastewater and achievable in treated effluent considering secondary and advanced tertiary processes (modified from Carey, et al., 2009)

Constituent (mg/L)	Untreated wastewater	Conventional activated sludge[a]	Activated sludge with BNR[b]	Activated sludge with BNR, microfiltration, and reverse osmosis[c]
Total Nitrogen	20–70	15–35	3–8	≤1
Ammoniacal-N	12–45	1–10	1–3	≤0.1
Nitrate-N	0–trace	10–30	2–8	≤1
Total Phosphorus	4–12	4–10	1–2	≤0.5

[a] Secondary treatment: activated sludge including a nitrification step
[b] Tertiary treatment: activated sludge and biological nutrient removal (BNR) of nitrogen and phosphorus
[c] Tertiary treatment: activated sludge and biological nutrient removal combined with advanced treatment

On-site wastewater treatment systems

On-site wastewater treatment has traditionally been via septic tank systems. A typical septic system consists of a septic tank and a leachate field. The septic tank digests organic matter and separates floatable matter (e.g., oils and grease) and solids from the wastewater. This occurs primarily under anaerobic (lacking oxygen) conditions. Soil-based systems discharge the liquid (known as effluent) from the septic tank into a series of perforated pipes buried in a leachate field, leaching chambers, or other special units designed to slowly release the effluent into the soil or surface water, providing an aerobic (with oxygen) treatment process.[14]

Alternative systems use pumps or gravity to help septic tank effluent trickle through sand, organic matter (e.g., peat and sawdust), constructed wetlands, or other media to remove or attenuate (reduce) pollutants (e.g. pathogens, nitrogen, and phosphorus).

A higher treatment is possible through advanced on-site treatment systems. Aerated water treatment systems (AWTS) and advanced sewage treatment systems (ASTS) are secondary treatment systems, that is, they involve both anaerobic and aerobic treatment to a higher level than a primary treatment system, resulting in effluent that is suitable for garden (excluding fruit and vegetables) and landscape irrigation. At the highest level of treatment (from ASTS), the treated effluent can be used in non-potable situations such as toilet flushing, vehicle washing and firefighting.[15]

4.3 Types considered and discharges in Otago

Wastewater discharges considered in this report are municipal wastewater treatment plants (WWTPs) and on-site systems. Contaminant classes contained in each discharge overlap considerably, however differences in individual chemicals may be evident as (a) WWTPs integrate community discharges, while on-site systems integrate discharges from individual households or small communities, (b) WWTPs may contain a proportion of stormwater, and industrial and trade waste, and (c) treatment processes are different.

[14] https://www.epa.gov/septic/how-your-septic-system-works
[15] http://www.level.org.nz/water/wastewater/on-site-wastewater-treatment/aerated-and-advanced-wastewater-treatment-systems/

4.3.1 Wastewater treatment plants

Information on wastewater treatment plants (WWTPs) in Otago was compiled from an ORC database of discharge consents to land and water, an audit of compliance (both provided by ORC), and Water New Zealand (Water NZ) WWTP inventory.[16] Neither database was comprehensive (see Appendix D for Tables). For example, Queenstown Lakes District Council (QLDC) and Waitaki District Council (WDC) did not participate in the 2014/15 National Performance Review by Water NZ (Water New Zealand, 2015) from which the WWTP inventory was compiled, so no current data were available from WWTPs in these districts. WWTPs identified in the ORC consent database that are not present in the current Water NZ database include those in Bannockburn, Cardrona Valley, and Lake Roxburgh Village. Similarly, no consent information was present in the ORC database for Waikouaiti, Tahuna, Green Island, Mosgiel, or Kaka Point WWTPs that were present in the current Water NZ database. Tahuna, Green Island/Mosgiel and Kaka Point all discharge to the ocean, which may explain why they are not in the ORC database.

The Water NZ inventory identifies publicly owned wastewater treatment plants (WWTPs) in the country.[16] Information included in the database includes location, level of treatment, volume of wastewater treated, discharge receiving environment(s), and proportion of trade waste. It has not been possible to independently check the accuracy of all of this information. These data indicate that Otago contains 36 WWTPs (Figure 10). This information is based on 24 WWTPs extracted from the most recent Water NZ dataset (updated 24th May 2016, see Appendix D), plus the 12 WWTPs from QLDC and WDC excluded from this list (provided by Lesley Smith, Water NZ, email communication). Important characteristics of the 24 WWTPs for which data are available[17] are summarised here and discussed in following sections:

- 11 WWTPs have primary level treatment, 9 have secondary level treatment and 4 have tertiary level treatment (Figure 10);[16]
- The majority of wastewater treated in the region (84%) is from treatment plants in Dunedin (Tahuna, Green Island) and Mosgiel (Figure 11). These all use tertiary treatment processes;[18]
- 15 WWTPs discharge to freshwater environments (rivers, lakes), 5 to land, and 4 to the coastal marine area.

[16] Source https://www.waternz.org.nz/WWTPInventory (Queenstown Lakes and Waitaki Districts excepted)
[17] WWTPs in Queenstown Lakes and Waitaki districts are generally small (with the exception of Queenstown).
[18] http://www.dunedin.govt.nz/services/wastewater

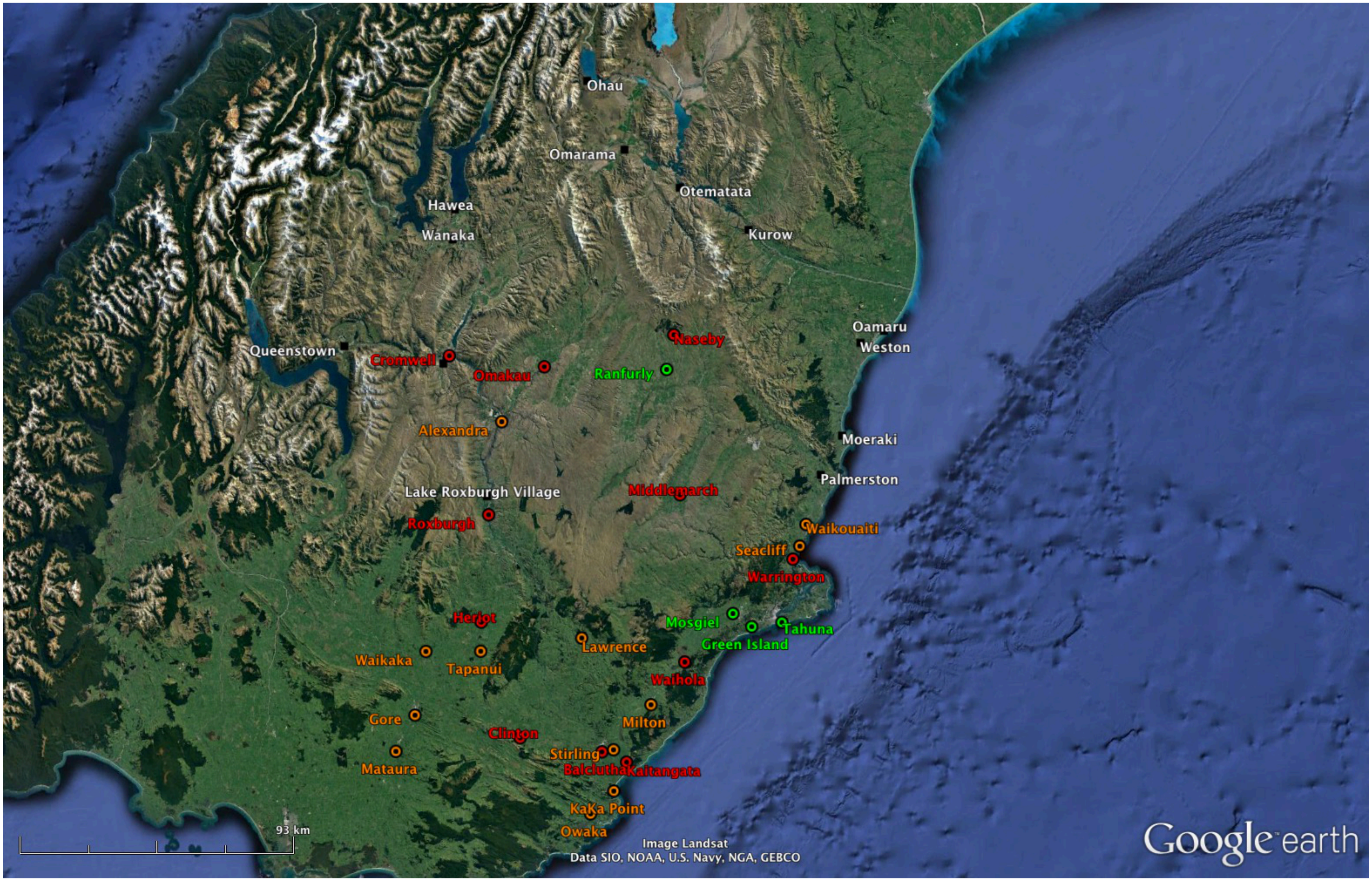

Figure 10. Treatment summary of publicly owned WWTPs in Otago.[16] Colour codes refer to: Primary treatment (red); secondary treatment (orange); tertiary treatment (green), no information available (white) (see report text).

Major WWTP discharge characteristics[19]

The seven largest WWTPs in Otago treat 95% of the reticulated wastewater volume (Figure 11). The three largest treatment plants - Tahuna (60%), Green Island (16.6%) and Mosgiel (7.2%) - treat 84% of the reticulated wastewater volume while Balclutha (3.8%), Cromwell (3.0%), Milton (2.2%) and Alexandra (1.8%) treat 11% of the volume. The three major WWTPs use tertiary treatment processes, while Balclutha and Cromwell use primary treatment and Milton and Alexandra use secondary treatment (Figure 10).

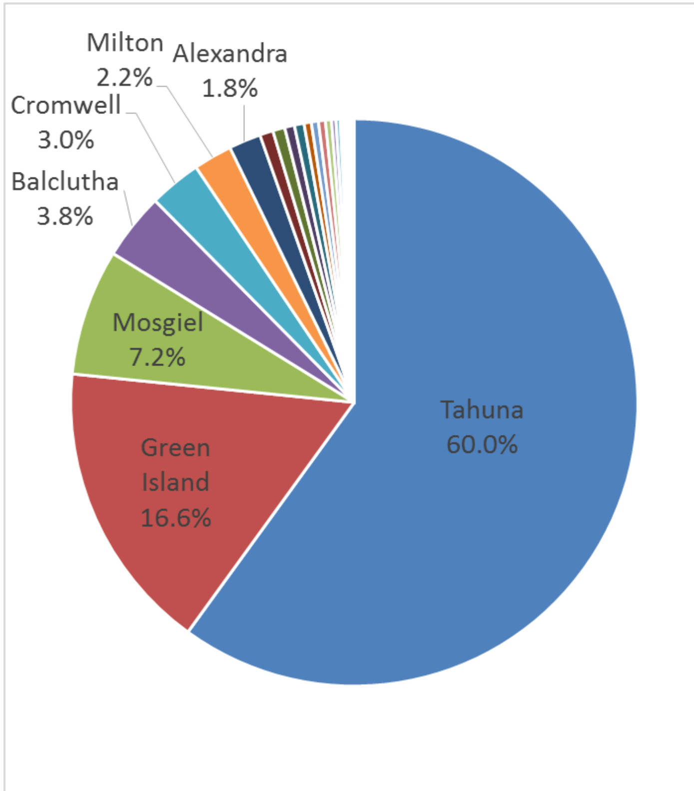

Figure 11. Relative proportion of wastewater treated for major WWTPs in Otago.[16] Note: Only WWTPs treating greater than 1% of the total volume are labelled.

Tahuna WWTP is the major WWTP in Otago, servicing around 80,000 residents, plus industry. The proportion of wastewater entering Tahuna WWTP that is classified as trade waste is estimated to be around 10%.[16] There are no discharges to land or freshwater. De-watered sludge is incinerated at around 825 °C, while treated wastewater flows by gravity where it discharges into the sea. Tahuna WWTP has undergone a major upgrade including 1.1 km sea outfall and improved treatment.

Green Island WWTP is the second largest WWTP in Otago. The proportion of wastewater entering Green Island WWTP that is classified as trade waste is estimated to be around 20%.[16] Wastewater processing liquid (centrate) is returned to the wastewater stream for further processing. Sludge is mixed with lime and disposed at the Green Island Landfill. The final treated effluent is UV disinfected and discharged via diffusers at the end of an 850m long ocean outfall.

[19] http://www.dunedin.govt.nz/services/wastewater

Mosgiel WWTP services around 10,000 residents as well as minor trade wastes. Major industrial wastes from around Mosgiel are piped separately through to the Green Island WWTP. Treated wastewater is also piped to Green Island WWTP, UV disinfected and discharged to the ocean as for Green Island treated waste.

Trade waste component

The trade waste component of WWTPs in Otago is estimated to vary between 0% and 20% with a median of 0% and mean of 1.7%[16], suggesting trade waste is a relatively minor component by volume of wastewater treatment in the region. However, it is not clear how these estimates have been made or whether they have been made consistently between districts.

4.3.2 On-site wastewater treatment systems

Discharges from septic tanks in Otago are a permitted activity under the Regional Plan: Water for Otago (RPW) as long as certain conditions are met. The Otago Regional Council (2015) estimate that Otago contains up to 14,600 on-site septic tanks, regionally divided into: Dunedin (39%); Central Otago (22%); Clutha (21%); Queenstown Lakes (17%); Waitaki (no data available).

4.4 Typical contaminants

The wastewater treatment process is efficient at reducing or removing many contaminants from the incoming wastewater stream, of which the efficiency (amount) of reduction is dependent on processes such as flow, residence time, input concentrations and the treatment process. However, thousands of chemicals are potentially present in wastewater discharges, the majority of which are not monitored under existing consents.

Typical constituents present in wastewater and associated effects are summarised in Table 10 along with a summary of effects, values affected and the most sensitive receiving environments for each contaminant class.

Table 10. Typical constituents present in wastewater discharges with associated values affected and most sensitive receiving environments

Type	Example	Effect	Values affected	Most sensitive receiving environments
Microorganisms	Pathogenic bacteria; Virus and worms eggs	Risk when drinking water, bathing, and eating shellfish	Drinking water; Cultural; Mahinga Kai Consumption; Primary Contact Recreation; Public Health; Recreational	Freshwater (lake; river; aquifer; wetland) Marine (bay; harbour; estuary; near-shore)
Biodegradable organic materials	Biochemical oxygen demand (BOD)	Oxygen depletion in rivers, lakes and coastal environments; Fish death; Odours	Aesthetic; Cultural; Ecosystem Health	Freshwater (lake; river; aquifer; wetland) Enclosed marine environments (harbour; estuary)
Nutrients	Nitrogen (ammonium and nitrate);	Eutrophication; Oxygen depletion; Toxic effect;	Aesthetic; Cultural; Ecosystem Health; Drinking water	Freshwater (lake; river; aquifer) Enclosed marine

Type	Example	Effect	Values affected	Most sensitive receiving environments
	Phosphorus	Leaching to groundwater		environments (harbour; estuary)
Trace organic chemicals	POPs; EOCs; Solvents; Cyanide	Toxic effect; Aesthetic inconveniences; Bio-accumulation in the food chain	Aesthetic; Cultural; Ecosystem Health; Drinking water; Irrigation; Mahinga Kai Consumption; Primary Contact Recreation; Public Health; Recreational; Stock	Freshwater (lake; river; aquifer) Enclosed marine environments (harbour; estuary)
Metals	Cadmium; Chromium; Copper; Lead; Mercury; Nickel; Zinc	Toxic effect; Bioaccumulation	Aesthetic; Cultural; Ecosystem Health; Drinking water; Irrigation; Public Health; Recreational; Stock	Freshwater (lake; river; aquifer; wetland) Marine (bay; harbour; estuary; near-shore)
Other inorganic materials	Acids; Bases	Corrosion; Toxic effect	Ecosystem Health; Public Health	Freshwater (lake; river; aquifer; wetland) Enclosed marine environments (harbour; estuary)
Suspended particulate material	Total suspended solids (TSS)	Smothering of aquatic life with associated oxygen depletion; Reduced water clarity; Transport of particulate associated contaminants	Aesthetic; Cultural; Ecosystem Health	Freshwater (lake; river) Enclosed marine environments (harbour; estuary)
Thermal effects	Hot water	Changing living conditions for flora and fauna	Ecosystem Health	Freshwater (river) Marine (estuary)
Odour (and taste)	Hydrogen sulphide	Aesthetic inconveniences; Toxic effect	Aesthetic; Cultural	Freshwater (lake; river; aquifer; wetland) Enclosed marine environments (harbour; estuary)

4.5 Adverse effects and indicators

Contaminants present in human wastewater discharges result in the potential for significant adverse effects on the receiving environment. The level of treatment of the wastewater and the characteristics of the receiving environment influence the potential for adverse effects on the uses and values associated with the receiving environment.

On-site wastewater treatment systems discharge to leachate fields, which can percolate into aquifers and surface water environments. In badly managed (or damaged) on-site systems, surface pooling may also occur, with potential for runoff into surface water.

Reticulated wastewater may also contain significant volumes of stormwater, and industrial and trade wastes prior to treatment at WWTPs. WWTPs may discharge treated wastewater to the freshwater environment (rivers, lakes, wetlands), land, or the coastal marine area. Land application may eventually percolate into aquifers and surface water environments.

MfE (2008) concisely summarised the effects of untreated or partially treated effluent discharging to the environment, which can include:

- Disease in people (especially young children) having direct contact with wastewater lying on the ground surface;
- Disease in people caused by drinking contaminated water (usually from shallow groundwater bores located near disposal fields);
- Flies and mosquitoes breeding in ponded effluent;
- Methemoglobinaemia ('blue baby syndrome') caused by elevated nitrate concentrations in groundwater used for drinking-water;
- Disease in people (most often young children) from contact recreation (swimming and paddling) in contaminated stormwater drains, streams, lakes, estuaries and beaches;
- Disease in people caused by eating contaminated shellfish, either from private or commercial shellfish gathering (shellfish tend to concentrate the pathogens that occur in the water, making their consumption a higher risk than contact with the water itself);
- Economic effects caused by having to close shellfish farms (even if no disease is actually caused);
- Nuisance weed growth and/or algal blooms caused by elevated nutrient levels, which can have secondary effects on people and aquatic animals from algal toxin reactions;
- Deterioration of freshwater ecosystems due to reduced water quality;
- Permanent soil degradation caused by high levels of sodium and other salts from washing powders being disposed of through disposal fields.

4.5.1 Indicators

Human wastewater can include a very broad cross-section of contaminants (see Section 4.4) and consequently a wide range of indicators can be relevant. General indicators of contaminants irrespective of the source in relation to effects thresholds are discussed in Section 2.7. Relevant broad indicators include faecal indicator bacteria, BOD, DO, suspended sediment, and animal and plant indices/biomass.

However, specific indicators of human wastewater that may be used to differentiate with other sources (e.g. stormwater, industrial and trade waste, and agricultural discharges) are present in the literature. Due to the complexities involved it is desirable to use multiple methods (weight-of-evidence approach) for human wastewater tracking.

Specific human wastewater indicators

Faecal indicator bacteria (e.g. *E. coli*) will not identify the source of microbial contamination. Microbial source tracking (MST) is a promising technique which combines a suite of methods and an investigative strategy for determination of faecal pollution sources in environmental waters. MST relies on the association of certain faecal microorganisms with a particular host.

One of the most promising set of tools to emerge from the MST toolbox has been a suite of assays based on the polymerase chain reaction (PCR). PCR assays detect and amplify specific DNA sequences. Differences within the DNA of members of some bacterial groups can be exploited. If these species of microbes are highly host specific, i.e., are resident in only humans or particular animal species, then a PCR assay of the DNA can be a useful MST tool. Specific PCR markers are reported for human, ruminant (sheep and cow), dog, horse, or wildfowl pollution (Field & Samadpour, 2007).

There are a wide variety of chemical markers that can be used as indicators of wastewater influence such as natural chemicals excreted by animals (faecal sterols/bile acids); and anthropogenic (man-made) chemicals specifically associated with laundry powders (fluorescent whitening agents and detergents) and those consumed only by humans (caffeine, nicotine, artificial sweeteners, pharmaceuticals, and even illicit drugs such as cocaine).

Faecal sterols are excreted in high quantities by all animals and so can be found in wastewater discharges, agricultural runoff, and road/urban stormwater runoff. However, it is possible to differentiate sources of faecal sterols - based on analysis of a few key sterols - and by association, the sources of contamination in a receiving environment. The use of the coprostanol:5β-stigmastanol ratio has been proposed by Evershed and Bethell (1996) as a useful index by which human faecal deposition and that of ruminants might be differentiated. Values greater than 1.5 were considered indicative of human-sourced pollution. Bile acids can provide further evidence of faecal source. This is possible because ruminant animals (e.g. bovines) produce predominantly deoxycholic acid whereas omnivores (e.g. humans) also produce significant quantities of lithocholic acid. Other bile acids can even differentiate between human, porcine (pig) and canine inputs (Bull et al., 2002).

Laundry powders contain surfactants and whitening agents. They also contain impurities that are neither surfactants nor whitening agents. Linear alkylbenzenes (LABs) are impurities in commercial detergents and so are present in municipal wastewater. LABs are a family of chemicals which degrade preferentially depending on the level of treatment (primary or secondary). This preferential degradation creates a “ratio” which can be used to indicate whether contamination is from secondary treatment (high ratio of 3-5) or untreated or primary treatment (low ratio of around 1) wastewater (Isobe et al., 2004; Tsutsumi et al., 2002).

Fluorescent whitening agents (FWAs) are added to laundry powders to improve the look of clothing and are useful markers for municipal and domestic wastewater. Two common FWAs have been studied; 4,4'-bis[(4-anilino-6-morpholino-1,3,5-triazin-2-yl)-amino]stilbene-2,2'-disulfonate (DAS1) and distyrylbiphenylsulfonate (DSBP) (Hayashi et al., 2002; Managaki and Takada, 2005). Due to a difference in photodegradation rate, the ratio of DSBP/DAS1 can be used to trace the distance that sewage water travels (Hayashi et al., 2002). However, in New Zealand, only DAS1 (also called FWA1) is used (Moriarty and Gilpin, 2009), so it is not possible to carry out sewage water transport studies described above.

Pharmaceuticals and Personal Care Products (PPCPs) have been used as potential markers of sewage. They offer greater specificity and faster monitoring response than traditional microbial monitoring.

Glassmeyer et al. (2005) suggested the pharmaceuticals carbamazepine, diphenhydramine, and even caffeine, would be potential sewage markers due to distinct increases in concentrations downstream of

WWTPs relative to upstream sites. Clara et al. (2004) proposed carbamazepine as a marker as it was shown to pass into groundwater after negligible degradation through extensive wastewater treatment and soil application. Crotamiton (scabicidal drug) and carbamazepine were determined as conservative markers of sewage effluent in freshwater and coastal environments as they are abundant and have low removal efficiency during secondary wastewater treatment (Nakada et al., 2008).

Although caffeine has high consumption, concentrations in natural waters are low. Most caffeine load to WWTPs is thought to be from discarded drinks as 97% is metabolised in the body. Furthermore, a similar rate of removal is observed by WWTP treatment processes (Buerge et al., 2003). Despite the low relative loads reaching the environment, caffeine is a commonly described wastewater marker in the literature and has been detected even in relatively remote marine waters around Rangitoto Island, in the Waitemata Harbour (Stewart et al., 2016a).

Artificial sweeteners are attractive chemical markers of wastewater as some pass through the human metabolic pathway largely unaffected, are completely excreted via urine and faeces, and so reach the environment through domestic wastewater discharges (Buerge et al., 2009). Acesulfame-K (Ace-K), sucralose, cyclamate, and saccharin are four artificial sweeteners commonly assessed as wastewater markers (Gan et al., 2013; Stolte et al., 2013; Tran et al., 2014).

Ace-K has been proposed as an “ideal marker” of domestic wastewater, as it has been detected consistently in treated and untreated wastewater, most surface waters and 65% of groundwater samples in Switzerland (Buerge et al., 2009).

Sucralose was shown to be a superior wastewater marker compared to 85 trace organic compounds - including caffeine, carbamazepine, DEET, gemfibrozil, primidone, sulfamethoxazole, and TCEP - in the U.S. Only sucralose was consistently detected in the source waters with known wastewater discharges, absent in the sources without wastewater influence, and consistently present in septic samples. All of the other compounds were prone to either false negatives or false positives in the environment (Oppenheimer et al., 2011).

Of particular importance, Ace-K, saccharin and cyclamate have been detected in landfill leachate or leachate-impacted groundwater at levels comparable to those of untreated wastewater (Roy et al., 2014), suggesting potential issues in using them as tracers where landfill sites are significant contributors to the catchment loads. The study showed that saccharin dominated old (pre-1990) landfills, while Ace-K and saccharin dominated newer landfills.

Nicotine, and its major metabolite cotinine are further chemical markers of human wastewater, although they have also been detected in landfill leakage water (Schwarzbauer et al., 2002). Furthermore, in urban areas, nicotine and cotinine could be associated with stormwater inputs. As with caffeine, nicotine and cotinine were also detected around Rangitoto Island (Stewart et al., 2016a).

Some illicit drugs, or drugs of abuse, will likely be present in wastewater effluent as, like PPCPs, they show preferential removal by treatment processes (Petrovic et al., 2009; Thai et al., 2014). However, there is no specific reason for why they should be included as source trackers, as PPCPs can provide the same result. Furthermore, analysis will likely be complicated due to regulation of these chemicals.

4.5.2 Specific WWTP discharges in Otago

Discharge to near-shore ocean environments

The major WWTPs in Otago (Tahuna, Green Island/Mosgiel) treat 84% of reticulated wastewater and discharge to a near-shore ocean environment.

Near-shore ocean discharges may cause adverse effects on ecosystem health, public health (through primary contact recreation, recreational and mahinga kai consumption), cultural, and aesthetic values. The severity of these effects vary but are generally relatively low due to: high energy environments (currents and waves) preventing settling of particulate matter (and associated contaminants); extremely high and rapid dilutions by sea water; rapid attenuation of some contaminants (microbial pathogens especially) by sea water; and engineering solutions (such as staged discharges and diffuser designs) to minimise adverse effects.

Microbes present in the discharge are likely to present a low risk of adverse effects on human recreational activities (swimming and boating), provided these activities do not occur in the immediate vicinity of the discharge. However, if shellfish harvesting were to occur near the discharge pipe, then its consumption may present an acute health risk due to microbial uptake by the shellfish. In contrast, the metal and organic contaminants that bioaccumulate in these shellfish present only a small risk to humans because continual harvesting and consumption is required to cause chronic effects (USEPA, 2000).

Cultural values may be adversely affected by discharge of wastewater to a near-shore ocean environment, particularly if there is a significant mahinga kai resource in the vicinity of the discharge. The severity of these effects depends on the type of mahinga kai resource available, and frequency of harvest.

Benthic aquatic intertidal and subtidal habitats in the vicinity of the outfall may be affected, leading to a reduction of mud and/or metal sensitive benthic species and a loss of biodiversity. The severity of ecosystem effects are likely to be low due to large dilutions and a high energy environment preventing contaminant build-up.

Intertidal reef communities are unlikely to be adversely affected by a near-shore ocean discharge, unless they are in the immediate vicinity although bioaccumulation of some contaminants (metals and organics) in fish and shellfish may lead to potential long term human health consumption risks.

Aesthetic values may be impacted through discolouration, freshwater mixing, and reduced water clarity caused by suspended particulates in the discharge. However, these can be mitigated through staged discharges, improved diffuser design to improve dilution, and discharge away from shore.

Discharge to rivers

Fifteen WWTPs in Otago discharge to the freshwater environment, with the total volume treated ~15% of the total reticulated wastewater for the region. Although this suggests that discharges to freshwater are generally a relatively low proportion of the total volume in the region, these are potentially significant volumes and adverse effects can be localised and severe if not mitigated effectively.

Effects on river ecosystems from WWTP discharge can be highly dependent on other factors, such as the state of the river, wastewater treatment level, diffuse catchment inputs (for example, nutrients, suspended sediment, and metals), the level of in-situ contaminant attenuation (for example, the ability of UV light to penetrate the water column and deactivate pathogens), and river flows. For example, Drury et al., (2013) assessed the impacts of WWTP effluent on the size, activity, and composition of benthic microbial communities by comparing two distinct rivers: a highly urbanized river receiving effluent from a large WWTP and a suburban river receiving effluent from a much smaller WWTP. The overall effect of the WWTP inputs was that the two rivers, which were distinct in chemical and biological properties upstream of the WWTPs, were almost indistinguishable downstream. These results suggest that WWTP effluent has the potential to reduce the natural variability that exists among river ecosystems and indicate that WWTP effluent may contribute to reduced variability in biota. Gücker et al., (2006) found evidence that even tertiary treated wastewater can have extensive effects on stream ecosystem structure and function (over and above diffuse catchment inputs) and adequate dilution should always be considered when discharging wastewater to river systems. This was supported by Englert et al., (2013) who noted that macroinvertebrate community structure downstream of a wastewater discharge was significantly more affected in summer (low dilution) over winter (high dilution).

Aesthetic values may be impacted by discolouration, reduced water clarity, algal growth and odour. These are likely to be more severe in smaller streams at seasons with low flow and higher temperatures (summer). The proximity of the general public to rivers and streams creates a higher risk profile as adverse aesthetic effects will be more noticeable than for near-shore ocean environments.

Contact recreation values may be impacted if microbial pathogens are present in the wastewater discharge in sufficient numbers to elicit a public health risk. The risk of an adverse illness outcome is increased during summer months where river dilution is reduced, water temperatures and the number of people swimming are increased. This risk is enhanced if popular swimming holes exist downstream and in the vicinity of the discharge point.

Cultural values may be adversely affected if important mahinga kai gathering resources are immediately downstream of the wastewater discharge point. Although generally in decline, freshwater mussels (if present), present a potential acute human health consumption risk from pathogenic microbial contamination (Oliveira, et al. 2011). Popular freshwater species high in the food-chain (e.g. eels and trout) present a potential long-term human health consumption risk from metal and organochlorine contaminants that bioaccumulate.

<u>Discharge to lakes</u>

Adverse effects of wastewater discharges in lake environments are similar to river discharges, however there are important distinctions between rivers and lakes. Unlike rivers, which flow, dispersal of a contaminant discharge (plume) through a lake is dependent on internal lake currents and wind. The lower flow in lakes increases the contaminant residence time markedly (lower flushing) and increases the propensity for settling to occur (lower energy environment) and accumulation of particulates (fine sediment) and particulate-associated pollutants. Lake environments are highly sensitive to increases in nutrient loads (the total mass of nutrient entering a lake). Wastewater discharges have the capacity to increase nutrient loads to a lake that will lead to eutrophication as nutrients accumulate in sediments over time and are then released back into the water column by internal lake processes.

Effects of wastewater discharge on lakes include increased algal growth (eutrophication), impaired aesthetic values (turbidity, odour, discolouration), contact recreation (swimming), and mahinga kai gathering (human health risk). Aesthetic, contact recreation and mahinga kai gathering values may be more significantly affected in the vicinity of the discharge point, due to limited flushing.

Due to the potentially high concentration of nutrients in wastewater discharge (see Table 9), lake eutrophication is likely the major determining risk factor for wastewater discharges to lakes. The susceptibility of a lake to increased eutrophication from wastewater discharges depends on the nutrient and particulate sediment loads (and hence level of treatment employed), the lake size, present water quality, and other nutrient/sediment inputs (both point source and diffuse catchment inputs). In Otago,[20] lakes vary from small and shallow (e.g. Lake Johnson (20 ha) and Lake Waihola (620 ha) to large and deep (e.g. Wanaka (18000 ha) and Wakatipu (28900 ha)). The level of eutrophication of a lake is related to a trophic level index (TLI). The TLI number is calculated using four separate water quality measurements – total nitrogen, total phosphorous, water clarity, and chlorophyll-a, with the lower the TLI number, the better the water quality. In Otago, lake water quality ranges from good (microtrophic (TLI <2), e.g. lakes Wakatipu, Dunstan, Hawea and Wanaka) to average (mesotrophic (TLI 3-4), e.g. Onslow) to very poor (supertrophic (TLI 5-6), e.g. Hayes and Johnston).

Increased eutrophication of lakes can have far reaching impacts including[21]:

- Excessive plant and algae growth and decay - especially invasive weed species.
- Decreased dissolved oxygen (DO) levels - fish 'breathe' oxygen through their gills, therefore a decrease in available oxygen (anoxia) in the water column threatens their ability to respire, which may lead to death.
- Increased turbidity and decreased water clarity - water becomes cloudy and coloured green and brown, which reduces the ability of fish to see prey and detect predators.
- Seasonal release of nutrients stored in the lake bed sediment (known as legacy loads), which contributes to the cycle of eutrophication.

Discharge to land

Five WWTPs in Otago (Warrington, Roxburgh, Naseby, Waikouaiti, and Seacliff) discharge to ground. Together these account for 1% of the total reticulated wastewater treated in the region. However, Warrington, Roxburgh, and Naseby only have primary treatment, and Waikouaiti and Seacliff secondary treatment. Furthermore, there are large clusters of on-site wastewater systems (septic tanks) in Otago, which discharge under the ground through disposal fields.

The most severe adverse effects of land discharge is the potential leaching of nitrate and pathogens into aquifers which supply human drinking water. Risk is increased if the aquifer is shallow and attenuation of nitrate (through soil denitrification processes) and pathogens is reduced.

Adverse aesthetic effects of land discharge of wastewater are largely related to odour, if application is by an above ground sprinkler system. This is removed if application is through below ground seepage systems. Careful management of discharge is necessary to avoid flooding. For example, the Omaha WWTP (Auckland)

[20] https://www.lawa.org.nz/explore-data/otago-region/lakes/
[21] modified from https://www.niwa.co.nz/our-science/freshwater/tools/kaitiaki_tools/impacts/nutrients/eutrophication

discharges treated wastewater through reticulated underground pipes to a Eucalyptus grove, golf course, or sand dunes. After high rainfall events (generally in winter), the soil in the Eucalyptus grove and golf course become saturated, so, to avoid pooling, discharge is almost exclusively to sand dunes (Cooke et al., 2015b).

Discharge to wetlands

Changes to wetlands arising from wastewater discharges that may lead to unacceptable conditions or can serve as indicators of change are:

- Changes in species composition;
- Nuisance growth of algae;
- Alteration of organic accumulation rates;
- Heavy metal accumulation in food chains;
- Net export of nutrients and suspended solids;
- Groundwater contamination;
- Pathogen problems;
- Damage to adjacent ecosystems;
- Downstream eutrophication.

These changes are manifest principally through impacts of wastewater on the hydrology, water quality, and ecology of the wetland (Cooke, 1991).

4.5.3 Other adverse effects

Other adverse effects from wastewater discharges that are potential stressors but are not due to contaminants include freshwater mixing in the marine environment. Freshwater intolerant aquatic species may be adversely affected around the discharge point. These effects are likely to be negligible in near-shore ocean environments, due to the enormous dilution capacity and strong currents. Discharges of freshwater to estuaries and enclosed harbours may be of potential concern due to the lower potential for dilution. Hydrodynamic modelling of dilutions under various discharge, tidal, wind and population scenarios are necessary to understand the potential for effects from freshwater discharges in these environments (for example Clarks Beach WWTP discharge to Waiuku Estuary: Oldman, 2016).

4.5.4 Summary of adverse effects from human wastewater

The severity of effects of wastewater discharges to each receiving environment is summarised in Table 11. However, there are knowledge gaps, specifically around virus and EOC composition and effects of wastewater. These are discussed further in Section 4.5.5.

Table 11. Summary of values affected and severity of effects from wastewater discharges

Activity	Values affected	Effects	Potential severity of effects	General Trend
Near-shore ocean discharge	Ecosystem health	Reduction in sensitive benthic species; loss of biodiversity	Low due to dilution effects	Increased adverse effects in low energy environments with inappropriate engineering solutions which do not maximise dilution
	Primary contact	Increased microbial and chemical contaminants		
	Mahinga kai consumption	Contaminated shellfish (POPs, metals, microbes)		
	Cultural	Contaminated mahinga kai	Variable: depends on frequency and species of kai gathering in area	
	Aesthetic	Reduced water clarity due to elevated suspended particulates	Low when mitigated through diffuser design and off-shore discharge	
River discharge	Ecosystem health	Reduction of ecosystem function	Variable: depends on current river state, treatment level, dilution, river flow	Increased adverse effects near discharge point and enhanced in low flow streams
	Cultural	Contaminated mahinga kai	Variable: depends on frequency and species of kai gathering in area	
	Aesthetic	Reduced water clarity due to elevated suspended particulates	Near-field effects likely to be greatest and worst under low flow conditions	
		Increased periphyton growth due to nutrient enrichment		
	Public health, primary contact and recreation	Increased microbial and chemical contaminants	Generally low due to high dilution, except immediately downstream of discharge point	
Lake discharge	Ecosystem health	Reduction of ecosystem function	Variable: depends on size and trophic level of lake	Smaller shallow lakes of high trophic level likely to be less resilient than large deep lakes of low
	Cultural	Contaminated mahinga kai	Variable: depends on frequency and	

Activity	Values affected	Effects	Potential severity of effects	General Trend
			species of kai gathering in area	trophic level
	Aesthetic	Reduced water clarity due to elevated suspended particulates	Near-field effects likely to be greatest due to low flow environment and large dilution. Smaller, shallow lakes likely to show greater severity of effects than larger deep lakes	
		Algal blooms due to nutrient enrichment		
	Public health, primary contact and recreation	Increased microbial and chemical contaminants	Generally low due to high dilution, except in vicinity of discharge point	
	Mahinga kai consumption	Contaminated fish (POPs, metals, microbes)	Low for most consumed species due to high mobility and low numbers of shellfish	
Wetland discharge	Ecosystem health	Reduction in sensitive plant and benthic species; loss of biodiversity	May be very localised flooding when ground is saturated	Severity of effects potentially low
	Secondary contact recreation	Illness through exposure to pathogens (e.g. duck hunters)	Low due to episodic exposure and dilution	
Aquifers (through discharge to land)	Drinking water	Increased nitrate and pathogens	Mild to severe, depending on nitrate and pathogen concentrations	The severity of effects are potentially higher for inadequately treated wastewater, such as that from septic tank failures and in shallow and coarse media aquifers
	Ecosystem health	Degradation of microbial communities by antibiotics with potential for multi-drug resistant strains	Unknown for most antibiotics due to lack of information on effects and fate	
	Aesthetic	Odour, surface ponding	Generally small and only if discharge is above ground	

4.5.5 Knowledge gaps and risks

Viruses

Direct monitoring of several viral pathogens in water is challenging and impractical, despite the recent development of real-time quantitative polymerase chain reaction (PCR) analyses (USEPA, 2012). Quantitative Microbial Risk Assessments (QMRAs) are relatively new approaches (see for example: (McBride, 2016)) to identify risks from specific classes of virus from wastewater that are of most concern for human health. These include:

- Adenovirus (linked with respiratory diseases) – chosen for contact recreation (swimming) only. This virus is highly infective and may be present in low numbers in treated wastewater;
- Enteroviruses (gastroenteritis) – chosen for swimming and shellfish consumption. This virus is less infective, but health consequences can be more severe than for adenovirus;
- Norovirus – implicated in swimming and shellfish consumption. There is increasing evidence of its prevalence in treated wastewater;
- Rotavirus – implicated in swimming and shellfish consumption. The most infective virus which particularly affects children.

A risk based approach of viruses from wastewater (such as QMRA) is necessary for each wastewater discharge and associated receiving environment. Until this has been undertaken, the risk from viruses is a significant knowledge gap.

EOCs

EOCs are by definition an emerging area of knowledge. EOCs encompass potentially thousands of individual chemicals, each with their own toxicity effect (many of which do not fit the classical acute toxicological profile) and environmental fate profile. Logistically, there is also a paucity of advanced methods to measure these effects and environmental concentrations.

Furthermore, many EOCs are not fully removed by current WWTP technologies (Luo et al., 2014; Margot et al., 2015). The amount of EOC removal is highly dependent on level of treatment, however it can be highly variable. To illustrate this, a qualitative summary of removal rates of EOC classes by treatment type is presented in Table 12, which demonstrates the large variability apparent within each EOC class for removal by conventional activated sludge (CAS) and more advanced membrane bioreactor (MBR) treatments. What is apparent from Table 12 is that advanced oxidative processes (AOPs) generally provide higher removal rates of EOCs than CAS or MBR.

Table 12. Qualitative summary of different treatment options for EOC removal (from Luo et al., 2014)

Treatment/EOC class	Common removal efficiency			
	P	PCP	SH	IC
CAS	Low-High	Medium-High	Medium-High	Low-High
MBR	Low-High	Medium-High	High	Medium-High
Ozone and AOPs	Medium-High	Medium-High	High	Medium-High

P = pharmaceutical; PCP = personal care product; SH = steroid hormone; IC = industrial chemical; AOP = advanced oxidation processes

EOCs and emergent viruses (and to a lesser extent emergent bacteria) present a unique challenge in wastewater management. Our recent experience in providing assessments of environmental effects from wastewater discharges (James et al., 2016a, 2016b, 2016c) is that, due to the complexity of the issues involved - for example, potential for population growth, discharge environment (land or freshwater, marine, estuarine aquatic environments) treatment used, and cultural issues - no two assessments are the same. Therefore a detailed assessment of effects that is specific to that WWTP is necessary and should include risks from viruses and EOCs.

Pathogen soil transport

Pathogen transport through soils is not well understood due to complexities which are enhanced by soil heterogeneity, temporal (time) variability in temperature, water inputs, and pathogen sources (Bradford et al., 2013) and so their risk can't be accurately assessed.

On-site wastewater systems

For logistical reasons, compliance monitoring of on-site wastewater (septic tank) discharges in Otago has been reactive, and on an individual scale. There is a lack of accurate information on so called 'silent' failures of on-site wastewater systems (i.e. those that go unreported) in the region (Otago Regional Council, 2015b). It is estimated that failure rates of on-site systems for different communities are estimated to range from 15 to 50 percent (Ministry for the Environment, 2008). The large range of estimated failures of on-site treatment systems is a significant knowledge gap, especially in areas that are not serviced by reticulated wastewater networks.

4.6 Management and mitigation practices

Management processes used in reticulated wastewater treatment plants to mitigate adverse effects include the level of treatment of the final discharge, location of discharge, and maintenance of the treatment systems and wastewater network. Management of on-site wastewater system discharges is an inherently more challenging task due to the geographic spread and variability in operating efficiency of each system.

WWTPs

Treatment level

As covered in Section 4.2.3, there are generally 3 levels of reticulated wastewater treatment; primary, secondary and tertiary. The quality of wastewater discharge (i.e. the propensity of that discharge to adversely affect the receiving environment) is dependent on the level of treatment employed at the treatment plant. Generally, the higher the treatment level, the lower the discharge concentrations of contaminants (for nutrient loads as an example see Table 9). The corollary to this is the higher the treatment level the higher the cost burden (including set-up, operation and maintenance).

Receiving environment

The sensitivity of the receiving environment is a major factor that dictates the level of treatment required from a WWTP discharge, to ensure the uses and values of the receiving environment are not significantly adversely affected. Higher concentrations of contaminants may be allowable in the discharge if there is high dilution within the immediate discharge, for example an open ocean discharge. We note that of WWTPs which discharge to the near-shore ocean environment, those in Dunedin use tertiary treatment, but that Kaka Point (Clutha District) uses secondary treatment.

On the other end of the scale, discharge to lakes (especially small lakes which are more sensitive to effects due to lower dilution and flushing capacity) may require a tertiary level of treatment to ensure long-term cumulative effects do not occur, i.e. through association with sediments and potential for subsequent re-suspension into the water column. Re-use of wastewater for a variety of purposes (drinking water, irrigation, stock) is increasing in countries with limited freshwater resources. A high level of tertiary treatment is required to achieve the stringent standards necessary.

Wastewater network

Contaminants can enter the environment in wastewater that is discharged prior to treatment, either in the form of wastewater overflows or as exfiltration from the network.

Wastewater overflows need to be actively managed. The potential for dry weather overflows is reduced through various operational procedures such as regular cleaning and other maintenance. Wet weather overflows occur as the result of stormwater ingress during rainfall, and are addressed through wastewater network capacity planning and the associated physical works. As noted in Section 3.4, wastewater overflows or cross connections to stormwater networks are relatively common and can lead to sewage contamination of receiving waters from stormwater outfalls.

Exfiltration is the leakage of wastewater from the wastewater network via pipes, pipe joints, manholes and other network structures, and is managed as part of normal operational procedures such as regular pipe surveys. Where sections of the network are recognised as giving rise to exfiltration, these are identified for renewal.

4.6.1 Leading regions and countries

Advances in wastewater treatment worldwide appear to be driven by the need for re-use of water (potable and non-potable) for economic and/or environmental gain. It is difficult to form conclusions on leading countries implementing water re-use as data are not readily available. A study by Sato et al., (2013) revealed approximately a third of countries provided information on water re-use (for example NZ do not provide this information while Australia do).

Within NZ, the level of wastewater treatment (primary, secondary, or tertiary) from Water New Zealand (2015) data was used to gauge regional differences in wastewater management. As shown in Figure 12, there does not appear to be any regional bias and the level of treatment is more closely associated with the urban area of the District. The major centres of Tauranga, Hamilton, Dunedin, Wellington, Christchurch and Auckland (Watercare) all employ virtually 100% tertiary wastewater treatment. The majority of the more rural Districts (including Clutha and Central Otago) employ significant primary and secondary treatment.

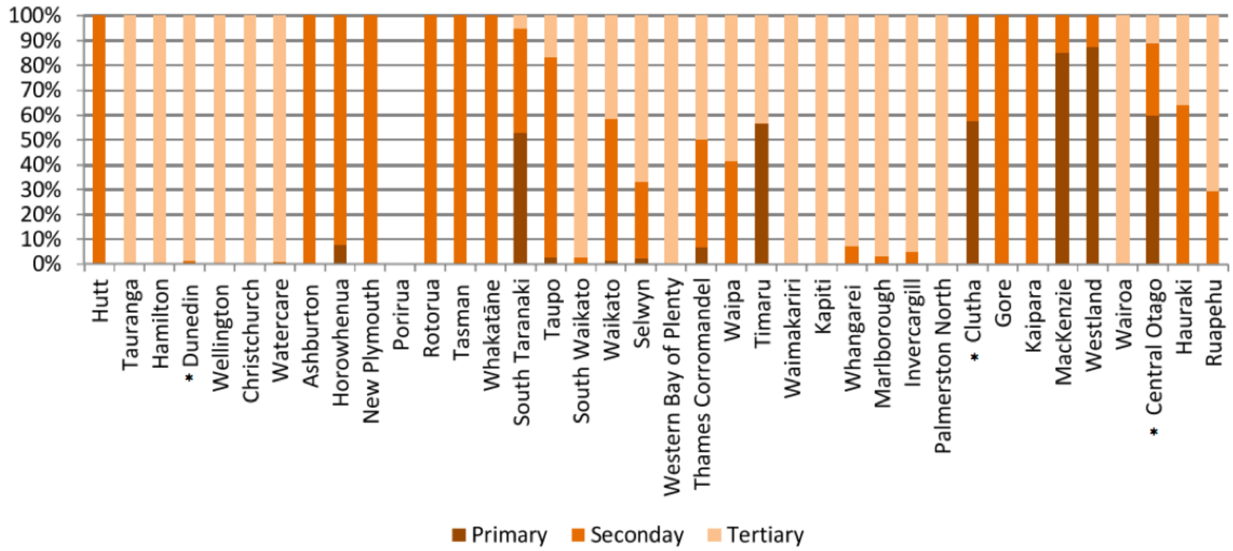

Figure 12. Level of wastewater treatment by District. Otago Districts are marked with an asterisk.

4.7 Specific matters

4.7.1 Common issues/challenges with management of human wastewater

Aside from challenges around management and mitigation practices of human wastewater (treatment level, discharge environment, infrastructure) covered in Section 4.6, there are common issues associated with management of human wastewater.

Monitoring of the major characteristics of human wastewater into, and discharging from, a reticulated WWTP (e.g., concentrations of suspended solids, BOD, TN, TP) is relatively straightforward, and will be consistent between different WWTPs. However, particularly in larger urban centres, there can be a very wide range of 'other' contaminants that could enter the sewerage system and it would generally not be feasible to continuously monitor for all potential contaminants entering into, or discharging from, a treatment system. This makes it challenging to appropriately identify, and address all potential contaminants (and associated adverse effects) of a WWTP discharge, and there will be a lack of consistency across individual WWTPs, even within a region.

To illustrate this, an analysis of consent conditions for monitoring of effluent from Tahuna WWTP (Consents 2002.623 and 2002.624) and Green Island WWTP (Consent 97530)[22] revealed there are a wide range of contaminants currently monitored, including those associated with acute toxicity (cyanide, sulphide, chlorine), particulate matter, organic contaminants (including organotins, phenols, semi-volatile and volatile organic compounds), nutrients, heavy metals/metalloids and microbes (Enterococci and Faecal Coliforms)

[22] As the 2 largest WWTPs in Otago, consent conditions are expected to be most encompassing in the region. For example Queenstown WWTP discharge consent conditions (RM13.215) require monitoring of DO, pH, BOD_5, TSS, NH_4-N, TN, TP and E. coli/faecal coliforms; whereas Oamaru WWTP discharge consent conditions (2002.655 and 2002.704) require these same parameters plus total cadmium, chromium, copper, lead, zinc, arsenic, mercury, nickel, and silver.

(Table 13). What is also apparent is considerable variation between the two major WWTPs regarding monitoring requirements for *specific* contaminants.

To further illustrate the differences, monitoring of discharges from Waiuku and Clarks Beach WWTPs (both situated in the South-West Manukau area, Auckland), are similar but not identical (Stewart et al., 2016c)[23]:

- Clarks Beach - DO, BOD, TSS, ammonia, TIN, TP, pH, temperature, faecal coliforms;
- Waiuku - DO, BOD, TSS, ammonia, TIN, TP, pH, temperature, faecal coliforms, enteric bacteria, phages.

Table 13. Parameters measured as part of consent conditions for Tahuna and Green Island WWTPs

Class	Parameter	Tahuna WWTP	Green Island WWTP
Acid/Base	pH	Yes	Yes
Organic material	BOD_5	Yes	Yes
Particulate matter	Settleable Solids	No	Yes
	Suspended Solids	Yes	Yes
Acute Toxicity	Cyanide	Yes	Yes
	Sulphide	Yes	Yes
	Total Residual Chlorine	Yes	No
Organics	Formaldehyde	Yes	Yes
	Grease and Oil	Yes	Yes
	Organotins	Yes	No
	Total Phenols	No	Yes
	Semi-volatile Organic Compounds	Yes	No
	Volatile Organic Compounds	Yes	No
Nutrients	Ammoniacal Nitrogen	Yes	Yes
	Nitrate Nitrogen	No	Yes
	Nitrite Nitrogen	No	Yes
	Dissolved Organic Nitrogen	No	Yes
	Total Nitrogen	No	Yes
	Dissolved Reactive Phosphorus	No	Yes
	Total Phosphorus	No	Yes
Heavy Metals/Metaloids	Aluminium	Yes	No
	Antimony	Yes	No
	Arsenic	Yes	Yes
	Boron	Yes	No
	Cadmium	Yes	Yes
	Chromium(III)	Yes	Yes

[23] Abbreviations: DO = dissolved oxygen; BOD = Biochemical Oxygen Demand; TSS = Total Suspended Solids; TIN = Total Inorganic Nitrogen; TP = Total Phosphorus.

Class	Parameter	Tahuna WWTP	Green Island WWTP
	Chromium (VI)	Yes	Yes
	Cobalt	Yes	No
	Copper	Yes	Yes
	Lead	Yes	Yes
	Manganese	Yes	No
	Mercury	Yes	Yes
	Molybdenum	Yes	No
	Nickel	Yes	Yes
	Selenium	Yes	No
	Silver	Yes	No
	Thallium	Yes	No
	Vanadium	Yes	No
	Zinc	Yes	Yes
Microbes	Enterococci	Yes	Yes
	Faecal Coliforms	Yes	Yes

The contaminants illustrated in the above text (and Table 13) are relatively well understood (in terms of concentrations and potential effects), however (under the RMA) wastewater managers are having to give regard to emerging contaminants (ECs) potentially present in wastewater discharges during re-consenting processes. The main challenge is the enormous number of chemicals (and microbes) that fit into this category and the paucity of information on ECs in wastewater, including what effects they may exhibit and at what concentration. This challenge is being addressed to some extent through risk assessment procedures to identify and measure applicable 'high risk' ECs in WWTP discharges, which will inform setting of applicable future consent limits. These limits (and ECs monitored) may need to be modified in the future (especially for long term consents) as more information becomes available.

4.7.2 Biosolids

The application of biosolids to land can have beneficial effects, improving physical, chemical and biological soil conditions. However, it can also result in excessive nitrate leaching and/or trace element accumulation in soil and plants. It is inappropriate to apply biosolids to areas where there is a risk of altering important natural habitat values; for example, in native bush reserves, wetlands, or in habitats of rare or endangered species. The increased level of nutrients resulting from the applications of biosolids may affect native plant communities that have adapted to soils of low fertility.

Current NZ Biosolids Guidelines exist for heavy metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc), organochlorine pesticides (for example, DDTs, dieldrin), polychlorinated biphenyls (PCBs) and dioxins (New Zealand Water Wastes Association, 2003). The trace element concentrations can be used to categorise the biosolids as grade "A" or "B".

Water NZ are currently reviewing the NZ Biosolids Guidelines. Although the Guidelines are still under revision, reviews commissioned have made recommendations that provide some vision as to what the new Guidelines may involve. A contaminant review (CIBR, 2014a) concluded that the threshold values for trace element concentrations in grade "A" biosolids are too conservative and currently prevent the beneficial reuse of these materials. They go a step further and suggest the current grade "A" thresholds could be abandoned, while leaving in place current grade "B" thresholds to prevent dumping of overly-toxic materials. A second review of the organic contaminants (CIBR, 2014b) has recommended the current organic contaminants can be considered obsolete and should be replaced with selected EOCs, including endocrine disrupting chemicals (EDCs) (e.g. steroids, nonylphenols), flame retardants (e.g. Hexabromocyclododecane (HBCD) and selected polybrominated diphenyl ethers (PDBEs)), antimicrobial agents (e.g. triclosan and ciprofloxacin); pharmaceuticals (e.g. carbamazepine, diclofenac); persistent herbicides (clopyralid); and surfactants (e.g. Linear Alkylbenzene Surfactants (LAS)). The authors state that at this stage, there is not enough information to derive NZ-specific limits but interim values could be used, based on European Union guidelines.

4.7.3 Re-use

As discussed in Section 4.6.1, wastewater re-use for potable and non-potable requirements appears to be driving advances in wastewater treatment technology. Any level of resulting water quality is theoretically possible (for example see Figure 13), however the cost required increases accordingly. Re-use applications range from urban settings, agricultural (food crops), environmental (including streams, lakes, wetlands, ground-water recharge), industrial (for example, power stations), and potable drinking water (for example: Lopes et al., 2016; Naidoo and Olaniran, 2014; USEPA, 2012).

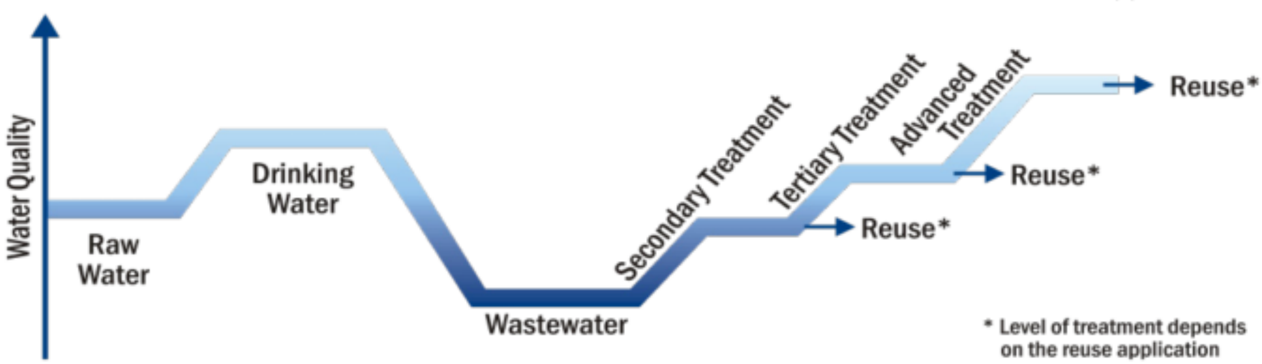

Figure 13. Schematic of level of wastewater treatment required to reach specified water quality (USEPA, 2012)

5. Industrial and Trade Waste

5.1 Key points for industrial and trade waste

- **Adverse effects** – The wide range of potential contaminants in trade waste discharges, the range of trade waste management and regulation approaches across the region including the management of wastewater infrastructure, and the different levels of treatment of the eventual wastewater indicate that there are risks of potentially significant adverse effects occurring. Generally, severity of effects would be expected to follow other discharges following a pattern of: near-shore ocean discharge < river < large lakes < small lakes.
- **Key contaminants** – Industrial and trade wastes can contain an extremely broad range of contaminants including microorganisms (bacteria, viruses); biodegradable organic material (BOD); nutrients (e.g., N and P); metals/metalloids; acids/bases; petroleum products, chlorinated hydrocarbons, specific organic materials (e.g. pharmaceuticals from hospitals).
- **Current management/mitigation** – The broad range of industrial and trade wastes in Otago has resulted in a similarly broad range of current management practices. The management of major individual industrial discharges is currently addressed by specific discharge permits that have been developed under a broad regional plan framework that has focused on specific effects arising from a discharge. Trade waste management and treatment varies significantly across the region because of: the very different nature of trade waste activities across the region; the different infrastructure and wastewater treatment systems in each urban centre; and different discharge permit requirements. Territorial authorities also have different trade waste bylaws/controls and approaches to developing and implementing these trade waste controls.
- **Key knowledge gaps/risks –** It is very difficult to identify specific knowledge gaps for industrial and trade wastes because of the very diverse nature of these discharges. There is also a risk of unplanned discharges entering a trade waste discharge system and the ability of the relevant wastewater infrastructure to manage these and avoid or mitigate the potentially significant adverse effects that could occur may not be present. The risk of accidental/unauthorised discharges into a wastewater system is generally higher in larger urban areas where there is a wider range of small businesses generating trade waste.

5.2 Introduction

5.2.1 What is industrial and trade waste?

Trade waste is any wastewater discharged into a district/city council sewerage system from an industrial or trade premise such as a restaurant, hospital or service station in the course of their activity. Trade waste discharges will also include waste from toilets and showers (human wastewater) that are present at a trade premise. This trade waste is incorporated in district/city wastewater discharges. In addition to trade wastes, many industries/trade premises discharge their waste via a standalone system separate from the district/city council sewerage system. This is usually because of the location of the activity.

5.2.2 Why are industrial and trade waste discharges an issue?

Wastes from industrial and commercial sources contain contaminants that when discharged onto land or into water could affect the quality of receiving waters. In addition, wastes that enter a district/city sewerage system have the potential to damage or block the sewerage infrastructure, adversely affect the waste treatment system and can be a hazard for people working in or around sewerage infrastructure.

5.3 Types considered and discharges in Otago

For the purposes of this report, industrial and trade waste are defined as those point discharges of contaminants to land or water authorised under the RMA but not discharges of stormwater (see Section 3), or landfill leachate, contaminated site discharges, or diffuse discharges such as the application of pesticides (all of which are covered in Section 6).

Industrial and trade waste discharges can come from a very wide range of activities including: restaurants and takeaways, schools, childcare centres, hospitals, medical centres, significant food processing industries, commercial laundries, and can include activities that use/store/transfer hazardous substances (such as heavy metals) with a risk that a hazardous substance could enter a discharge. Industries, businesses or organisations that can generate hazardous substances that can enter a waste stream include laboratories, metal finishing, timber treatment plants, hospitals, veterinarians, vehicles servicing. Mining has been separated out (see Section 6) as a specific industry because of both the scale of gold mining in Otago and because of the recognised potentially hazardous nature of discharges from mining.

Larger industries, such as meatworks and dairy factories, usually have individual discharge permits for the discharge of their waste, generally onto specific land treatment systems. However, the majority of small industries, businesses or organisations based in urban centres in Otago that generate a waste stream (in addition to sewage/domestic wastewater) discharge those wastes to the relevant territorial authority wastewater/sewerage system and then to some form of treatment prior to a final authorised discharge. As described in Section 4.3.1, the reported trade waste component of WWTPs in Otago is only a minor volumetric component (mean of 1.7%) of municipal wastewater in the region.

5.4 Typical contaminants

The range of contaminants that can be present in trade wastes and the potential adverse effects have been understood for many years (e.g. Walmsley, 2014). A key aspect of industrial and trade waste discharges is that there is a vast range of small industries that operate in Otago, from a restaurant or service station in Alexandra to food processing and engineering businesses in Dunedin City. The vast range of activities that come under this category means that the range of potential contaminants is also comprehensive. These range from primarily biologically-based wastes, where the main contaminants are microorganisms (pathogenic and non-pathogenic), nutrients (N and P), suspended solids (TSS) and biological oxygen demand (BOD), to a wide range of potentially hazardous chemical substances incldiuing organic (e.g., chlorinated hydrocarbons and petroleum products) and inorganic (e.g., copper, chromium and arsenic). However, even for wastes from food processing industries, there are risks that these discharges can sometimes also include small quantities of hazardous substances such as chlorine-based cleaning products. Table 14 provides examples of the sources and types of contaminants that may be present in industrial and trade waste.

Table 14. Examples of contaminants present or potentially present in industrial and trade waste and associated values affected[1,2]

Industry	Example	Examples of Effects	Values affected	Most sensitive receiving environments
Automotive refinishing and repair	Some metals and metal dust; various organic compounds; solvents; paint and paint sludges; scrap metal; waste oils	Toxic effects; Aesthetic effects	Aesthetic; Cultural; Ecosystem Health; Groundwater Quality for drinking water; Irrigation; Public Health; Recreational; Stock	Freshwater (lakes; rivers; groundwater; wetlands) Marine (bays; harbours; estuaries; near-shore)
Waste management/ transfer and recycling centres	Heavy metals, acids, biodegradable organic materials, nutrients, cleaning chemicals, suspended solids, faecal indicator organisms	Toxic effects; Oxygen depletion; Accelerated eutrophication; Effects on suitability of water for contact recreation	Aesthetic; Cultural; Ecosystem Health; Groundwater Quality; Irrigation; Public Health; Recreational; Stock; Mahinga Kai Consumption	Freshwater (lakes; rivers; groundwater; wetlands)
Dairy factory	Biodegradable organic materials, nutrients, cleaning chemicals, suspended solids, and faecal indicator organisms	Toxic effects; Oxygen depletion; Accelerated eutrophication; Effects on suitability of water for contact recreation	Aesthetic; Cultural; Ecosystem Health; Groundwater Quality; Irrigation; Public Health; Recreational; Stock	Freshwater (lakes; rivers; groundwater; wetlands) Marine (bays; harbours; estuaries; near-shore)
Dry cleaning activities	Various solvents such as tetrachloroethylene and decamethylcyclopentasiloxane ("liquid silicone")	Toxic effects	Aesthetic; Cultural; Ecosystem Health; Groundwater Quality; Irrigation; Public Health; Recreational; Stock	Freshwater (lakes; rivers; groundwater; wetlands) Marine (bays; harbours; estuaries; near-shore)
Electroplating operations	Various metals such as cadmium, chromium, cyanide, copper, and nickel	Toxic effects	Aesthetic; Cultural; Ecosystem Health; Groundwater Quality; Irrigation; Public Health; Recreational; Stock	Freshwater (lakes; rivers; groundwater; wetlands) Marine (bays; harbours; estuaries; near-shore)
Hospitals	Biodegradable organic materials, suspended solids, nutrients, cleaning chemicals, faecal indicator organisms, formaldehyde, radionuclides, solvents, mercury, ethylene oxide, chemotherapy chemicals	Toxic effects Oxygen depletion; Accelerated eutrophication; Effects on suitability of water for contact recreation	Aesthetic; Cultural; Ecosystem Health; Groundwater Quality; Irrigation; Public Health; Recreational; Stock	Freshwater (lakes; rivers; groundwater; wetlands) Marine (bays; harbours; estuaries; near-shore)
Hotels, motels, hostels, etc.	Biodegradable organic materials, suspended solids, nutrients, cleaning chemicals, faecal indicator organisms, fat, oil and grease	Toxic effects; Oxygen depletion; Accelerated eutrophication; Effects on suitability of water for contact recreation	Aesthetic; Cultural; Ecosystem Health; Groundwater Quality; Irrigation; Public Health; Recreational; Stock	Freshwater (lakes; rivers; groundwater; wetlands) Marine (bays; harbours; estuaries; near-shore)

Industry	Example	Examples of Effects	Values affected	Most sensitive receiving environments
Tanning/ leather manufacturing	Chromium (including CrVI), manganese, copper, ammonia, nitrite, sulphides, acids, sodium hydroxide, lime, formaldehyde, solvents, cyanide, detergents, pesticides, and bleaching agents	Toxic effects	Aesthetic; Cultural; Ecosystem Health; Groundwater Quality; Irrigation; Public Health; Recreational; Stock	Freshwater (lakes; rivers; groundwater; wetlands) Marine (bays; harbours; estuaries; near-shore)
Machine shops/metal fabrication	Metals; chlorinated hydrocarbons; degreasing agents; solvents; waste oils	Toxic effects	Aesthetic; Cultural; Ecosystem Health; Groundwater Quality; Irrigation; Public Health; Recreational; Stock	Freshwater (lakes; rivers; groundwater; wetlands) Marine (bays; harbours; estuaries; near-shore)
Meatworks	Biodegradable organic materials, suspended solids, nutrients, cleaning chemicals, faecal indicator organisms.	Toxic effects; Oxygen depletion; Accelerated eutrophication; Effects on suitability of water for contact recreation	Aesthetic; Cultural; Ecosystem Health; Groundwater Quality; Irrigation; Public Health; Recreational; Stock	Freshwater (lakes; rivers; groundwater; wetlands) Marine (bays; harbours; estuaries; near-shore)
Restaurants & takeaways	Biodegradable organic materials, suspended solids, nutrients, cleaning chemicals, faecal indicator organisms.	Oxygen depletion; Accelerated eutrophication; Effects on suitability of water for contact recreation		Freshwater (lakes; rivers; groundwater; wetlands) Marine (bays; harbours; estuaries; near-shore)

[1] Sources: http://www.ehso.com/contaminants.htm and the Ministry for the Environment Hazardous Activities and Industries List (HAIL) http://www.mfe.govt.nz/land/hazardous-activities-and-industries-list-hail.

[2] Note that district/city council trade waste bylaws and Otago Regional Council regional rules/resource consents impose restrictions on the amounts of contaminants allowed in discharges to sewerage infrastructure and the wider environment respectively.

5.5 Adverse effects and indicators

There is potential for discharges from industrial and trade wastes to result in significant adverse effects on the receiving environment. However, the type of waste and its management, broader site management, the level of treatment on site or at the final treatment point, and the characteristics of the receiving environment will all influence the potential for adverse effects on the uses and values associated with the receiving environment.

One key driver of potential adverse effects related to trade wastes is the risk of accidental discharges of hazardous substances into wastewater infrastructure and the risks associated with unplanned discharges from the wastewater infrastructure because of blockages, leaks, breakdowns, and power cuts. This also has potential consequences for wastewater systems and is covered in more detail in Section 5.7.

5.5.1 Indicators

Industrial and trade wastes can include a very broad cross-section of contaminants (see Section 5.4) and consequently a wide range of indicators can be relevant depending on the type of industry and/or trade wastes in the discharge. General indicators of contaminants irrespective of the source in relation to effects thresholds are discussed in Section 2.7. Relevant indicators for trade wastes in municipal wastewater discharges can include faecal indicator organisms, BOD, DO, suspended sediment, and animal and plant indices/biomass. However, because trade wastes are included in municipal wastewater the indicators would generally be similar to those for wastewater (See Section 4.5). Specific discharges from individual industries would usually require specific contaminant monitoring rather than an indicator. Indicators for discharges from dairy or meat processing facilities would be similar to those for municipal wastewater discharges.

5.6 Knowledge gaps and risks

It is very difficult to identify specific knowledge gaps for industrial and trade wastes because of the very diverse nature of these discharges. There are undoubtedly knowledge gaps for individual industries and/or trade wastes. However, at this stage no one specific individual industry or trade waste stands out with an identifiable knowledge gap that warrants investigation. However, there is a gap in the understanding of the measures taken by trade waste dischargers in parts of Otago, because of the different situations in parts of Otago with different wastewater infrastructure, treatment and overall management by the relevant territorial authority.

There is also a risk of unplanned discharges entering a trade waste discharge system and then entering a wastewater system that may not have significant robustness incorporated into the wastewater infrastructure or treatment systems, that could otherwise avoid or mitigate the potentially significant adverse effects that could occur. For example, a small accidental discharge of a hazardous substance such as diesel into a very large volume of sewage that is ultimately treated to a high level is unlikely to result in any significant adverse effects in the final receiving environment. Conversely, a large diesel spill into a small wastewater system with limited treatment may result in significant adverse environmental effects.

There are also risks related to the level and state of the relevant wastewater infrastructure and the management of wastes being discharged into that infrastructure. For example, if the infrastructure has limited capacity for dealing with blockages or power outages, then unplanned and potentially unauthorised discharges may occur.

A critical part of many of these issues is that such risks are challenging to identify and mitigate and there may not be an obvious signal that such a risk exists. The mitigation of these risks usually requires significant proactive initiatives designed to prevent incidents and where that is not feasible to implement measures to minimise the potential for adverse effects. For trade waste discharges, the design of the wastewater treatment system is an important part of risk management, e.g. land treatment systems can provide an effective mechanism that contains and treats relatively minor unplanned trade waste discharges.

The risk of accidental/unauthorised discharges into a wastewater system is generally higher in larger urban areas where there is a wider range of small businesses generating trade wastes. However, this can be mitigated by proactive initiatives by the trade waste generator and by the territorial authority. In addition, the potential adverse effects of such accidental/unauthorised discharges will generally be reduced by the greater volume of wastewater in larger centres and further reduced if there is a comprehensive robust wastewater treatment system.

5.7 Management and mitigation practices

Most small industries, businesses and organisations within urban areas discharge their wastes into the relevant territorial authority wastewater/sewerage systems, while large industries located outside urban centres usually have standalone discharge systems, or occasionally tanker waste to a municipal wastewater treatment plant.

Many small businesses that discharge wastes into a sewerage system use, store or transport hazardous substances and there are risks that those hazardous substances could accidentally enter a waste stream (e.g. Auckland Council, 2014; Walmsley, 2014).

Each territorial authority in Otago sets its own approach to the management of industrial and trade waste discharges into their wastewater infrastructure. For example, apart from the Clutha District Council, each council has their own trade waste bylaw, generally based on the Standards NZ Model general bylaws (NZS 9201.23:2004) (Standards New Zealand, 2004), that is the primary tool used to control the access to the sewerage system. The Clutha District Council uses the Building Act to control access to their sewerage systems e.g., in Balclutha and Milton.

A related issue for wastewater infrastructure is the physical capability of the infrastructure to manage the potential for unauthorised discharges (e.g., unauthorised discharges of fats and grease that can clog a sewer) and to manage the potential for events such as sewage pump breakdowns and electricity outages. These events can result in unplanned and unauthorised discharges that can potentially have significant adverse effects. Overflows and spills from territorial authority sewerage systems occur from time to time, for example spills of untreated sewage into Lake Wakatipu were reported by the media in 2008, 2009, 2013 and 2014. The effects of these discharges generally appear to be short-term restrictions on swimming and other water contact recreation in the vicinity of the spill. However, spills involving significant quantities of some trade waste have the potential for more significant adverse effects.

There is also a need for an appropriate level of advice, compliance monitoring and enforcement by district/city councils to ensure that trade waste dischargers are aware of, and comply with, trade waste bylaw requirements.

5.8 Specific matters

5.8.1 Common issues/challenges with management of industrial and trade waste

The intermittent nature of many trade waste discharges and the extensive nature of inputs to sewerage systems can make it challenging to ensure that trade waste requirements (territorial authority bylaw/trade waste permits) and the eventual discharge permit conditions (issued by the regional council) are adhered to. Monitoring of the major characteristics of waste inputs to, and outputs from, a treatment plant (e.g., concentrations of BOD, TN, TP) is relatively straightforward. However, particularly in larger urban centres, there can be a very wide range of potential contaminants that could enter the sewerage system and it would generally not be feasible to continuously monitor for all potential contaminants entering into, or discharging from, a treatment system. This makes it challenging to appropriately identify, and address all potential adverse effects of a discharge.

The management of large meatworks (e.g., at Pukeuri) and dairy factory (e.g., at Stirling) waste can both have significant contaminant loadings in their discharges, particularly of nitrogen and phosphorus. However, compared to many trade waste and small industries these discharges are; generally very predictable organic wastes, well characterised with a very low risk of hazardous substances, and reliable treatment methods have been developed over many years. The combination of these characteristics mean that such discharges do not generally have a significant risk of unanticipated adverse effects. However, as noted in Section 5.6, there are risks that chemicals used in some food processing systems can be present in discharges (e.g., antimicrobials, detergents, sanitisers, water treatment chemicals, and insecticides) either in small concentrations or as a result of accidental discharges.

5.8.2 High risk industries

We have undertaken a preliminary simplistic assessment of current industry discharges to land or water in Otago to identify those discharges that would generally have the potential to discharge contaminants that can result in significant long-term adverse effects on the uses and values of water and/or soils that are difficult to mitigate or remedy. This assessment makes an assumption that generally accepted good practice treatment and/or risk management measures would be applied via resource consent or permitted activity conditions that would address the potential for discharges to have adverse effects. However, it is also assumed that the risk of significant adverse effects occurring cannot be reduced to zero, and that some industries have more or less inherent risk or difficulties in ensuring that adverse effects are limited at all time to an acceptable threshold.

Three factors were considered to identify the riskiest industries:

- The potential for significant quantities of hazardous substances to be in the discharge;
- The potential for significant intermittent discharges influenced by rainfall events, and;
- The ability for generally accepted good practice to address potential adverse effects.

We emphasise that this is a "first cut" to identify broad categories of the "riskiest" industries. A more detailed assessment would be required to consider the extent to which those potential adverse effects can be avoided, mitigated or if necessary remedied. We also emphasise that this is a preliminary scoping approach that would not acknowledge actual quantities of contaminants, specific location factors such as soil types, annual rainfall, etc., or the sensitivity of specific receiving waters.

The result of that assessment has identified two groups of discharges (which may contain trade waste or industrial contaminants), tentatively described as follows:

- Very high risk: contaminated sites[24], landfills;
- High risk: stormwater, mining, municipal wastewater.

This assessment is, by necessity, 'broad-brush' and includes discharge groups covered in other sections. It will clearly need to be refined in the next phase of the project where a water quality risk assessment will be carried out having regard to the values and sensitivity of various receiving environments.

[24] A site where hazardous substances are found at significantly higher concentrations than their normal levels, and there is likely to be a risk to human health or the environment.

5.8.3 Good practices for trade waste management

There is limited publicly available guidance on good practice for trade waste management in NZ and good practice can be a difficult concept to define for such a wide range of discharges going into sewerage systems with a variety of other wastes and into different infrastructure and treatment systems, and with different discharge permit conditions and different receiving waters. Good practice is driven largely by current legal requirements, resources and community expectations. The main legislation is the Resource Management Act, the Local Government Act and the Building Act, which provide for planning provisions, asset management plans, infrastructure strategies, and bylaws that set a framework for discharge permits, trade waste permits and wastewater infrastructure planning, operation and maintenance. Each trade waste discharge into a sewerage system is authorised via the relevant trade waste bylaw (except the Clutha District Council, that relies on the Building Act), which in turn is driven in part by the conditions of the relevant wastewater discharge permit issued by the ORC.

Trade waste bylaws generally provide for some small discharges to not require an individual permit, and include thresholds and criteria that are used to assist in determining appropriate trade waste conditions. When a trade waste permit is granted, a key consideration is that full compliance should contribute to ensuring that the eventual wastewater discharge fully complies with the discharge permit conditions.

All the trade waste bylaws in Otago include provisions that enable requirements to be imposed on trade waste permits relating to cleaner production, waste minimisation, and contingency management procedures (controls on trade waste permitted activities currently don't allow for any additional controls beyond those specified). However, there appears to be little guidance or information available on how such measures are applied to specific trade wastes. This may simply reflect the different situations that can apply for trade wastes in different locations e.g., different discharge permit requirements, different 'assimilative capacities' of the wastewater treatment systems, and different eventual receiving water environments.

A small number of territorial authorities provide written guidance information on their websites for trade waste generators on their responsibilities under a trade waste bylaw (e.g., Dunedin City Council), and each council allocates resources to providing advice and compliance monitoring/enforcement. A few professional organisations provide a forum for discussion (e.g., NZ Trade and Industrial Waste Forum, via a LinkedIn group) and/or guidance on issues such as risk reduction and waste minimisation. Some industries and/or insurance companies provide guidance on risk management measures to minimise adverse effects, and environmental and/or legal risks associated with unauthorised spills (e.g., on how motor vehicle repairers can reduce environmental risks).

The information on council websites indicate a range of approaches to managing trade wastes by territorial authorities in Otago, specifically in terms of trade waste permit conditions and approaches to information provision, compliance monitoring and enforcement. The different approaches are likely to be a consequence of a number of factors, including the following:

- The range and type of trade wastes that discharge into the sewerage system;
- The sensitivity of the eventual receiving waters;
- The discharge permit condition requirements;
- The resources available;

- The potential significance of any contaminant spills, overflows or other non-compliance related to trade wastes, and;
- The wider policy context such as national, regional or district policies on waste management and infrastructure strategies.

However, it is possible to identify one broad relevant trend for trade wastes discharged to council wastewater treatment systems that has occurred in NZ over the past 30 years that is relevant to these issues. That is, a general move to secondary and land treatment of the eventual wastewater for the majority of urban centres apart from the major urban municipal wastewater discharges (e.g., Auckland, Wellington, Christchurch, and Dunedin) (e.g. Lowe et al., 2016). This trend has been driven by a range of factors, particularly social and cultural pressures to remove sewage treatment plant discharges from surface fresh waters. A benefit of this trend has been that the intermittent nature of some trade waste discharges into sewerage systems and the risks of spills of hazardous substances from trade waste premises are mitigated by secondary treatment and land treatment of the wastewater. Within Otago, a significant number of municipal WWTPs located in provincial towns still use primary treatment processes (see Section 4.3.1).

Both territorial authorities and the ORC undertake programmes of compliance monitoring and enforcement to endeavour to ensure that requirements specified in permits (trade waste permits and discharge permits) are being complied with. There are national guidelines for monitoring wastewater discharges (NZ Water Environment Research, 2002) and the ORC reports on the results of compliance monitoring and enforcement. However, there are no national guidelines for monitoring trade waste discharges into sewerage systems.

For a major urban centre such as Dunedin, there is clearly a proactive approach to trade waste management as evidenced by the guidelines and public implementation reporting (e.g. Bishop, 2012; Wood, 2001). Similarly, the Queenstown Lakes District Council has relatively recently (2015) reviewed their trade waste bylaw and issued a guide[25] that highlights trade waste requirements and the monitoring that will be undertaken by council during the year.

Good practice guidelines

The available good practice guidelines can be divided up into those that are specific to fat, oil and grease (FOG) (e.g. Arthur and Blanc, 2013) and other trade wastes (e.g. WasteMINZ, 2012). There are a range of guidelines and factsheets for trade waste published by councils and made available on council websites (e.g., Dunedin City Council). Many of these documents provide useful high level general guidance. While it is not appropriate or within the scope of this work to provide detailed good practice guidelines for all trade wastes, there are a few guidance documents that provide a relevant framework.

Most trade waste bylaws include a purpose for the trade waste controls which is based on the model trade waste bylaw and wider best practice trade waste guidance such as those published for the states of Victoria (EPA Victoria and The Victorian Water Industry Association, 2004) and New South Wales (NSW Government: Department of Water and Energy, 2009). The overall purpose of New Zealand trade waste bylaws usually specify the following, as contained in the DCC Trade Waste Bylaw (Dunedin City Council, 2008):

- Protect the environment;

[25] http://www.qldc.govt.nz/assets/Uploads/Council-Documents/2014-Full-Council-Agendas/27-November-2014/Item-9/9d-Trade-Waste-Bylaw-FAQs.pdf

- Promote cleaner production;
- Protect the sewerage system infrastructure;
- Protect sewerage system workers;
- Protect the stormwater system;
- Ensure compliance with consent conditions;
- Provide a basis for monitoring discharges from industry and trade premises;
- Provide a basis for an equitable charging to trade waste users of the sewerage system to cover the cost of treating and disposing of or reusing such wastes;
- Ensure that the costs of treatment and disposal are shared fairly between trade waste and domestic dischargers;
- Encourage waste minimisation;
- Encourage water conservation.

A recent review of Wellington City Council's trade waste bylaw (Wellington City Council, 2015) has highlighted some key best practice trends:

- A shift to applying a risk management approach;
- An increase in the flexibility for industries to meet bylaw objectives through the formal introduction of trade waste agreements as an alternative to a trade waste discharge consent, and;
- Fostering continuous improvement.

Councils adopting this approach are focussing on assessing individual trade wastes within the context of the specific risks posed by those wastes in the wider context of other waste stream inputs, the wastewater infrastructure and treatment system and its receiving environment. The existing trade waste bylaws in Otago generally provide a sufficient basis for this approach, including a broad range of permit consideration criteria.

This trend is illustrated in South Australia's support for cleaner production at trade waste premises (South Australia Water, 2014) where the following practices are particularly relevant for Otago:

- 'Dry cleaning', i.e., minimising the use of water and maximising clean-up;
- Using pre-strainers & drain baskets – to reduce suspended solids contributing to wastewater;
- Minimising spills – identifying and rectifying issues;
- Reviewing chemical use – both amounts and types of chemicals;
- Maximise recycling opportunities;
- Promote staff awareness – ensure all staff are aware of legal requirements and risks.

Encouragement of Good practice by territorial authorities

It is important to appreciate that good practice trade waste management is unlikely to be broadly adopted in the absence of an integrated approach to encourage, support and where necessary, enforce requirements.

The DCC have published an outline of their trade waste implementation strategy (Bishop 2012, Wood, 2001). However, there is little public information available on how other territorial authorities implement trade waste bylaws, particularly in terms of trade waste conditions and requirements related to clean production, waste minimisation, risk management, or the extent and frequency of compliance monitoring and enforcement undertaken.

Trade waste bylaws in NZ and specifically in Otago set charges primarily based on the category of trade waste. The DCC trade waste charges include unit charges based on volume, BOD and suspended solids. The latter approach does provide an incentive for the discharger to reduce the volume and specific contaminant load to minimise charges.

Examples of effective mitigation measures

There are many examples of effective mitigation of risks to water quality and the wider environment from trade waste activities in NZ. However, much of this is not documented formally. In addition, because of the nature of trade wastes, the wastewater collection and treatment systems and the different receiving environments, it is usually very difficult to demonstrate a linkage between risk mitigation and water quality benefits.

The predominant focus of resource consent conditions and trade waste permits is on compliance with specific conditions that define for example, the quality and quantity of the discharge. There are few NZ examples of requirements that encourage environmental risk mitigation via regional planning/resource consent provisions and/or trade waste provisions/permits, e.g. to adopt practices that minimise trade waste generation and/or reduce risks of accidents or incidents that may result in adverse effects on water quality. Some regional councils, e.g., the Auckland Council require environmental management plans for certain industrial and trade waste generators that do focus on risk mitigation (Auckland Council, 2014).

Examples of effective mitigation range from design and implementation of an individual trade waste management system to the design, installation and management of a sewerage system including the wastewater treatment system.

Some effective mitigation examples include:

- Good practice guidelines for vehicle repairers/servicing (Ministry for the Environment, 2010);
- Design specifications for sewage pumping stations, for example, (a) comprehensive design specifications that minimise the risks of spills and overflows from pumping stations (Christchurch City Council, 2015), and (b) tools[26] designed to assist in minimising or preventing unplanned/unauthorised discharges from wastewater infrastructure;
- Waste minimisation initiatives;
- Risk management mechanisms that can include a very wide range of initiatives, e.g., bunding, barriers, backflow prevention, emergency shutoff valves that enables a trade waste facility stormwater drain to be closed to prevent a spillage discharging into the stormwater system.

[26] https://www3.epa.gov/region1/sso/toolbox.html

6. Other Hazardous Substances

6.1 Key points for other hazardous substances

Discharges that are likely to contain hazardous substances include those from mining, municipal landfills, contaminated sites, and primary industries including agriculture, horticulture and aquaculture.

- **Adverse effects –** The potential for adverse effects are linked to industry type. The potential for effects from mining, landfill and contaminated sites increase in vicinity to these industries and effects are generally near-field. Primary industry activities are more diffuse and effects are related to density of livestock/orchards/aquaculture species.
- **Key contaminants -** There is significant contaminant overlap with other discharges, (metals, sediment, POPs) and the same adverse effects will arise. However, pesticides in agriculture and fungicides in horticulture are likely to be specific to the industry and effects need to be on a case-by-case basis for each industry type.
- **Key knowledge gaps/risks -** Specific pesticide and fungicide chemicals used in agriculture/horticulture by industry type is a significant knowledge gap as usage data is limited and dated (2004). Tracing landfill leachate is a complex problem, while economic barriers may prevent some contaminated sites from being properly investigated.
- **Current management/mitigation -** It is necessary to more accurately define the specific risks involved in the other hazardous substances discharges category. This is an ever changing and potentially politically charged playing field, with the EU and US leading the way in this area.

6.2 Types considered and discharges in Otago

In the context of this report, other hazardous substance discharges are defined as those that are not covered by stormwater, wastewater and specific industrial discharges, which are covered in previous sections. Discharges in this category that are likely to contain hazardous substances include those from mining, municipal landfills, contaminated sites, and primary industries including agriculture, horticulture and aquaculture.

6.3 Mining

6.3.1 Types considered and discharges in Otago

New Zealand has a rich history of mineral extraction, with commercial mining of gold and coal commencing around the mid-1860s (Harding and Boothroyd, 2004). Today, the main coal mining areas are the West Coast and Southland in the South Island and the Waikato Region in the North Island, with only limited coal operations in Otago. The three largest gold mines are in Otago, Coromandel and the West Coast, whereas alluvial (placer) gold mining and exploration occur mainly in Otago, West Coast and Southland. Other minerals that have been mined in New Zealand include gravel, tin, copper and uranium. Lignite and tungsten are also mined in Otago.

Underground mining methods have been the most widespread and are used extensively in the coal industry. Opencast mining has been used for both gold and coal extraction (Harding and Boothroyd, 2004). This technique involves the extraction of gold fines that have eroded from seams in the mountains, washed naturally down to the valley floors and filtered into the deep riverbed gravels. Alluvial (placer) mining operations excavate the riverbed, often down to bedrock, to sift out the gold. Each of these extraction methods can cause marked changes to mining landscapes, and consequently surface water and groundwater associated with mines may be significantly affected by mine leachate, sediment and by mine operations.

6.3.2 Specific mining discharges in Otago

Gold mining

Gold rushes occurred in Otago in the 1860s. The easily accessible resources, able to be worked by individuals using simple equipment, were quickly exhausted and larger-scale mining techniques were adopted. Despite this, production of gold in New Zealand peaked in 1905. The Macraes gold mine in east Otago (100 km north of Dunedin) is the largest active gold mine in New Zealand. The mine has produced more than 3 million ounces of gold since opening in 1990. The mine is operated by Oceana Gold (NZ) Ltd, who also operate an open-cast mine near Reefton. At Macraes mine, the ore is accessed via the Macraes open cast mine and the Frasers underground mine, with the ore from all 3 mines being processed at the Macraes mine. A comprehensive water quality monitoring programme has been undertaken since the early 1990s.

Placer (alluvial) mining and gold dredging operations became widespread in Central Otago and Westland in the 1870s and these areas continue to be reworked as both technology and the price of gold improve. There are currently 15 resource consents issued to companies involved in small alluvial gold mining operations in Otago. Kokiri Lime Company recently received approval to establish a large-scale alluvial gold mine at Coal Creek Flat, Roxburgh.

Coal mining

Coal mining activities are limited in Otago. The Kai Point Coal Company has been mining coal at Kaitangata since 1951 and produces coal for local industry and domestic heating. The open-cast mine produces lignite, which is primarily used in household fires and industrial boilers. In Central Otago there are large lignite deposits at Home Hills, Hawkdun and Roxburgh. Harlwich Coal mine is an opencast lignite mine located near Roxburgh. Holcim (New Zealand) Ltd operates Ngapara Lignite mine as a source of fuel for its cement production plant.

Historic coal mines are also present in Otago, for example Wangaloa, and represent a potential source of contamination via filled pit lakes, which capture rainfall and runoff, the quality of which is influenced by the surrounding mineralised geology.

Other extractive industries

There are a number of sand and gravel or quarry operations registered in Otago, which discharge to land or water (freshwater and/or marine environments), depending on the nature of their resource consents.

6.3.3 Typical contaminants

Mesothermal[27] gold mines and rocks that host epithermal[28] mineralisation produce acidic or neutral drainages that are variably enriched in a broad suite of trace metals/metalloids, including copper (Cu), zinc (Zn), lead (Pb), manganese (Mn), mercury (Hg), antimony (Sb), arsenic (As), nickel (Ni) iron (Fe) and boron (B) (Table 15). Further, mine drainage chemistry may change with time so that neutral mine drainages become acidic as reactions proceed within the rock mass that is impacted by mining. Active gold mines treat site water to prevent discharges that would cause unacceptable downstream impacts.

Table 15. Common mineral deposits found in Otago and their typical environmentally significant metal associations. Not all minerals in each deposit type are present in a single deposit

Deposit type	Metallic minerals	Metals discharged	pH
Schist-hydrothermal (mesothermal)	Pyrite (FeS2); stibnite (Sb2S3); arsenopyrite (FeAsS), gold (Au), scheelite (CaWO4), cinnabar (rare) (HgS)	As, Sb	6 - 8
Coal	Pyrite (+ trace As)	As, Ni, Fe, Zn, Cu, B	3 – 7
Alluvial gold	Au; Au-Hg amalgam; pyrite and/or marcasite	Hg, Ni, Fe, Zn, Cu	3 - 8

At historical mines, the impact of untreated drainages in downstream environments is variable depending on the chemistry, the volume of discharge and amount of attenuation/dilution. Concentrations of these contaminants in surface waters can be orders of magnitude above applicable guideline values (Figure 14).

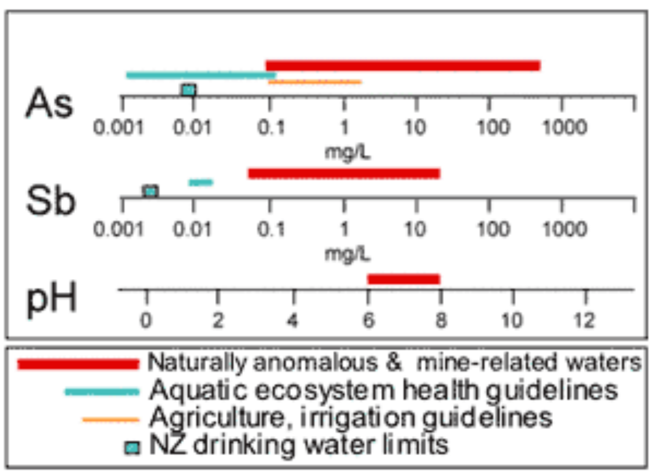

Figure 14. Summary of metal concentrations in waters associated with schist-hosted gold deposits in the South Island[29]

Other typical contaminants from mining are summarised in Table 16, which is based on groundwater and surface water quality monitoring undertaken since the early 1990s for a range of contaminants at Macraes

[27] Formed at moderate depths and temperatures
[28] Formed at shallow depths below a boiling hot spring system (also called hydrothermal)
[29] http://www.otago.ac.nz/geology/research/environmental-geology/metals-in-the-nz-environment/intro-metals-in-nz.html

Gold Mine, the largest gold mine in Otago (Hickey, 2016). Large scale mining results in the mobilisation of naturally occurring metals and other substances from the rock mass. These can find their way through groundwater and overland drainage to the surface water bodies in and around the mine area, giving rise to impacts on surface water quality.

One of the primary contaminants of concern that results from mining activities here is sulphate (Golder Associates, 2011).

Table 16. Typical constituents present in mining discharges with associated values affected and most sensitive receiving environments (modified from Hickey (2016))

Type	Example	Effect	Values affected	Most sensitive receiving environments
Metals and metalloids	Metals (copper, zinc, nickel, chromium, silver) Reduced metals (iron, manganese) Metalloids (arsenic, antimony)	Toxic effect Bioaccumulation	Aesthetic; Cultural; Ecosystem Health; Groundwater Quality; Irrigation; Public Health; Recreational; Stock	Freshwater (lake; river; aquifer; wetland) Marine (bay; harbour; estuary; near-shore)
Hydrocarbons	From transport activities on site	Toxic effect Aesthetic		
Other inorganic materials	Acids, bases	Corrosion Toxic effect	Ecosystem Health; Public Health	Freshwater (lake; river; aquifer; wetland) Enclosed marine environments (harbour; estuary)
	Sulphate, cyanide	Toxic effect	Ecosystem Health; Public Health	Freshwater (lake; river; aquifer; wetland) Enclosed marine environments (harbour; estuary)
Suspended particulate material	Total suspended solids (TSS)	Smothering of aquatic life with associated oxygen depletion Reduced water clarity Transport of particulate associated contaminants	Aesthetic; Cultural; Ecosystem Health	Freshwater (lake; river) Enclosed marine environments (harbour; estuary)
Thermal effects	Hot water	Changing living conditions for flora and fauna	Ecosystem Health	Freshwater (river) Marine (estuary)
Odour (and taste)	Hydrogen sulphide	Aesthetic inconveniences Toxic effect	Aesthetic; Cultural	Freshwater (lake; river; aquifer; wetland) Enclosed marine environments (harbour; estuary)

6.3.4 Adverse effects and indicators

The most relevant indicators of the impacts of mining and extractive indicators are similar to those for other industrial wastes, namely metals, pH, suspended sediment concentrations, and biotic indices (MCI, QMCI). In some cases, site-specific guideline values have also been developed, which reflect the naturally mineralised nature of waters in mining regions. Aquatic biota (algae, invertebrates and fish) are useful for monitoring the influence of discharges associated with mining and subsequent treatment of mining waste on stream ecosystems because they reflect a history of water quality across an organism's life. Macroinvertebrates are the most commonly used biological monitoring tools in New Zealand, as they are:

- Easy to sample and identify;
- Long lived, and thus reflect water quality changes over time;
- Have variable tolerance to stressors such as low pH and metals.

Up until the 1970s, mining was conducted with little regulation of the impact on downstream water quality or ecosystems (Harding and Boothroyd, 2004). Much of the mining activity in New Zealand is associated with running water ecosystems. No major lakes in New Zealand currently receive mine discharges. Effects from gold and coal mining may arise from high sediment loads, low pH and high metal concentrations or other water quality issues specific to the geological setting of the mine (Cavanagh et al., 2015b). The effects of mine drainage on stream life can be direct or indirect. Direct effects include toxicity associated with low pH or high metal concentrations and may be acute (lethal) or sub-lethal (e.g. affect reproductive systems). Indirect effects can occur if the mine drainage affects the food supply (e.g. invertebrates for a fish) or habitat of stream organisms.

Mining operation or extraction activities invariably result in the generation of suspended solids which can enter waterways, via mine drainage pathways or, in the case of sand and gravel extraction, through direct disturbance of the river bed. The nature and quantity of suspended solids is influenced by climate and geology specific to a site.

Coal mining activities may result in the generation of acid mine drainage (AMD) and it is this which has the most potentially severe impacts on life in aquatic environments. Acidic water can be stressful or even lethal to some organisms, and high concentrations of dissolved metals (facilitated by the low pH acidic water) can also be toxic to aquatic biota. In addition, the metal precipitates associated with AMD (Fe and Al oxyhydroxides), while generally not toxic to aquatic biota, alter the streambed. These precipitates can coat the streambed and clog the areas around rocks where animals live, leading to poor habitat for all aquatic life.

The primary effects of sand and gravel extraction activities is through direct disturbance to the stream bed, along with the generation of high suspended sediment loads, with the effects as described above.

Other adverse effects

Mining activities (including sand and gravel extraction) require significant amounts of water. As a result stream hydrological regimes may be impacted through direct water extraction, through diversion of stream channels or, in some cases, destruction of headwaters. In addition, construction of water supply reservoirs may occur in conjunction with large mines. If stratification (separation into distinct layers) in these reservoirs occurs, there is the potential for deoxygenation of the hypolimnetic (bottom layer) waters. In turn, the release of such water downstream may result in adverse effects associated with low/no dissolved oxygen, toxicity associated with elevated hydrogen sulphide and ammonia, and production of iron and manganese flocs which settle on the stream bed. In addition, algal blooms may develop within the reservoir if nutrient concentrations within the catchment are sufficiently high.

Lignite is a very poor quality coal and contains less energy, less carbon and more water than other types of coal (Parlimentary Commissioner for the Environment, 2012). As a consequence of these physical characteristics, using lignite creates particularly high emissions of carbon dioxide, the principal greenhouse gas.

Other mining

New Zealand Tungsten Mining Ltd is actively exploring for tungsten with the aim of re-opening the old scheelite mines in the Glenorchy area.

6.3.5 Knowledge gaps and risks

One of the most significant knowledge gaps is predicting the long-term effects of mitigation and management strategies implemented during mine operation. The Centre for Minerals Environmental Research (CMER) has recently initiated a research programme which aims to provide greater certainty on appropriate mitigation strategies for the life of a mine (Cavanagh et al., 2015a).

6.3.6 Management and mitigation practices

International Best Practice in Mining

The Australian mining industry is at the forefront of the global pursuit of sustainable development. The Leading Practice Sustainable Development Program in Mining initiative[30] was a collaborative effort launched in 2006 by the Australian government and the mining industry. The Leading Practice Program aimed to identify the key issues affecting sustainable development in the mining industry and provide information and case studies to enable a more sustainable basis for its operations. The output of the Program was a series of handbooks relevant to all stages of a mine's life—exploration, feasibility, design, construction, operation, closure and rehabilitation.

There are 14 handbooks in the Program plus an Overview. The titles of the handbooks are (in alphabetical order):

- Airborne Contaminants, Noise and Vibration;
- Biodiversity Management;
- Community Engagement and Development;
- Cyanide Management;
- Evaluating Performance: Monitoring and Auditing;
- Hazardous Materials Management;
- Managing Acid and Metalliferous Drainage;

[30] http://www.industry.gov.au/resource/Programs/LPSD/Pages/default.aspx

- Mine Closure and Completion;
- Mine Rehabilitation;
- Risk Management;
- Stewardship;
- Tailings Management;
- Water Management;
- Working with Indigenous Communities.

The Global Mining Standards and Guidelines Group[31] facilitates global mining collaboration on solutions to common industry problems, needs and technology through standards, guidelines and best practices. GMSG operates on the five principles of inclusivity, collaboration, innovation, optimisation and technology.

New Zealand Best Practice in mining

Mining is a regulated industry primarily governed by requirements under the Crown Minerals Act 1991 and Resource Management Act 1991 (RMA). Three types of regulatory requirements need to be met prior to mining operations proceeding:

- A permit or licence granted under the Crown Minerals Act;
- An access arrangement negotiated with all landowners and occupiers; this may include individuals or government departments such as DOC;
- Resource consents (e.g. use of land and water, discharges to water, air) (district and regional councils).

A recent publication provides a framework to assist with planning of future mine developments (Cavanagh et al., 2015c). This framework focuses on water quality issues associated with coal and gold mining, specifically pH, acidity, metals and turbidity, and rehabilitation of mined areas. It does not address other water quality measures such as salinity, temperature, or environmental issues that also may need to be considered during mine planning and consenting such as stream diversions, water quantity, noise, traffic, visual, dust, and subsidence issues.

Management and mitigation of mining effects

Impacts on stream ecosystems from coal and gold mining can be mitigated through management of mining operations, particularly management of mine waste (tailings, mine water and waste rocks), through water treatment techniques, or a combination of both. In general, best management practices to prevent or reduce the formation of AMD and high total suspended solids (TSS) will be more cost-effective than ongoing treatment of AMD discharge. In particular, mine waste management techniques are critical to minimising AMD. However, in many situations mine waste management will be insufficient to mitigate the impacts of such drainage on receiving systems, and additional treatment may be required.

Operational management can be a cost-effective means of minimising mining impacts on adjacent streams, and is the preferred first stage of any environmental management programme. Operational management to reduce mine drainage impacts focuses on preventing or reducing the amount of water entering the mined area, reducing the contact of water and/or oxygen with acid-forming materials, and neutralising or reducing

[31] http://www.globalminingstandards.org

the level of contaminants present in any mine drainage. Methods to achieve these goals involve evaluating the factors that influence mine drainage at each site and applying appropriate site-specific management options to reduce the amount of impacted mine drainage.

Treatment of mine drainage may still be required even with good mine waste management practices. Treatment can be accomplished by either active or passive treatment systems, or a combination of both. Active systems typically require continuous dosing with chemicals (such as lime); they consume power and require regular operation and maintenance, but are very reliable. Their main advantages are that they are very effective at removing acid and metals from mine drainage, particularly from AMD, and can be designed and operated to produce specific water chemistries. Further, they can be accommodated in locations where only a small land area is available. The main disadvantages of active treatment are the high capital cost and high ongoing operational and maintenance costs. Passive systems rely on natural physical, geochemical and biological processes, but can fail if not carefully selected and designed. Passive systems have limitations with respect to treating high flow and high acidity drainages. Mine drainage must have long enough residence times in these systems to allow these processes to occur, which means that these systems typically require large areas of land.

Effective rehabilitation is required to minimise medium-term and long-term adverse effects associated with mining disturbance.

6.4 Landfills

6.4.1 Specific landfill discharges in Otago

According to ORC consents data there are 68 currently operating landfill sites in Otago, divided by District as:

- 17 in Central Otago;
- 24 in Clutha;
- 10 in Dunedin;
- 7 in Queenstown Lakes;
- 10 in Waitaki.

6.4.2 Typical contaminants

Kjeldsen et al. (2002) categorised contaminants in landfill leachate into four groups (which have been summarised in Table 17):

- Dissolved organic matter (DOM): quantified as Chemical Oxygen Demand (COD) or Total Organic Carbon (TOC), volatile fatty acids, and more refractory (inert) compounds such as fulvic-like and humic-like compounds[32];
- Inorganic macrocomponents: calcium, magnesium, sodium, potassium, ammonium, iron, manganese, chloride, sulphate and bicarbonate;
- Heavy metals: cadmium, chromium, copper, lead, nickel, and zinc;
- Xenobiotic[33] organic compounds (XOCs) originating from household or industrial chemicals. XOCs can include legacy POPs and EOCs (see Section 2.5.1).

[32] The major organic constituents of soil (humus), peat and coal.

Table 17. Summary of typical contaminants in landfill discharges with associated effects, values affected and sensitive receiving environments

Type	Example	Effect	Values affected	Most sensitive receiving environments
Biodegradable organic materials	Biochemical oxygen demand (BOD)	Oxygen depletion in rivers, lakes and coastal environments Fish death Odours	Aesthetic; Cultural; Ecosystem Health	Freshwater (lake; river; aquifer; wetland) Enclosed marine environments (harbour; estuary)
Inorganic macrocomponents	Calcium, magnesium, sodium, potassium, ammonium, iron, manganese, chloride, sulphate and bicarbonate	Eutrophication Toxic effect	Aesthetic; Cultural; Ecosystem Health; Groundwater Quality	Freshwater (lake; river; aquifer) Enclosed marine environments (harbour; estuary)
Other organic materials	Xenobiotic organic compounds (XOCs)	Toxic effect Bio-accumulation in the food chain	Cultural; Ecosystem Health; Groundwater Quality; Irrigation; Mahinga Kai Consumption; Primary Contact Recreation; Public Health; Recreational; Stock	Freshwater (lake; river; aquifer) Enclosed marine environments (harbour; estuary)
Metals	Cadmium, chromium, copper, lead, nickel, and zinc	Toxic effect Bioaccumulation	Aesthetic; Cultural; Ecosystem Health; Groundwater Quality; Irrigation; Public Health; Recreational; Stock	Freshwater (lake; river; aquifer; wetland) Marine (bay; harbour; estuary; near-shore)

Kjeldsen et al. (2002) found that high leachate concentrations were observed for all components (except heavy metals for which very low concentrations are generally observed) in the early anaerobic acid decomposition phase due to strong decomposition and leaching. In contrast, the concentration of ammonia often constituted a major long-term pollutant in leachate. Kulikowska and Klimiuk (2008) stated that as landfill age increased the principal pollutants in leachate were organics and ammonia. Fluctuation of other leachate chemicals (phosphorus, chlorides, calcium, magnesium, sulphate, dissolved solids, heavy metals, and single ring aromatic organic contaminants (BTEX)) depended more on seasonal variations than landfill age.

There is significant overlap in the EOC content between landfill leachate and wastewater discharge. To illustrate this, many of the 19 classes of EOC identified by Eggen et al. (2010) in landfill leachate are common to wastewater discharge. These included: aliphatic alcohols and ethers; aldehydes and ketones; aliphatic acids and esters; aromatic carboxylic acids and ethers; alkanes and cycloalkanes; benzothiazoles; benzene derivatives; drugs and metabolites; N-containing compounds; pesticides; phthalate plasticisers; phosphoric acid derivatives; phenolic compounds; pharmaceuticals and personal care products (PPCPs) – including non-

[33] The term xenobiotic refers to a foreign chemical substance found in an organism, however is very often used in the context of pollutants.

steroidal anti-inflammatory drugs (NSAIDs); sulphonamides; polycyclic aromatic hydrocarbons (PAHs) and substituted PAHs; sulphur containing compounds; and terpenoids. However, concentrations of EOCs identified in landfill leachate are elevated compared to those in wastewater discharge (Eggen et al., 2010; Slack et al., 2005).

6.4.3 Adverse effects and indicators

Landfill discharge effects have considerable overlap with wastewater discharges as the same primary contaminants are present (e.g. heavy metals, nutrients, BOD, EOCs). Similarities with septic tank systems are apparent where contamination of groundwater by landfill leachate may ultimately lead to contamination of aquifers and surface waters. The severity of effects from landfill leachate will depend on the size and age of the landfill.

As stated in the previous section, concentrations of EOCs identified in landfill leachate are elevated compared to those in wastewater discharge. Therefore, even though the effects can be expected to be similar between landfill and wastewater discharges (septic tanks especially), the *severity* of effects in landfill leachate (from EOCs) is likely to be higher than for wastewater discharges. As these effects are not currently well understood, it is not known whether these differences will be significant.

A key indicator of landfills would be presence or absence of specific contaminants (tracers) leaching into groundwater from a landfill site. However, as stated below, differentiating sources is a complex undertaking.

6.4.4 Knowledge gaps and risks

The severity of human health effects from living in proximity to landfills are not well understood as epidemiological links are hard to establish with any certainty (Porta et al., 2009; Vrijheid, 2000).

Determination of whether a specified landfill is leaching significant amounts of contaminants is a likely knowledge gap for many landfills, but solving this is highly complex. Some chemicals within landfill leachate have high stability and have been suggested as markers of pollution from landfills (Schwarzbauer et al., 2002). However, these chemicals are also present in wastewater, so careful consideration of wastewater discharges near a landfill would be necessary before attempting this. A local exploratory study used stable isotope ratios of C and N to trace Green Island landfill leachate (North et al., 2004). This may have some potential, however further research would likely be necessary.

6.4.5 Management and mitigation practices

The presence of EOCs in landfill leachate necessitates increasingly advanced treatment of such waste streams. From the perspective of sustainable management, two major avenues exist for reducing the load of EOCs in landfill leachate and preventing downstream effects: (1) treatment of landfill leachate to reduce the load of EOCs or (2) reduction in the mass of discarded items containing EOCs.

Treatment of EOCs in landfill leachate follows a similar route to wastewater, with technologies such as membrane bioreactors (MBRs), membrane systems, and oxidation processes representing advanced treatment options for EOCs (Ramakrishnan et al., 2015).

6.5 Contaminated sites

6.5.1 Types considered and discharges in Otago

ORC has estimated (Otago Regional Council, 1997) that there are over 500 contaminated sites[34] in Otago. A more recent report estimated 140 confirmed, managed, remediated or not contaminated sites in Otago[35]. These sites have arisen as a consequence of a range of past land use practices including sites used for: timber treatment processing, gasworks, waste disposal, mining, petroleum storage/use/transfer, orchards, sheep dips, and various industries that use hazardous substances. Given the range of potential contaminated sites and the level of investigation needed to identify such sites, it is very difficult to provide an accurate estimate of the number of contaminated sites in Otago.

The Dunedin Gasworks site is on a formal priority list for remediation under the MfE administered Contaminated Sites Remediation Fund[36]. It is understood that discussions are continuing between MfE, DCC and ORC on potential investigations and remediation options for this site. Legacy effects of the gasworks in terms of discharge of PAHs in stormwater were noted in Section 3.5.2.

6.5.2 Typical contaminants

A summary of typical contaminants found at contaminated sites is provided in Table 18.

The discharges arising from contaminated sites in Otago will vary significantly, depending on the scale and type of contamination, site characteristics such as soils, topography, climate as well as any efforts undertaken to remediate or manage a site. A wide range of contaminants can be present in leachate and/or runoff from contaminated sites. With older contaminated sites the primary contaminants of concern are usually hazardous substances such as heavy metals, petroleum compounds, chlorinated hydrocarbons, and arsenic. Each contaminated site will essentially be unique and the level of investigation and management/remediation of each site will vary significantly depending on the specifics of each site and the estimated associated risks.

[34] A site that has a hazardous substance in or on it that - (a) has significant adverse effects on the environment; or (b) is reasonably likely to have significant adverse effects on the environment.
[35] https://geog397.wiki.otago.ac.nz/index.php/Contaminated_Sites_in_Dunedin_(2011)
[36] http://www.mfe.govt.nz/more/funding/contaminated-sites-remediation-fund/csrf-priority-list

Table 18. Summary of typical contaminants from contaminated site discharges with associated effects, values affected and sensitive receiving environments

Type	Example	Effect	Values affected	Most sensitive receiving environments
Chlorinated hydrocarbons	DDT, PCBs, dioxins	Toxic effect Bio-accumulation in the food chain	Cultural; Ecosystem Health; Groundwater Quality; Irrigation; Mahinga Kai Consumption; Public Health; Stock	Freshwater (lake; river; aquifer) Enclosed marine environments (harbour; estuary)
Metals/metalloids	Cadmium, arsenic	Toxic effect Bioaccumulation	Cultural; Ecosystem Health; Groundwater Quality; Irrigation; Public Health; Stock	Freshwater (lake; river; aquifer; wetland) Marine (bay; harbour; estuary; near-shore)
Petroleum chemicals	TPH, PAHs	Toxic effect	Ecosystem Health; Public Health	Freshwater (lake; river; aquifer; wetland) Enclosed marine environments (harbour; estuary)

6.5.3 Adverse effects and indicators

Contaminated site discharge effects can have considerable overlap with stormwater and wastewater discharges, as the same contaminants can be present (e.g. heavy metals, BOD). One specific characteristic of contaminated sites is that many of them are not obviously contaminated and therefore the potential adverse effects are not necessarily appreciated. For example, at former timber treatment sites, significant quantities of pesticides will have been used and the moist treated timber stored. These types of contaminated sites can have high soil concentrations of copper, chromium, arsenic and other contaminants that can result in significant adverse effects. A key indicator is information on previous land use.

6.5.4 Knowledge gaps and risks

A critical knowledge gap is usually the limited information on historical land use. In addition, a characteristic of some contaminated sites is that the costs of investigation and remediation/management to fully comply with all the current relevant standards/guidelines can be extremely high and in some situations, unaffordable for the current land owner who may not have had full knowledge of the site prior to purchase. This means that there will be a risk that at some contaminated sites ongoing/intermittent discharges of contaminants may be occurring.

6.5.5 Management and mitigation practices

The Ministry for the Environment has developed a series of contaminated land management guidelines so contaminated land is assessed and managed consistently throughout the country (Ministry for the Environment, 2012).

6.6 Agriculture and horticulture

6.6.1 Types considered and discharges in Otago

Livestock data (2015)[37] show that sheep farming (87% of numbers) is the dominant agricultural practice in Otago, followed by dairy (6.5%), beef (4.6%), deer (2.1%) and pigs (0.2%) (Figure 15). Horses account for only 0.03%. Sheep numbers in Otago are over-represented compared to all NZ data (72%) while dairy and beef are under-represented compared to all NZ data (16.1% and 8.8%, respectively). Poultry are not classed as livestock so are excluded from these data, however according to the Poultry Industry in 2014 there were 100 Million chickens farmed in NZ,[38] suggesting a significant industry. Regional data are not available, however, based on census employment data, Otago is a minor producer of poultry.[39]

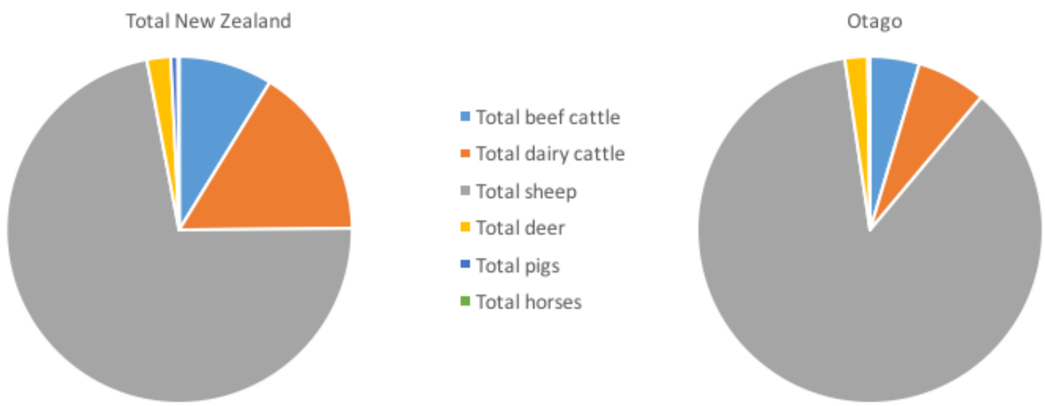

Figure 15. Comparison of total NZ and Otago livestock data in 2015

In terms of horticulture, grapes (68% by area), apples (28%) and potatoes (3%) are the dominant industries in Otago (Figure 16). Wine grapes are grown predominantly in Central Otago.

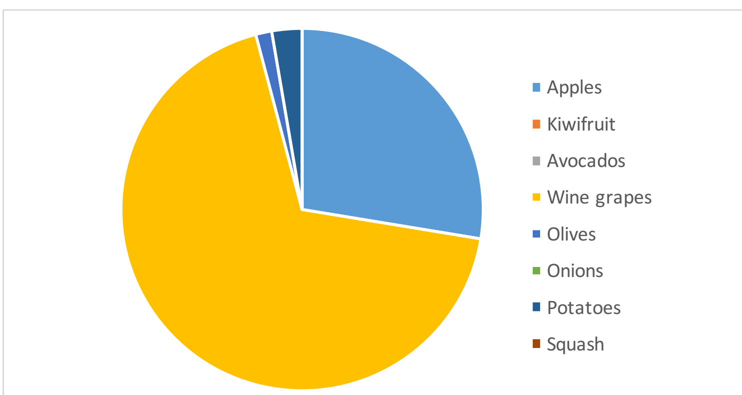

Figure 16. Horticultural industries (by area) in Otago

[37] http://nzdotstat.stats.govt.nz/wbos/Index.aspx?DataSetCode=TABLECODE7423#
[38] http://pianz.org.nz/industry-information/industry-statistics/poultry-production/poultry-meat-production
[39] https://figure.nz/chart/oV7dFFYk8cY5ipCp

6.6.2 Typical contaminants in agriculture

Veterinary antibiotics

A wide range of veterinary antibiotics are used in the agriculture sector within NZ (Figure 17). The pig, poultry and dairy industries use the most significant mass of antibiotics, with the majority of those antibiotics being administered to pigs and poultry in feed and/or water. The primary use of antibiotics in the NZ dairy industry is by intramammary and injectable antibiotic administration, with the greatest proportion of that use being attributed to intramammary administration of mostly penicillins (Ministry for Primary Industries, 2013a).

Figure 17 illustrates that a cocktail of different antibiotics are used in NZ, and are species specific. For example bacitracin is used only in the poultry and pig industry. MPI states that 95% of use is for poultry. The equine and ovine industries use predominantly sulphonamides/trimethoprim while cattle (dairy and beef) industry uses cephalosporins and penicillins.

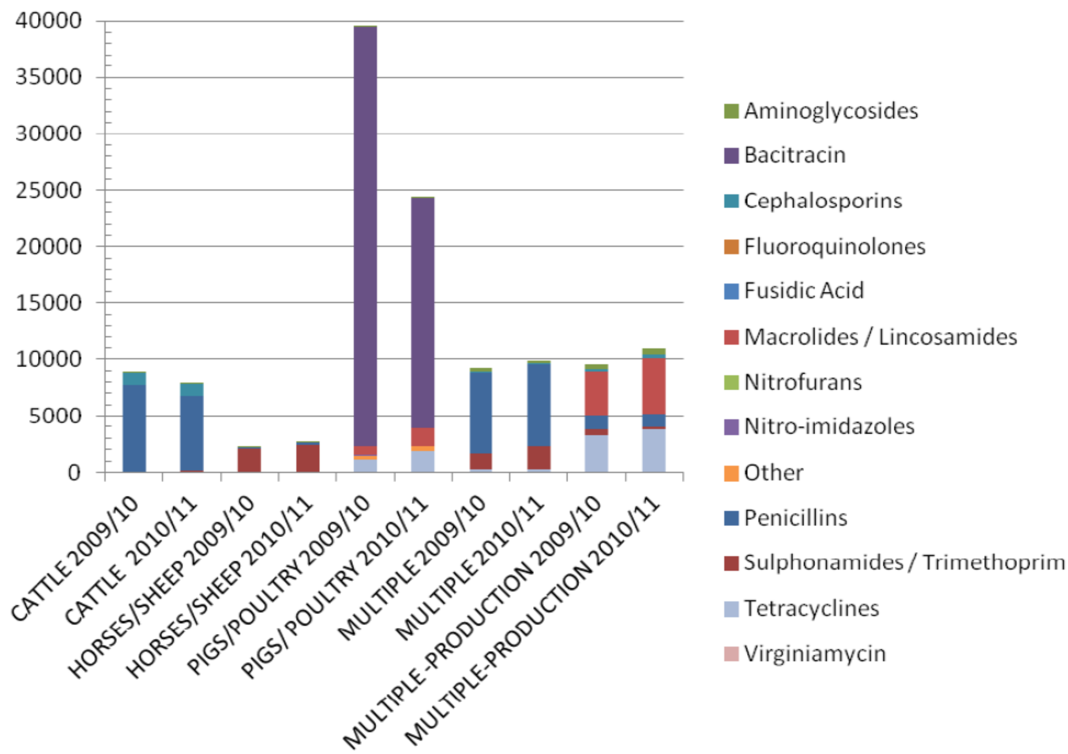

Figure 17. Antibiotic sales (kg of active ingredient) for use in production animals by approved label species and antibiotic class, 2009/10 and 2010/11 (Ministry for Primary Industries, 2013a)

Pesticides

Pastoral farming uses many different pesticides including fungicides/bactericides, herbicides and insecticides. In 2004[40] it was estimated that 1278 tonnes (T) of active ingredient was used per year (Table 19). Phenoxy hormone herbicides (e.g. 2,4-D, MCPA (2-methyl-4-chlorophenoxyacetic acid), mecoprop) were the most

[40] 2004 data was the most up-to-date information that we could obtain.

widely used, with 914 T, or 72% of the total. Phosphonyl herbicides (e.g. glyphosate) comprised 105 T, or a little over 8%, and organophosphates (e.g. chlorpyrifos) were the dominant insecticides with 71 T, or 5.5% of the total. Fungicide/bactericide use was minimal compared with other pesticides, with use significantly higher for horticulture (see Section 6.6.3).

Table 19. Estimated pesticide use in pastoral farming for 2004 (modified from Manktelow et al., 2005)

Group	Tonnes active ingredient/year	Percentage
Fungicides & bactericides	**16.5**	**0.6**
Benzimidazoles	1.1	0.1
Dithiocarbamates	4.0	0.3
Other fungicides	0.4	0.03
Strobilurins	4.2	0.3
Triazoles and Diazoles	6.8	0.5
Herbicides	**1183**	**46.6**
Amides	39	3.0
Dinitroanilines	16.1	1.3
Aryloxyphenoxy propionate and Cyclohexanediones	0.2	0.02
Other herbicides	4.1	0.3
Other hormone types	57.8	4.5
Phenoxy hormones	914	71.5
Phosphonyls	105	8.2
Sulfonylureas	3.0	0.2
Triazines	22.8	1.8
Urea derivatives	20.5	1.6
Insecticides	**79**	**3.1**
Carbamate insecticides	3.5	0.3
Insect growth regulators	0.8	0.1
Organophosphates	71	5.5
Other insecticides	3.8	0.3
Pyrethroids	0.4	0.03
TOTAL	**1278**	**100**

Fertilisers

Phosphates processed from rock phosphate deposits have been identified as the predominant source of most of the metals of concern in commercial fertilisers. Arsenic, cadmium, selenium, molybdenum, vanadium, and uranium are present at higher concentration in most phosphate rock deposits than is average for the earth's crust or soils, and a large proportion of these elements remain in the processed phosphate fertiliser (McBride and Spiers, 2001).

Taylor et al. (2011) stated that phosphate fertiliser contains appreciable amounts of cadmium and uranium, as well as the minor element fluoride. They stated that cadmium and uranium measurements were significantly higher in soils under annual cropping, horticultural, dairy pasture and other pasture land uses than in soils under native and forestry consistent with the application contaminants in phosphate fertiliser. The issue of cadmium in soils has been recognised by industry, central government and regional government with the establishment of a Cadmium Working Group and a National Cadmium Management Strategy (Rys, 2011).

Fertiliser use has also been implicated in elevated zinc concentrations in NZ soils (Taylor and Percival, 2001). However, facial eczema treatment of stock using zinc adds further loads to agricultural areas where this occurs. Facial eczema disease is currently restricted to warmer climates and is not present in Otago.

Steroid hormones

Livestock wastes are potential sources of endocrine disrupting compounds to the environment. Steroid hormones such as estradiol, estrone, and estriol are a particular concern because there is evidence that extremely low (ng/L) concentrations of estrogens in water can adversely affect the reproductive biology of fish and other aquatic vertebrate species (Hanselman et al., 2003). In NZ the dairy farming industry is a significant source of steroid hormones released into the environment (Gadd et al., 2010). However, Otago is not a major dairy area in NZ (Figure 15), suggesting steroid estrogen loads will be less than in dairy intensive areas.

Dairy maintenance compounds

Chemicals used to clean, sanitise or maintain dairy milking plants need to be approved by the Director General of Ministry for Primary Industries (MPI). A register of chemicals either approved or recognised for specific purposes currently contains over 650 products,[41] which include antimicrobials, detergents, sanitisers, water treatment chemicals, and insecticides.

Table 20. Summary of typical contaminants in agricultural discharges with associated effects, values affected and sensitive receiving environments

Type	Example	Effect	Values affected	Most sensitive receiving environments
Microorganisms	Pathogenic bacteria, virus and worms eggs	Risk when bathing and eating shellfish	Cultural; Groundwater Quality; Mahinga Kai Consumption; Primary Contact Recreation; Public Health; Recreational	Freshwater (lake; river; aquifer; wetland) Marine (bay; harbour; estuary; near-shore)
Nutrients and metals from fertilisers	Nitrogen, phosphorus, cadmium, zinc, uranium	Eutrophication Oxygen depletion Toxic effect	Aesthetic; Cultural; Ecosystem Health; Groundwater Quality	Freshwater (lake; river; aquifer) Enclosed marine environments (harbour; estuary)
Agricultural use	Herbicides and	Toxic effect	Cultural; Ecosystem	Freshwater (lake;

[41] http://www.foodsafety.govt.nz/industry/general/maintenance-compounds/dairy-maintenance-compounds.htm

Type	Example	Effect	Values affected	Most sensitive receiving environments
chemicals	insecticides	Bio-accumulation in the food chain	Health; Groundwater Quality; Irrigation; Mahinga Kai Consumption; Primary Contact Recreation; Public Health	river; aquifer) Enclosed marine environments (harbour; estuary)
Suspended particulate material	Total suspended solids (TSS)	Smothering of aquatic life with associated oxygen depletion Reduced water clarity Transport of particulate associated contaminants	Aesthetic; Cultural; Ecosystem Health	Freshwater (lake; river) Enclosed marine environments (harbour; estuary)

6.6.3 Typical contaminants in horticulture

Pesticides

Horticulture has the most intensive use of pesticides in NZ compared with other land uses (Manktelow et al., 2005). In 2004[42] it was estimated that 1898 T of active ingredient was used per year in horticulture (Table 21), which is approximately 1.5 times that used in agriculture. Fungicides and bactericides dominated pesticide use with 789 T, or 42% of the total use. The most widely used fungicides were dithiocarbamates (22.4%) and inorganic (copper and sulphur compounds) (11.0%). Herbicide use (281 T, 15%) was varied with phosphonyls (glyphosate) the most widely used (5.5%). Insecticides comprised 142 T (7.5%), of which organophosphates (4.5%) were the dominant class.

Table 21. Estimated pesticide use in horticulture for 2004 (modified from Manktelow et al., 2005)

Group	Tonnes active ingredient/year	Percentage
Fungicides & Bactericides	**789**	**42**
Benzimidazoles	5	0.3
Botanicals and Biologicals	0.5	0
Diazines, Morpholines & other EBIs	1.6	0.1
Dicarboximides	10	0.5
Dithiocarbamates	426	22
Inorganics	208	11
Other fungicides	129	6.8

[42] 2004 data was the most up-to-date information that we could obtain.

Group	Tonnes active ingredient/year	Percentage
Strobilurins	2.8	0.1
Triazoles and Diazoles	7.0	0.4
Herbicides	**281**	**15**
Amides	60	3.2
Bipyridyls	8.9	0.5
Carbamate herbicides	2.1	0.1
Dinitroanilines	7.3	0.4
FOPs and DIMs	2.2	0.1
Other herbicides	31	1.6
Other hormone types	0.03	0
Phenoxy hormones	0	0
Phosphonyls	104	5.5
Sulfonylureas	0.01	0
Triazines	40	2.1
Urea Derivatives	25	1.3
Insecticides	**142**	**7.5**
Acaricides	1.0	0.1
Botanicals and Biologicals	6.1	0.3
Carbamate insecticides	24	1.3
Insect Growth Regulators	15	0.8
Organophosphates	86	4.5
Other Insecticides	8.4	0.4
Pyrethroids	1.7	0.1
Plant growth regulators	**263**	**14**
TOTAL	**1898**	**100**

Antibiotics

Antibiotics have limited use for horticulture in NZ. MPI (Ministry for Primary Industries, 2013a) state that between 2009 and 2011 only one antibiotic product was registered for horticultural use in NZ. The product, containing streptomycin as the active ingredient, is registered for use in tomatoes for bacterial disease, in pipfruit for fireblight, and in stonefruit for blast and bacterial spot.

Maize as dairy support

Maize is primarily grown to support the dairy industry. Pesticides are widely used in the maize industry, with herbicide use the major load. Unlike other horticultural practices, the maize industry appears to use different types of herbicides, with the dominant being amides and triazines (Manktelow et al., 2005). Maize is generally grown in the North Island, with Waikato (4400 ha); Gisborne (3433 ha); Bay of Plenty (3000 ha);

Hawkes Bay (3000 ha); and Manawatu/Wanganui (2500 ha) the largest areas of production (Millner and Roskruge, 2013). However, with extensive dairy conversions occurring in Southland, there may be a future economic gain from production of maize in a closer geographic region.

Table 22. Summary of typical contaminants in horticultural discharges with associated effects, values affected and sensitive receiving environments

Type	Example	Effect	Values affected	Most sensitive receiving environments
Nutrients and metals from fertilisers	Nitrogen, phosphorus, cadmium, zinc, uranium	Eutrophication Oxygen depletion Toxic effect	Aesthetic; Cultural; Ecosystem Health; Groundwater Quality	Freshwater (lake; river; aquifer) Enclosed marine environments (harbour; estuary)
Horticultural use chemicals	Fungicides	Toxic effect Bio-accumulation in the food chain	Cultural; Ecosystem Health; Groundwater Quality; Irrigation; Mahinga Kai Consumption; Primary Contact Recreation; Public Health	Freshwater (lake; river; aquifer) Enclosed marine environments (harbour; estuary)
Suspended particulate material	Total suspended solids (TSS)	Smothering of aquatic life with associated oxygen depletion Reduced water clarity Transport of particulate associated contaminants	Aesthetic; Cultural; Ecosystem Health	Freshwater (lake; river) Enclosed marine environments (harbour; estuary)

6.6.4 Adverse effects and indicators

The potential for adverse environmental effects from diffuse agricultural discharges include leaching of nutrients (N especially) and heavy metals (cadmium especially) from fertilisers, microbes (from animal waste) and sediment (from land workover). Adverse effects from these contaminants are well understood and in common to other discharges and include toxicity (cadmium and other metals), eutrophication (N and P), ground water contamination (nitrate), and illness from microbial ingestion (through drinking water and some food species).

Horticultural discharges also contain nutrients and sediment with the same adverse effects reasons alluded to for agricultural discharges.

More specific adverse effects from agricultural and horticultural discharges are attributed to the use of pesticides. Pesticides have been implicated in endocrine disruption (Mnif et al., 2011), cancer (Bassil et al.,

2007) and a host of other human health effects (Sanborn et al., 2007). Effects are difficult to ascertain as there are a multitude of different pesticides utilised, and there are many different potential adverse effects (including synergistic and non-target effects). Furthermore, environmental pathways are complex with differences in chemical stability (half-life) and preferred environment (water or particulate) of each chemical. Metabolites and breakdown products often have differing and unknown effects to the parent chemical. In short, there is a paucity of information to accurately assess environmental effects from pesticides.

Natural steroid estrogen hormones, excreted from farmed animals are present in agricultural discharges. These estrogens are known potent endocrine disrupting chemicals causing adverse effects at extremely low levels (low nanogram per litre concentrations). The largest risk from these steroid estrogens are from dairy shed effluent due to the high density and frequency of dairy cows in the milking sheds. Compared with dairy, adverse effects from steroid estrogens produced by sheep and beef farming – where stock numbers are significantly reduced and sparsely populated in paddocks – is significantly reduced.

Indicators

Maximum acceptable values (MAVs) for some pesticides in drinking water have been established by the Ministry of Health (Ministry of Health, 2008) and these are used to assess potential groundwater contamination by pesticides through national surveys, the most recent of which is described by Humphries and Close (2014). These 4-yearly surveys allow for identification of areas of concern and for temporal trend analysis but the list of pesticides surveyed likely only represents a minority of those that are applied to land in rural areas. Many pesticides which may be considered EOCs (i.e. those for which information is not present to set MAVs) cannot be assessed by this approach. Therefore assessing pesticides against drinking water MAVs can only be considered an *indicative* analysis of risk.

To illustrate this point, examples of pesticides that do not have MAVs but are undergoing international and/or national reviews of their approval status - namely glyphosate (one of the highest use herbicides worldwide), neonicotinoid insecticides, and some organophosphate and carbamate insecticides (carbaryl, and diazinon but not chlorpyrifos) - are discussed in Section 6.10.

ANZECC water quality guidelines are of limited use for these discharges as they only include a few limited EOCs and are generally of interim and indicative quality (see Section 2.5.1).

6.6.5 Knowledge gaps and risks

Significant knowledge gaps from discharges of other hazardous substances include the need for accurate current knowledge of pesticide usage for specific agricultural practices of relevance to Otago, especially sheep farming. Pastoral farming uses many different pesticides, however the information is (a) not specific to each industry (e.g. sheep, beef, dairy) and (b) the information is considerably dated (Manktelow et al., 2005). A detailed review of pesticide use in Otago (including a possible farm survey) would be necessary to address this gap. In contrast, much more is known about veterinary antibiotic usage in agriculture. The antibiotic class used is specific for each species and is relatively up-to-date (2009/10) (Ministry for Primary Industries, 2013a).

6.6.6 Management and mitigation practices

Control of many of these other hazardous substances occurs under the Hazardous Substances and New Organisms (HSNO) act. However, there is no monitoring requirement for pesticide/herbicide use, so compliance with regulations relies on users following instructions and use recommendations.

6.7 Aquaculture

According to Aquaculture New Zealand, Otago is not a major aquaculture area in NZ.[43] However, ORC received an application in 2015 from Southern Clams Ltd for resource consents to establish three aquaculture sites within Otago Harbour (around Port Chalmers). Species included Bluff Oysters, Queen Scallops, Tuaki Clams and Paddle Crabs.[44] The application was subsequently withdrawn. However, Southern Clams Ltd have plans to pursue another application in the future.[45] Apart from a salmon farm near Wanaka that has recently been granted consent and is currently being developed, we are not aware of any other significant finfish aquaculture (current or planned) in Otago.

Although aquaculture is not a significant industry in Otago, this may change in the future, where changes in demand or climate may create an economic driver for aquaculture in the region. Chemicals associated with the aquaculture industry are therefore included briefly in this report.

Nutrients from shellfish and finfish food waste and excreta are of most environmental concern with aquaculture, potentially impacting benthic communities and water quality underneath and in the vicinity of the aquaculture farms.

Shellfish aquaculture

The Ministry for Primary Industries (MPI) commissioned an independent literature review of the ecological effects of aquaculture in NZ (Ministry for Primary Industries, 2013b). The authors stated that shellfish farm operations do not require the ongoing use of chemicals that can introduce contaminants to the marine environment. However, “wooden racks used in oyster farming are constructed from treated timber and therefore have the potential to leach trace contaminants such as copper, chromium and arsenic (CCA), with the concern that these metals/metalloids may cause adverse ecological effects and/or human health risks, if the metals bioaccumulate. However, it was noted that “farmed shellfish are subjected to metals testing as part of water quality programmes, which would presumably detect biologically relevant accumulation should it occur”.

Finfish aquaculture

The MPI review stated that, unlike shellfish aquaculture, therapeutants are used to some extent in finfish aquaculture (Ministry for Primary Industries, 2013b).

Currently, there is minimal use of chemicals such as antibiotics, antibacterials and other therapeutants in the NZ aquaculture industry; however, culture of native species (e.g. kingfish and hapūku) may lead to the emergence of diseases that may require new treatments. As there is minimal use of chemicals, background

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[43] http://www.aquaculture.org.nz/industry/farming-areas/

[44] http://www.orc.govt.nz/News-and-Notices/Public-Notices/Archives/2015/Resource-Consent-Application/

[45] http://www.stuff.co.nz/business/farming/aquaculture/77696402/Exporter-confident-of-aquaculture-in-Otago-Harbour

data on the use and impact of chemicals locally are very limited. Information on therapeutant use comes from either international studies where aquaculture is much more intensive or from the salmon industry.

Chemicals used in finfish aquaculture can include: Anaesthetics for harvesting or sorting; detergents and disinfectants, which can persist in the environment; plastics, which can leach plasticisers and degrade to form plastic debris (including microplastics[46]); antibiotics, which have the potential to elicit bacterial resistance with chronic use and interfere with important bacterial processes (nitrification/denitrification); antiparasitics, which can invoke non-target effects or parasite resistance, and; antifouling agents, generally copper-based formulations.

Many of these chemicals fit the definition of EOCs. They may not be regulated (in the case of detergents and disinfectants), or little is known on their environmental fate or non-target species effects.

6.8 Summary of adverse effects from other hazardous substances

The severity of effects of discharges from other hazardous substances is summarised in Table 23. However, there are knowledge gaps, specifically around specific pesticide and fungicide usage in agriculture and horticulture, and what effects these individual chemicals may be having on the receiving environment.

Table 23. Summary of values affected and severity of effects from other hazardous discharges

Activity	Values affected	Effects	Potential severity of effects	General Trend
Mining	Aesthetic	Reduced water clarity due to elevated suspended particulates	Generally low if discharge is in areas of low human density	Increased potential for adverse effects in vicinity of mine
	Ecosystem health	Reduction of ecosystem function due to increases in metal toxicants, sulphide and pH	Potentially high in vicinity of discharge	
Landfill	Aesthetic	Reduced water clarity due to elevated suspended particulates	Near-field effects likely to be greatest and worst under low flow conditions	Heavy metals low, ammonia high and EOCs unknown
	Ecosystem health	Reduction of ecosystem function due to increases in ammonia and other toxicants	Potentially high in vicinity of landfill sites	

[46] Although not included in the review, microplastics (defined as <1mm) are degraded from macroplastics and have recently been the cause for environmental concern not least because they facilitate the transfer of chemical additives or hydrophobic waterborne pollutants to biota (Cole et al., 2011).

Activity	Values affected	Effects	Potential severity of effects	General Trend
	Cultural	Contaminated mahinga kai (chemical toxicants)	Variable: depends on frequency and species of kai gathering in area	
Contaminated site	Cultural	Contaminated mahinga kai (chemical toxicants)	Variable: depends on frequency and species of kai gathering in area	Increased potential for adverse effects in vicinity of contaminated site
	Ecosystem health	Reduction of ecosystem function due to increases in toxicants	Potentially high in vicinity of contaminated site	
	Public health	Increased bioaccumulation of toxicants in species consumed	Potentially high in vicinity of contaminated site	
Agriculture	Public health, primary contact and recreation	Increased microbial contaminants	Generally low due to high dilution, except in areas of high intensity farming and where few mitigation measures (e.g. riparian planting, fencing)	Microbial contamination risk higher in streams where stock are present. Pesticides contamination risk linked to industry type
	Public health, ecosystem health	Metal toxicants from fertiliser and pesticides	Low, except in areas of high intensity farming	
		Increase in pesticides in groundwater and surface water	Low, based on limited information for a few pesticides in groundwater	
Horticulture	Public health, ecosystem health	Metal toxicants from fertiliser and fungicides	Low, except in horticultural areas	Fungicide dominant class with contamination risk linked to industry type
		Increase in insecticides in groundwater and surface water	Low, based on limited information for a few fungicides in groundwater	
Aquaculture	Ecosystem health	Reduction of ecosystem function due to nutrients in food and fish excreta	Potentially high underneath and in vicinity of aquaculture facility	Few aquaculture facilities in Otago

6.9 Management and mitigation

6.9.1 Leading regions and countries

It is necessary to more accurately define the specific risks involved in the other hazardous substances discharges category. This would involve (a) defining what are the *specific* chemicals (not chemical classes) involved for each discharge category (b) defining what potential risks they provide (in comparison with those for which information is readily available such as nutrients, heavy metals, BOD) and (c) defining, based on risks, whether mitigation is required, and what level is required as a pragmatic and cost-effective solution. For example, certain pesticides may be identified as high risk, and there are a multitude of mitigation steps possible, including substituting the pesticide with an alternative, or invoking regulatory procedures to ban the pesticide.

This is an ever changing and potentially politically charged playing field. Recent international developments include the SOLUTIONS project, which is developing the tools for the identification, prioritisation and assessment of those water contaminants that may pose a risk to ecosystems and human health. This research will inform the EU Water Framework Directive (Brack et al., 2015). Similar programmes are undertaken in the United States by Government Departments - The United States Geological Survey (USGS); The United States Environmental Protection Agency (USEPA) - and independent scientific research organisations such as Water Environment Research Foundation (WERF) (see Section 5 of Stewart et al. (2016b) for an overview).

6.10 Specific challenges

6.10.1 Chemicals used in NZ but banned overseas

Through the provisions of the Stockholm Convention, organic chemicals classed as persistent, bioaccumulative and toxic (i.e. POPs) must be either *eliminated* from production and use (Annex A), *restricted* from production and use (Annex B), or measures taken to reduce or eliminate releases from *unintentional* production (Annex C).

NZ ratified the convention in 2004, so any bans or restrictions imposed by the Stockholm Convention must be adhered to by NZ.

Many legacy POPs (e.g. dieldrin, PCBs, chlordane) are listed under Annex A, while DDT is listed under Annex B. Annex C includes polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/PCDF) and PCBs (Note: PCBs are also in Annex A (production) but included here through unintended release).

The list has been amended since 2001 to include some EOCs. In 2009, four brominated diphenyl ethers (BDEs) [hexabromodiphenyl ether and pentabromodiphenyl ether, the main components of commercial octabromodiphenyl ether; tetrabromodiphenyl ether and pentabromodiphenyl ether, the main components of commercial pentabromodiphenyl ether] were listed as POPs in Annex A. Hexabromobiphenyl was also included in Annex A in 2009 (UNEP, 2009). In 2013, Annex A was amended to include the flame retardant hexabromocyclododecane (HBCD) (UNEP, 2013).

Perfluorooctanesulfonic acid (PFOS), its salts and perfluorooctanesulfonyl fluoride (PFOSF) are man-made fluorosurfactants and global pollutants. They were added to Annex B in 2009 (UNEP, 2009).

<u>Specific chemicals</u>

There are many chemicals not included in Annexes of the Stockholm Convention, but that are undergoing reviews by respective regulatory bodies (for example European Union (EU) and the United States Food and Drug Administration (USFDA)). This is a rapidly changing space where developments are almost daily, so the following contains a brief overview at the time of writing of chemicals that are gaining the most attention.

Triclosan

Triclosan is a biocide incorporated predominantly into personal care products (cosmetics, soaps/detergents, shampoos) but also has medical applications (including veterinary). Due to concerns over development of triclosan resistance due to widespread usage, some jurisdictions have restricted or withdrawn the use and sale of TCS.

In New Zealand TCS currently has Environmental Protection Authority (EPA) approval status in the cosmetic products group standard, with a maximum authorised concentration of 0.3%.[47] A recent application to the NZ EPA to assess whether a reassessment of triclosan is justified on the basis of sufficient new information has been upheld and a reassessment of the chemical is to be undertaken.

Bisphenol A

Bisphenol A (BPA) is a plasticiser used in the manufacture of certain plastics, including drink bottles. BPA is an endocrine disrupting chemical (EDC) and the major concern was it's incorporation into babies bottles. Bans of BPA have been in place since 2010 (Canada), in 2010[48], 2011 (EU)[49] and 2012 (US).[50]

In NZ BPA currently has EPA approval status.[51]

Glyphosate

Glyphosate is a broad spectrum herbicide, usually produced commercially as a formulation with surfactant additives as wetting agents. Glyphosate based herbicides are one of the highest use herbicides worldwide in agricultural (including orchards, vineyards, pastures) and other areas (vegetable patches, roadways, parks and sports fields, and home gardens). There is concern that high glyphosate use has led to the increase of glyphosate-resistant weeds (Heap, 2014), necessitating the use of more glyphosate.

There is much debate over health effects of glyphosate, which is claimed to have endocrine and carcinogenic effects. The WHO International Agency for Research on Cancer recently classified glyphosate as *probably carcinogenic to humans* (Group 2A).[52] The debate is ongoing, with the UK media reporting that the European Union recently gave a last-minute reprieve to glyphosate, just hours before it faced a recall from shops across the continent.[53]

In NZ, glyphosate is on the EPA's Chief Executive Initiated Reassessment Programme list. The EPA are actively monitoring its status and international developments and (in light of the WHO classification) commissioned a review of the evidence relating to glyphosate and carcinogenicity, which concluded that glyphosate is unlikely to be genotoxic or carcinogenic to humans and does not require classification under HSNO as a carcinogen or mutagen.[54]

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[47] http://www.epa.govt.nz/publications/gs-cosmetic.pdf
[48] http://www.chemicalsubstanceschimiques.gc.ca/challenge-defi/batch-lot-2/bisphenol-a/bpa-risk_hazard-eng.php
[49] http://europa.eu/rapid/press-release_IP-11-664_en.htm
[50] https://www.federalregister.gov/articles/2012/07/17/2012-17366/indirect-food-additives-polymers
[51] http://www.epa.govt.nz/search-databases/Pages/ccid-details.aspx?SubstanceID=4763
[52] http://www.iarc.fr/en/media-centre/iarcnews/pdf/MonographVolume112.pdf
[53] https://www.theguardian.com/business/2016/jun/29/controversial-chemical-roundup-weedkiller-escapes-immediate-ban
[54] http://www.epa.govt.nz/hazardous-substances/pop_hs_topics/glyphosate_learn/Pages/Glyphosate_regulation.aspx

Neonicotinoid pesticides

Concerns have been raised over the effects of neonicotinoid pesticides on bees and aquatic insects. The EU is restricting the use of three neonicotinoid pesticides; clothianidin, imidacloprid and thiametoxam for two years from 2013 to 2015 (European Commission, 2013). Ontario (Canada) introduced new regulations from July 2015 to reduce the use of neonicotinoid pesticides.[55]

In NZ, the use of neonicotinoid insecticides has been strictly controlled for many years, including special measures to protect bees. EPA are keeping a watching brief on neonicotinoid insecticides and may initiate a re-assessment if there was evidence that they were causing harm in NZ.[56]

Nonylphenols

Nonylphenols (NPs) are a group of related chemicals that are precursors to nonylphenol ethoxylates (NPEOs) which are used in detergents, paints, pesticides, personal care products, and plastics. Importantly, these ethoxylates break down to the precursor nonylphenols, which have high environmental persistence. Nonylphenols are considered weak EDCs due to their ability to mimic estrogen and disrupt the normal hormonal balance. Their weak activity is compensated to some extent by high use and environmental persistence.

Restrictions of NP and NPEO concentrations have been in place in the EU since 2003 (European Commission, 2003). In June 2015, the European Chemicals Agency (ECHA) recommended branched and linear 4-NPEOs should be included on the list of substances in Annex XIV of REACH.[57] These recommendations (known as a candidate list) are the first step in the process of banning or significantly reducing the use of these chemicals (via incorporation into an authorisation list). Other chemicals in this list of relevance to this report are discussed below. In 2014, the USEPA proposed a significant new use rule[58] under the Toxic Substances Control Act for four NPs and eleven NPEOs. This rule would require the EPA to be notified 90 days prior to manufacture (including import) or processing of these chemicals for a significant new use.

In NZ, NPEOs have current EPA approval (with controls).[59]

Flame retardants

Although associated more with urban than rural environments, flame retardants are common in the environment. As far back as 1987, their detection in remote areas provided evidence that flame retardants were global pollutants (Jansson et al., 1987).

In addition to certain BDEs and HBCD that are covered by the Stockholm Convention other flame retardants are raising concerns.

The ECHA recommended the inclusion of a chlorinated alkylphosphate flame retardant into the candidate list of REACH.[57] In the US, concern regarding the toxicity of flame retardants has resulted in proposals to ban

[55] http://news.ontario.ca/ene/en/2015/06/regulating-neonicotinoids.html
[56] http://www.epa.govt.nz/Publications/EPA_neonicotinoid_insecticides_information_sheet_2015.pdf
[57] http://echa.europa.eu/view-article/-/journal_content/title/echa-proposes-15-substances-for-authorisation
[58] http://www.epa.gov/oppt/newchems/pubs/cnosnurs.htm
[59] http://www.epa.govt.nz/search-databases/Pages/controls-details.aspx?SubstanceID=14780&AppID=3287

certain flame retardants from upholstered furniture and children's products, and review the safety of all flame retardants. These include brominated[60] and chlorinated[61] flame retardants.

We are unaware of any initiatives to remove or reduce flame retardants in NZ.

Phthalate plasticisers

Like flame retardants, many plasticisers are global pollutants, with evidence for phthalate plasticisers in the open-ocean environment as far back as 1978 (Giam et al., 1978).

A wide range of chemicals are used as plasticisers, and are used to increase the plasticity or fluidity of a material. Phthalate plasticisers are primarily used to soften PVC and have gained the most attention worldwide due to their implications in breast cancer, endocrine disruption, and developmental effects on children.

In 2005, the EU restricted the use of six phthalate plasticisers (DEHP, DBP, BBP, DINP, DIDP and DNOP) to concentrations not exceeding 0.1% in toys and childcare articles.[62] The Canada Consumer Protection Act Phthalate regulations also restrict the concentration of phthalates in children's' toys.[63]

Four phthalate plasticisers are currently included in Annex XIV (authorisation list) of REACH, with six additional phthalates recommended by ECHA for inclusion.

We are unaware of any initiatives to remove or reduce phthalates in NZ.

Organophosphate and carbamate insecticides

In January 2016, EPA revoked approval for 18 veterinary medicine and insecticide products containing carbaryl, chlorpyrifos and diazinon (EPA, 2016). One liquid product containing 1.3% carbaryl was approved with controls. A three year phase out period (until 28 February 2019) has been put in place.

As well as acute toxicity, there are concerns over the potential for organophosphate and carbamate (OPC) insecticides to cause longer term adverse health effects in humans. These include the potential for chronic health effects following acute poisoning, and effects as a result of chronic exposure to lower levels that do not cause the clinical signs or symptoms of poisoning. OPCs are also harmful to the environment. They are very toxic to the aquatic environment and to terrestrial invertebrates (e.g. bees) (EPA, 2016).

Sodium fluoroacetate (1080)

Sodium fluoroacetate (1080) is a vertebrate pesticide. It was estimated by EPA in their 2007 reassessment of 1080 that NZ used approximately 80% of the world production of 1080. EPA granted approval with strict controls. EPA stated at that time that other countries also use 1080, it was not registered for use in others

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[60] 2-ethylhexyl-2,3,4,5-tetrabromobenzoate (TBB); Bis(2-ethylhexyl)-3,4,5,6-tetrabromophthalate (TBPH); decabromodiphenyl ether (DecaBDE); hexabromocyclododecane (HBCD); tetrabromobisphenol-A (TBBPA)

[61] Tris(1-choro-2-propyl)phosphate and Tris(2-choro-2-methylethyl)phosphate (TCPP); Tris (1,3,dichloro-2-propyl)phosphate (TDCPP); Tris(2-chloroethyl)phosphate (TCEP); chlorinated paraffins

[62] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32005L0084&from=en

[63] http://www.hc-sc.gc.ca/cps-spc/pubs/indust/toys-jouets/index-eng.php#a345

while a few had placed bans on its use (EPA, 2006). Exposure to sub-lethal doses has been shown to have harmful effects on the heart and testes in animal studies, and good management practices are necessary to minimize non-target effects on birds and other mammals (Eason et al., 2011).

6.10.2 Best practice guidelines

Regulatory mitigation procedures in NZ are specific to an individual chemical.

Some hazardous chemicals have been re-classed as persistent organic pollutants (POPs) and (as discussed in Section 6.9) will be eliminated or restricted through NZ's obligations under the Stockholm Convention.

Hazardous substances need to be approved before they can be used in NZ, a process which takes place under the Hazardous Substances and New Organisms (HSNO) Act[64]. Therefore, there is a process in place to prevent hazardous chemicals from entering NZ, provided they are an "active ingredient" (e.g. a new pesticide or pharmaceutical) and not arriving through incorporation into other materials (e.g. flame retardants).

Re-assessment of currently approved chemicals by the HSNO process is an avenue where approvals may be revoked. Any person or company may apply for a re-assessment to the EPA (who administers the HSNO Act). Re-assessments can also be initiated by the Chief Executive of the EPA, who – after considering factors such as the hazardous properties of the substance and estimates of the potential level of exposure – may add them to the list of substances for reassessment under the Chief Executive-initiated Reassessment Programme (CEIR).[65]

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[64] http://www.epa.govt.nz/hazardous-substances/about/Pages/default.aspx

[65] http://www.epa.govt.nz/hazardous-substances/reassessments-reviews/Pages/Chief%20Executive%20Initiated%20Reassessment%20list.aspx

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Glossary

Acute toxicity	Rapid adverse effect (e.g., death) caused by a substance in a living organism. Can be used to define either the exposure or the response to an exposure (effect).
Ammonia gas (NH_3)	Toxic to many aquatic animals. Also referred to as free ammonia. (This term should not be used to describe ammoniacal nitrogen – see below).
Ammoniacal nitrogen	The sum of unionised ammonia gas (NH_3) and ionised ammonia (NH_4).
Ammonium	Ionised ammonium (NH_4). Does not include ammonia gas (NH_3).
Anthropogenic	Effects, processes, or materials that are derived from human activities.
ANZECC	Australia and New Zealand Environment and Conservation Council.
Aquatic	Dwelling in water.
Assimilative capacity	The capacity of a natural system to assimilate contaminants without adverse effects on biota.
BBP	Butylbenzyl phthalate (plasticiser).
Benthic	Associated with the river bed, sea bed or lake bed.
Best practice	A method or technique that has been generally accepted as superior to any alternatives.
Bioaccumulation	A process by which chemicals are ingested and retained by organisms, either from the environment directly or through the consumption of food containing those chemicals.
Bioavailable	That fraction of a chemical which is available for uptake for an organism.
Biomass	The total weight of live organisms in a sampled population or community.
Biosolids	Primarily organic solid product produced by sewage processing. Until such solids are suitable for beneficial use, they are defined as wastewater solids or sewage sludge.
Biota	All living organisms in a given area.
BOD_5	Five day biochemical oxygen demand. A common measure of the organic strength of a water sample. The amount of dissolved oxygen consumed in five days by biological processes breaking down organic matter, and hence an indication of the demand put on dissolved oxygen in a water sample.
BPA	Bisphenol A (plasticiser).

Bunding Secondary containment provided for storage areas, particularly for materials with the propensity to cause environmental damage.

Catchment An area of land from which water from rainfall drains toward a common watercourse, stream, river, lake, or estuary.

Chlorinated hydrocarbons A series of chemicals consisting of organic compounds (i.e., compounds containing carbon) with one or more chlorine atoms bonded to them. Usually persistent and toxic in the environment. Examples include chlorinated pesticides, PCBs and TCE, used as an industrial solvent.

Chronic Characterised by a time period that represents a substantial portion of the life span of an organism (e.g., chronic toxicity is the characteristic of a chemical to produce a toxic response when an organism is exposed over a long period of time).

CIBR Centre for Integrated Biowaste Research.

COD Chemical oxygen demand. A measure of the oxygen required to oxidise all compounds, both organic and inorganic, in water. Note that BOD is a subset of COD.

Concentration The measure of how much of a given substance there is mixed with another substance. Relates to the amount of a contaminant in water or sediment.

Contaminant/pollutant Any substance (including gases, liquids, solids, and micro- organisms) or energy or heat, that either by itself or in combination; (a) when discharged into water changes or is likely to change the physical, chemical, or biological condition of the water; or (b) when discharged onto or into land or into air, changes or is likely to change the physical, chemical or biological condition of the land or air onto or into which it is discharged.

DDT Dichlorodiphenyltrichloroethane. Persistent OCP used historically in NZ.

DEHP Bis(2-ethylhexyl)phthalate (plasticiser).

Denitrification The anaerobic biological reduction of nitrate to nitrogen gas.

Detection limit A value below which the laboratory analyst is not confident that any apparent concentration is real.

Diffuser Structure designed to enhance the dispersion of the effluent as it is discharged into the receiving environment.

Dioxins The by-products of various industrial processes (such as bleaching paper pulp, and chemical and pesticide manufacture) and combustion activities (such as burning rubbish, forest fires, and waste incineration).

Disinfection	Inactivation of micro-organisms by addition of a chemical (such as chlorine), boiling, or irradiation with ultra-violet light.
Dissolved oxygen	Oxygen gas that is freely available in water to sustain the lives of fish and other aquatic organisms.
Dissolved reactive phosphorus	Phosphorus in a water sample that passes a 0.45 micron filter. Used as a measure of the phosphorus that is readily available as nutrients to aquatic plants.
Drainage	The removal of water from any part of a water body or land, resulting in the creation of a dry area, lower groundwater levels or minimising the build-up of surface water ponding.
E. coli	*Escherichia coli*. A subgroup of faecal coliforms that are used as indicator for the presence of pathogens in fresh water.
EC	Emerging Contaminant.
EDC	Endocrine Disrupting Chemical.
Effluent	The liquid discharged following a wastewater treatment process.
Enterococci	A subgroup of faecal streptococci that are used as indicators for the presence of pathogens in marine waters and estuaries.
Enteroviruses	A sub-group of viruses that are derived from human sources (e.g. sewage effluent). Human enteroviruses are indicators of the presence of domestic sewage in water, but can vary markedly depending on the disease burden in the community.
EOC	Emerging Organic Contaminant.
EPA	Environmental Protection Authority.
Eutrophic	Abundant in nutrients and having high rates of productivity, frequently resulting in algal blooms and oxygen depletion below the surface layer of a waterbody. In general, an undesirable state for natural water bodies.
Faecal coliforms	Thermo-tolerant bacteria from the coliform group found in the intestinal tracts of mammals (including humans). Used as indicator for the possible presence of pathogens in wastewater, receiving waters, and shellfish.
Flocculation	The process by which suspended colloidal or very fine particles coalesce and agglomerate into well- defined flocs of sufficient size to settle rapidly.
FSANZ	Food Standards Australia New Zealand.

Groundwater	Natural water contained within rock formations below the surface of the ground.
Guideline	Numerical threshold (for example toxicity) for a chemical, or a narrative statement, recommended to support and maintain a designated water use.
Hazardous	Having the capacity to adversely affect either the health of an organism or the environment.
Heavy Metals	Metals of high atomic weight which in high concentrations can exert a toxic effect and may accumulate in the environment and the food chain. Examples include mercury, chromium, cadmium, nickel, lead and zinc.
HSNO	Hazardous Substances and New Organisms Act 1996.
Indigenous	Native, or belonging naturally to a given region or ecosystem, as opposed to exotic or introduced (can be used for people, animal, or plant species or even mineral resources).
ISQG	Interim Sediment Quality Guideline.
Macrophyte	Aquatic plant, individually visible to the naked eye.
Mahinga kai	Refers to iwi interests in traditional food and other natural resources and the places where those resources are obtained.
Median	In statistics, the middle score in a range of samples or measurements (that is, half the scores will be higher than the median and half will be lower).
Mesocosm	Any outdoor experimental system that examines the natural environment under controlled conditions. In this way mesocosm studies provide a link between field surveys and highly controlled laboratory experiments.
MfE	Ministry for the Environment.
MoH	Ministry of Health.
MPI	Ministry for Primary Industries.
NIWA	National Institute of Water & Atmospheric Research.
NP	Nonylphenol (surfactant).
NSAID	Nonsteroidal anti-inflammatory drug (e.g. acetaminophen, diclofenac).
NTU	A standard unit of turbidity measurement. Relates to the side-scatterance (usually 90°) of light by particles in the water.

Nutrient Any substance assimilated by living things that promotes growth. The term is generally applied to nitrogen and phosphorus in the aquatic environment, but is also applied to other essential and trace elements such as potassium.

OCP Organochlorine Pesticide.

Organochlorine A chemical that contains carbon and chlorine atoms joined together. Some organochlorines are persistent (remain chemically stable) and present a risk to the environment and human health, such as dioxin, DDT and PCBs.

PAH Polycyclic Aromatic Hydrocarbons.

Pathogens Disease-causing organisms. Include viruses, bacteria, protozoa and helminths (worms).

PCB Polychlorinated Biphenyl.

Periphyton Plants Usually algae, which grow on stones, logs and other plants.

Persistent organic pollutant A general term for all organic chemicals (referred to as POPs) that are resistant to degradation in the environment, and are potentially toxic to biota. Includes phenols, chlorinated hydrocarbons, pesticides and herbicides.

Pesticide Pesticides are the only toxic substances released intentionally into our environment to kill living things. This includes substances that kill weeds (herbicides), insects (insecticides), fungus (fungicides), and rodents (rodenticides).

pH A measure of acidity or alkalinity of an aqueous solution, expressed as the logarithm of the reciprocal of the hydrogen ion (H+) activity in moles per litre at a given temperature; pH 7 is neutral, below 7 is acidic and above 7 is alkaline.

Phenols A class of aromatic organic compounds contain one or more hydroxyl groups attached directly to a benzene ring. Toxic to aquatic biota.

Phytoplankton Small, free-floating usually microscopic plants (such as algae), found in rivers lakes and the sea. They include diatoms, desmids, and dinoflagellates.

PNEC Predicted-No-Effect Concentration.

ppb 1 part per billion = 1 mg/m^3 = 1 µg/L.

PPCP Pharmaceutical and Personal Care Product.

ppm 1 part per million = 1 g/m^3 = 1 mg/L.

Receiving environment	With respect to discharge activities, any land or water body to which a discharge occurs.
Resilience	Resilience is a term that is sometimes used interchangeably with robustness to describe the ability of a system to continue functioning amid and recover from a disturbance.
Risk Assessment	The determination of a quantitative or qualitative value of risk related to a concrete situation and a recognised threat.
RMA	Resource Management Act 1991.
Rohe	Tribal boundary, district, region, territory, area, border (of land).
Salinity	The degree of saltiness in seawater as measured by conductivity at a given temperature e.g. offshore seawater has a salinity of ~35.
Sediment	Particles or clumps of particles of sand, clay, silt, or plant or animal matter carried in water.
SETAC	Society of Environmental Toxicology and Chemistry.
Sewage	Wastewater that contains a component of human faeces and urine, as well as other household wastewater (e.g., from showers, sinks and washing machines). Often also contains a proportion of commercial and industrial wastewater (see trade wastes).
Sewer	A pipe or conduit that carries wastewater to a treatment plant or receiving waters. ‘Sanitary’ sewers carry household, industrial, and commercial waste. ‘Storm’ sewers carry runoff from rain.
SIG	Special Interest Group.
Sludge	The solids that are removed from wastewater by treatment.
SoE	State of the Environment.
Soluble	Fraction of material that passes though a filter (international convention uses a 0.45 micron membrane filter).
Species	One of the basic units of biological classification. A species comprises individual organisms that are very similar in appearance, anatomy, physiology, and genetics, due to having relatively recent common ancestors; and can interbreed.
Stormwater	Surface water runoff (and any contaminants contained therein), from land or the external surface of any structure which is diverted or discharged to a water body or land as a result of rainfall.

Suspended solids	Solid particles suspended in water. Some of these particles may settle out in quiescent conditions, but a fraction of the (smaller) suspended solids will always remain in suspension.
Tangata whenua	People of the land, locals, residents, people born of the whenua.
TCS	Triclosan (antimicrobial).
Temporal	Varying over time.
Total nitrogen	The sum of all forms of nitrogen (N) in a sample, i.e., organic N + ammoniacal N + nitrate N + nitrite N, expressed in mass of nitrogen.
Total phosphorus	The sum of all forms of phosphorus in a sample, i.e., dissolved reactive phosphorus + particulate phosphorus, expressed in mass of phosphorus.
TPH	Total petroleum hydrocarbon.
Trade waste	Definition in NZS 92011999 Model General Bylaws Part 23 - Trade Waste is 'any liquid, with or without matter in suspension or solution, that is or may be discharged from a trade premises in the course of any trade or industrial process or operation, or in the course of any activity or operation of a like nature; but does not include condensing or cooling waters; storm water, or domestic sewage.'
Trophic state	In the context of receiving waters, refers to the nutrient status of the water body. Eutrophic, mesotrophic and oligotrophic are typical examples of trophic levels, ranging from nutrient-enriched (i.e., degraded water quality) to low nutrient (i.e., high water quality), respectively.
Turbidity	A measure of water clarity - the cloudiness in a fluid caused by the presence of finely divided, suspended material. Usually measured using a turbidity meter. Turbidity is related (but not directly proportional) to the amount of suspended solids in the water.
USEPA	United States Environmental Protection Agency.
USGS	United States Geological Survey.
Volatile	Readily vaporisable at a relatively low temperature.
WERF	Water Environment Research Foundation.
Whānau	Extended family, family group.
WWTP	Wastewater Treatment Plant.

Appendix A: Scope of services

1. **Service Components**
   i. Stormwater
   ii. Human wastewater
   iii. Industrial and trade waste
   iv. Other hazardous substances (including agricultural chemicals)

2. **Matters to be covered for each Service Component**

For each Service Component, the literature review must cover the following elements:

- An overview of the type of discharges considered (e.g. reticulated stormwater vs. stormwater from roads; on-site vs. community wastewater treatment schemes), and common disposal systems;
- A detailed description of the adverse effects of the type of discharges considered on the values of different receiving environment, considering:
  - The following values: ecosystem health, public health, cultural values, aesthetic values, the suitability of groundwater for drinking and irrigation, primary contact recreation, the suitability of fish / shellfish for human consumption, the suitability for irrigation and for stock drinking (freshwater), recreational values etc.
  - The following receiving environments: freshwater (lakes – both shallow and deep, rivers, wetlands and aquifers – confined and unconfined), marine environments (bays, harbours, estuaries, and near-shore coastal environments).
- A description of the contaminants that are usually contained in the type of discharges considered:
  - The link between those contaminants and the adverse effects on the values identified above.
  - The factors that determine the severity of adverse effects from those contaminants.
  - The relationship / correlation between those contaminants.
  - An identification of key contaminants of concern and / or surrogates for the key contaminants.
- An identification of indicators to help quantify the potential severity of adverse effects from those discharges (including cumulative effects);
- An overview of other adverse effects from the type of discharges considered.
- An overview of knowledge gaps / identified risks which are not yet fully known.
- An overview of management / mitigation practices and their costs and benefits.
- The identification of leading regions / countries in the management of the types of discharge considered.

3. **Specific matters to be covered for stormwater**

Aside from the specifics identified in 2 (above), the literature review on stormwater should:

- Give a broad overview of the hydrological adverse effects of stormwater in urban areas, and of new urban developments, and assess the costs and benefits of management options on those effects.

4. **Specific matters to be covered for human wastewater**

Aside from the specifics identified in 2 (above), the literature review on wastewater should:

- Briefly describe the main or most common issues / challenges with the management of wastewater in New Zealand.
- Provide an overview of the environmental challenges of, and latest advances on, the management of biosolids (sewage sludge); and the re-use of wastewater.
- Outline the adverse effects from wastewater according to their receiving environments (e.g. discharges to land).

5. Specific matters to be covered for industrial and trade waste

Aside from the specifics identified in 2 (above), the literature review on industrial and trade waste should:

- Briefly describe the main or most common issues / challenges with the management of those wastes in New Zealand.
- Identify the industries which are riskiest in terms of potential adverse effects on water quality and / or soils.
- Describe good practices around trade waste management, including best practice guidelines in Australia and New Zealand, and examples of effective mitigation measures.

6. Specific matters to be covered for other hazardous substances

Aside from the specifics identified in 2 (above), the literature review on other hazardous substances should:

- Identify common sources of hazardous substances in New Zealand, including agricultural chemicals, landfill leachate and mining).
- Describe the types and purpose of chemicals commonly used in the agricultural sector in New Zealand.
- Provide an overview of the risks and adverse effects of mining activities and the operation of landfills on water quality.
- Identify chemicals commonly used in New Zealand but banned overseas; and include a summary of the perceived risks in the use of the chemicals that have lead them to be banned overseas.
- Provide an overview of the range of potential environmental adverse effects from those chemicals, beyond their adverse effects on water quality (e.g. soil contamination, effects on pollinating insects etc.).
- Reference existing best practices guidelines for the use of these chemicals in New Zealand.

Appendix B: Indicators and methods

This Appendix contains indicators and methods standardly used to assess adverse effects. Although the project scope requested indicators only, we suggest that some methods (for example Quantitative Microbial Risk Assessment (QMRA)) are becoming more widespread and they are equally as important as indicators in assessing risk of adverse effects.

Ecosystem Health

Freshwater

The NPS-FM (Ministry for the Environment, 2014) defines ecosystem health for a freshwater management unit as being in a state which supports a healthy ecosystem appropriate to that freshwater body type (river, lake, wetland, or aquifer). In a healthy freshwater ecosystem ecological processes are maintained, there is a range and diversity of indigenous flora and fauna, and there is resilience to change. Current water quality indicators (attributes) that relate to the assessment of ecosystem health include:

- Lakes – trophic state indicators = phytoplankton, total nitrogen, total phosphorus; toxicity indicators = ammonia
- Rivers – trophic state indicators = periphyton; toxicity indicators = nitrate, ammonia; ecosystem health below point sources = dissolved oxygen.

Estuarine indicators

A pilot Estuaries National Objectives Framework is currently under development (Green, pers comm 2016) and is proposing a number of attribute states, with associated measures, analogous to those defined by the NPS-FM.

Hamill et al. (2014) provide advice on possible attributes and thresholds relevant to the ecosystem health of intermittently closed and open lakes and lagoons (ICOLLS) and brackish lakes, and their potential for consideration as part of the National Objectives Framework in the National Policy Statement for Freshwater Management. They recommend the inclusion of two additional attributes relevant to these water body types, namely anoxia caused by macroalgae (using Gross Eutrophic Zones (GEZ) as a proxy), and macrophytes.

Trigger values for protection of species

Trigger values are defined for a range of toxicants and physical and chemical stressors, for a chosen level of protection of aquatic ecosystems. Both freshwater and marine trigger values are defined (ANZECC & ARMCANZ, 2000).

Freshwater ecological indicators

Freshwater ecological indicators include:

- Macroinvertebrate Community Index (MCI) and Quantitative Macroinvertebrate Community Index (QMCI) are biological indices based on the relative sensitivity or tolerance of macroinvertebrates to pollutants. MCI is based on presence/absence, while QMCI has an abundance component.

- Other macroinvertebrate-based metrics, including % Ephemeroptera, Plecoptera and Trichoptera (EPT), which are species sensitive to changes in water/habitat quality.
- Fish Index of Biotic Integrity (IBI) – a multi-metric based on 6 measures that integrate taxonomic richness, several measures of habitat preference, tolerance to degradation, and invasive species (Joy, 2013).
- Lake Submerged Plant Indicators (LakeSPI) is a method which provides a quick and cost-effective bio-assessment tool for monitoring and reporting on the ecological condition of lakes (Burton and Clayton, 2014). It combines indicators of Native Condition Index, and Invasive Impact Index and an overall LakeSPI Index to assess the ecological condition of New Zealand lakes.

Marine ecological indicators

Marine ecological indicators include:

- Benthic Health Model (BHM) - has been developed by Auckland Regional Council to provide a tool for classifying intertidal sites within the region according to categories of relative ecosystem health (Anderson et al., 2006). To date, models relating gradients of community change to two key environmental contaminants have been developed for Auckland estuaries, namely mud (percent of particles <63μm) (CAPMud) and stormwater contaminants (copper, zinc, lead) (CAPMetal). The BHM has proven to be extremely robust and has been widely applied in the Auckland Region (Hailes and Hewitt, 2012a and b; Hewitt et al., 2012; Parkes and Lundquist, 2015). A comparable CAP analysis method has been applied in Wellington Harbour (Kelly, 2010b) and models for mud, nutrients and contaminants have been developed for Tauranga Harbour (Ellis et al., 2015).
- Trait Based Index (TBI) – based on a broad cross-section of macrofaunal functional types, with one trait group selected from each of seven broader functional trait categories (organism size, shape, mobility, feeding mode, position in the sediment, sediment reworking behaviour, and type of topographic feature created), which were found to be sensitive to mud and metals (van Houte-Howes and Lohrer, 2010; Lohrer and Rodil, 2011). The TBI also integrates across the interactions between the effect of heavy metals and mud on the macrofaunal communities.
- AZTI Marine Benthic Index (AMBI) - assesses estuary condition by placing individual species into 5 ecological groups able to tolerate different levels of environmental degradation. Based on the groupings of species present, it is then possible to classify the overall quality of the environmental conditions, ranging from normal, through polluted, to azoic (without life). The formula produces a Biotic Coefficient that, similar to the BHMs, can be used to grade the macrofaunal community on a five-point scale from "Unpolluted" to "Azoic (devoid of life)" (Robertson and Stevens, 2010; Robertson et al., 2016).

Estuarine Trophic Index (ETI) Toolbox

The ETI Toolbox, which is currently being developed in an Envirolink Tools project by NIWA, Wriggle Coastal Management, Hawkes Bay Regional Council and Greater Wellington Regional Council, assembles a wide range of information on ecological thresholds from overseas and New Zealand sources.

Screening Tool 1 of the ETI Toolbox (Robertson et al., 2016a) provides a method for assessing susceptibility to eutrophication. The tool produces a "physical susceptibility score", which can be combined with nutrient load data to produce a "combined physical and nutrient load susceptibility rating". In general, the approach taken by the ETI to provide guidance on the susceptibility of NZ estuary types to eutrophication is to use a combination of:

- A typological system for classifying estuaries;
- Existing physical susceptibility indicators;
- Additional physical indicators to account for shallow estuary types in NZ;
- Nutrient loads and, to a lesser extent, concentrations.

Screening Tool 2 of the ETI Toolbox is a monitoring approach that characterises the ecological gradient of estuary trophic condition for relevant ecological response indicators (e.g. macroalgal biomass, dissolved oxygen), and provides a means of translating these ratings into an overall estuary trophic condition rating/score (the ETI) (Robertson et al., 2016b). It provides guidance on monitoring primary (direct e.g. macroalgae phytoplankton) and secondary (indirect) symptoms of eutrophication where the "monitoring indicators" vary by estuary type. Screening Tool 2 also gives "numeric impairment bands" (e.g., very high, high, moderate, low) for monitoring indicators listed by estuary type (where appropriate). Key outputs of Screening Tool 2 are:

- Determination of appropriate monitoring indicators to assess estuary trophic state, based on estuary habitat type;
- Determination of where an estuary sits along an ecological gradient of estuary trophic condition (i.e. from non-eutrophic to eutrophic) using data for relevant ecological response indicators (e.g. macroalgal biomass, dissolved oxygen).

This ETI combination package of ecological response indicators, thresholds, and nutrient loads, tailored for estuary type, provides a more direct risk-based linkage to estuary ecological values than nutrient concentrations or loads alone. Its weight of evidence approach, with multiple ecological response indicators and indicator thresholds and load/response relationships developed from relevant estuary ecological gradients, is expected to produce a robust assessment of eutrophication for most NZ estuary types, and to provide preliminary, screening-level, load limit guidance.

<u>Periphyton</u>

The NOF provides guidance on acceptable levels of periphyton growth in rivers, measured as mg chlorophyll a per square metre, which are defined based on the type of river (from the River Environment Classification).

Biggs (2000) suggests limits for periphyton growth in relation to amenity values (a combination of contact recreation and aesthetics), biodiversity and trout angling/habitat. Beyond these limits periphyton biomass is defined as a nuisance growth, which is a condition to be avoided if possible. While regarded as provisional, these guidelines and thresholds are in common usage in New Zealand, although in some places they are superseded by plans and regulations reflecting specific local conditions and needs. Guidelines usually present both a periphyton cover and biomass threshold to allow for variation in study format; cover data is quicker and cheaper to collect allowing greater spatial coverage while biomass data requires greater time and resources, but provides a higher resolution data set.

In addition, Matheson (2012) defined the following guidelines for aquatic macrophytes and periphyton in freshwaters:

- A provisional guideline of ≤50% of macrophyte channel cross-sectional area or volume (CAV) is recommended to protect instream ecological condition, flow conveyance and recreation values;
- A provisional guideline of ≤50% of macrophyte channel water surface area (SA) is recommended to protect instream aesthetic and recreation values;
- A periphyton weighted composite cover (PeriWCC) can be calculated as %filamentous cover + (%mat cover/2) with an aesthetic nuisance guideline of ≥30%;
- Provisional general guidelines of <20%, 20-39%, 40-55% and >55% periphyton weighted composite cover are recommended as indicators of 'excellent', 'good', 'fair' and 'poor' ecological condition, respectively, at sites where other stressors are minimal.

Sediment

Suspended sediment is a significant impacting factor in freshwater and marine environments, affects water clarity, drinking water quality and recreation suitability. Sediment accumulates on the channel and sea bed and degrades habitat. It also carries other pollutants, such as phosphorus, nitrogen, carbon, metals and organic pollutants. Excessive suspended sediment in aquatic systems can be very harmful. Suspended sediment can be measured in a number of ways, depending on the purpose of the measurement. For example, it can be reported as an instantaneous measure of the amount of suspended material in the water column as mg/L). Turbidity is frequently (and sometimes inappropriately) used as an analogue for estimating suspended sediment concentrations. However, it differs in that it is a measure of the cloudiness of a liquid and is usually quantified in nephelometric turbidity units (NTUs). Either organic matter, such as algae, or inorganic particles, like silt, can cause turbidity. ANZECC/ARMCANZ (2000) defines default trigger values for turbidity for slightly disturbed systems.

Clapcott et al. (2011) developed protocols for measuring assessing the effects of deposited fine sediment on in-stream values. Results indicated that the bankside visual estimate of % sediment had the strongest and most consistent relationship with biological indicators of in-stream values.

Public Health

Public health is restricted to drinking water as contact recreation values are separate.

The Drinking-water Standards for New Zealand (Ministry of Health, 2008) provide requirements for drinking-water safety by specifying the:

- Maximum amounts of substances or organisms or contaminants or residues that may be present in drinking-water (maximum acceptable values (MAVs));
- Criteria for demonstrating compliance with the MAVs;
- Remedial action to be taken in the event of non-compliance with the different aspects of the Standards.

MAVs are set for a range of microbiological, chemical (inorganic and organic) and radiological substances of human health significance.

Cultural

Cultural Health Index (CHI)

The Cultural Health Index (Tipa and Teirney, 2006) provides a means to evaluate the health of streams and rivers within a rohe that expresses and accommodates the values and beliefs of iwi, while at the same time enabling effective communication and working relationships with water managers.

The CHI score is made up of three components:

- The status of the site as a traditional and current significant site for tangata whenua;
- Assessment of mahinga kai values of a site (including mahinga kai species present at the site, changes in species over time, site access and likelihood of return to the site), and;
- Cultural stream health – determined on the basis of 8 individual indicators of water and habitat quality.

Marine Cultural Health Index

A Marine Cultural Health Index (MCHI) monitoring toolkit (Schweikert et al., 2012) has been developed to enable Ngāi Tahu to establish restoration targets and sustainable mahinga kai harvest strategies within their taiāpure, mātaitai, and other coastal protection areas. The toolkit, derived from local and traditional knowledge, incorporates a range of environmental indicators. The MCHI is currently being updated[66], extending it using a web-based interface and online (realtime) analysis tools.

Aesthetic

The Drinking-Water Standards for New Zealand (Ministry of Health, 2008) provide guideline values (GVs) for a range of aesthetic determinands in drinking water, including taste, colour and odour.

Groundwater quality

Drinking-Water

The Drinking-Water Standards for New Zealand (Ministry of Health, 2008) provide MAVs for groundwater quality, for the use of bore water as a source of drinking water.

The National Groundwater Monitoring Programme (NGMP) is a long-term research and monitoring programme operated by GNS Science in collaboration with regional authorities. It provides:

- A national perspective on groundwater monitoring used to define "baseline" groundwater quality;
- Associates groundwater quality with certain causes such as anthropogenic influence;
- Best-practice methods for sampling and monitoring as well as groundwater quality data interpretation.

[66] https://www.takiwa.org.nz/pages/about-mchi.html

Samples are collected quarterly (by regional council staff) from over 100 groundwater monitoring sites around New Zealand. Samples are subsequently analysed for 17 water quality indicators (i.e. major ions, nutrients, metals).

ANZECC water quality guidelines for surface water generally apply to groundwaters (ANZECC & ARMCANZ, 2000).

National Environmental Standards (NES)

Groundwater contamination from soil leaching of contaminants is protected by National Environmental Standards (NES). The Ministry for the Environment (MfE) have set a series of soil contaminant standards (referred to as NES) for metal (arsenic, boron, cadmium, chromium, copper, lead, and mercury) and organic (benzo(a)pyrene, dieldrin, pentachlorophenol, dioxins and dioxin-like polychlorinated biphenyls) contaminants in soil (Ministry for the Environment, 2012). Maximum limits are set for five different landuse scenarios (rural residential/lifestyle block 25% produce; residential 10% produce; high-density residential; recreation; commercial/industrial outdoor worker (unpaved)) that reflect degree of risk to human health.

Primary contact recreation

The Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (Ministry for the Environment, 2003) have been developed for the agencies involved in the monitoring and reporting of recreational waters. There are two components to grading recreational water bodies:

- The Sanitary Inspection Category (SIC), which generates a measure of the susceptibility of a water body to faecal contamination;
- Historical microbiological results, which generate a Microbiological Assessment Category (MAC). This provides a measurement of the actual water quality over time.

The two combined give an overall Suitability for Recreation Grade (SFRG), which describes the general condition of a site at any given time, based on both risk and indicator bacteria counts. Separate MACs have been developed for freshwater and marine waters.

Quantitative Microbial Risk Assessment (QMRA) is a quantitative way of estimating the health risk to people who are swimming in and consuming raw shellfish harvested from waters which are near sources of microbial contamination such as river plumes and wastewater outfalls. It can be used to assess, for example:

- Swimming suitability of beaches near outfalls and polluted river plumes;
- Safety of wild shell fish harvesting near outfalls and polluted river plumes;
- Comparison of existing wastewater disposal options with proposed ones in regard to their impact on public health;
- Public health risk for the location of shell fish aquaculture;
- Disease transmission in human populations.

QMRA is being increasingly adopted in New Zealand as a means of quantifying and comparing human health risks arising from the discharge of treated wastewater to waters that are used for recreational or shellfish gathering purposes (McBride, 2014). QMRA assesses the risk of human exposure to a representative pathogen or model “virus”. The procedure uses a “Monte Carlo” quantitative statistical modelling technique to calculate risk profiles for each exposure scenario identified within the receiving water. The approach uses variable inputs including viral concentrations in the discharge, wastewater dilution, dispersion and die-off data, swim contact time and shellfish meal size. Exposure sites are identified, preferably in close consultation with the community. A random sample is "taken" from each of 100 people on 1000 separate "visits". For each of these 100,000 simulated "events" a random sample is taken (as for the roll of a dice-hence the term "Monte Carlo") and the risk of virus exposure profile calculated. This risk profile represents a percentage of the time that a given number of infections may occur at an exposure site. This profile is presented as the Individual Infection Risk (IIR), which is calculated by the number of cases divided by the number of exposures.

Human consumption of aquatic organisms

Food Standards Australia New Zealand (FSANZ) is based on a partnership between the governments of Australia and New Zealand, and is responsible for developing, varying, and reviewing food standards for food available in Australia and New Zealand. Food standards were revised on 1st March 2016, with maximum levels of contaminants and natural toxicants provided for a variety of foods (FSANZ, 2016). The European Commission (EC) guidelines may be used as non-regulatory assessment of human health where the applicable FSANZ guideline does not exist, for example cadmium in fish (European Commission, 2006).

The Ministry for Primary Industries monitors shellfish toxins by collecting shellfish and seawater samples every week from popular shellfish gathering areas around New Zealand. These are tested for the presence of toxic algae. If the shellfish are not safe to eat, then public health warnings are issued and signs are posted at affected beaches.

ANZECC & ARMCANZ (2000) define guidelines for the protection of human consumers of fish and other aquatic organisms from bacterial infection for both marine and freshwater species, with faecal coliforms as the indicator. Guidelines are also provided for chemical compounds in water found to cause tainting of fish flesh and other aquatic organisms.

Irrigation

Guidelines for irrigation water quality are given in the ANZECC guidelines (ANZECC & ARMCANZ, 2000) for biological parameters, salinity and sodicity, inorganic contaminants (i.e. specific ions, including heavy metals and nutrients), organic contaminants (i.e. pesticides) and radiological characteristics. The guidelines are trigger values below which there should be minimal risk of adverse effects.

Stock

Good water quality is essential for successful livestock production. Poor quality water may reduce animal production and impair fertility. In extreme cases, stock may die. A range of indicators are used to determine the suitability of water for drinking by stock, including cyanobacteria, bacteria, ions (calcium, magnesium, nitrate and nitrite, sulphate, TDS), heavy metals and metalloids, and radioactive contaminants (ANZECC & ARMCANZ, 2000). Pesticides and organic contaminant guidelines for humans are applied where information specifically derived for livestock is absent.

Recreational

As described above, the Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas define acceptable water quality for primary contact (swimming). Indicators for secondary contact (occasional immersion associated with wading or boating) are included in the National Objectives Framework of the NPS-FM and include *E. coli* (lakes and rivers) and planktonic cyanobacteria (lakes and lake fed rivers) (Ministry for the Environment, 2014). Values for both are set for 5 categories, including a "National Bottom Line" below which a high risk of infection (in the case of *E. coli*) or health risks are likely. ANZECC refers New Zealanders to the above Microbiological Guidelines (ANZECC & ARMCANZ, 2000).

Appendix C: Review of Otago Stormwater Consent Monitoring Reports

Not surprisingly, most of the work on contaminants in Otago stormwater and the effect on receiving environments is centred on Dunedin. There appear to be no reports on stormwater quality in Otago outside the Dunedin metropolitan area. Immediately prior to, and since the granting of resource consents for stormwater in 2007, there have been a myriad of monitoring reports commissioned by Dunedin City Council, which have provided information on the concentration, and in some cases, loads of contaminants entrained in Dunedin's stormwater system. For the sake of brevity, we cite only the most recent of an annual monitoring report series, except where an additional report has been commissioned to address a specific issue. While there have been more recent monitoring reports on new urban developments (see Section 3.7.2), the majority of reports have concentrated on the stormwater discharges to the Upper Harbour. There are a number of reasons for this including:

- Because of its geography, much of Dunedin (particularly the central city) drains into the Upper Harbour;
- Because it is an old city by NZ standards, there are a number of legacy issues that may lead to particular contaminants being an issue in stormwater;
- Much of the infrastructure is aged and hence there is a greater risk of sewer overflows or cross-connections;
- The Upper Harbour is relatively quiescent and hence there is a greater risk of ecological effects (compared with suburbs such as St Clair draining to the open coast).

Stewart and Ryder (2005) summarised earlier work on stormwater discharges draining to the Upper Harbour and their potential effects on the coastal environment. The preponderance of stormwater outlets entering the Upper Harbour can be clearly seen in a figure from their report which also illustrates the relative size of stormwater catchments (Figure 18). They reported that Dunedin's stormwater contained various contaminants which were typical of those found in NZ urban stormwater. Levels of contaminants were within the range found for other NZ urban centres. An exception was polycyclic aromatic hydrocarbons (PAHs) and total petroleum hydrocarbon (TPH) loadings which were at the high end of ranges reported in NZ and internationally. However, these high concentrations were considered to be a consequence of a decommissioned gas works in the Portobello catchment and levels had dropped from those found in previous studies.

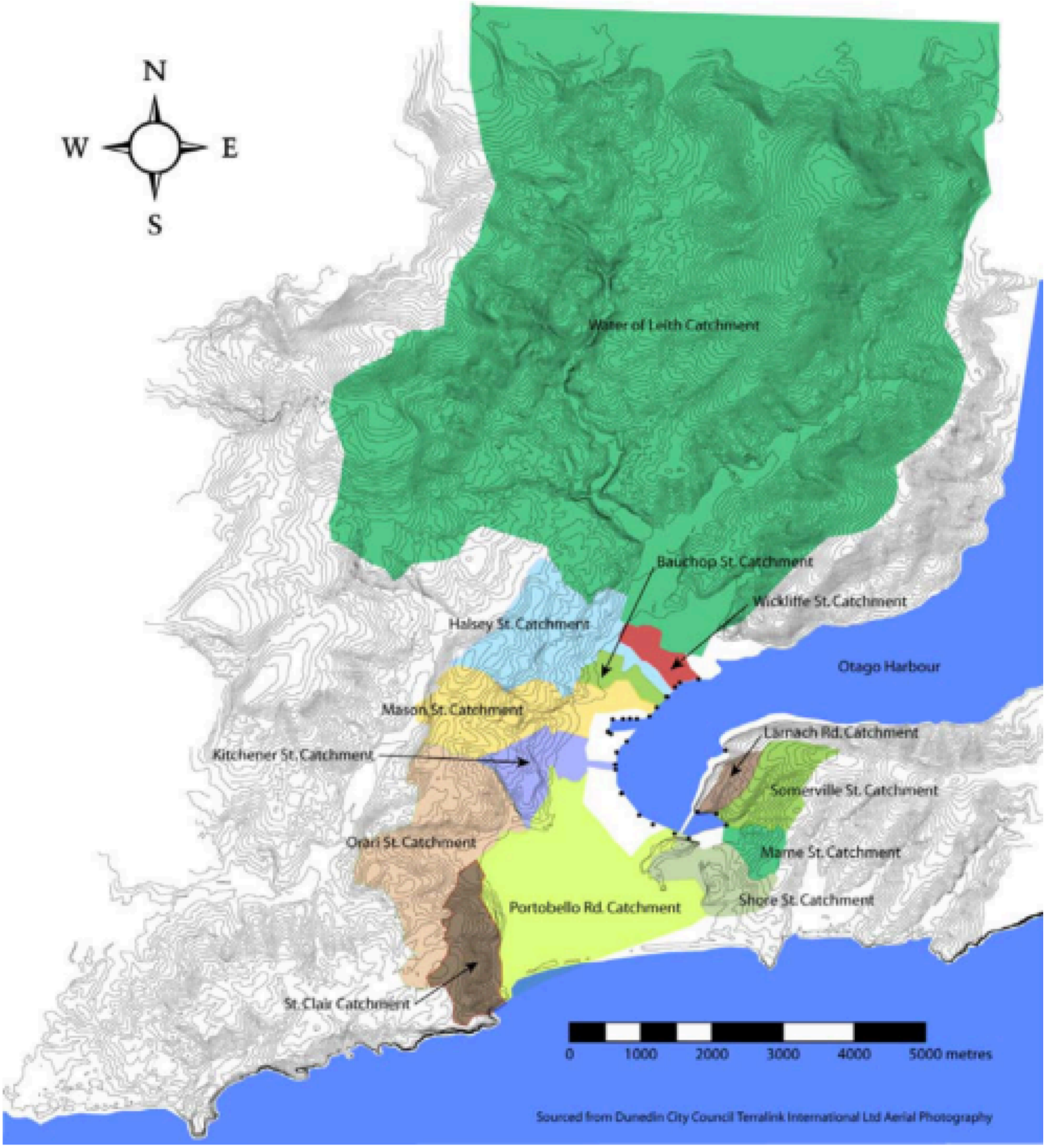

Figure 18. Map showing the locations and relative sizes of Dunedin's stormwater catchments that discharge to coastal water. Black dots around harbour edge indicate stormwater outfall locations (Fig 1.2 from Stewart, & Ryder (2005)).

In addition to the Upper Harbour monitoring, Stewart (2005b) also assessed stormwater outfalls at Port Chalmers. He reported that contaminant levels were fairly typical of other relatively non-industrialised catchments in the Dunedin area. There were isolated 'hot points' such as Carey's Bay, which had high copper levels due to it being the site of boat building and repairs, high zinc levels at the railway stormwater outlet, and high lead levels at the George Street outfall. However, Stewart (2005b) concluded that despite occasional high levels of some metal contaminants in stormwater entering the sea, the high dilution rates from tidal currents would ensure that effects were negligible.

Additional studies carried out prior to the granting of the 2007 consents include looking at effects of the de-icing agent calcium magnesium acetate (CMA) application to Dunedin streets, in terms of the contaminant profile in stormwater (Stewart, 2006). While this study focussed on effects on mussels and sea tulips we note that monitoring included calcium and magnesium levels. Because calcium and magnesium are common in the environment (i.e. at relatively high levels) it is perhaps not surprising that there was no significant difference in the concentration of these elements in mussels gathered at treatment and control sites.

Since the granting of the 2007 consents there has been annual monitoring of both the established stormwater outfalls (see Stewart (2015) for most recent) as well as for new developments (Stewart, 2012, 2011a, 2011b, 2010). Monitoring at the established outfalls (14 reasonably large and permanent outfalls as per Figure 18 and a number of smaller outfalls) has included both dry weather and wet weather sampling. Harbour water (last two monitoring years) and biota (cockles plus infauna) have also been monitored as part of the effects assessment (Section 3.5.2). Relatively high enterococci levels (often > 2400 MPN/100 mL under dry weather flows) have been a feature of both dry weather, and wet weather monitoring. While Stewart (2015) concludes that because there is not corresponding high levels of fluorescent whitening agent (FWA), which has been used historically as a 'sewage indicator' because it is used in washing powders, then this indicates that a combined sewer overflow (or cross linkage) is not the cause of the relatively high enterococci. However, in our view, the common nature of the contamination together with information from a plethora of international studies makes it unlikely that a non-sewage source is the sole reason, and this may be an area worth further investigation. As well as enterococci, Stewart (2015) also noted that heavy metals were generally in the same range as those seen since 2007 with the exception of lead and zinc, which were significantly higher than previous years. This he attributed to a significantly longer antecedent dry period (5 days) than was usual for previous years which may have led to accumulation of these metals in particulate material (suspended sediment was also significantly higher).

The monitoring of new developments at Sunninghurst (Stewart, 2011a, 2011b) found no evidence of chemical contaminants above ANZECC guidelines for the protection of 80% of species, though there was evidence of faecal pollution (faecal coliforms in this instance). Follow up studies using FWA failed to provide definitive results, and the author attributed the high faecal coliforms to farm runoff. The monitoring of another greenfield development at Grandvista (Stewart, 2012, 2010) did not report high faecal pollution, but phosphorus levels were well above the ANZECC trigger values of 0.033 g/m^3 in the 2010 survey. By 2012, however, phosphorus did not feature in the discussion but heavy metals, particularly copper and zinc exceeded ANZECC guidelines at some monitoring sites. The report does not come to a definitive conclusion as to the ecological significance of the contaminants, however given the location of the estate (close to SH1) it is difficult to see it being significant.

The only academic study of stormwater contaminants in Otago that we have found is a University of Otago PhD study together with a subsequent publication (Brown, 2002a; Brown and Peake, 2006). Brown's studies focussed on heavy metals and PAHs in the Portobello catchment and compared it with the more rural Water of Leith catchment. Interestingly, calculations of the annual contaminant loading (kg/ha/yr) from each catchment into Otago Harbour showed that the Portobello Road catchment exported less suspended sediment but considerably more heavy metals and PAHs (up to 20 times more per hectare). Road debris was also a significant contributor to the contaminants in the Portobello Road catchment, but significantly higher metal and PAH concentrations than the Water of Leith catchment suggested that additional contaminant sources were present. For Cu and Pb, higher concentrations probably arose from a greater intensity of urban and industrial land uses within the catchment. Additional zinc was traced to runoff from extensive use of zinc-galvanised roofing iron within the catchment's residential areas. We note this is a common finding in NZ (Kelly, 2010a). Input of PAH-rich sludge from the closed gasworks facility was implicated in at least one storm event, and this source was the likely explanation for the high annual PAH loading from this catchment. We note that subsequent monitoring (Stewart, 2005b) reported a decrease of PAH from this source.

Appendix D: WWTP data

Water New Zealand Data

Council	Name	Northing	Easting	Treatment Level	Volume treated	Freshwater discharge	Land application	Ocean discharge	Trade waste %	Current capacity
Dunedin City Council	Tahuna	4913495.82	1408957.46	Tertiary	12775000			100%	10.0%	43800000
Dunedin City Council	Green Island	4912281.81	1398925.10	Tertiary	3540500			100%	20.0%	4015000
Dunedin City Council	Mosgiel	4916744.19	1392780.46	Tertiary	1533000			100%	5.0%	4288750
Clutha District Council	Balclutha	4871781.00	1348499.00	Primary	808358	100%			0.0%	912500
Central Otago	Cromwell	5003607.60	1300502.70	Primary	633276	100%			3.0%	1606000
Clutha District Council	Milton	4887123.00	1365065.00	Secondary	468224	100%			0.0%	593125
Central Otago	Alexandra	4981491.20	1317481.70	Secondary	389778	100%			1.0%	1022000
Clutha District Council	Kaitangata	4868225.00	1356596.00	Primary	162562	100%			0.0%	43800
Central Otago	Ranfurly	4997655.30	1372417.30	Tertiary	146297	100%			0.5%	547500
Dunedin City Council	Waikouaiti	4945693.02	1417546.00	Secondary	118625		100%		0.0%	365000
Clutha District Council	Lawrence	4909610.00	1342577.00	Secondary	117542	100%			0.0%	91250
Clutha District Council	Tapanui	4905792.00	1308958.00	Secondary	88040	100%			0.0%	169725
Central Otago	Omakau	4999347.90	1331984.00	Primary	86068	100%			0.3%	127750
Clutha District Council	Owaka	4851196.00	1344295.00	Secondary	83844	100%			0.0%	131400
Clutha District Council	Clinton	4876880.00	1321451.00	Primary	73000	100%			0.0%	146000
Dunedin City Council	Warrington	4934320.90	1413002.60	Primary	54020		100%		0.0%	86870
Central Otago	Roxburgh	4950893.10	1312557.20	Primary	51523		100%		1.0%	171600
Clutha District Council	Waihola	4901059.00	1376530.00	Primary	36724	100%			0.0%	248200
Central Otago	Naseby	5009006.40	1375007.70	Primary	30000		100%		0.3%	73913
Clutha District Council	Stirling	4872402.00	1352360.00	Secondary	29520	100%			0.0%	51100
Clutha District Council	Kaka Point	4858671.00	1352186.00	Secondary	26400			100%	0.0%	127750
Dunedin City Council	Middlemarch	4956307.20	1376024.10	Primary	21900	100%			0.0%	131400
Clutha District Council	Heriot	4915443.00	1309328.00	Primary	21013	100%			0.0%	38325
Dunedin City Council	Seacliff	4938570.70	1415350.80	Secondary	2555		100%		0.0%	15768

ORC Consent Data

Town	Maximum consented discharge limit (m^3)	In WaterNZ database?
Alexandra	Not specified	Yes
Balclutha	2500	Yes
Bannockburn	Not specified	No
Cardrona Valley	Not specified	No
Clinton	400	Yes
Cromwell	Not specified	Yes
Heriot	Not specified	Yes
Kaitangata	Not specified	Yes
Lake Roxburgh Village	86	No
Lake Waihola	1020	Yes
Lawrence	Not specified	Yes
Middlemarch	360	Yes
Milton	Not specified	Yes
Milton/Milburne	Not specified	Yes
Naseby	Not specified	Yes
Omakau	Not specified	Yes
Owaka	Not specified	Yes
Queenstown	Not specified	No
Ranfurly	Not specified	Yes
Roxburgh	3300	Yes
Seacliff	Not specified	Yes
Stirling	Not specified	Yes
Tapanui	Not specified	Yes
Wanaka	Not specified	No
Warrington	Not specified	Yes